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Agricultural Production Systems and Climate Change Ductility Enhancement in the Fitri Watershed in Chad

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Abstract: Chad is one of the most vulnerable countries affected by climate changes. The combination of poverty, demographic pressure and overexploitation of natural resources coupled with the risks of drought and flooding, expose the country to numerous humanitarian emergencies. The objective of this study is to understand the role of agricultural production systems in building resilience to climate change in the Fitri watershed in Chad. The *Faidherbia albida* agroforestry system increases water infiltration and soil fertility rates and conserves biodiversity by limiting the consequences of climate change. Mixed cropping significantly reduces the risk of crop failure due to climatic variations. The survey was carried out on a sample of 178 households divided into 49, 57 and 72 households, respectively in the Mochi, Zegue and Yao areas. The floristic inventory was carried out using 50m square plots. A total of 165 plots were determined in the different farming systems. The area under each agricultural crop varies from one village to another. The ecologically important species are *Faidherbia albida*, *Balanites aegyptiaca*, *Prosopis juliflora* and *Mangifera indica*. Regardless of the area studied, the Fabaceae, Balanitaceae, Mimosaceae, Arecaceae, Rhamnaceae, Capparaceae, Meliaceae and Asclepiadaceae families have an IVF of 10 or more. The high density of woody plants in the agrosystems shows that the individuals are full of seed potential that could contribute to their renewal. The height dominance of the trees implies their carbon sequestration capacity since the sequestered carbon accumulates in the above-ground and below-ground biomass.

Keywords: Agroforestry Systems, Resilience, Climate Change, Biological Diversity, Fitri, Chad

1. Introduction

Chad is one of the vulnerable countries affected by climate changes. The combination of poverty, demographic pressure and overexploitation of natural resources to which drought and flooding risks are added, expose the country to numerous humanitarian urgency and fight efficiently against climate change consequences [1]. Rural populations are the most vulnerable and the most exposed to climate changes. The watershed of the lake Fitri of Chad is a semi-humid ecosystem situated in the Sahelian zone and keep reduces because of the drought and the increase of water capture for irrigation [2, 3]. This situation impacts crops yield, pastures and population livelihoods. However, the watershed of Fitri is characterized by humid and dry periods of interchanges. The vegetation remains green there for a long part of the year and constitutes a refuge habitat for biodiversity [4]. Soil fertility, water presence and vegetal cover are in proportion favourable factors to activities of diversification inside the Chadian watershed [5]. These have permitted the development of many activities among which agriculture, breeding and fishery according to years and seasons. The diversity of trees conserved in production systems by farmers varies in function of social, cultural, ecological and economic order needs [6, 7]. The establishment and maintenance of the ecological equilibrium in a sustainable way in Fitri pass through rational management of natural resources [8]. The necessity to improve natural resources management sustainably refers to agroforestry practices [9, 10]. These practices are land managements which associate woods and annual crops and/or animals in spatial conciliation and in time [11]. For many years, agroforestry raises interest in farmers of the Fitri zone of Chad. It is among the alternatives which can mitigate the actual trend which damages natural ecosystems. It focus on the valorization of soil management practices following the environment in its agroecological, economical and cultural context and permits to increase in total production of the cultivated systems [12]. Agroforestry is made up of multifunctional agriculture. It addresses questions of soil fertility loss, rehabilitation of degraded soil, restoration of biodiversity and sequestration of carbon [13]. However, agroforestry is threatened by climate change effects such as desertification, irregularity of rain, high temperature and floods. Among agroforestry species targeted to mitigate these effects of climate changes in the Fitri watershed of Chad, appears *Faidherbia albida*. This species plays a fundamental role in agropastoral activities mainly in soil fertility and forage for livestock. The purpose of the present study is to understand the function of agricultural production systems in the enhancement of ductility against climate changes in the Fitri watershed of Chad. Specifically, it is to: determine farmer strategies developped by farmers to mitigate climate changes; evaluate the exploitation size of different lands; identify wood species suitable to palliate climate changes and determine floristic parameters of the different production systems.

