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Research Article

Influence of environmental conditions on *Faidherbia albida* Parklands in the Sudano Sahelian Zone of Cameroon

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Abstract

Natural populations or landraces contain a high level of genetic variation that can be used for the selection of *plus trees* in *Faidherbia albida* agroforestry parklands in the Sudano-Sahelian zone of Cameroon. With the high rate of deforestation and overpopulation in recent times, there is the danger of losing these naturally adapted landraces of trees. This study investigates the influence of environmental conditions (altitude, human activity, rainfall and soil types) on four (Kodex, Mambang, Dinao and Parkine) *Faidherbia albida* agroforestry parklands in Cameroon. A forest inventory sampling method with a set of 33 plots 200 m in diameter was established in the parklands to collect data. Phenotypic measurements (height, diameter at breast height, number of branches, crown diameter and calculated biovolume) were taken and leaf phenology was observed on 156 trees in addition to environmental conditions of the parklands. Species diversity was recorded only in the transects of Kodek and Parkine agroforestry parklands during the inventory. Significant differences were observed among the agroforestry parklands, the soil types, altitude, and human activities on the morphological parameters measured. The inverse phenology of *Faidherbia albida* was observed in three of the parklands with Mambang still conserving its leaves in the rainy season. A total of 1904 trees (1233 from Kodek and 671 from Parkine) were recorded during the species diversity inventory process from 63 species with Parkine parkland being the most diverse in species types with Shannon H = 2,058 index at

Kodek and Shannon H = 2.53 index at Parkine. The results of this study indicated that diverse environmental conditions do exist in these parklands and have influenced the measured parameters. This information can aid in the selection of *plus-trees* for breeding, conservation and management of the species while the information on species diversity will assist in monitoring the dynamic of the parklands.
Keywords: Agroforestry parklands, *plus-trees*, morphology, phenology, species diversity

Introduction

An agroforestry tree *Faidherbia albida* (Del.). A. Chev. is mainly a species of the Sudanian and Sahelian zones of Africa, introduced in West Africa a long time ago during the transhuman trade from Sudan and Ethiopia which is reported to be the center of origin of the species (Vandenbeldt, 1991). Along the transhumant trade route, the cattle transported the seeds of this species in their digestive tracts and deposited them in their waste in the Sudano-Sahelian zone of Cameroon. The exhaustion of cultivated soils in the Far North region around the 1990s, accompanied by the low soil fertility led to the initiation of projects known as conservation agriculture that encouraged the integration of trees on farmlands in Mayo Danay and agroforestry in Mayo Tsanga (Pelissier, 1980). Many species (*Faidherbia albida*, *Acacia seyel*, *Acacia nilotica*, *Khaya senegalensis*, *Vitellaria paradoxa*, *Adansonia digitata*, *Parkia biglobosa*, *Leucaena spp.*, *Combretum spp.*) resulting from natural regeneration were protected on farmlands and developed as agroforestry parklands. They are found in mixed stands and names have been assigned to some parklands based on the dominant tree species (Seignobos, 1978; Seignobos, 1982a; Raison, 1988). *Faidherbia albida* species dominated most of the parklands because of its agroforestry potential from its inverted phenology and importance to the local communities. These trees have survived severe environmental conditions, from drought in the 1960s to 1980s to frequent flooding and extreme temperatures (Engref, 2003; Nicholas et al., 2018). Over their lifetimes they show how they are well adapted as a landrace. According to Zeven 1998, landraces are genetic resources that have evolved continuously under natural and farmer's selection practices rather than through gene bank collection or plant breeding programs. The conditions where landraces are grown are usually associated with different patterns of genetic diversity or variability reflecting processes of adaptation of germplasm to the environmental factors making these landraces likely to have greater adaptation potential than genotype that may be introduced (Rauf et al., 2010; Manphool et al., 2014). The high rate of deforestation, the effect of climate change and overpopulation in recent times are leading to a reduction in farmland, there is a danger of losing these naturally adapted landraces of trees. There is an urgent need to identify the environmental variables that have influenced the desired traits throughout the life span of *Faidherbia albida* to inform plus-tree collections for improving the planting, management and conservation of the species. This work investigates the influence of environmental conditions on morphological traits and describes the population structure of *Faidherbia albida* agroforestry parklands in the Sudano-Sahelian zone of Cameroon.

