Vol. 15(1), pp. 20-27, January 2021
DOI: 10.5897/AJPS2020.2018
Article Number: 77FE89765899
ISSN 1996-0824
Copyright © 2021
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJPS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Plant Science

Full Length Research Paper

Variation of *Parkia biglobosa* morphological traits according to land use and agro-climatic zones in Southern Mali

Bokary Allaye Kelly[1*], Amadou Malé Kouyaté[1] and Sidiki Gabriel Dembélé[2]

[1]Institut d'Economie Rurale, Programme Ressources Forestières, Centre Régional de la Recherche Agronomique de Sikasso, BP 16 Sikasso, Mali.
[2]Institut Polytechnique Rural de Formation et de Recherche Appliquée (IPR/IFRA) de Katibougou, Mali.

Received 12 May, 2020; Accepted 9 December, 2020

A study was conducted in southern Mali to contribute to the domestication of *Parkia biglobosa*. Three agro climatic zones (North Sudanian "NS", South Sudanian "SS" and North Guinean "NG") and two stands (field and fallow) were concerned. Three plots of 0.25 ha each, were installed in each stand. Diameter at Breast Height (DBH), Total Height (TH) and Crown Diameter (CD) of adult trees were measured. The effect of agro-climatic zone on growth parameters was significant. The South and North Sudanian zones showed significantly higher means of DBH, TH and CD compared to the North Guinean zone. The mean DBH varied from 45.46 cm (NG) to 65.96 cm (NS). The mean TH varied from 10.68 m (NG) to 12.59 m (NS). The mean CD in the field stand varied from 10.50 m (NG) to 16.12 m (SS) and in fallow stand it varied from 11.21 m (SS) to 13.64 m (NS). Stand effect was not significant but the interaction zone*stand was significant. The effect of agro-climatic did not display an influence of the climatic gradient, suggesting that management practices played an important role in the growth of this species.

Key words: Domestication, fallow, field, growth parameters, management practices, Parkland species.

INTRODUCTION

Forest tree species are characterized by high genetic diversity. This diversity is important for the adaption of species to various climatic and environmental conditions. The high diversity is linked to geographical origin and to the difference between individuals within the same population (Goba et al., 2019). The diversity within a species can be assessed through morphological and molecular traits (Ikabanga et al., 2017; Avana-Tientcheu et al., 2019).

However, within climatic zones, environmental conditions can cause significant variations in the morphological characteristics of species populations (Dicko et al., 2019). Variability studies are needed to increase plant productivity and also for future breeding work (Freigoun et al., 2017). Phenotypic variability of a species could be assessed by identifying morphological descriptors and morphological data from geographical origins have been used in first studies of genetic diversity of tree species

*Corresponding author. E-mail: bokarykelly@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

(Kouonon et al., 2020). According to Samim et al. (2018), morphological descriptors are the basis for the characterization of plant genotypes on the basis of their phenotype.

Parkia biglobosa is a forest tree species of the family of Leguminosae/Fabaceae (Sacande et al., 2016), common in agroforestry parklands in the Sudanian Zone. It is an agroforestry species of major socio-economic importance in Benin, but also in the whole West African region (Ayihouenou et al., 2016). These authors reported that its conservation and domestication for the diversification of agricultural production depend on its ability to adapt to climate change. But, populations of this species are highly threatened in large parts of its range due to overexploitation and environmental degradation (Lompo et al., 2017).

According to Lompo et al. (2017), a sound conservation strategy for *P. biglobosa* and the promotion of its sustainable management should be based on scientific information about threats as well as ecological and genetic processes affecting this species. Assessment of the variation of the morphological traits of this species in relation to agro-climatic zones could contribute to this scientific information needed for a successful conservation strategy. Also, it is essential to know the phenotypical variability of this species for domestication purposes to preserve goods and services provided by *P. biglobosa* (Kouonon et al., 2020). Very recent studies have focused on the variability of morphological traits and to the identification of morphological descriptors of several trees species like *Adansonia digitata* (Bamba et al., 2019), *Lophira lanceolata* (Dicko et al., 2019; Lankoande et al., 2020), *P. biglobosa* (Avana-Tientcheu et al., 2019; Kouonon et al., 2020), and *Pterocarpus erinaceus* (Johnson et al., 2020).

In Mali, *P. biglobosa* is one of the most important parkland tree species, present in the north and the south of Sudanian Zones in the regions of Kayes, Koulikoro, Ségou, Sikasso; and in the north Guinean zones in the regions of Kayes and Sikasso (FAGUI, 2015). It is a forest tree species which regenerates naturally. The cultivation of *P. bigolobsa* began only recently and it is still very limited. The limitation of its cultivation in Mali was linked to some traditional considerations in rules that were established during the recent two to three decades. First, nursery experiments for seedling production and on-field plantation experiments started in Mali in the 1990's, and a relative success was only observed in the NG zone.

