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Effect of climatic gradient on species diversity and structure of *Faidherbia albida* parkland in Burkina Faso (West Africa)

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Abstract

Background: *Faidherbia albida* parkland provide many ecosystem goods and services to people, ranging from provisioning to regulating services. Despite this importance, these parks are degraded due to overexploitation, which is accentuated by the adverse effects of climate change. In this context of climate change, little information exists on the state of these *F. albida* parkland, particularly their diversity and structure along the North-South climatic gradient. This study aims to determine the effect of climatic gradient of *F. albida* parklands in order to provide updated data for sustainable management. Floristic diversity and population structure were assessed through forest inventories in the three climatic zones of Burkina Faso. Thus, 99 circular plots of 1 ha were sampled in three zones, including 33 per climatic zone. The data processing concerned the calculation of diversity indices (Shannon, Piélou equitability, and species richness), importance value indices, and the calculation of the means of the dendrometric parameters. The analyses were based on the comparison of medians using the Kruskal-wallis test, and the effect of the climatic gradient on the different variables was tested using generalized linear models. All of these analyses were carried out using the R.4.0.5 software.

Results: The dendrometric parameters and floristic diversity vary significantly ($Pv<0.05$) according of climatic zone. Furthermore, based on ecological importance value indices and diameter class structure, the majority of dominant species (11) show a regressive dynamic in all three climatic zones characterized by abundance of old individuals at expense of young ones. This reflects an ageing and continuous destruction of these parklands. However, species such as *V. tortilis* (Sahelian zone) and *A. indica* (Sudano-Sahelian and Sudanian zones) show good dynamics. As for *F. albida*, its structure is regressive in all climatic zones.

Conclusion: Although the climatic gradient has a significant effect on the diversity and species structure of *F. albida* parkland, their current dynamics are thought to be due to unsustainable management of local populations.

Keys words: agroforestry systems, *F. albida*, climate variability, Burkina Faso

Introduction

Agroforestry parkland is a rational land use system developed by African farmers over several generations. It is a sustainable land management system that increases production, combining agricultural crops, forest plants and/or animals simultaneously or in sequence (Bene et al. 1977). Thus, the woody species deliberately maintained in these farms allow people to have a diversity of uses (Orwa et al. 2009). In Burkina Faso, agroforestry parklands represent a large part of agricultural landscape and are particularly characterized by species such as *Faidherbia albida* (Delile) A. Chev., *Vitellaria paradoxa* C. F. Gaertn and *Parkia biglobosa* (Jacq.) R. Br. Ex G. Don (Boussim et al. 2004) as well as many other local and exotic species. Among these numerous agroforestry species, *F. albida* is one of the most important from an agronomic, fodder and medicinal point of view that populates the numerous parklands in the three climatic zones of Burkina Faso (from Sahelian to Sudanian zone). Indeed, by its presence in the fields, this species improves soil fertility from the decomposition of litter and propagation of roots improve their physico-chemical properties (Zommer et al. 2009). Furthermore, its presence does not lead to competition with cultivated plants due to its reversed phenology (Tsegu 2019). Because of this phenology, it provides farmers with fodder (leaves and fruit) of great nutritional value for livestock during dry season, especially when pastures are poor in nutrients. In addition, these leaves and roots are rich in antioxidants that could help fight against many diseases (Tchebemou et al. 2020). *F. albida* has a high carbon absorption capacity (Beedy et al. 2015, Moussa et al. 2015) and would contribute to mitigate the effects of climate change.

In Burkina Faso*, F. albida* benefits from special protection under 1987 forestry code, revised in 2003 (MECV 2004), and has been subject of numerous studies on its distribution (Bonkoungou, 1987), on fruit production and seeds become (Depommier 1996). Other studies have also focused on the diversity and structure of this species in these parklands (Ouédraogo 1996, Depommier 1998) and have reported on their ageing. In addition, more recent studies have focused on phenology (Nanéma et al. 2015, Nanéma et al. 2016) and on the regeneration of *F. albida* parkland species (Traoré et al. 2020), which have reported a disruption of parkland regeneration dynamics. However, the majority of these studies concerned restricted ecological zones and do not provide precise information on scale of three climatic zones. Moreover, in recent decades, *F. albida* parklands as a whole have been declining due to climatic variability and anthropogenic factors that have made regeneration difficult (Nanéma et al. 2015). Indeed,

demographic growth and the search for fertile land by local populations lead to agricultural overexploitation and overgrazing of parklands without any fallowing. The combination of these factors is a threat to this agroforestry species, which does not benefit from sowing by populations (Traoré et al. 2020). In addition, recent data on the dynamics of adult species in these *F. albida* parklands are almost non-existent. Since most juveniles only live for one season. This situation does not allow decision-makers to orientate sustainable management actions for these formations. Thus, determining the dynamics of dominant species in the parklands makes it possible to better monitor their evolution and to orient sustainable management policies.

Elsewhere, floristic inventories have less focus on the interactions between environmental factors and plant species (Thiombiano et al. 2006), including the effect of climatic gradient on floristic diversity. However, existing studies on the climatic gradient have mainly focused on dense formations such as protected areas (Da et al. 2018; Ganamé et al. 2020), on certain species families, notably Combretaceae (Thiombiano et al. 2006). However, very few studies have focused on the effect of climatic gradient on agroforestry parklands in general, and those on *F. albida* parklands are almost non-existent since most of the studies on this species have been carried out in restricted areas. Since some authors have reported on the decline in floristic diversity under a number of factors (Wezel et Schmelzer 2002, Madsen et al. 2004). Thus, determining this floristic diversity and the effect of climatic gradient on these parklands will allow us to better understand the ecology of species, to know the companion plants that will permit to lead a better orient reforestation projects and to diversify farmer's sources of income. According Thiombiano et al. (2006), the failures of many reforestation campaigns are partly due to inappropriate choices of ecological zone and species used. This study aims to determine the effect of climate gradient on diversity and evolutionary trend of Faidherbia companion species in order to orientate the best management strategies to ensure a rational and sustainable exploitation of Faidherbia parklands in Burkina Faso. The following research questions were formulated: (i) what is the state of floristic diversity of the parklands along climatic gradient? (ii) What is the dominant species dynamic in *F. albida* parklands?

