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(RESEARCH ARTICLE)

Floristic structure and diversity of agro-sylvopastoral systems of Batha in Chad

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Abstract

The study was carried out in the agroforestry zone of Batha province in Chad. The aim was to assess the structure and floristic characteristics of woody stands. To do this, a survey of woody plant was carried out in 2500 m^2 (50 m x 50 m) quadrangular plots. A total of 210 individuals were determined, 35 for each land-use system. The results show that the woody flora is rich and diverse, with 33 species distributed into 24 genera and 15 families. The Fabaceae-Capparaceae families dominated in terms of genera and species. 11 species are ecologically important, while 6 families have a family index value greater than or equal to 10%. The Shannon Weaver diversity index and Piélou equitability are less than 2.5 bits and 0.5 bit, indicating that the agroforestry systems of Batha province have low diversity and a more or less irregular distribution of vegetation. The woody stands are dominated by *Faidherbia albida*, *Balanites aegyptiaca*, *Tamarindus indica* and *Mangifera indica*. The ecological services of these agroforestry systems will be assessed in the coming studies.

Keywords: Agroforestry systems; Agro-sylvopastoral, Batha; Chad; Plant characteristics; Wood diversity

1. Introduction

The agrosylvopastoral systems exploited for the agriculture and stock farming play a fundamental role in the satisfaction of the rural population vital needs [1,2]. In fact agrosystems contribute to the welfare of the riparian population and protect the environment. They provide ecosystem services and are a response to the complexity of the climate [3]. The floristic diversity of these systems are influenced by natural and anthropic factors which impact their regeneration [4,5]. In the Sahelian zones of Chad, these areas are situated in shrub savannahs, steppes and agrarian landscapes [6,7]. The woody population preserved in these production systems plays an important role in human and animal nutrition, particularly in times of famine [8,9]. Grazing, agricultural land clearing and trampling are the main causes of vegetation cover degradation in agroforestry systems [10]. Overgrazing and bush fires are responsible for the disruption of biodiversity in these ecosystems. A high loading capacitiy can lead to a reduction in herbaceous biomass, while encouraging the development of unpalatable woody plants [11]. A fair load helps to maintain the balance of ecosystems [12]. Thus, overgrazing affects the density of the structure of trees and shrubs in sahelian zone. However, these agrosystems generate between 50% and 80% of essential natural resources [13]. In addition to these properties, they play a role in the proper functioning of the biogeochemical cycle, promoting plant productivity and contributing to the formation of litter and the infiltration of water into the soil [14,15]. Chad, like other sub-Saharan countries, is facing environmental degradation due to its precarious climate, drought and desertification [16]. These factors are accentuated in the sahelian zone of Chad especially in the province of Batha. For the population of this province, soil degradation leads to a risk of deterioration of ecosystems and loss of natural resources. The consequences of assessing progress include loss of biodiversity and soil degradation. To address this situation, a proper assessment of the structure and diversity of the flora will provide a better understanding of the importance of production systems in order to propose sustainable management strategies. The rational management of a locality's floristic diversity is an essential

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tool for implementing a sustainable development programme [17]. It was with this view that the present study set out to characterize the structure and floristic characteristics of pastoral and agro-pastoral systems in the Batha province of Chad was conducted. The purpose of the study is to assess the structure and floristic characteristics of agro-sylvopastoral systems of the Batha province of Chad.

2. Material and Methods

2.1 Study site

This study was carried out in Batha province, which covers an area of 88,800 km^2, or 21% of Chad's territory. The area lies between the 12-16th Parallel North and the 17-18th Meridian East [18,19]. The selected sites are Koundjourou, Assinet and Abourda.