P. biglobosa is a useful, multi-purpose tree species having almost the same uses in the three study sites. The species provides food for human beings (such as, pulp and grains used to produce the spice called "soumbala" or "dawadawa"). This spice is rich in proteins and contains lipids, essential amino acids, essential fatty acids, vitamins and mineral compounds (Ouoba et al., 2003). It is particularly appreciated and widely used in Africa. *P. biglobosa,* which also provides food for animals (pulp) and contributes to income generation for rural populations; and therefore it contributes to fighting poverty. It provides medicine and sometimes craft wood (mainly in the NS and SS zones).

In all study zones, the main constraint in conducting this study was the low density of *P. biglobosa* populations in farmed fields as well as in fallows. The low density could be explained by several causes like natural mortality, density reduction by farmers in the field to reduce competition with associated crops (mainly cash crops like cotton which was in expansion in the whole southern Mali) and the weak natural regeneration in the fallow. Despite its importance, very few studies, if any, were published on the state of this resource despite climatic changes and the several constraints; while according to Lompo et al. (2017), in the light of climatic changes, safeguarding the genetic diversity of the species is crucial to foster adaptation and to support its long-term survival. Hence, to contribute to fill this knowledge gap in Mali, this study was funded by the Malian Government within the frame of the Competitive Funds for Research and Technological Innovation (CFRTI).

The objective of the study was to contribute to the domestication of the species in Mali. More specifically, it aims to (i) understand the state of the resource *P. biglobosa* in different agro-climatic zones, (ii) identify morphological descriptors important for the resilience of the species and (iii) develop strategies of renewal of *P. biglobosa* Parklands.

MATERIALS AND METHODS

Study sites

The study was conducted in three agro-climatic zones (the North Sudanian NS, the South Sudanian SS, and the North Guinean NG). These zones were selected based on climatic and environmental conditions as well as management practices (land use system and tree management). In the NS zone, the mean annual rainfall varies from 500 to 800 mm. It is a zone of slightly undulated plains, lowlands and depressions with heavy soils quite wet, and actively cultivated. It also contains extensive, fine-textured plains. The natural vegetation is constantly being degraded, and the existing woody species are those spared by man. In the SS zone, the mean annual rainfall varies from 800 to 1100 mm. Soils are deep alluvial, often the most fertile in the country, used for continuous cultivation and short fallow systems. The soils on rocky foundations are shallow or moderately deep. There are open or moderately dense woody stands on shallow soils. In the NG zone, the rainfall is over 1100 mm per year. The valleys in this area are cultivated in a continuous regime. Fallow system is longer and the density of woody species is higher. It is an excellent zone of timber exploitation. It is important to notice that the average altitude of parcels of studied populations of *P. biglobosa* increased from north to south but the difference in altitude was not very substantial. These altitudes in average were 276 m in NS zone, 312 m in the SS zone and 332 m in the NG zone.

Land and parkland trees are managed differently in the study sites. In the NG zone, land is less scarce and shifting cultivation still