2. Materials and Methods

2.1. Study Site

The study was made in three villages (Yao, Mochi and Zegue), located in Fitri Division in the province of East – Batha of Chad (Table 1). The choice of these lands was based on the presence of agroforestry systems in which farmers practice association of annual crops with trees and/or animals [9, 14].

Table 1. *Geographic charactéristic data of villages explorés.*

Village	Latitudes	Longitude	Altitude (m)
Yao	12° 85' 093”	17° 55’ 9.24 ‘’	280
Mochi	12° 80 ‘ 604”	17° 60’ 8.35”	290
Zegue	13° 03’ 627”	17° 41’ 8.48”	300

They are located in Sahelian zones with thermic schemes ranging from 23 to 44°C. They present important constraints between the Northern arid part and the South sahelo-soudanian characterized by a rainfall oscillating between 500 and 800 mm [15]. These contrasts determine different activities between the North with pastoral vocation and the South where the rainfall conditions permits agricultural practices associated with sedentary semi-transhumant breeding [16]. The uneven is a little damaged and covered by Endoreique Rivers the most important is Lake Fitri where the duration of flow depends on rainfall variability. Five types of soil are distinguished: vertisoils, steppic soils, holomorphic soils, hydromorphic soils and mineral raw soils [17]. Three occupation zones are distinguished: pasture zone, agricultural and mixed zones [4]. The vegetation corresponds to the forest with dense wood of different plant groups: forest of *Acacia nilotica* at the border of the lake, gallery forest at the edge of rivers and forest of *Hyphaene thebaica* located in the northwest of the lake [18]. The savannah regroups a woody formation and perennial herbaceous stratus [5]. 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.

2.2. Methodological Approach

2.2.1. Household Surveys

The methodology of inquiry dealts with semi-structural interviews with a first elaborate questionnaire. Farmers were the head of the household and were chosen randomly. A total of 178 households participated in interviews of which 49, 57 and 72 were respectively in Mochi, Zegue and Yao. These numbers were done in function of the census of each village [19, 20]. The main rubric of the questionnaire was based on agricultural production systems, farmer perception of climate changes and endogenous strategies to reinforce their resilience.

2.2.2. Floristic Inventory

Agricultural production systems identified in the watershed of Fitri in Chad are *Faidherbia albida* agroforestry parklands, mixed crops systems and farms of sorghum established out individually (*Sorghum durra*). In each of these systems, plots of 50 m x 50 m were delimited. Inside each of them, trees, shrubs and lianas of diameter at breast height (DBH) or more than 1.30m were measured with a double decameter and the height of trees was determined with the calliper [21]. A total of 165 plots were registered and distributed as follows: 69, 39 and 57 in Yao, Zegue and Mochi respectively. The geographic data of each site was recorded with a GPS (Global Positioning System).

2.2.3. Data Analysis

Different floristic parameters of the agricultural production systems of Fitri watershed were determined. The Importance Value Index (IVI) of species [22] was used:

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

with $\frac{n_i}{N} x100$ = relative density of the species i; $\frac{g_i}{G}$ = the basal area of the i specie; $\frac{f_i}{F} x100$ = The relative frequency of the i specie i.

This index permits the evaluation of the specific preponderance of the plant population. Each specie with the importance value index is equal to or more than 10% (IVI ≥ 10%) is considered ecologically important [23, 24]. In the same way, the Family Importance Index (FIV) [25], was equally used. Each family in which the FIV is equal to or more than 10% (FIV ≥10%° is ecologically important [26-28]:

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

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.

The allometric equation developed in Senegal [29] was successfully applied in similar ecosystems [13] was used to calculate the biomass of woody species.

$$BM\ (kg) = 25.58h - 7.006h^2 + 0.662h^3$$

BM = Biomass (t); h = the height (m). The carbon is determined by the followiong conversion [30, 31]:

$$C = 0.47*BM$$

C = Carbon (tC/ha) and BM (t/ha). The carbon stock (tC/ha) is converted into CO_2 equivalent absorbed using the ratio 44/12 (=3.67) corresponding to the ratio CO_2/C [32].