The province of Batha belongs to the sahelian bioclimatic zone comprised between isoyets 200 and 800 mm. The thermal regime is marked by a long 9 months dry season, the hottest of which is April (40 - 43 °C) and the relatively cold December to February (11-23 °C) [20]. It belongs to the Sahelian bioclimatic zone between isohyets of 200 and 800 mm. The landscape is relatively flat and crossed by endoreic watercourses, the most important which is Lake Fitri, the flow which varies according to rainfall. Five soil types are distinguished: vertisoils, steppic soils, halomorphic soils, hydromorphic soils and rough mineral soils [21]. Three occupation zones are distinguished: grazing areas, agricultural areas and mixed areas. The vegetation includes forests with dense woods of different plant groups: *Acacia nilotica* forest on the edge of the lake, gallery forest on the banks of the rivers and *Hyphaene thebaica* forest to the north-west of the lake [22]. The savannah is made up of a wooded formation and a perennial herbaceous stratum [23]. The lake of Fitri zone is an excellent refuge medium which assures by its multiple resources (water, fish, pasture, wood) a vital role for neighbouring populations. Nevertheless, it is particularly sensitive to climate change effects. Steppe contains scattered shrub vegetation separated from vast areas of bare ground and annual herbaceous vegetation corresponding to temporary grassland. This class also includes former fallow land. The marshy or permanent grasslands represents the flooded herbaceous vegetation of *Echinochloa stagnima* around the lake. It is in direct contact with open water and is a favourable area for grazing [24]. The lake concentrates the free water from the lake and surrounding basins. The water body concentrates the flows from the lake and surrounding basins. Rainfed crops cover vast areas during the rainy season. Subsistence crops and shifting cultivation cover equally large areas during the dry season [25]. The high proportion of Poaceae, Mimosaceae and Fabaceae makes the various pastures of particular agrostological interest [26]. Among the woody species, the presence of *Balanites aegyptiaca*, *Acacia nilotica*, *Faidherbia albida*, *Dalbergia melanoxylon*, *Cordia sinensis* and *Ziziphus mauritiana.* For the herbaceous, that of *Ludwigia stolonifer*, *Panicum maximum*, *Andropogon gayanus*, *Cymbopogon schoenanthus* which are appreciated by livestock is noted [22]. These species constitute an important fodder reservoir in the province of Batha. The Batha population is growing rapidly, with around 20 inhabitants/km^2 [27]. Agriculture, livestock farming and fishing are the main activities of the population. Agrobiodiversity ensures the production of *Pennisetum americanum* in association with *Vigna unguiculata* or *Arachis hypogaea*, *Zea mays*, *Ipomoea batatas*, *Sesamum indicum* and potato cultivation. These species form a counter season crop based on *Sorghum durra*. Market garden produce includes species such as *Hibiscus esculenta*, *Lycopersicum esculentum*, *Citrullus vulgaris*, *Cucumis sativus* and *Capsicum frutescens*. Livestock farming is widely practised by traditional breeders, with a trend towards sedentarization around Lake Fitri, a refuge area of excellence offering a wealth of resources (water, fish, pasture, wood, etc.), plays a vital role for the neighbouring population.

2.2 Methodological approach

2.2.1 Floristic inventory

The inventory of woody flora was carried out in quadriangular sub-plots of 2500 m^2 (50 m x 50 m). In each square, an exhaustive inventory of trees and shrubs was carried out, including the sub-Saharan domain, the wooded steppe, the Sahelian domain, home gardens, busfarms and orchards. In each ecosystem, all woody individuals were measured using the well-known method [28]. Georeferential data for each site were determined using a global positioning system (GPS). A total of 210 records were determined per land-use system.

2.2.2 Structural and floristic parameters

In each agroforestry system, dendrometric measurements were taken to assess certain size parameters :

- Diameter at breast height was used to determine basal area and analyse the demography of the tree population :

- The basal area or basal cover which represents the basal area of tree at the bottom of its trunk. It is expressed in square meter per hectare (m^2/ha) through the following formula :

$$St = \frac{\sum \Pi(\frac{do.3}{2})}{SE}$$

St = basal surface ; d0.3 = diameter of trunk at 0.3 m ; *SE* = Area of the sample per ha;

- - the density is the number of individuals per unity of surface. It is expressed in number of individuals/ha is obtained by dividing the total number of individuals in the sample by the area sampled

$$Dob = \frac{n}{S}$$

Dob = Observed density ; n = total effective of individuals in considered sample and S=surface of the sample per ha.

Different floristic parameters of the agro-sylvopastoral systems of Batha were determined. The Importance Value Index (IVI) of species developed was used [29] :

$$IVI = 100 * \left[(\frac{n_i}{N}) + (\frac{g_i}{G}) + (\frac{f_i}{F}) \right]$$

with $\frac{n_i}{N} x100$ = relative density of the species i ; $\frac{g_i}{G}$ = the basal area of the i species

; $\frac{f_i}{F} x100$ = The relative frequency of the i specie i.