Material and methods

Study area

This study was conducted in Burkina Faso (**Fig**. 1), a country located in the heart of West Africa. Study sites are located in three climatic zones following a rainfall gradient. These are Séno province in Sahelian zone, Boulkièmdé in Sudano-Sahelian zone and Tuy province in Sudanian zone. Sahelian zone is characterized by an annual rainfall from 300 to 600 mm and high temperature ranges of 15°C to 45°C (Dipama 2010). This site is characterized by the alternation of two seasons: a short rainy season from June to September and a long dry season from September to May. Sahelian character of area offers favorable conditions for development of livestock farming, given low development of pathogens. Natural vegetation is composed of tree and shrub steppes, tiger bushes with characteristic woody species such as *Pterocarpus lucens* Guill. & Perr., *Combretum micranthum* G. Don, *Grewia flavescens*, Juss., *Commiphora africana* (A. Rich.) Engl., *Vachelia tortilis* (Forssk) Hayne and *Dalbergia melanoxylon* Guill. & Perr. (Nacoulma et al. 2019). Besides, *F. albida* is found on sand dunes and in fields.

Sudano-Sahelian zone, with annual rainfall ranging from 600 to 900 mm, is characterized by inter-annual irregularity with temperatures ranging from 20 to 30 °C (Dipama, 2010). This climate is characterized by two seasons, a rainy season from May to October and a dry season from November to April. Vegetation is essentially made up of anthropogenic tree park formations with *Vitellaria paradoxa*, *Bombax costatum* Pellegr. & Vuillet, *Tamarindus indica* L., *Parkia biglobosa* (Nacoulma et al. 2019), which are conserved for social and economic reasons. In addition, *F. albida* parklands are also found in this area around houses.

As for Sudanian zone, it has a Sudanian climate type with an average annual rainfall of over 1100 mm and thermal amplitudes of 20-25 °C (Dipama 2010). It is characterized by two alternating seasons: a dry season lasting 6 months from October to March and a rainy season lasting 5 to 6 months from April to October (Bambara et al. 2019). Vegetation is characterized by the presence of all types of savannah (from wooded to grassy savannah) which are usually burnt each year. Main species are *Senegalia erythrocalyx* (Brenan) Kyal. & Boatwr., *Anogeissus leiocarpa* (DC) Guill. & Perr., *Celtis toka* (Forsst.) Hepper & J.R.I.Wood, *Diospyros mespiliformis* Hochst. Ex A. DC., *Pterocarpus erinaceus* Poir. (Boussim 2010). In addition, parklands with an agrarian appearance dominated by *Vitellaria paradoxa* and *F. albida* are also encountered (Zomboudré, 2009).

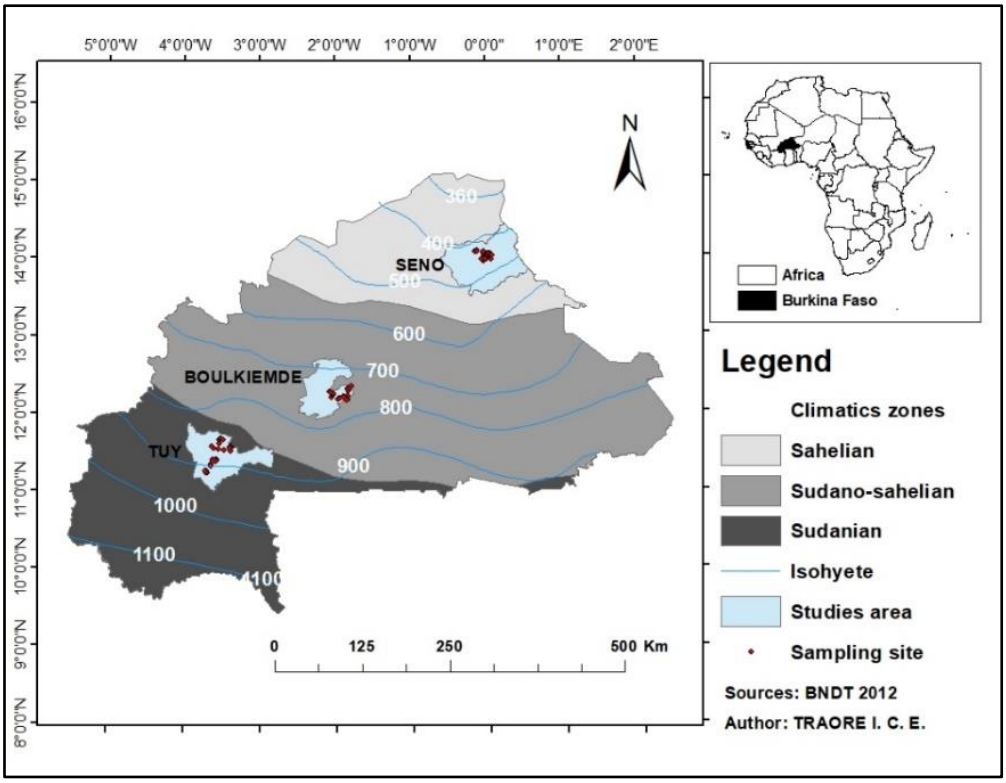


Fig.1 Studies area

Sampling

In order to describe floristic diversity and demographic structure of woody plants in *F. albida* parklands, a survey was carried out from August to September 2018 in three climatic zones. Objective was to select sites along climatic gradient in order to assess influence of climate on dynamics of *F. albida* parklands. Floristic and dendrometric data collection were carried out between December 2018 and February 2019. Dry season period was chosen for data collection, as it corresponds to the end of field work, thus allowing free access to parklands and to full foliage, flowering and fruiting phases of species.