The density and mean diameter of woody species of each production system was calculated according to the following formula.

$$D = Density\ (Stems/ha) = n/S * 100$$

n = number of individuals in the plot;
S = area of the plot (ha).

$$DM = \sqrt{\frac{1}{n} \sum_{i=1}^{n} d_i^2}$$

DM represents the mean diameter in cm, n is the number of stems measured, di is the diameter at the breast height of the stem i at 1.30 m above ground.

Data collected were subjected to an analysis of variance (ANOVA). Significant means were separated by the Duncan Multiple Range Test. The statistical program used for the ANOVA was Statgraphics plus 5.0. The Excel spreadsheet was used to draw the graphs. The program Microsoft Excel 201 6 serves to classify numeric data and draw graphs.

3. Results

3.1. Farmer Perceptions on Climate Changes in Fitri Watershed

The opinion of farmers is diversified concerning climate change perceptions. The climate parameters mostly announced are among others temperature amplification (87.93%), irregularity of rainfall (77.59%) and flood (68.97%) (Table 2).

Table 2. *Farmer climate change perceptions.*

Perceptions	Farmer answers (%)		
	Yes	**No**	**neutral**
Desertification	12. 07	68.97	18.97
Temperature growth	87.93	1.2	10.34
Irregular Rainfall	77.59	8.62	13.79
Floods	68.97	22.44	8.62

The majority of farmers (87.93%) interviewed estimate that temperature is the main reason for climate changes whereas 68.97% of them are unanimous that, desertification is not involved in climate changes. The irregularity of rain and high temperatures modify the phenology of crops.

3.2. Endogenous Resilience Strategies Against Climate Changes

Various endogenous strategies were adopted by farmers against climate changes. They developed powerful agricultural production systems among which the key strategy was the *Faidherbia albida* agroforestry parklands. They associate cereal crops with *Faidherbia albida*. This multipurpose tree presents a reverse phenology. Its shades off its leaves during the rainy season and recovers them during the dry one [33, 34]. Farmers are unanimous that this Fabaceae is an agroecological species. Its presence in the agricultural production system improves soil fertility, protects crops against wind erosion and controls the sand flow. The yield of sorghum cultivated under *F. albida* is 1.7 times higher than those of plots without it [35].

3.3. Characteristics of Agricultural Production Systems in Fitri Watershed of Chad

In the Fitri watershed of Chad, different agricultural production systems are practised in Yao, Mochi and Zegue villages. The most promising are *Faidherbia albida* agroforestry parklands, mixed crops and Sorghum planted out (*Sorghum durra*) systems. The area allocated to each speculation varied from one village to another. Superficies dedicated to *Sorghum durra* are very low (3.70 ± 1.4 ha) (Figure 1).

The area of *F. albida* agroforestry parklands (7.32ha) and mixed crops systems (5.14ha) are large. The extension of suface areas of *F. albida* agroforestry parklands is due to the important role played: it increases the rate of water infiltration, improves soil fertility and conserves biodiversity by limiting the effects of climate changes. According to respondents, *Sorghum durra* planted out, on the contrary, degrades soil and produces poor yields. This situation results from the decrease in soil fertility and physical degradation of soils due to clearing practices and the destruction of plant cover. Thus, the presence of *F. albida* in agricultural production systems improves productivity (Figure 2).