Materials and methods

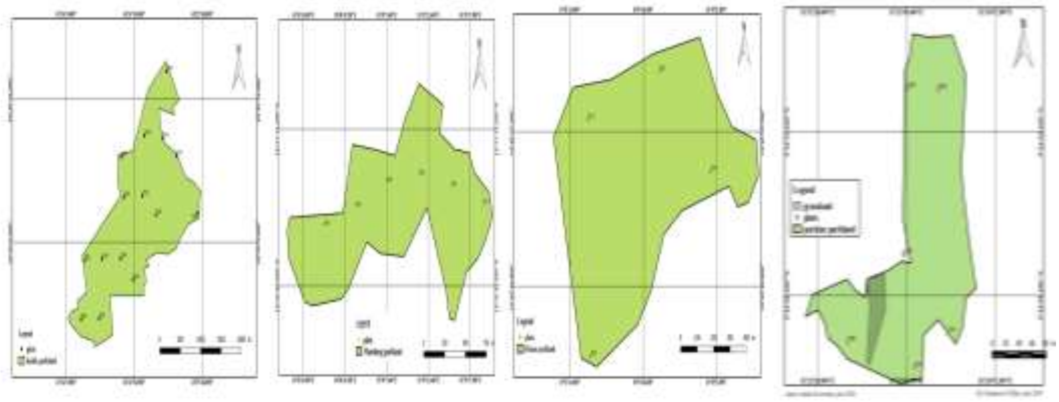
Geographical description of the zone

This study was conducted in four *Faidherbia albida* agroforestry parklands in the Sudano-Sahelian zone covering the two northern regions of Cameroon (Fig. 1) which are the main production areas of the species. The northern zone is characterized by a long dry season and a short rainy season with rainfall varying between 400 and 1200 mm/year. The Sahel of Cameroon is situated between latitude 9^{o} -11^{o} N and longitude 13^{o} -15^{o} E with altitude ranging from 350-450 m above sea level (asl) and temperature between 20°C and 45°C. The vegetation of this agro-ecological zone is characterized by the presence of thorny steppes made up of trees, shrubs, and grasses. It covers a surface area of 102,068 km^2 and includes the major ecological relief of the Mandara Mountains, Far North Plains and Benue Plains.

Forest inventory method

Forest inventory method was used for the sampling with GPS and QGPS to delimit the total surface area of the parklands and the geographical position of each sampled tree. Transects were laid across each parkland with a distance of 390 m between each transect subdividing the sites into plots located 200 m apart. A set of 33 plots of 200 m in diameter was established in the parklands in which to collect data, determined for each park on the basis of the total park surface area and the total number of plots (Fig. 2). Morphology data (diameter at breast height, height, crown diameter, number of branches, biovolume calculated and leaf fall) were measured on 156 trees (78 in Kodex, 30 in Mambang, 18 in Dinao and 30 in Parkine) of *Faidherbia albida*. Environmental variables (altitude, Longitude, Latitude, human activity (pruning and clear-cut where all the branches are removed from a tree and only the trunk or stem remains), rainfall and soil types) were recorded at each site and confirmed using the Institute of Agricultural Research for Development (IRAD) unpublished report. The foliage assessment was done through observation in the months of May, June and July 2016 on the percentage of the foliage present on the trees found in each plot. These percentages were grouped into 3 categories of classes distributed as follows: from 0 to 25% of the leaves found are considered as leafless trees, from 26 to 75% and more than 75% are considered as medium leafy and fully leafed trees, respectively. Rainfall data collection (water quantity in mm) was done at the rainfall stations installed by SODECOTON agents in each park decades ago. This helped us to see the effect of rainfall on leaf fall and to investigate the inverse phenology of *Faidherbia albida*. Inventory of species diversity and richness in Kodek and Parkine agroforestry parklands were recorded because their trees were very big in diameter and height and were considered to be the oldest parklands in the two regions (IRAD, unpublished report and personal communication with Tapsou). However, no information was available about the ages of these trees or when the agroforestry parklands were established. The number of transects and plots was increased (16 transects and 102 plots for Kodek and 8 transects and 38 plots for Parkine) by reducing the distance between them so that data for all possible tree species could be obtained in these agroforestry parklands.