Sampling method used was oriented towards agroforestry formations dominated by *F. albida*. In each *F. albida* parkland, a minimum density of 10 individuals in field was required for installation of inventory plot. First, based on a position that would allow a high number of *F. albida* individuals to be included in the survey sample, one tree of this species was selected and retained as the plot center. Circular plot with a radius of 56.42 m, i.e. one (1) hectare has a surface area. This size was chosen in order to accurately report the real tree densities per hectare in these parklands, as extrapolation of sample data to the hectare may be subject to error. Furthermore, spatial distribution of trees in *F. albida*

parklands is rather sparse (low density), which justifies the choice of surveying of this plot size. A similar plot size was used (Elias, 2013) in shea parklands in Burkina Faso. Circular shape was chosen because it does not have any preferred directions. It considerably reduces the border effect during colleting and is easy to install in agroforestry parklands (Rondeux, 1999). In order, to obtain sufficiently independent data and to cover a large area of study sites, minimum distances of 1 km were observed between sampling points following the example of (Moussa et al. 2015) works. Within each plot, woody individuals with a trunk diameter at 1.30m from ground greater than or equal to 5 cm were considered mature: their circumference at 1.30 m from the ground was measured and their height was estimated. Individuals with a diameter of less than 5 cm were considered to be part of the regeneration (Ouédraogo et al. 2015, Dimobé et al. 2019), however, this category of individuals was not taken into account in this study. A total of ninety-nine (99) plots were installed for all study sites, i.e. thirty-three (33) surveys per climatic zone. Samples, notably leafy branches, were collected from unidentified species in the field and brought to the Laboratory of Plant Biology and Ecology of University Joseph KI-ZERBO. The task was to determine them with the help of existing flora and the assistance of botanists. The nomenclatures adopted for the classification of species are those of APGIII (Bremer 2009) and (Kyalangalilwa et al. 2013).

Data processing and analysis

Floristic diversity

In order to determine variation in the diversity of woody species in *F. albida* parklands, four indices, namely species richness (S), Shannon diversity (H), Piélou equitability (E) and Jaccard equitability (J) were calculated according to following formula:

$$\boldsymbol{S = \sum_{i=1}^{n}(\text{Species in plot } i)}$$

$$\mathbf{H = -\sum_{i=1}^{n}(p_i \ lnp_i)}$$

With pi = the relative abundance of the i^{th} species in a plot.

$$\mathbf{E = \frac{H}{lnS}}$$

$$\boldsymbol{J = \frac{c}{a+b-c}}$$

a: represents the number of common species between two habitats,

b: represents the number of species present only in habitat 1,

c: represents the number of species present only in habitat 2.

High values of the Shannon diversity index (H) reflect favorable environmental conditions for the establishment of many species. It generally varies from 0 to 5 bits

The Piélou index (E) varies from 0 to 1. Values close to 1 indicate an even distribution of individuals between species, while values close to 0 indicate the dominance of a small number of species or one species.

The index J varies between 0 and 1. If J is high, a large number of species occur in the habitats, suggesting low inter-habitat biodiversity (similar environmental conditions between habitats). In the opposite case, a low number of species present in both habitats will be encountered (De Bello et al. 2007).

Ecological importance value index of woody species in F. albida parkland

In general, the installation of parklands follows a selection of species according to the needs of the populations, which favors a strong dominance of certain species. To determine the dominant species in *F. albida* parklands, the importance value index (IVI) was calculated. This allows a better appreciation of their importance in plant community (Traoré et al. 2011). The IVI is the sum of relative density, relative frequency and relative dominance with values between 0 and 300%. These, parameters were calculated from the following formula:

IVI i= relative density i + relative frequency i + relative dominance i

- **relative density** $_i$ **=** $\frac{\text{Total individuals of species i}}{\text{Total individuals of all species}}$**x100**
- **relative frequency** $_i$ **=** $\frac{\text{Frequency of species i}}{\text{Total frequencies of all species}}$**x100**
- **relative dominance** $_i$**=** $\frac{\text{basal area of species i}}{\text{total basal area of all species}}$**x100**

Demographic structure of woody species in F. albida parklands

The study of dynamics of *F. albida* parklands species was carried out on the basis of the IVI. It allows us to highlight problems in the dynamics of woody species (Traoré 2008). To this end, only individuals

with an IVI ≥ 10% were considered ecologically important in addition to *F. albida* which is the dominant species. Thus, on the basis of diameter at 1.30 m calculated, six (6) classes with intervals of 10 cm were carried out, namely [5-15[, [15-25[, [25-35[, [35-45[, [45-55] and ≥55 cm, with the exception of *H. thebaica* species because it does not show growth in diameter according (Condit et al. 1998). For this purpose, its dynamics was evaluated on basis of height of individuals considering amplitudes of 2 m intervals. For a better observation of dynamics of *F. albida* parklands species, demographic trend of dominant species was characterized (Condit et al. 1998) method. As these formations have small numbers of tree, linear regressions using only the median value of the diameter classes as independent variable and density per diameter class as dependent variable were established. The resulting parameters are slope, r^2 (variance) and probability value. The slope values derived from these regression equations and r^2 are considered as indicators of population structure (Obiri et al. 2002). Thus, a negative slope indicates that small-diameter individuals are more numerous, while a positive slope indicates abundance of large-diameter individuals. In addition, the value of coefficient of determination r^2 makes it possible to observe whether there is a good transition between number of individuals and diameter classes, based on its significance (p-value <0.05).

In addition, the demographic and dendrometric parameters of all species such as mean density, mean diameter, mean height and mean basal area of all species were calculated and age (Eq. 1.) of *F. albida* stands was estimated in order to compare their dynamics in three climatic zones. These calculations were based on the following formulae:

$\mathbf{Average\ DBH} = \frac{\sum_1^n Di}{N}$ Di is the diameter of individual i and N, the total number of trees

$\mathbf{Density} = \sum_{i=1}^{N} i$

$\mathbf{Average\ height} = \frac{\sum_1^n hi}{N}$, hi is height of the individual

$\mathbf{Age = 5.3 + 0.66 \times DBH^{1.13}}$ (Eq. 1)

DBH represents the diameter at breast height. Age of each individual calculated in years was used to calculate the average age of *F. albida* stands in each climatic zone (Sida et al. 2018).

Statistical analyses of the data

The Shapiro Wilks test was performed on demographic, dendrometric and diversity indices to test data normality. After this test, non-parametric Kruskal-Wallis test followed by Mann Whitney-Wilcoxon pairwise post-hoc test through multcompview package at the 5% threshold were applied and Generalized Linear Model (GLM) were also applied to the data to evaluate effect of climatic zone on different variables. All analyses were performed using R 4.0.4.