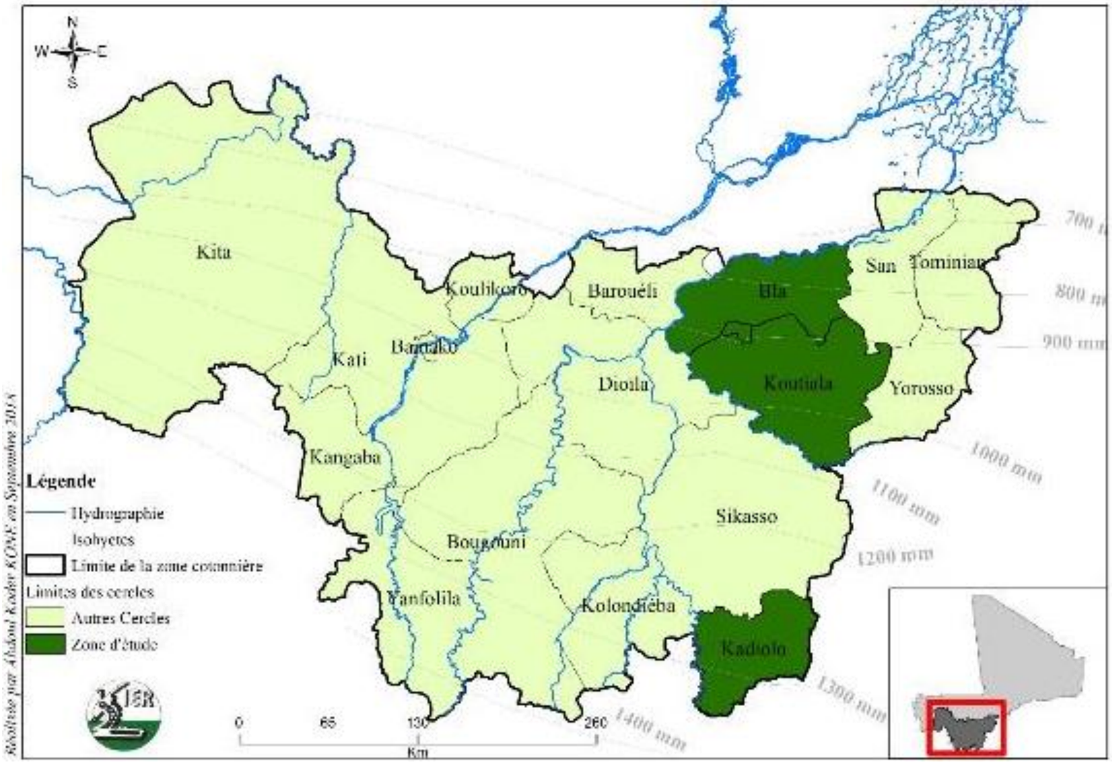

Figure 1. Map1 showing the study zones (green areas).

exists whereas in the other two zones, because of land scarcity, the same parcels are used continuously or with short fallow period. Also, like Burkina Faso (Lompo et al. 2017) and other West African countries, *P. biglobosa* is officially protected by national legislation in Mali. However, despite this protection, the species is cut for various purposes according to zones. In the NG zone, due to the presence of relative abundant vegetation, *P. biglobosa* trees are less exploited for purposes like fuel wood, charcoal or craft wood in contrary to the Sudanian zones where cases of their exploitation for various purposes were observed. Hence, *P. biglobosa* tree densities in the Sudanian zones are lower compare to the NG zone and because of the use of the same parcels continuously, *P. biglobosa* trees are older and bigger and therefore pruned to favour associated crops.

In each zone, one site was selected based on the availability of *P. biglobosa* populations in fields and fallows, the accessibility in all seasons, and the willingness of farmers to collaborate in research activities. The selected sites were Somasso (district of Bla) in the NS zone, Zanzoni (district of Koutiala) in the SS zone and Diou (district of Kadiolo) in the NG zone. Map 1 (Figure 1) shows the three study zones in green; and Map 2 (Figure 2) shows site localizations within the respective districts.

The site of Somasso (51°31'N, 36°27'W) in the NS zone has a little uneven relief composed of cultivable plains. The climate is North Sudanian, characterized by two seasons (the long dry season from October to May and the short rainy season from June to September). Agriculture is the main activity and the cultivated areas are large, dominated by cereal crops. Cotton and groundnuts are the cash crops. Vegetation is shrubby savannah with some big trees spared in the fields such as *Parkia biglobosa*, *Vitellaria paradoxa*, *Faidherbia albida* (PDESC-Somasso, 2019). The site of Zanzoni (36°52'N, 32°05'W) in the SS zone has little hilly relief composed of plains favourable for off-season crops. The climate is South Sudanian, with also two seasons with lengths similar to those of Somasso. The agriculture comprises food and cash crops such as cotton and peanuts. Vegetal resources are similar to those of Somasso but some protected forests and sacred woods are present (PDESC-Zanzoni, 2019). The site of Diou (35°46'N, 58°33'W) in the NG zone has a slightly uneven relief. The climate is North Guinean, with a dry season from November to May and a rainy season from May to October. Agriculture is the main activity and cereal production is mainly composed of Maize, while Cotton is grown as a cash crop. There are important forest resources consisting of natural formations, artificial plantations and sacred woods (PDESC-Diou, 2017).

Study design

The study design consisted of square plots of 50 x 50 m = 2500 m^2 (0.25 ha). Two factors were studied: the agro-climatic zones (ACZ) factor with three levels (NS, SS and NG) and the land use factor "called stand in the paper" with two levels (fields and fallows). Three plots were installed in each stand within each zone, giving six plots per agro-climatic zone. The total number of *P. biglobosa* populations was 18 (6 plots x 3 agro-climatic zones). All adult *P. biglobosa* trees (DBH ≥ 10 cm) in the plots were marked and measured. The geographical position of each tree was recorded using a GARMIN eTrex 10 GPS (accuracy ± 3 m).