Figure 1. Map showing the Sudano–Sahelian zone and the position of the four agroforestry parklands in Cameroon



Kodek **Mambang** **Dinao** **Parkine**

Figure 2. Delimitation of the agroforestry parklands showing the number of plots for measured parameters in *Faidherbia albida*

Data analysis

All measurements were entered into an Excel file and transferred to the SPSS statistical package (version 20) for analysis. Histogram or frequency distribution diagrams were used to describe the vertical and horizontal structures of the parklands studied. Descriptive statistics were tabulated and one-way Analysis of Variance (ANOVA) was computed on measured parameters in relation to the environmental variables of the parklands. The DUNCAN multiple range test was used for the comparison of means. Species diversity was estimated using the Shannon Diversity Index:

- $$H = -\sum_{i=1}^{S} Pi \ln(Pi)$$ (Magurran, 1988)

I = a species of the study environment, Pi = proportion of a species i compared to the total number of species (S) in the study environment (Pi = Ni / N). This index makes it possible to quantify the heterogeneity of the biodiversity of a study environment. H values indicate when species diversity is high, with a large number of species or low when different frequencies between the species are encountered. Species richness was calculated as: F = Ni / N * 100. Ni = the number of individuals in a particular species, the total number of species in the parklands.

Results

Effect of agroforestry parklands on measured parameters

Analysis of variance results showed that the differences among the agroforestry parklands were highly significant on all the measured parameters with p-values ranging from 0.000 for diameter and the number of branches to 0.007 for calculated biovolume (Fig. 3). Kodek Park had the highest values for all of the parameters studied, followed by Parkine for height, diameter and number of branches. Dinao had the lowest values in all measured parameters. Mambang values were higher than Parkine only in biovolume and crown diameter. Heights varied from 8 m to 12 m, diameters between 1m to 2 m, biovolumes from 200 to 1005 cm^3, crown diameters from 5 cm to 8.4 cm and number of branches from 6 to 12. The trend of variation in plant height, diameter, number of branches, crown diameter and biovolume among the parklands was very similar (Fig. 3). The variation in ages of the trees, could be the origin of the differences in these parameters. Studies on the morphological diversity of *Faidherbia albida* in common garden experiments gave similar results. Results reported previously from genetic diversity studies (number of alleles) using SSRs markers showed less differences in variation overall (Tchatchoua et al., 2020). However, the effect of environment is known to be significant on morphological traits while not on genetic diversity, hence the reason for conducting common garden experiments. Future studies could assess associations between growth parameters, genetic variation and the environment through analyses such as GWAS (genome wide association studies) on the factor of tree age.

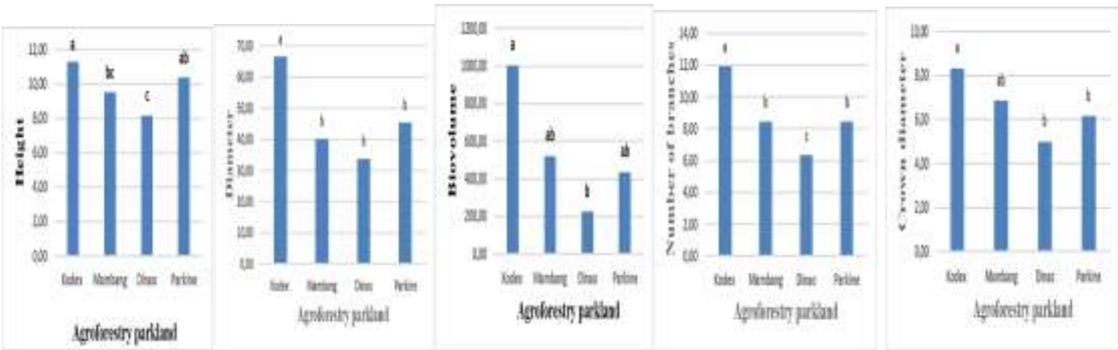


Figure 3. Comparison of variables in the different agroforestry parklands.