Results

Floristic diversity of F. albida parklands

The floristic characteristics of *F. albida* parklands are specific to each climatic zone with low similarity indices (Table 1). However, floristic similarity is particularly high (50%) between the Sudano-Sahelian and Sudanian zones**.**

Table 1 Floristic similarity of climatic zones

Table 1 Floristic similarity of climatic zones

	Sahelian	**Sudano-sahelian**	**Sudanian**
Sahelian	1		
Sudano-sahelian	29,93	1	
Sudanian	15,91	50	1

The floristic richness of *F. albida* parklands increases with climatic gradient. Indeed, 19 species were sampled in Sahelian zone, 33 in Sudano-Sahelian zone and 32 in Sudanian zone. Nineteen (19) species from Sahelian zone are divided into 12 families and 17 genera. The most represented families are Fabaceae and Apocynaceae (Table 2). Thirty-three (33) species were recorded in Sudano-Sahelian zone and made up of 17 families and 31 genera, the main families being Fabaceae, followed by Anacardiaceae, Apocynaceae and Malvaceae (Table 2). Thirty-two (32) species were recorded in Sudanian zone and classified in 13 families and 27 genera with Fabaceae and Moraceae as dominant families. Furthermore, the values of diversity indices (H and S) decrease along climatic gradient and statistical tests show significant differences ($Pv<0.05$) between medians of three climatic zones (Table 3). Moreover, H and E were influence by climatic zone (Table 4).

Table 2 Species and family repartition by climatic zone

Species	Family	Climatic Zones		
		Sahelian	Soudano-sahelian	Sudanian
***Adansonia digitata* L.**	Malvaceae	x	x	x
***Afzelia africana* Sm. ex Pers.**	Fabaceae		x	
***Anacardium occidentale* L. [cult.]**	Anacardiaceae			x
***Azadirachta indica* A.Juss. [cult.]**	Meliacea	x	x	x
***Balanites aegyptiaca* (L.) Del.**	Zygophyllaceae	x	x	
***Bauhinia rufescens* Lam.**	Fabaceae	x		
***Borassus aethiopum* Mart.**	Arecaceae		x	
***Calotropis procera* (Aiton) R.Br.**	Apocynaceae	x	x	x
***Senna siamea* (Lam.) H.S.Irwin & Barneby**	Fabaceae			x
***Senna sieberiana* DC.**	Fabaceae		x	
***Ceiba pentandra* (L.) Gaertn.**	Malvaceae		x	x
***Citrus limon* (L.) Burm.f. [cult.]**	Rutaceae		x	
***Combretum glutinosum* Perr. ex DC.**	Combretaceae	x		
***Combretum micranthum* G.Don**	Combretaceae		x	
***Combretum paniculatum* Vent.**	Combretaceae			x
***Crescentia cujete* L. [cult.]**	Bignoniaceae		x	
***Diospyros mespiliformis* Hochst. ex A.DC.**	Ebenaceae		x	
***Eucalyptus camaldulensis* Dehnh. [cult.]**	Myrtaceae		x	x
***Euphorbia balsamifera* Aiton**	Euphorbiaceae	x		
***Faidherbia albida* (Delile) A.Chev**	Fabaceae	x	x	x
***Feretia apodanthera* Delile**	Rubiaceae		x	x
***Ficus ingens* (Miq.) Miq.**	Moraceae			x
***Ficus sur* Forssk.**	Moraceae		x	x
***Ficus sycomorus* L.**	Moraceae		x	x
***Gmelina arborea* Roxb**	Lamiaceae			x
***Guiera senegalensis* J.F.Gmel.**	Combretaceae		x	
***Hyphaene thebaica* (L.) Mart.**	Arecaceae	x		
***Jatropha curcas* L. [cult.]**	Euphorbiaceae		x	x
***Khaya senegalensis* (Desr.) A.Juss.**	Meliaceae		x	x
***Lannea microcarpa* Engl. & K.Krause**	Anacardiaceae		x	x
***Leptadenia hastata* (Pers.) Decne.**	Apocynaceae	x	x	
***Maerua crassifolia* Forssk.**	Capparaceae	x		
***Mangifera indica* L. [cult.]**	Anacardiaceae		x	x
***Mitragyna inermis* (Willd.) Kuntze**	Rubiaceae			x
***Moringa oleifera* L.**	Moringaceae			x
***Parkia biglobosa* (Jacq.) R.Br. ex G.Don**	Fabaceae		x	x
***Piliostigma reticulatum* (DC.) Hochst.**	Fabaceae		x	
***Piliostigma thonningii* (Schumach.)Milne-Redh.**	Fabacea		x	x
***Prosopis juliflora* (Sw.) DC.**	Fabaceae	x		
***Saba senegalensis* (A.DC.) Pichon**	Apocynaceae		x	x

***Sarcocephalus latifolius* (Sm.) E.A.Bruce**	Rubiaceae			x
***Sclerocarya birrea* (A.Rich.) Hochst.**	Anacardiaceae		x	
***Senegalia senegal* (L.) Britton**	Fabaceae	x		
***Sterculia setigera* Delile**	Malvaceae		x	
***Stereospermum kunthianum* Cham.**	Bignoniaceae	x		
***Tamarindus indica* L.**	Fabaceae		x	x
***Terminalia macroptera* Guill. & Perr.**	Combretaceae			x
***Terminalia mantaly* H.Perrier [cult.]**	Combretaceae			x
***Vachellia nilotica* (L.) P. J. H. Hurter & Mabb**	Fabaceae	x	x	x
***Vachellia seyal* (Delile) P.J.H.Hurter**	Fabaceae	x	x	x
***Vachellia tortilis* (Forssk.) Hayne**	Fabaceae	x		x
***Vitellaria paradoxa* C.F.Gaertn.**	Sapotaceae		x	x
***Ziziphus mauritiana* Lam.**	Rhamnaceae	x	x	x

Table 3 Floristic diversity climatic zones

	Climatic zones			
	Sahelian	**Sudano-sahelian**	**Sudanian**	**K.W**
	A±SE	**A±SE**	**A±SE**	**Pv**
H	1.17 ± 0.36 a	1.12 ± 0,39 a	0.71 ± 0,43 b	<0.001
E	0.76 ± 0.11 a	0.68 ± 0.12 a	0.59 ± 0.48 b	<0.001
S	5.00 ± 1.18 a	5.36 ± 1.18 b	3,38 ± 1.89 c	0.005
SR Total	19	33	32	

A±SE: Average ± standard error; H: Shannon index; E: Piélou equitability index; Pv: P-value
RS: specific richness; RS: Specific richness; K.W= Kruskal-wallis test.