Data collection and analysis

The variables measured were the diameter at 1.30 m above the ground (DBH) measured with a forest compass, the total height (TH) measured with a 12 m ruler, the crown diameter (CD) in the

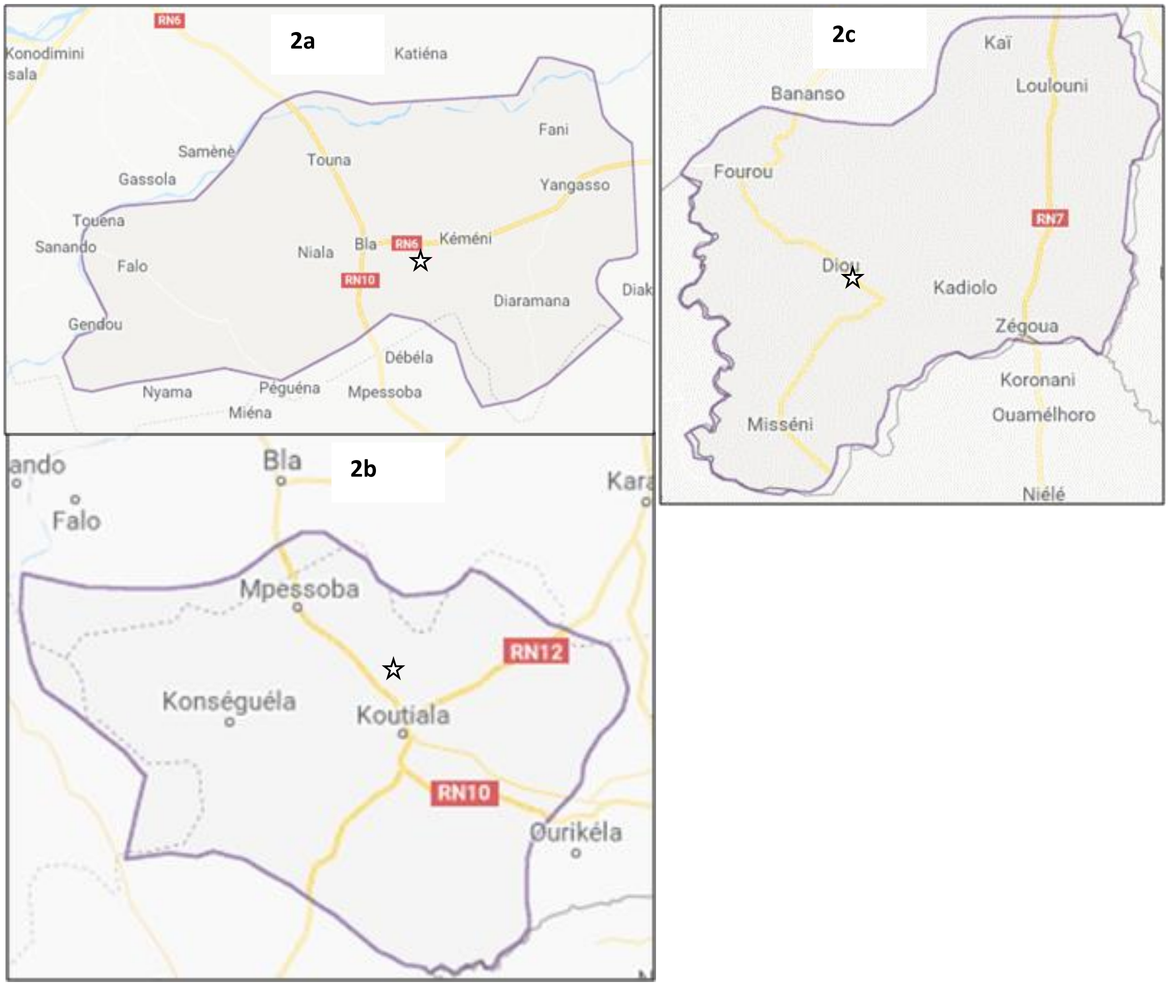

Figure 2. Map 2 showing sites localized in the respective districts each indicated by a star (2a Somasso in the district of Bla, 2b Zanzoni in the district of Koutiala and 2c Diou in the district of Kadiolo).

east-west and north-south directions measured with a 30 m measuring tape. Collected data were analysed using SYSTAT9 FOR WINDOWS software. Descriptive statistics and analysis of variance (ANOVA) were used as analysis methods. For the factors whose effects were significant, multiple comparisons of the means were made to distinguish the levels of the factor that were significantly different according to Bonferonni's method. The density of *P. biglobosa* in field and fallow stands in each zone was estimated based on the number of trees measured in the plots. Correlation coefficients between measured variables were also computed.

RESULTS AND DISCUSSION

Density and growth of *P. biglobosa* according to agro-climatic zones (NS, SS, NG) and stands (field, fallow) are presented and discussed as follows.