Effect of soil types on measured parameters

Analysis of variance shows that the type of soil significantly influences certain parameters (Diameter, p = 0.018 and the number of branches, p = 0.012). However, it did not significantly influence the height of plants (p = 0.111); biovolume (p = 0.151) and crown diameter (p = 0.152) (Fig. 4). The trend among the soil types of variation in plant height, crown diameter and biovolume are similar (Fig. 4). The morphological parameter values could be grouped into three categories depending on the type of soil: 1) in loamy and sandy loam soils, the highest values were recorded for height (11.6 and 10.6 m), biovolume (1000 and 800 cm3), crown diameter (8.5 and 7.5 m) and diameter (1,85 m and 1,84 m); 2) in lateritic soils the lowest for these parameters were recorded and 3) for number of branches per plant trees in the lateritic soil presented the largest values (13 branches) while those in loam-clay soil had the least number of branches (Figure. 4).

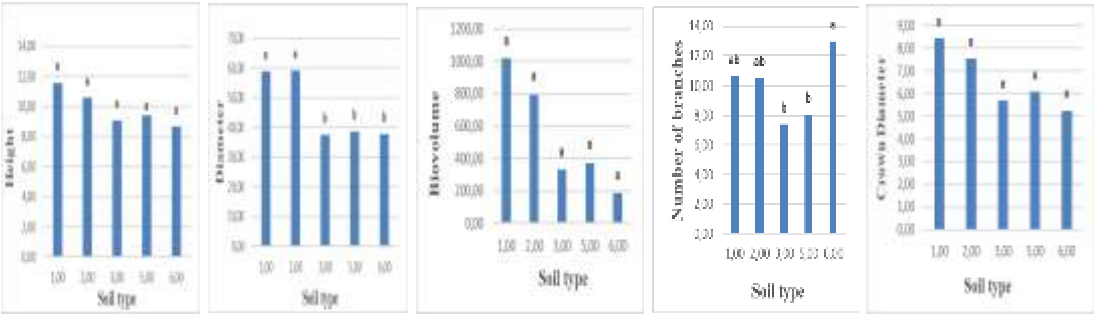


Figure 4. Comparison of variables to the different soil types. 1 = Loamy; 2 = Sandy-loam; 3 = Loam-clay; 4 = Sandy-clay; 5 = lateritic soil, 6 =Vertisol

Effect of altitude on measured parameters

Analysis of variance shows that differences in altitude among the parklands significantly influenced all of the measured parameters (Table 1). The general patterns of the curves were the same for all the measured traits (Fig. 5) with no trend observed. The maximum values were generally recorded at altitudes 361m, 375m, 382m and 452 m. The lowest values were generally noted in the interval (364-372m) and (434-443m). This shows altitude is not a good determinant when selecting plus trees of *Faidherbia albida* in the different agroforestry parklands contrary, consistent with the studies of Woldeselassie Ogbazghi et al., (2006).

Table 1. ANOVA of measured parameters to altitude

Measured parameters	Sum of squares	DF	MS	F	Sig. value
Height	384,431	19	20,23	2,03	,011
Diameter above 1.3 m	42709,852	19	2247,89	2,31	,003
Calculated Biovolume	40518936,039	19	2132575,58	1,99	,012
Number of branches	916,150	19	48,22	3,75	,000
Crown diameter	553,490	19	29,131	2,05	,010