This index permits the evaluation of the specific preponderance of the plant population. Each species with the importance value index is equal to or more than 10% (IVI ≥ 10%) is considered ecologically important [3,30]. In the same way, the Family Importance Index (FIV) developed, was equally used [31]. Each family in which the FIV is greater or equal to 10% (FIV ≥10%) is ecologically important [32,33] :

$$FIV = 100 * \left[\frac{Ni}{\sum N_i} + \frac{G_i}{\sum G_i} + \frac{D_r}{100} \right]$$

Ni = the number of species of the family i ; Gi = basal area of the specie in the family i; Di = relative density or the number of species in the family i. This indice suplies informations on each family as well as its potential founding in the population [33].

The specific diversity is determinated by the calcul of indices of diversity

- Shannon-Weiner (H') index is in bits :

$$(H') = -\sum_{i=1}^{s} P_i \log_2 P_i$$

$P_i = \frac{n_i}{N} x100$, is the relative abundance each species i.

H'is minimal (H' = 0), if all the individuals of population belong to one and the same species ; H' is maximal when all the individuals are distributed in the equally way [34]. This index is used to calculate the species diversity, comparatively to the maximal diversity which is the logarithm in base 2 of species number (S) :

$$H_{\max} = \log_2(S)$$

The Shannon index is often associated with Pielou's Equitability or R [35], known as the equi-repartition index or regularity, which represents the H'/Hmax ratio in the population:

$$R = \frac{H'}{H_{\max}}$$

is the realisation degree of the maximal diversity [35].

Simpson's diversity index (D'): is the probability that two randomly selected individuals may be different. The maximum diversity is represented by the value 1 and the minimum diversity by the value 0.

$$(D') = 1 - \sum (n_i / N)^2$$

ni = number of individuals for the species i ; N = Total effective of individuals of all the species.

2.3 Data statistique analysis

Microsoft Excel 2016 was used to classify numerical data and produce various graphs. Statgraphics plus 5.0 was used for the analysis of variance. Duncan's multiple test was used to separate significant means. The diametric structure of the trees was divided into different diameter classes with a span equal to 5 or 10 cm according to the recommendations which are recommended for practical reasons [36].

3. Results

3.1 Floristic characteristics of tree population

In the sylvopastoral zone of Batha province, a total of 33 species distributed in 24 genera and 15 families were recorded. The predominance of the Fabaceae and Capparaceae was noted according to the genera and species. The families of Anacardiaceae-Myrtaceae-Arecaceae follow with 2 species as well as the genera. The genera *Acacia* is abundant with 8 species (Table 1).

Table 1 List of ligneous taxa

Species	Genus	Families
Acacia senegal	*Acacia*	Fabaceae
Acacia seyal	*Acacia*	Fabaceae
Acacia sieberiana	*Acacia*	Fabaceae
Acacia nilotica	*Acacia*	Fabaceae
Acacia laeta	*Acacia*	Fabaceae
Acacia kirkii	*Acacia*	Fabaceae
Acacia tortilis	*Acacia*	Fabaceae
Acacia goumaensis	*Acacia*	Fabaceae
Prosopis juliflora	*Prosopis*	Fabaceae
Bauhinia rufescens	*Bauhinia*	Fabaceae

Dalbergia melanoxylon	*Dalbergia*	Fabaceae
Tamarindus indica	*Tamarindus*	Fabaceae
Faidherbia albida	*Faidherbia*	Fabaceae
Boscia senegalensis	*Boscia*	Capparaceae
Maerua crassifolia	*Maerua*	Capparaceae
Capparis decidua	*Capparis*	Capparaceae
Capparis fascularis	*Capparis*	Capparaceae
Mangifera indica	*Mangifera*	Anacardiaceae
Sclerocarya birrea	*Sclerocarya*	Anacardiaceae
Borassus aethiopum	*Borassus*	Arecaceae
Hyphaene thebaica	*Hyphaene*	Arecaceae
Leptadenia arborea	*Leptadenia*	Asclepiadaceae
Leptadenia pyrotechnica	*Leptadenia*	Asclepiadaceae
Eucalyptus camaldulensis	*Eucalyptus*	Myrtaceae
Psidium guajava	*Psidium*	Myrtaceae
Khaya senegalensis	*Khaya*	Meliaceae
Azadirachta indica	*Azadirachta*	Meliaceae
Ziziphus mucronata	*Ziziphus*	Rhamnaceae
Ziziphus mauritiana	*Ziziphus*	Rhamnaceae
Balanites aegyptiaca	*Balanites*	Balanitaceae
Citrus limon	*Citrus*	Rutaceae
Cordia sinensis	*Cordia*	Boraginaceae
Moringa oleifera	*Moringa*	Moringaceae