Density

The density of *P. biglobosa* by stand in each agro-climatic zone is shown in Table 1. The mean density of *P. biglobosa* increased from north to south (Table 1). The density was almost the same for the two stands (14 trees ha^{-1} and 13 trees ha^{-1} for fields and fallows, respectively). The same density was observed for the fields of the NS and SS zones (13 trees ha^{-1}). Higher density was observed for those of the NG zone (17 trees ha^{-1}). For fallows, the density increased from north to south (Table 1). The density of *P. biglobosa* was higher in the NG zone and a decreasing trend was observed from south to north for all stands together as well for fallow stands. For field stand, the highest density was observed in the NG (17 trees ha^{-1}), while the SS and NS zones had the same density (13 trees ha^{-1}). In the NG zone, the more abundant vegetal resources implying less pressure on *P. biglobosa trees* and the shifting cultivation implying new cleared parcels with more possibility to spare young *P. biglobosa* trees could explain the higher density observed in this zone. Mechanization of the agriculture could also explain the differences observed between zones. The mechanisation is more developed in the Sudanian zones

Table 1. Density of *P. biglobosa* by Agro-climatic zone and Stand.

Parameter	**Density (ha^{-1})**		
Agro-climatic zones (ACZ)	**Fields**	**Fallows**	**Mean ACZ**
North Sudanian (NS)	13	9	11
South Sudanian (SS)	13	13	13
North Guinean (NG)	17	18	18
Mean stands	14	13	

Table 2a. Mean diameter at body height (DBH) by stand and agro-climatic zone.

Agro-climatic zones (ACZ)	**Mean DBH (cm)**		
	Fields	**Fallows**	**Mean ACZ**
North Sudanian (NS)	70.53±21.43	61.40±8.57	65.96^a
South Sudanian (SS)	78.40±17.94	54.13±13.59	66.26^a
North Guinean (NG)	37.46±11.40	53.46±18.01	45.46^b
	Df	**F-ratio**	**P**
ACZ	2	17.121	0.000
STAND	1	3.039	0.085
SITE*STAND	2	12.456	0.000

Means with the same letter were not significantly different.

because of the intense production of cotton. Engines used require more space, which implies significant reduction of densities in production parcels. Also, because of this intense cash crop production to reduce competition between crops and trees, farmers reduce tree densities and prune mainly during cropping season.

For *P. biglobosa*, Dotchamou et al. (2016) reported a significant difference in density in both agro-ecological zones in Benin and the density of *P. biglobosa* is highest in the North (Sudanian zone 13 tree ha^{-1}) compared to the South (Sudano-guinean zone about 10 trees ha^{-1}). Their results contrast with ours as we observed the inverse but the density they observed for the Sudanian zone in Benin is the same as observed for the Sudanian zones in Mali (13 trees ha^{-1}) and the density they observed for Sudano-guinean is much lower than what we observed for NG zone (18 trees ha^{-1}). Avana-Tientcheu et al. (2019) reported a mean density of *P. biglobosa* in Tchad varying from 18 ± 12.73 to 28 ± 5.7 trees ha^{-1} for open forest and agricultural field systems, respectively. From our results, in the driest zone (NS) the density was higher in field stand compare to fallow (13 trees ha^{-1} vs 9 trees ha^{-1}). The scarcity of wood and land tenure system (resources in fallows are a common good of the community) could explain this result. Due to this system and to the need of craft wood, *P. biglobosa* trees in fallow stands are more exposed to exploitation. Studies carried out in the NS, SS and NG zones in southern Mali have reported densities of *P. biglobosa* varying from 4 to 16 trees ha^{-1} along the north south gradient (Diarra, 2017).

Growth parameters

The global analysis of variance on growth parameters of *P. biglobosa* showed a significant effect of ACZ on the diameter at body height ($p < 0.001$), the total height ($p = 0.001$) and the crown diameter ($p = 0.022$). The effect of stand was not significant for all variables, but the interaction between the two factors was significant. The means of measured variables as well as ANOVA output are shown in Table 2. Marginal means were shown for significant factors with F-ratios higher than that for the interaction. The mean of diameter at body height by stand and agro-climatic zone were shown in Table 2a.

The highest (78.40 cm) and lowest (37.46 cm) mean DBH values were observed in the Fields, in the SS and NG zones, respectively. The NG zone showed mean DBH significantly lower than those of Sudanian zones, which are not significantly different (Table 2a). Despite the non-significant effect of stand, in the Sudanian zones, fallows showed lower means compared to fields, while the inverse was observed in the NG zone. The Mean of total height by stand and agro-climatic zone were shown in Table 2b.

The highest (13.57 m) and lowest (10.22 m) means TH also were observed in the Fields in the SS and NG

Table 2b. Mean total height (TH) by stand and agro-climatic zone.

Agro-climatic zones (ACZ)	Mean TH (m)		
	Fields	**Fallows**	**Mean ACZ**
North Sudanian (NS)	12.53±1.83	12.65±189	12.59[a]
South Sudanian (SS)	13.57±1.26	10.89±1.82	12.23[a]
North Guinean (NG)	10.22±1.59	11.15±2.98	10.68[b]
	Df	**F-ratio**	**P**
ACZ	2	8.020	0.001
STAND	1	1.710	0.195
SITE*STAND	2	7.059	0.001

Means with the same letter were not significantly different.