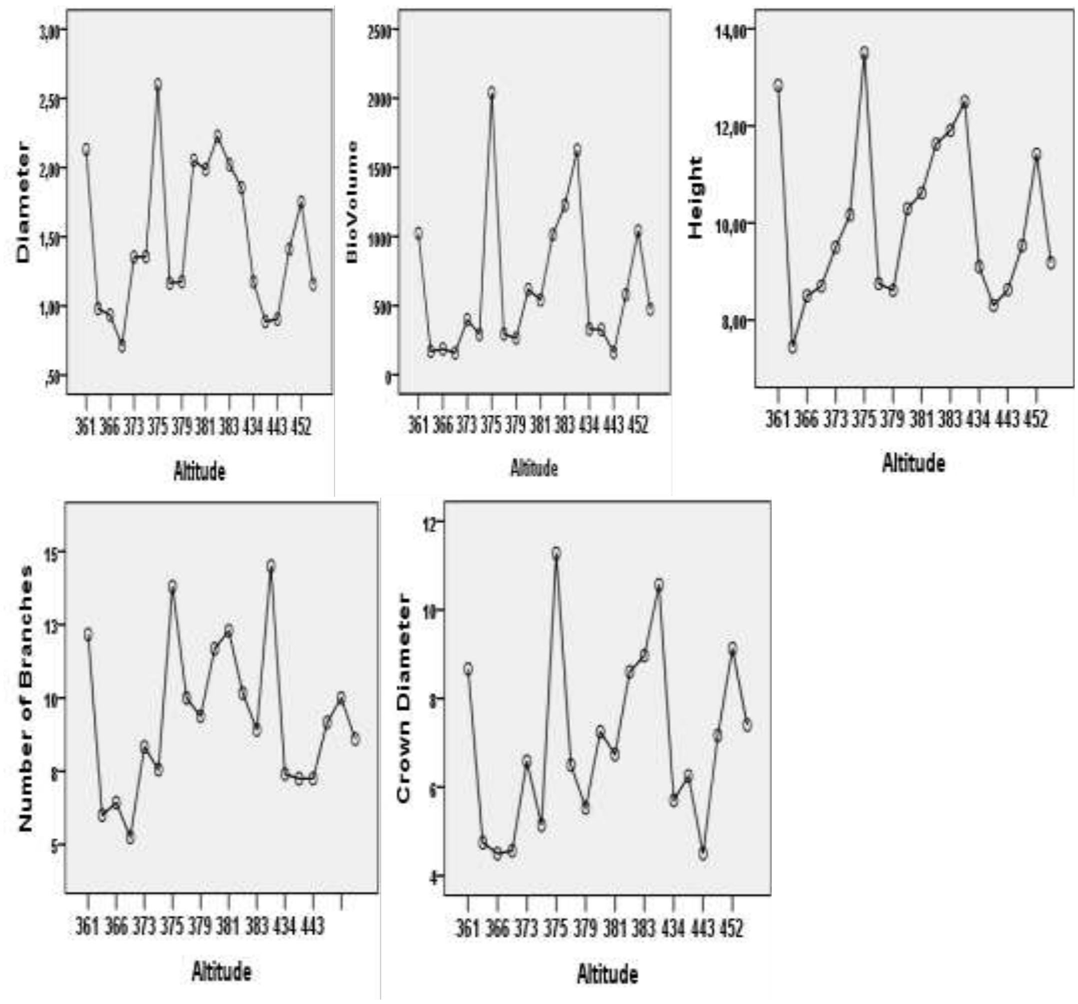


Figure 5. Comparison of variables to altitude.

Effect of human activities on measured parameters

The highest values for all the measured parameters were found on trees subjected to both the horizontal or crown cut (clear cut) and partially pruning while the lowest values were in totally pruned plants and those showing no trace of human activities (Fig. 6). The cattle rearers because of their desire to preserve the trees to continue producing forage for their cattle, usually collect forage from large trees. However, total pruning of these trees is mostly done when the cattle are sent to the field to feed on the small-sized trees. No published report has been found on this phenomenon but observed in the field in this study. Also, because most of the big trees are either cut horizontally or pruned they produce few seeds leading to poor regeneration. The danger in this activity is that it affects the evolutionary potential of the species. All measured parameters were significantly influenced by human activity ($p < 0.05$). Similar trends were observed in four of the parameters with the exception of a number of branches. The partially pruned trended higher than those horizontally cut (Fig. 6). Many scientists (Breman & Kessler 1995; Hamawa et al., 2018) in the Sahel zone of Cameroon and Africa have been interested on studying the effect of human activities on population structure but not on how these activities affect tree morphological parameters.