Table 4 GLM showing the effect of climatic zones on floristic diversity

	Estimate	**Std.Erro**	**z value**	**Pr(>|z|)**
S	-0.07827	0.10987	-0.712	0.4762.
H	-1.5384	0.5671	-2.713	0.006677 **
E	-7.565	2.088	-3.623	0.000291 ***

Std.Erro: standard error; H: Shannon index; E: Piélou equitability index, Pr (>|z|): probability

Demographic characteristics of F. albida parklands

The values of dendrometric and demographic parameters of *F. albida* parklands are different from along climatic zone (Table 5). Indeed, Sahelian zone presents the lowest values of average diameter (31.19 ± 8.51 cm), average height (8.48 ± 1.82 m), average basal area (2.36 ± 1.11 m²) and average density (26.48 ± 11.68 ind.ha^{-1}). The highest mean values were recorded in Sudano-Sahelian zone. Furthermore, results of statistical analyses of different variables showed significant differences between three sites (Pv<0.05). Moreover, GLM indicated that climatic zones impact significantly all variables (Table 6).

Table 5 Dendrometric characteristic of *F. albida* parklands

	Climatic zones			
	Sahelian	**Sudano-sahelian**	**Sudanian**	**KW**
	A±SE	**A±SE**	**A±SE**	**Pv**
Density (Tree.ha^{-1})	26.48±11.68a	55.88±29.53b	32.21±21.17a	<0.001
Height (m)	8.48±1.82 a	9.38±2.19ab	10.22±2.49b	0.017
DBH (cm)	31.19±8.51a	36.83±10.68b	36.26±15.78ab	0.08
G ($m^2.ha^{-1}$)	2.36 ± 1.11a	8.69±5.62b	4.16 ± 3.17c	<0.001

G: Basal area ($m^2.ha^{-1}$); DBH: diameter at breast (1.30m); A±SE: Average ± standard error; Pv: Pvalue, KW: Kruskal-wallis test

Table 6 GLM showing the effect of climatic zones on *F. albida* parklands dendrometric characteristic

	Estimate	Std. Error	z-value	Pr(>|z|)
Height (m)	0.3074	0.1172	2.623	0.00871 **
G (m^2ha^{-1})	0.5779	0.1549	3.732	0.00019 ***
Densty (Tree.ha^{-1})	0.03981	0.01328	2.997	0.00272 **
DBH (cm)	0.04305	0.02146	2.006	0.0448 *

Std. Erro : standard error; H: Shannon index; E: Piélou equitability index; Pr (>|z|): probability

Demographic characteristics of F. albida

The dendrometric and demographic characteristics of *F. albida* stands in three climatic zones vary significantly along the climatic gradient (Table 7). Indeed, the density of individuals increases from Sahelian zone to Sudanian zone. As for the other parameters, highest values are observed in Sudano-Sahelian zone and the lowest in Sahelian zone, except for DBH. Furthermore, oldest stands considering Sida et al. (2018) equation based on the diameter at 1.30 m from ground, are observed in Sudano-Sahelian zone (59.35±19.75 years); statistical tests comparing their median differ significantly from one zone to another (Pv=0.004). In addition, some populations have extreme ages of over 80 years. Moreover, DBH and age are not influenced by climatic zones condition. However, density and basal area are depended of climatic zones according to GLM test (Table 8).

Table 7 Means and statistical tests of Dendrometric characteristic of *F. albida*

	Climatic zones			
	Sahelian	**Sudano-sahelian**	**Sudanian**	**KW**
	A±SE	**A±SE**	**A±SE**	**Pv**
Density (Tree.ha^{-1})	13.27 ± 5.50a	21.15 ±18.37a	25.33±19.60ab	0.006
Height (m)	10.97 ±2.53a	13.51 ±3.08 b	11.10 ±2.86ac	<0.001

DBH (cm)	38.51±13.54a	42.13 ±16.02b	36.55 ±18.18ac	0.005
G ($m^2.ha^{-1}$)	1.67 ±0.91a	4.59 ±3.10 b	2.87 ±2.11 c	<0.001
Age (years)	46.96±16.18a	59.35 ± 19.75 b	44.92 ± 22.21ac	0.004

G: Basal area ($m^2.ha^{-1}$); DBH: diameter at breast (1.30m); A±SE: Average ± standard error; Pv : P-value, KW: Kruskal-wallis test

Table 8. GLM showing the effect of climatic zones on *F. albida* dendrometric characteristics

	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
G ($m^2.ha^{-1}$)	0.5487	0.1672	3.281	0.00104 **
Density(Tree.ha^1)	0.08089	0.03193	2.534	0.0113 *
DBH (cm)	0.01469	0.01325	1.109	0.268
Age (Years)	0.01303	0.01094	1.191	0.234

Std. Erro : standard error; Pr (>|z|): probability

Ecological importance and dynamics of dominant species in F. albida parklands

Based on the importance value index (IVI ≥ 10%), 11 dominant species of *F. albida* parklands in the three climatic zones were selected (Table 9) for the study of population structure. The majority of these species show an unstable structure (**Fig**. 4, 5, 6). Indeed, these species have regressive dynamic characterized in most cases by low numbers of young individuals (positive slope) and problem of transition between classes (Pv > 0.05) which marks an important loss of individuals from lower classes. Structure of *F. albida* is characterized in all three zones by a positive slope and a non-significant probability (Pv>0.05), which means an unbalanced demographic and structural trend with a higher number of individuals in the intermediate diameter classes and a lower number in first class [5-15[. However, *V. tortilis* in Sahelian zone and *A. indica* in Sudano-Sahelian and Sudanian zone have a stable structure.