Table 2c. Mean crown diameter (CD) by stand and agro-climatic zone.

Agro-climatic zones (ACZ)	Mean CD (m)		
	Fields	**Fallows**	
North Sudanian (NS)	14.62±3.22	13.64±4.00	
South Sudanian (SS)	16.12±2.04	11.21±2.65	
North Guinean (NG)	10.50±2.89	13.31±3.98	
	df	**F-ratio**	**P**
SITE	2	4.015	0.022
STAND	1	2.300	0.133
SITE*STAND	2	10.827	0.000

Table 3. Pearson correlation matrix.

	DBH	**HT**	**CD**
DBH	1		
HT	0.702	1	
CD	0.7	0.713	1

zones, respectively. The NG zone showed mean TH significantly lower than those of Sudanian zones, which are not significantly different (Table 2b). Stand effect was not significant; but in the SS zone, Fields showed higher means compared to Fallows and the inverse was observed in the NG zone. The Mean of crown diameter by stand and agro-climatic zone are shown in Table 2c.

The same trend as for the DBH was observed for the variation of the mean CD according to Stands and Agro-climatic zones. A relative high correlation was observed between the three measured variables (Table 3). Correlation coefficients between the three variables are of same magnitude (70 to 71%).

The analysis of variance showed non-significant effects of Agro-climatic zone on growth variables for Fallow stands; whereas, the effect was significant on the three variables for Field stands. Means of measured variables by Agro-climatic zone in Field stands are shown in Table 4.

For the three Agro-climatic zone variables, the NG zone showed significantly lower means than the Sudanian zones, which are not significantly different (Table 4).

The mean DBH varied from 45.46 to 66.26 cm, the mean TH varied from 10.68 m to 12.59 m and the mean CD varied from 10.50 m to 16.12 m, according to Agro-climatic zones. Differences between zones were significant for all these variables, and lowest means were observed in the NG zone which was the wettest zone. This result could be explained by changing cultivation patterns, as the new cleared parcels have relatively young *P. biglobosa* trees with small sizes compared to Sudanian zones where the same parcels are being used for very long cultivation times. Also, due to the presence

Table 4. Means of measured variables by agro-climatic zone in field stand.

Agro-climatic zones (ACZ)	Mean DBH (cm)	Mean TH (m)	Mean CD (m)
North Sudanian (NS)	70.53±21.43[a]	12.53±1.89[a]	14.62±3.22[a]
South Sudanian (SS)	78.40±17.94[a]	13.57±1.82[a]	16.12±2.04[a]
North Guinean (NG)	37.46±11.40[b]	10.22±2.98[b]	10.50±2.89[b]
F-ratio	23.28	18.38	16.61
Probability	0.000	0.000	0.000

Means with the same letter are not significantly different.
DBH = diameter at body height, TH = total height, CD = crown diameter.

of relative abundant vegetation and the production system in the NG zone, *P. biglobosa* trees are subject to higher competition and lower benefit from cultivation activities.

Several authors have reported morphological variation of *P. biglobosa* according to study zones and sites. In southern Mali, Diarra (2017) observed the highest mean DBH (25.8 cm) and mean CD (9.44 m) of *P. biglobosa* in the NS zone compared to the SS and NG zones. Other characteristics of the species were also found to vary according to study zones. For instance, Dembélé (2019) observed that the onset of the flowering and the fruiting progressed from the south (NG zone) to the north (NS zone); but the length of flowering (4-5 months) and fruiting (5-6 months) is almost the same for the three zones. Traoré (2019a) observed that some leaf morphological traits were discriminant between zones and the NS and SS zones had lower number of pairs of pinnae and leaflets compared to the NG zone. Regarding fruit production of *P. biglobosa*, Traoré (2019b) observed that there was not a climatic gradient effect; but the production was rather explained by farmers' land use and tree management practices according to zones.

In the south-west of Nigeria, Oyerinde et al. (2018) observed a difference between three sites with respect to CD of *P. biglobosa*; the least rainy site (Ekiti) have the highest average CD (13.71 m), but they did not observe a significant difference between sites with respect to TH and DBH. The TH mean values in the three sites (6.92 m; 7.11 m and 7.43 m) observed by these authors are lower than that of this study, whereas the means DBH (147 cm, 150 cm and 161 cm) they observed are higher. Variation according to climatic zones was also reported for other forest tree species regarding various aspects. For instance, Kelly et al. (2018) observed the highest mean DBH and mean CD of *V. paradoxa* in the NS zone compared to the SS and NG zones in southern Mali. Houètchégnon et al. (2015) reported that for *Prosopis africana*, variables discriminating climatic zones were: DBH, trunk height, diameter and number of leaflets, number of seeds and pod diameter. Thangjam et al. (2019) observed highly significant differences ($p<0.001$) between the agro climatic zones of *Parkia timoriana* in the North-Eastern states of India for the seed and pod traits.