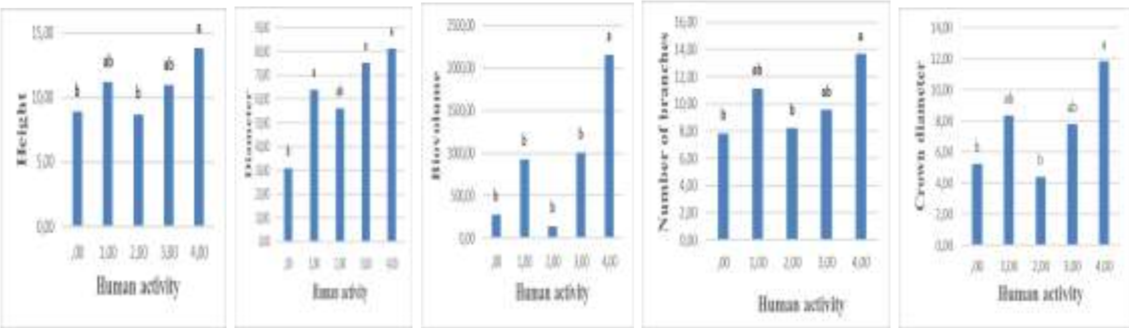


Figure 6. Comparison of variables to human activities. 0 = absent; 1 = partially prunned; 2 = totally prunned; 3 = clear cut; 4 = clear cut and prunned

Variation in leaf phenology

A study was initiated in the four populations on the effect of two climatic conditions on the reverse leaf phenology response of *Faidherbia albida*. The results indicated that in leaf fall among and within populations varied, with the Mambang park still maintaining its leaves during the rain (Fig. 7). At the beginning of the rainy season (end of May), the percentage of leaves remaining on the trees is high, 45% in Dinao, 35% in Kodek and 54% at Parkine with the precipitations recorded in these sites as 55mm, 43mm and 105 mm respectively. When the rainy season reaches its peak in mid-June, these percentages fall sharply to 5% in Dinao, 16% in Kodek and 32% in Parkine. Thus individuals of Dinao Park have lost the most leaves, while those of Parkine preserved the most despite the highest precipitation compared to other sites (98 mm in Parkine against 85 mm in Dinao, and 56 mm in Kodek). At the end of rains, leaf percentage is low, they are absent in Dinao (when rains are finished), 9% Kodek (27 mm of precipitation) and 14% in Parkine (28 mm of precipitation). The Mambang site presented a different variation to that of the three sites. The percentage of leaves per individual at Mambang did not decrease during the rainy season. At the end of May, the precipitation is absent in this park and the leaf percentage is 23%. This percentage is maintained as precipitation reached 54 mm in mid-June and increased to 33% when the precipitation was 4 mm at the end of June. It was previously noted that defoliation is a result of the fall in temperature at the beginning of the rainy season (data not shown, World Agroforestry Center (2009). Many environmental factors have been reported to trigger and hasten leaf senescence. Temperature and photoperiod are regularly mentioned for temperate species (Estrella & Menzel, 2006) along with stresses such as drought (Hwang et al., 2014; Estiarte & Peñuelas, 2014), water logging, and mineral deficiencies (Smart, 1994). In Acacia Senegal leaf buds were found in the first week of April and leaf completely developed in August at the peak of the rainy season while leaf senescence starts in late September (Diatta et al., 2022). No study has been reported on the leaf phenology of *Faidherbia albida* in Cameroon, however, previous results that flowering and fruiting in this species occur between the months of December and April (Zeh-Nlo & Joly 1990) can confirm our findings with leaves. Even in temperate forest trees where leaf senescence is a phenomenon that leads to tree dormancy, there is very little literature on the topic. Vitasse et al. 2009, concluded that this is because leaf senescence does not much affect tree productivity.