Of the 33 species inventoried in the agro-pastoral zone, 11 have an important value index greater than or equal to 10% (IVI ≥ 10%) (Table 2)

Table 2 Ecological important species in agro-sylvopastoral systems

Species	**Relative dominance (%)**	**Relative density (%)**	**Relative frequence (%)**	**IVI (%)**
Acacia nilotica	2.93	8.51	5.82	17.26
Acacia senegal	5.68	7.18	3.05	15.91
Acacia seyal	6.97	4.06	3.06	14.09
Balanites oegyptiaca	5.29	4.08	3.69	13.06
Bauhinia rufescens	6.51	3.72	2.24	12.47
Faidherbia albida	5.30	6.32	5.16	11.48
Capparis decidua	5.15	2.19	1.09	10.29
Leptadenia pyrotechnica	5.07	3.02	2.38	10.47
Ziziphus mauritiana	7.01	2.19	1.09	10.29
Tamarindus indica	2.91	5.04	2.11	10.06
Hyphaene thebaica	2.56	5.89	1.59	10.04

IVI = Important Value Index

These indices vary from 10.04% for *Hyphaene thebaica* to 17.26% for *Acacia nilotica*. There was a significant difference between tree species (0.0064 < 0.01). This ecological importance is linked to relative dominance, relative density and relative frequency. The *Acacia* genus is the most diverse with 3 species, while the *Capparis*, *Leptadenia* and *Ziziphus* genera follow with 2 species each.

The most diversified families are Fabaceae and Capparaceae, with 12 species and 4 species respectively (Fig.1). Despite the variability observed, there was no difference between families (0.2873 ≥ 0.05).

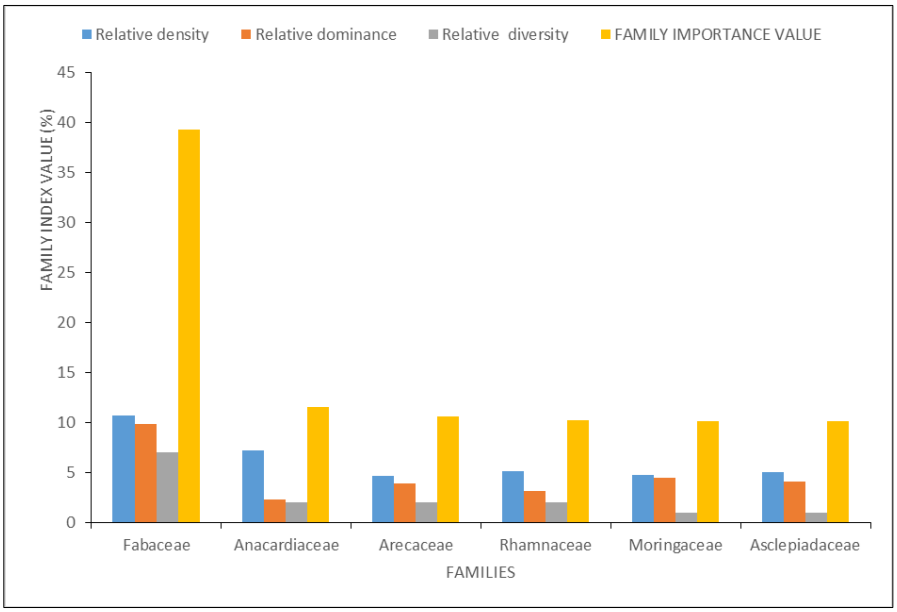

Figure 1 Family Index Value

3.2 Floristic diversity and dendrometric characteristics of tree species

The dendrometric parameters and the indices of diversity vary according to the agro-sylvopastoral systems. Basal area increased from 0.51 ± 0.27 m^2/ha in steppe to 0.74 ± 0.34 m^2/ha in schrubyland (Table 3).