Table 9 Ecological importance index and dominant species structure of *F. albida* parklands

	Climatic zones											
	Sahelian				Sudano-sahelian				Sudanian			
Espèces	**IVI**	**Pente**	**r²**	**P.v**	**IVI**	**Pente**	**r²**	**P.v**	**IVI**	**Pente**	**r²**	**P.v**
***Adansonia digitata* L.**	-	-	-	-	-	-	-	-	18.83	-0.0001	-0.11	0.885
***Azadirachta indica* A.Juss. [Cult.]**		-	-	-	63.23	-0.032	0.547	0.006	10.92	-0.0064	0.48	0.011
***Balanites aegyptiaca* (L.) Delile**	28.24	0.317	0.115	0.164		-	-	-		-	-	-
***Bauhinia rufescens* Lam.**	12.45	-0.008	0.582	0.004								
***Diospyros mespiliformis* Hochst. A.DC.**		-	-	-	11.71	-0.003	0.46	0.061		-	-	-
***Faidherbia albida* (Delile) A.Chev.**	141.62	0.005	-0.072	0.58	126.32	0.027	-0.45	0.469	178.88	-0.024	0.1	0.181
***Hyphaene thebaica* (L.) Mart.**	36.22	-0.01	-0.023	0.402	27.17	-	-	-		-	-	-
***Lannea microcarpa* Engl. & K.Krause**		-	-	-		0.002	-0.042	0.46	10.46	0.002	0.46	0.013
***Sclerocarya birrea* (A.Rich.) Hochst.**	17.48	-0	-0.134	0.145		-	-	-		-	-	-
***Vachellia* tortilis (Forssk.) Hayne**	30.94	-0.01	0.823	<0.001	10.08	-0.00005	0.189	0.101				
***Vitellaria paradoxa* C.F.Gaertn.**		-	-	-		-	-	-	26.35	0.008	0.287	0.051

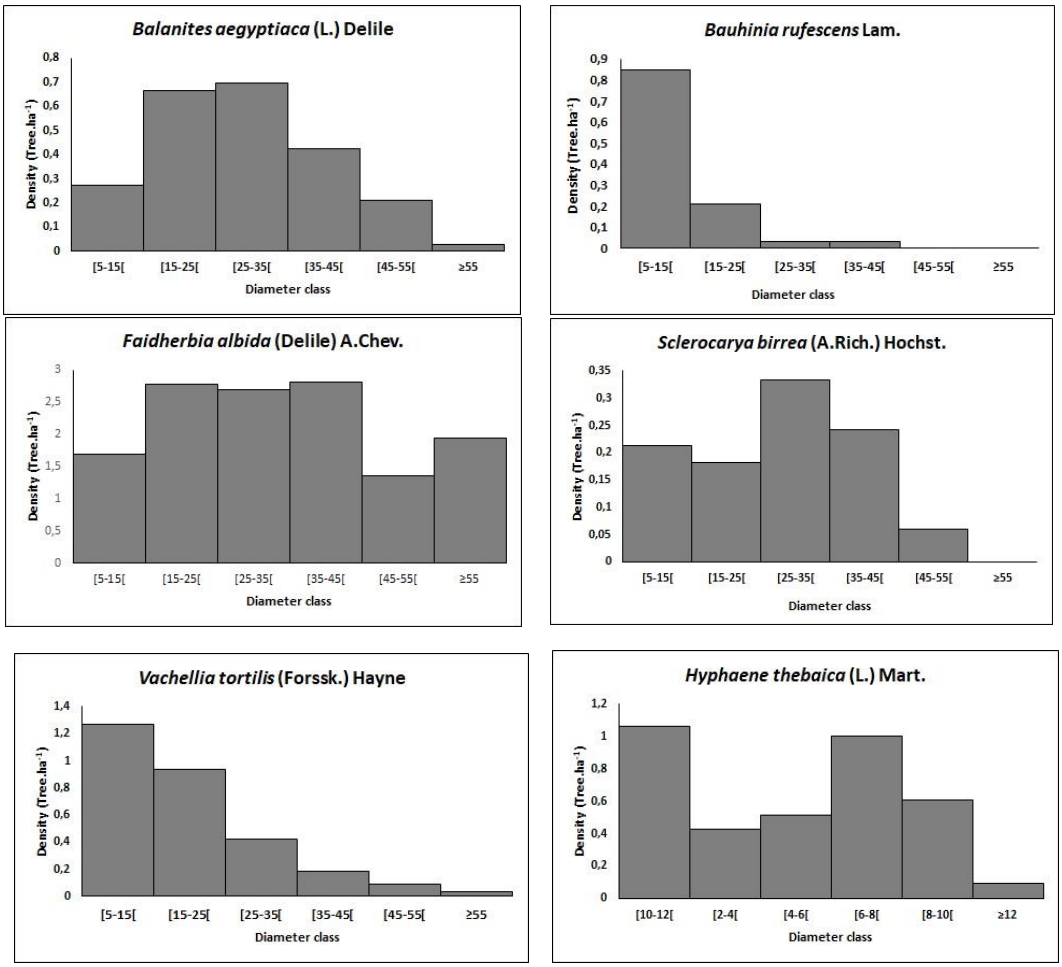
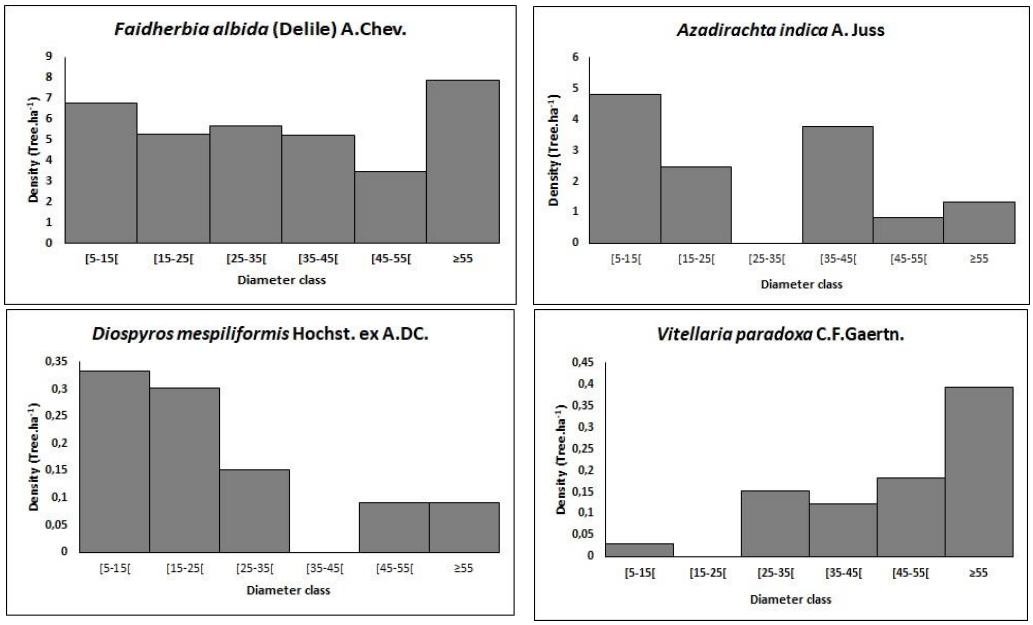