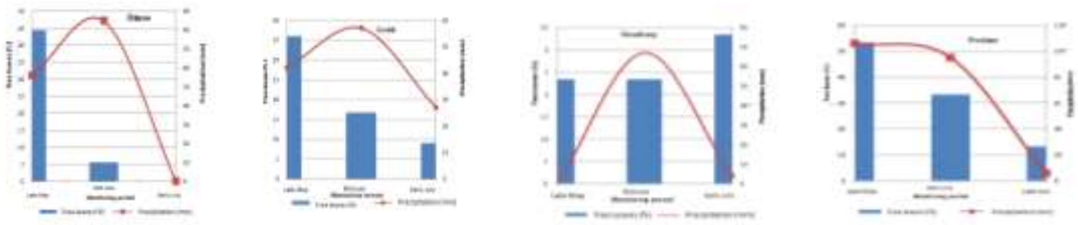


Figure 7. Leaffall and precipitation in the agroforestry parklands studied

Species diversity and richness

The floristic inventory made it possible to take stock of woody plant species in two parks (Kodek and Parkine). The Shannon diversity index was considered broadly as the species richness recorded in the agroforestry parklands. Species richness (S) represents the total number of woody species recorded in each park. A total of 1904 trees (1233 from Kodek and 671 from Parkine) were recorded during the species inventory process. In Kodek Park, a total of 1233 trees of 20 species were registered. The predominant species was *Faidherbia albida* with 504 registered individuals belonging to the family of Mimosaceae. Species *Acacia nilotica* (137 individuals), *Azadirachta indica* (135 individuals), and *Balanites aegyptica* (101 individuals) were also dominant. Other species that were the least represented, presenting fewer than 100 individuals were *Annona senegalensis* (01 individual), *Adansonia digitata* (01 individual), *Boswellia dalzielii* (01 individual), *Acacia senegal* (02 individuals), *Mitragyna inermis* (02 individuals), *Acacia ataxacantha* (03 individuals). At Parkine Park a total of 671 trees belonging to 43 species were recorded. *Faidherbia albida* (260 individuals) was the most represented species in this park. The other species had less than 100 individuals. Nevertheless, *Azadirachta indica* (65 individuals) and *Anogeissus leiocarpus* (55 individuals) were also well represented in this park. *Borassus aethiopum* (01 individual), *Calotropis procera* (01 individual), *Ficus thonningii* (01 individual), *Acacia senegal* (01 individual), *Cassia sieberiana* (01 individual) were the least represented.

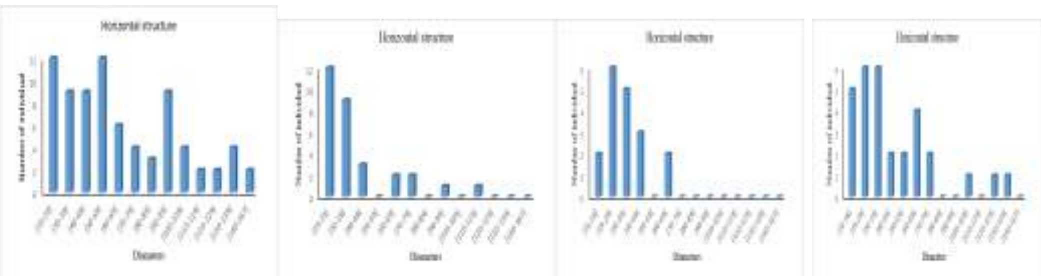
Discussion

The floristic diversity was determined, based on the following indices: Species frequency (Fi) and Shannon Index. For Kodek the frequency of *Faidherbia* was F = 40.90%, and the Shannon H = 2,058 index. This shows that the environment is heterogeneous and species diversity is represented despite the marked frequency of *Faidherbia albida* in this park. At Parkine the frequency of *Faidherbia albida* (F = 38.86%), was also very high out of the total of 43 species that are present in this park. The Shannon H = 2.53 index shows that the environment is heterogeneous. Comparing the species diversity in both parks, it was noticed that *Acacia ataxacantha, Acacia nilotica, Dalbergia melanoxylon, Hyphaene thebaica, Mitragyna inermis, Acacia Senegal* were absent in Parkine even with the high number of species recorded in that park. This result indicates that the conservation of both parklands is necessary because of the diversity and differences of species found. At Kodek, it showed that not only was *Faidherbia albida* the most dominant parkland tree, it was also the only tree species found under all of the parkland agroforestry practices by about 80.8% of the households (Kahsay, 2020). Large species diversity was found in this agroforestry parkland as compared to those recorded in the woody savanna of the Sudano–Sahelian zone of North Cameroon (Ntoupka, 1998). This was due to low human disturbance in these protected agroforestry parklands as compared to open woody savannas.