For all growth variables, the difference between stands was not significant in all agro-climatic zones. A similar result was observed by Avana-Tientcheu et al. (2019) in Chad. These authors reported that growth parameters of *P. biglobosa* such as tree diameter, total height, and basal area are not significantly influenced by the type of production system (open forest, agricultural field, fallow and home garden) despite the observed differences in values. The means they observed (62.97±16.53 cm in fallow to 73.92±14.10 cm in field for the diameter, and 12.54 m in open forest to 14.68 m in fallow for total height) are close to the results of this study.

The differences observed between agro-climatic zones did not display an effect of climatic gradient. This result suggests that climatic conditions are not the only important factor influencing *P. biglobosa* growth and in determining phenotypic traits of adult trees. The way farmers are managing parklands and the production systems would be important factors. Another factor influencing phenotypic traits of *P. biglobosa* trees would be the genetic factor. For instance, according to Lompo et al. (2017), *P. biglobosa* is structured according to a South-North gradient and there would be a phenotypic variation, depending on the origin, due to the environment and the genetic difference according to latitude. Oyerinde et al. (2018) also, in explaining their results, referred to the genetic factor as a source of differences displayed in relation to the growth parameters of *P. biglobosa* in addition to environmental (rainfall, humidity, temperature), agro-ecological zone and soil factors. The same phenomenon was observed for other forest tree species as well. Goba et al. (2019) observed geographical structure of phenotypic variation in *Pterocarpus erinaceus* Poir in Côte d'Ivoire.

Conclusions

The results of this study revealed significant effect of climatic zone on growth parameters of *P. biglobosa,* which did not display a climatic gradient trend. This result suggests that other factors like production systems and management practices have influence on the growth parameters of *P. biglobosa* as has been observed for other Parkland tree species, such as *V. paradoxa*. The effect of stand was not significant; but for most cases, variable means were higher in field stand compared to fallow. This result could also be explained by management practices and by the care brought to the crops that can benefit the trees. Hence, growth parameters of *P. biglobosa* highlighted the importance of management practices and any domestication strategy must take this into account.

CONFLICT OF INTEREST

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors are grateful to the Malian government for funding the *Parkia* project through the Competitive Fund for Research and Technological Innovation (CFRTI). They also appreciate Somasso, Zanzoni and Diou villages' authorities and populations for the permission given to conduct this study on their field and fallow parcels and also for cooperating in field activities. They are also grateful to the field technicians (Isaïe Dembélé, Younoussa Diarra and Mamadou Diabaté), who carried out the work of monitoring and data recording.

REFERENCES

Avana-Tientcheu MLA, Keouna S, Dongock Nguemo D, Mouga Masdewel B (2019). Structure des peuplements et potentiel de domestication de *Parkia biglobosa* dans la région de Tandjilé-Ouest (Tchad). International Journal of Biological and Chemical Sciences 13(1):219-236.

Ayihouenou E, Fandohan A, Sode I, Gouwakinnou G, Djossa B (2016). Biogéographie du néré (Parkia biglobosa (Jack.) R. Br. ex. Don.) sous les conditions environnementales actuelles et futures au Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB). Numéro Spécial Agronomie, Société, Environnement and Sécurité Alimentaire.

Bamba H, Korbo A, Sanou H, Ræbild A, Kjær ED, Hansen JK (2019). Genetic differentiation in leaf phenology among natural populations of *Adansonia digitata* L. follows climatic clines. Global Ecology and Conservation 17:e00544.

Dembélé AS (2019). Influence de l'utilisation des terres en fonction des zones agro-climatiques sur la floraison et fructification de *Parkia biglobosa* (Jacq.) Benth (néré) au sud du Mali. Mémoire de fin d'étude pour l'obtention du diplôme d'ingénieur, spécialité Eaux et Forêts, session de décembre 2019. IPR/IFRA. Koulikoro, Mali.

Diarra I (2017). Evaluation de la disponibilité des espèces d'arbres et d'arbustes locaux comestibles dans la région de Sikasso. Mémoire d'Ingénieur des Eaux et Forêts. IPR/IFRA de Katibougou. Mali 68 p.

Dicko A, Natta AK, Biaou HSS, Akossou A (2019). Assessing Morphological Traits Variation and Fruit Production of *Lophira lanceolate* (Ochnaceae) in Benin. American Journal of Plant Sciences 10:1048-1060.

Dotchamou FT, Atindogbe G, Sode AI, Fonton HN (2016). Density and spatial pattern of *Parkia biglobosa* under climate change: the case of Benin. Journal of Agriculture and Environment for International Development 110(1):173-194.

FAGUI (2015). Répertoire des espèces forestières des régions de Kayes, Koulikoro, Sikasso et Ségou. Mali P 339.