Fig. 2 Diameter class structure of dominant species in sahelian zone



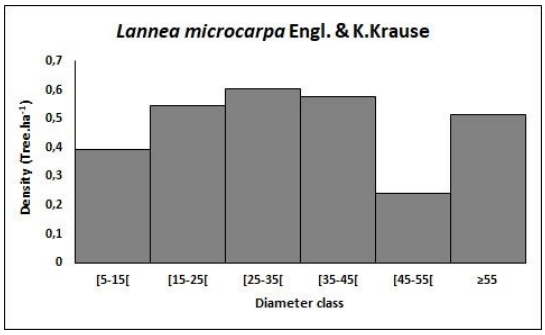


Fig. 3 Diameter class structure of dominant species in Sudano-Sahelian zone

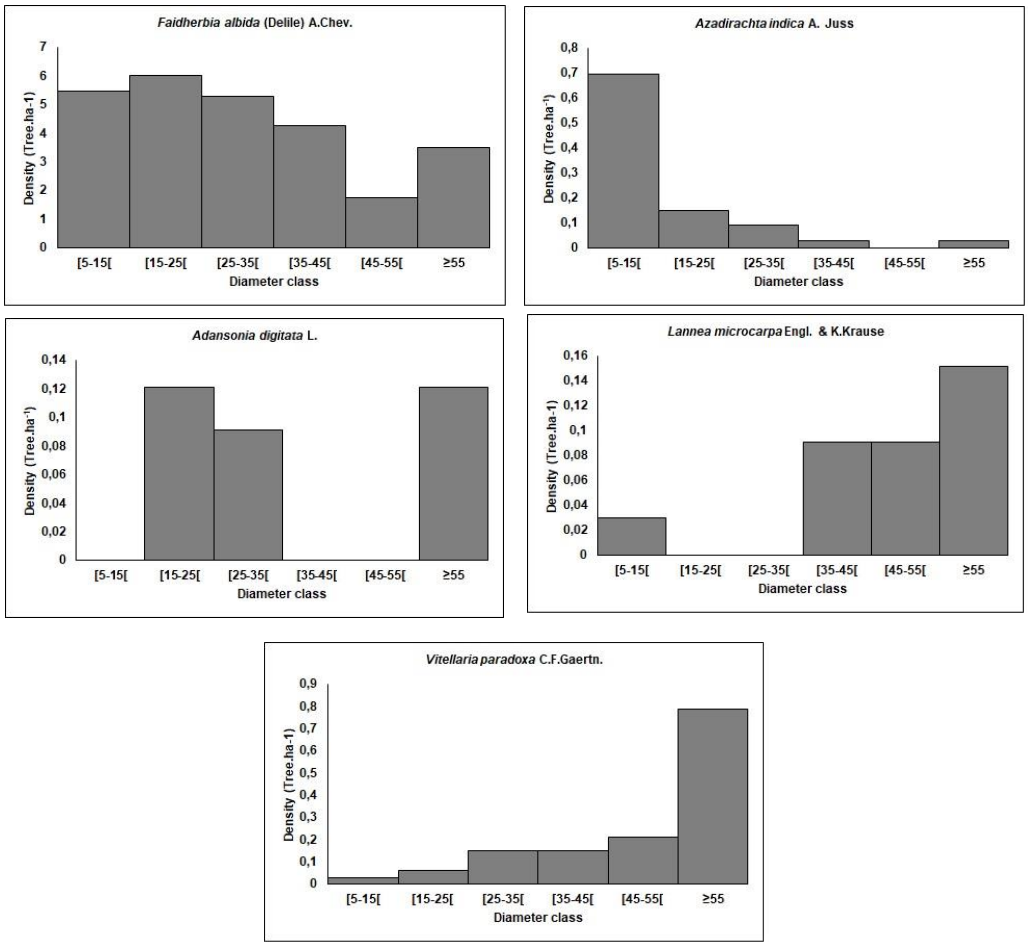


Fig. 4 Diameter class structure of dominant species in Sudanian zone

Discussion

Floristic diversity of woody plants in F. albida parklands

The floristic richness of *F. albida* parklands depends on climatic zone. It increases from Sahelian zone to Sudanian zone. This could be explained by the fact that the forests of Sudanian zone are origin richer in flora than those of Sahelian zone. Indeed, according (Ouédraogo et al. 2006), the number of species in the forests of Sudanian domain is considerably higher than in Sahelian domain. Therefore, the species

that have been recorded in these *F. albida* parklands could only be relics of clearing (Dan Guimbo et al. 2010) of forests and savannahs for crops installation. Furthermore, the selections made during the clearing of land would be the origin of low indices of species diversity in the parklands in Sudano-Sahelian and Sudanian zones, low similarities observed and dominance of a small number of species. The density of dwellings is higher in Sudano-Sahelian and Sudanian zones than in Sahelian zone (INSD, 2019), which leads to an overexploitation of species in the vegetation formations of these zones, especially the trees in the fields, which constitute main energy and wood resources in the vicinity and to which the populations have free access. Indeed, strong pressure of sustained population growth in Sudano-Sahelian and Sudanian zone considerably increases the demand for wood and non-wood forest products. According (Nassirou et al. 2011), high population density around natural resources has a negative impact on species diversity. For example, the surroundings of *F. albida* parklands in Sahelian zone are less populated than those in Sudano-Sahelian zone and Sudanian zone. Hence the decrease in diversity indices along the climatic gradient. Only a minority of species survive these different pressures and dominate these parklands. These results are in agreement with those (Moussa et al. 2015) who found that stands of *Prosopis africana* Guill, Perrot and Rich and *F. albida* in Niger are dominated by a minority of species. These same observations were made (Neya et al. 2018) in certain parklands in Burkina Faso. Moreover, the poor soils, harsh climatic conditions as well as livestock activities in the Sahel force people to maintain a large number of leguminous species in the fields to meet agricultural needs.