Table 3 Floristic and diversity parameters of agro-sylvopastoral systems

Land use systems / Parameters	Grass steppes	Woody steppes	Shruby savannahs	Homegardens	Bushfarms
Basal area	0.51 ± 0.27	0.62 ± 0.31	0.66 ± 0.46	0.69 ± 0.32	0.74 ± 0.34
Mean density	61.15±23.52	68. 28 ± 42.31	74.58± 37.21	82.56± 14.52	96.27±68.16
Shannon	2.003 ± 0.59	2.006 ± 0.35	2.06 ± 0.62	2.09 ± 0.71	2.25 ± 0.43
Piélou	0.37 ± 0.22	0.42 ± 0.09	0.45 ± 0.14	0.47 ± 0.13	0.48 ± 0.07

However, there was no significant difference between the agrosystems (0.9977 > 0.05). Plant diversity is better conserved in the bushfarms. The local population has a good knowledge of biodiversity management. Density varies considerably in the different agro-sylvopastoral systems. Depending on the land-use systems, density fluctuates from 61.15 ± 23.52 individuals/ha in the herbaceous steppe to 96.27 ± 68.16 individuals/ha in the bush farms.

The lowest density was observed in the herbaceous steppe. This situation may be attributed to the precariousness of the climate and/or the overexploitation of vegetation on the effect of grass cover by livestock.

3.3 State of tree populations

The diametric distribution of the main ecological tree species presents a belt shape except in *Tamarindus indica*. The demographic structure of *Faidherbia albida*, *Balanites aegyptiaca* and *Mangifera indica* according to the diameter at

breast height shows a normal distribution with an optimum at 40.1-65 cm (Fig.2). *Tamarindus indica* shows its place in the class of diameters >65cm. This analysis reveals a low representation of young individuals in all populations.

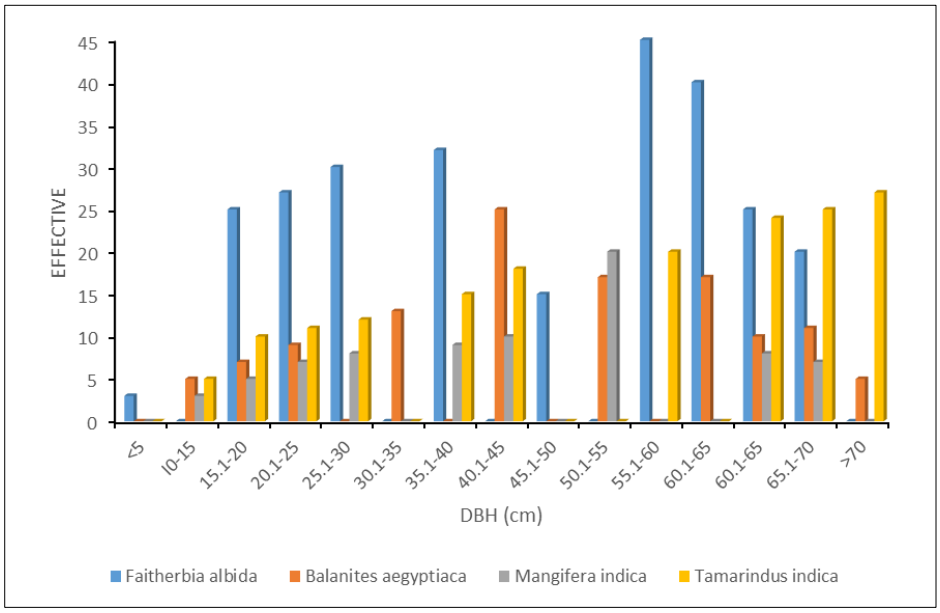

Figure 2 Diametric distribution of major ligneous species of Batha

4. Discussion

4.1 Floristic characteristics of the tree population

The sylvopastoral zone of Batha province, totalize of 33 species distributed in 24 genera and 15 families. This species richness is higher than that reported in the dune vegetation of southern Maine Sora in Niger, where 10 woody species were recorded [37]. However, this result is low compared with that reported in the Sahelian Ferlo of the Senegal (38 species) and in the northern Sudanian zone of Niger (55 species) [38,39]. This difference is linked to intense agro-pastoral activities and the deterioration of the climate in the Batha province over the last few decades. Climate plays an essential role in the floristic composition and structure of an ecosystem [40]. The combined effect of these two factors reduces or leads to the rarefaction of many species, particularly woody species. Fabaceae and Capparaceae are two plant families with important ecological value in Batha province. Species of these families tolerate hot temperatures and are well adapted to water stress [41], arid and semi-arid soils [24]. The significant presence of *Acacia* and *Caparis* genera testifies the monospecification of the woody flora in this marginal zone and the adaptation of these specimens to Sahelian ecological conditions.