Freigoun SAB, Raddad EYA, Elagib TY (2017). Provenance Variation in Seed Morphological Traits and Early Seedling Growth of *Balanites aegyptiaca* Del. Sudan Journal of Agricultural Research 27:93-108.

Goba KAE, Kouonon LC, Koffi KG, Bony BS, Diomandé I, Sié RS (2019). Morphological Diversity within *Pterocarpus erinaceus* Poir. (Fabaceae), an overexploited species in the savannahs of Côte d'Ivoire. American Journal of Plant Sciences 10(9):1675-1688.

Houètchégnon T, Gbèmavo DSJ, Ouinsavi C (2015). Morphological variability of *Prosopis Africana* (Guill., Perrot. Et Rich.) Taub in Benin, West Africa. American Journal of Plant Sciences 6:1069-1079.

Ikabanga DU, Stévart T, Koffi KG, Monthé KFS, Nzigo-Doubindou EC, Dauby G, Souza A, M'Batchi B, Hardy OJ (2017). Combining morphology and population genetic analysis uncover species delimitation in the widespread African tree genus. Santiria Phytotaxa 321(2):166-180.

Johnson BN, Marie Luce A, Adjonou QK, Segla KN, Kokutse AD, Kokou K (2020). Morphological Variability of *Pterocarpus erinaceus* Poir. in Togo. Available at: https://www.hindawi.com/journals/ijfr/2020/4878169/

Kelly BA, Poudyal M, Bouvet JM (2018). Variation of *Vitellaria paradoxa* phenophases along the north-south gradient in Mali. Research in Plant Biology 8:8-16.

Kouonon LC, Koffi KG, Adjoumani K, Mobio AD, Goba KA (2020). Caractérisation phénotypique du néré (*Parkia biglobosa* (Jacq.) R. Br. ex G. Don, Fabaceae) dans trois types de savane de Côte d'Ivoire. International Journal of Biological and Chemical Sciences 14(2):555-569.

Lankoande B, Ouédraogo A, Kouyaté AM, Boussim IJ, Lykke AM (2020). Production and morphological traits of Lophira lanceolata fruits in natural stands. Forests, Trees and Livelihoods 29(3):176-186.

Lompo D, Vinceti B, Gaisberger H, Konrad H, Duminil J, Ouedraogo M, Sina S, Geburek T (2017). Genetic conservation in Parkia biglobosa (Fabaceae: Mimosoideae)-what do we know?. Silvae Genetica 66(1):1-8.

Ouoba LII, Rechinger KB, Diawara B, Traoré AS, Kakobsen M (2003). Degradation of proteins during the fermentation of African locust bean (Parkia biglobosa) by strains of Bacillus subtilis and Bacillus pumilus for production of Soumbala. Journal of Applied Microbiology 94(3):396-402.

Oyerinde OV, Olusola JA, Adebo AA (2018). Variation in morphometric traits of trees, pods and seeds of *Parkia biglobosa* (Jacq) G. in southwestern Nigeria. International Journal of Conservation Science 9(1):185-192.

PDESC (2017). Programme de Développement Economique Social et Culturel 2017-2021. Commune rurale de Diou.

PDESC (2019). Programme de Développement Economique Social et Culturel 2018-2022. Commune rurale de Somasso.

Sacande M, Sanogo S, Beentje H (2016). Guide d'identification des arbres du Mali. Royal Botanic Gardens.

Samim S, Sood S, Singh A, Verma A, Kaur A (2018). Morphological Characterization of Okra [*Abelmoschus esculentus* (L.) Moench]. International Journal of Current Microbiology and Applied Sciences 7:2011-2019.

Thangjam U, Sahoo UK, Thong P (2019). Effect of agroclimate on seed and seedling traits of tree bean (*Parkia timoriana* (DC) Merr.) in North East India. Indonesian Journal of Forestry Research 6(1):17-26.

Traoré AB (2019a). Influence de l'utilisation des terres en fonction des zones agro-climatiques sur la morphologie des feuilles et des fruits de *Parkia biglobosa* (Jacq.) Benth (néré) au sud du Mali. Mémoire de fin d'étude pour l'obtention du diplôme d'ingénieur, spécialité Eaux et Forêts, session de décembre 2019. IPR/IFRA. Koulikoro, Mali.

Traoré L (2019b). Contribution à l'étude de la variation des caractères dendrométriques des arbres adultes de *Parkia biglobosa* (Jacq.) Benth (néré) et la quantification de la production de fruits en fonction de l'utilisation des terres et des zones agro-climatiques au sud du Mali. Mémoire de fin d'étude pour l'obtention du diplôme Universitaire de Technicien Supérieur (DUTS), spécialité Eaux et Forêts filière (AGRFH), session de septembre 2019 IPR/IFRA. Koulikoro, Mali.