Woody species structure of F. albida parklands

The values of dendrometric and demographic parameters of *F. albida* parklands show variable trends along climatic gradient. This is related to the morphology of the different species that dominate these formations. Thus, the lower values of dendrometric parameters found in Sahelian zone reflect the dominance of shrubs and bushes in these parklands. Indeed, the landscapes of this zone are dominated by shrubs (Nacoulma et al. 2019) that are regularly subjected to pressure from livestock, lack of water and high temperatures, whereas Sudano-Sahelian and Sudanian zones are characterized by the presence of large-sized and large-diameter individuals (**Pho**. 1, 2, 3) associated with a less rigorous climate.

Furthermore, the overall density of trees is low compared to the standard recommended by the Ministry of the Environment (100 trees/ha). This is due to the fact that in the fields, a high number of trees would make it difficult to carry out various cultivate operations. Thus, the trees are scattered (**Pho**. 1, 2, 3) in order to facilitate field work (Thiombiano et al. 2010). Only certain old individuals are maintained in these parklands, hence the very advanced ages (over 40 years) of *F. albida* stands sampled (**Pho**. 4). Furthermore, the significant differences observed in the average age of the parklands between the three climatic zones could be explained by the creation of new *F. albida* parklands in Sudanian zone (Traoré et al. 2020). However, (Sida et al. 2018) found that in *F. albida* parklands in Ethiopia, a large number of individuals are older than 25 years. Ageing of the parklands in climatic zones is based on the poor management of these plant formations which hardly experience any rest (fallow). Thus, these formations do not have the opportunity to rebuild themselves, since fallowing fields is one of the best methods of revitalizing its diversity and rejuvenation (Kaboré et al. 2012). The continuous exploitation of *F. albida* parklands is said to be at the origin of the instability of the dynamics of the dominant species of which they are composed. Majority that species are protected by the forestry code but are at the same time harvested in clandestinely (**Pho**. 5) for energy and fodder purposes. This situation is farmer's logic of resource management oriented towards satisfying present needs, rather than towards concern for sustainability (Yaméogo et al. 2019). Furthermore, observed species dynamics characterized by the absence of certain individuals in the diameter classes carried out was reported (Yaméogo et al. 2019) in Vilpalgo's parklands in central region of Burkina Faso. Similar results were reported on *Parkia biglobosa* and *Vitellaria paradoxa* structure in North of Burkina Faso (Thiombiano et al. 2010; Néya et al. 2018) in certain parklands.



Pho. 1 *F. albida* scattered in a field (Sahelian zone)



Pho. 2 *F. albida* scattered in a field (Sudano-sahelian zone)



Pho. 3 *F. albida* scattered in a field (Sudanian zone)



Pho. 4 old tree of *F. albida*



Pho. 5 wood of *F. albida* for household use

However, species with good dynamics would have been domesticated by farmers or would have a good capacity for resilience face of degradation factors. Indeed, *V. tortilis* is a fodder species exploited by populations. Its stability could be linked to its capacity to adapt to multiple disturbance conditions through a good ability to produce offsets after cutting and a potential for massive seed production. As for *A. indica*, its good dynamics in Sudano-Sahelian and Sudanian zone is due to its adoption by populations who keep it in their fields for later use as an energy source. In addition, its very high regeneration capacity gives it a good ability to colonize any type of environment (Traoré et al. 2020). For this species, it should be noted that the dissemination of its seeds is facilitated by certain birds that leave the seeds in parklands, thus contributing to its proliferation (Depommier, 1995). Most *F. albida* stands in Sudano-Sahelian zone are in association with *A. indica*. Another author (Traoré et al. 2020) also reported the stability of *V. tortilis* and *A. indica* in the juvenile layer of *F. albida* parklands.

Faidherbia albida, Vitellaria paradoxa and *A. digitata* are protected by the forestry code, but despite their social, ecological and pastoral importance, these species receive almost no maintenance from farmers. They are rather overexploited. Their structures are characterized by a high number of large-diameter individuals, which indicates an ageing of their populations. These results are in line with those (Issoufou et al. 2013) who state that uses for which harvesting causes the most damage to individuals are fodder and animal feed. Thus, *F. albida* is one of species most impacted by these harvesting pressures. On the other hand, the unstable structures observed in *F. albida* parklands in three sites are different from those obtained (Aboubacar et al. 2018) in parklands with *Neocarya macrophylla* (Sabine) Prance. This difference is due to the elaboration of *N. macrophylla-F. albida* (Nm-Fa) and *F. albida-Hyphaene thebaica* (Fa-Ht) species group structures. These established groups create a compensation effect that does not account for individual dynamics of species present. However, these results corroborate (Noulekoun et al. 2016) who studied the dynamics of *F. albida* parklands in Ethiopia.

Conclusion

This study highlighted the effect of the climatic gradient on the diversity and structure of *F. albida* parklands. It also highlighted the issue of sustainable management of *F. albida* parklands in Burkina Faso. Thus, although the climate has a significant influence on the characteristics of these agroforestry

parklands, they are partly impacted by the management of the populations, which threatens their sustainability. This requires the urgent adoption of sustainable management policies by managers and technical services responsible for the protection of forest resources in order to mitigate the effect of climate change on these agroforestry parklands.

Abbreviations

Not applicable.

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Authors' contributions

TICE designed the field study, analyzed the data and drafted the manuscript. ZA, BL DD and HBS participated in the data collection, analyzed and revised the manuscript. OO critically reviewed the different sections of the manuscript. All authors read and approved the final manuscript.

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