The ecological importance of *Acacia nilotica*, *Acacia senegal*, *Acacia seyal*, *Balanites oegyptiaca*, *Bauhinia rufescens* and *Faidherbia albida* in the agrosylvopastoral zone can be explained by the positive effect of controlled pasture which causes the appearance of new specimen by the phenomenon of endozoochory [8, 42]. The presence of animals in the pasture can favour directly or indirectly the germination and development of ligneous species through dispersion of seeds. The passage of animals can modify biodiversity and the increase in tree diameter of tree species [9]. The most diversified families determine the phytogeographical physiognomy of the study area. The Fabaceae family plays an important role in soil fertility and richness [43]. In the pastoral point of view, densification negatively affects the family of Capparaceae, Asclepiadaceae and Rhamnaceae. These families constitute an important forage resource. Overgrazing induces the growth of species that are not consumed to the detriment of those that are [44,45]. Rotational grazing by the herd encourages the regeneration of palatable species, thus balancing pastoral ecosystems. These results are in agreement with those of certain authors [8, 46].

4.2 Dendrometric characteristics of tree species

In the context of sustainable management of the biodiversity, *in situ* convervation measures must be carried out to favour regeneration of vegetation. Shannon diversity index and Pielou equitatbility are less than 2.5 and 0.5 bits respectively, suggesting that plant diversity of the agro-sylvopastoral systems of Batha province is poor with an allotment more or less regular. These systems are distinguished by their degree of anthropization and climate

deterioration. This situation is reported in Benin[47] and in Niger [48]. Nevertheless, the strong density (96.27 ± 68.16 individuals/ha) found in farms is due to the preservation of trees by farmers in their plots. The Shannon diversity indices vary from 2.003 ± 0.59 in grass steppe to 2.25 ± 0.43 bits in bush. These values are comparable to those reported in parklands of Tamour (1.96bits) and Simir (1.24bits) in West Niger [38]. However, these indices are less than those obtained in *Guiera senegalensis* - *Piliostigma reticulatum* parklands in Guidon Roumdji [48]. The low plant diversity of these agrosystems is related to the pressures made by agro-pastoral activities and to the persistent drought in Batha province.

4.3 State of tree population

The demographic structure of *Faidherbia albida*, *Balanites aegyptiaca* and *Mangifera indica* according to the diameter at breast height shows a normal distribution. The poor regeneration of all the species in the systems justifies the overexploitation of the systems, and for trees such as *F. albida*, all the fruit of which is harvested and eaten by animals, preventing it from germinating. The maintenance of mature trees is also due to overexploitation, which prevents them from producing seeds. Trees of large size are overexploited as reported [49]. These findings are in line with those reported in Burkina Faso [50]. The leaves and fruits of *Balanites aegyptiaca* are harvested for consumption or sale. The fruit pulp and seeds are rich in carbohydrates and lipids, which are appreciated by local populations. These results are similar to those obtained in Senegal [51]. According to some authors, species with edible fruits/seeds are experiencing regeneration and productivity problems [52]. The fruits of *Mangifera indica* provide people with carbohydrate-rich food and various vitamins [53], while the pods of *Tamarindus indica* are used in folk medicine and the pulp of the ripe fruit is used to make a refreshing drink [54]. The presence of juvenile species can be justified by the presence of seeds which escaped pressure. Various studies carried out in Sahelian and Sudanian zones confirm these results [7, 55, 56,57, 58].

5. Conclusion

The province of Batha is rich in flora, with 33 species in 24 genera and 15 families. It is dominated by the Fabaceae and Capparaceae in terms of species and genera. Eleven species present high IVI as well as 6 families with a high family importance value. However, plant diversity in the area is low. The predominant species are *Faidherbia albida*, *Balanites aegyptiaca*, *Tamarindus indica* and *Mangifera indica*. With the exception of *Tamarindus indica*, these tree species are distributed in a belt shape. The next step of this work will be focused on ecological services of these agroforestry systems.

Compliance with ethical standards

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Disclosure of conflict of interest

The author has no any conflict of interest for publishing this paper.

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