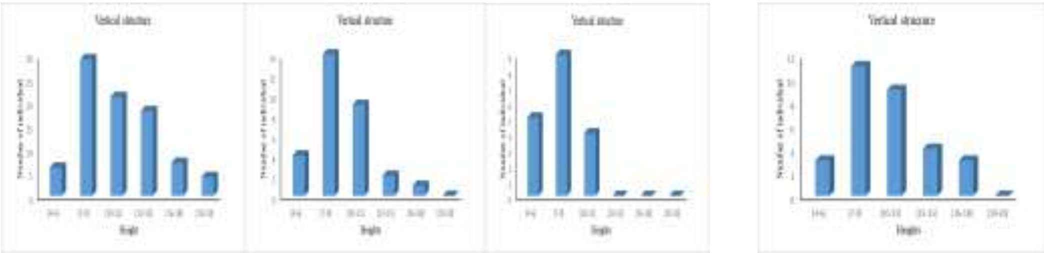
Population structure

Vertical (height) and horizontal (diameter) forest structure data were used to compare the evolution potential of the populations of *Faidherbia albida* in the agroforestry parklands studies. A histogram of the results showed that vertical and horizontal structures were skewed towards most individuals being concentrated in the lower size classes (Fig. 8). Horizontal structure analysis showed that the most diversified diameters classes are present in Kodek which also had the most recorded number of individuals with diameters greater than 80 cm, followed by Parkine, while Dinao and Mambang being least diversified. At Dinao most trees were in the lowest diameter size class (Fig. 8a). The analysis of the vertical structure showed that more than

80% of individuals in all parklands had a height lower or equal to 15 m (Fig. 8b). Thus, trees in these agroforestry parklands are mostly young or are of poor growth. This is similar to that reported by Hamawa et al., (2018) in *Balanites aegyptiaca* (L.) Delile in the Sahel of Cameroon with the common problem of tree branches being harvested for forage. However, in *Faidherbia* in particular, human activities include some big trees being given a horizontal cut at the top of the trees for forage and other activities. This destructive cutting method prevents the trees from early sprouting or even from sprouting at all, leaving them at a lower diameter or height class. The effect of human activity is very common in Kodek while in Mambang the small sizes of trees are due to recent regenerations as the parkland is protected and managed by farmers who had recently encroached into this locality. Kodek parkland presented the most diversified individuals on both the horizontal and vertical levels followed by Parkine which was also diversified with most trees of height between 7 and 9 m while Dinao Park was the least diverse with trees not exceeding 12 m high. These results confirm the study by Djingui (2015), in the territory of Kodek and Mambang on "The socio-economic aspect of *Faidherbia albida* which showed that Kodek Park is an old park that has been maintained over 20 years while noting significant difference ($p < 0.05$) in crown diameters in the Mambang park. Similar results were obtained by Oumarou et al., (2008) by studying the structure of the woody groups of Arly National Park in Burkina Faso which found that the adaptation of plants depended on environmental conditions (soil properties and fire regime) and their distribution depended on the topo-edaphic gradient. This diversity reveals the good compatibility of the forest trees (genetic material) with the environmental conditions of these parklands and can also be justified by the establishment (regeneration or planting) ages of these parklands.



a) kodek Mambang Dinao Parkine



b) kodek Mambang Dinao Parkine

Figure 8. Histograms of the horizontal and verticle structure data collected from the four agroforestry parklands studied. a) horizontal (diameter) classes in cm; b) vertical (height) classes in meters; structure of parklands studied; y-axes are number of individuals measured; x-axes are size classes

Conclusion

Significant differences were observed among the agroforestry parklands, with soil types, altitude, and human activities affecting the morphological parameters measured. The result of this study indicates that these variables have an impact on the measured parameters and therefore provide possibilities for *plus tree* selections. Selected *plus trees* can be used to establish a common garden experiment to confirm the genetic potential of the trees or multiplied by vegetative propagation for use in reforestation projects. Species diversity were noted in the two parklands indicating that the conservation of both parklands is necessary. Species richness and frequency are important measures of diversity for conservation and management purposes of these agroforestry parklands in Cameroon.

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