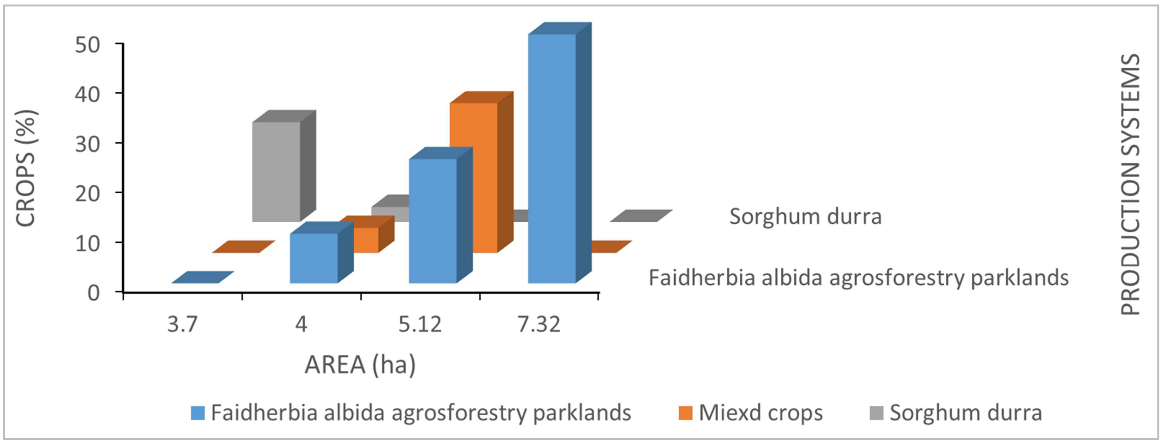

Figure 1. *Agricultural production systems in the watershed of Fitri.*

Figure 2. *Ipomoaea batatas crop under Faidherbia albida trees.*

F. albida is an important plant species used in soil restoration in the Sahelian zone [36]. It is a fixing nitrogen species because of symbiotic association with *Rhizobium* spp. It uses this association to improve the soil fertility level in nitrogen in other to boost agricultural productivity. However, the dendrometric characteristics of trees found in these agricultural production systems of the watershed of Fitri reflect a certain degree of anthropization. Their density fluctuates between 34.42 in Mochi to 93.51 ± 2.7 stems /ha in Zegue (Table 3). The high density observed is registered in Zegue where woody species abounded and produced seeds which could permit their replenishment. This trend was reported in Burkina Faso [37] and Benin [38]. The diameter of trees varies from 0.32 ± 0.59 cm in Mochi to 0.72 ± 0.28 cm in Zegue. Despite the variability observed, there was no significant difference among the site (0.7870 > 0.05). These findings are similar to those reported in the Centre of Niger [39]. The presence of trees about 5 m in the height could be explained by the selective choice of the farmers.

Table 3. *Dendrometric parameters of tree species.*

Dendrometric parameters	Mochi	Yao	Zegue	Mean
Density (stems/ha)	34.42 ± 2.25	73.95 ± 3.48	93.51 ± 2.7	67.29±2.81
Diameter (cm)	0.32 ± 0.59	0.47 ± 0.63	0.72 ± 0.28	0.50±0.5
Height (m)	7.94 ± 2.9	10.16 ± 2.39	14.09 ± 5.1	10.73±3.46

3.3.1. Ecological Importance of Species in Fitri Watershed in Chad

The ecological importance value index of the various species varies from 10.03 in *Acacia seyal* in the site of Zegue to 32.52 for *F. albida* in Moschi. Among the plant species recorded in Fitri watershed, four present index values equal to or more than 10% (Table 4). There is not a significant difference among the villages of Fitri watershed (0.8714 > 0.05). The importance value index of *F. albida* confirms what is above mentionned. It is an important ecological and socio-economic species: its leaves litter fertilize the soil, its tap roots increase the percentage of water infiltration and organic matter in the soil. Its fruits are excellent fodder for animals thus, *F. albida* plays an important role in enhancing resilience against climate changes in Fitri watershed of Chad.

Table 4. *Percentage of importance value index of plant species.*

Sites/Species	Mochi	Yao	Zegue	Mean
Faidherbia albida	32.52	23.25	15.62	23.80
Balanites aegyptiaca	28.84	20.31	17.16	22.10
Prosopis juliflora	16.07	21.58	13.16	16.94
Mangifera indica	12.63	11.19	10.36	11.39
Tamarindus indica	11.08	-	10.04	7.04
Hyphaene thebaica	12.56	-	11.14	7.90
Borassus aethiopum	-	13.11	11.06	8.06
Acacia tortilis	13.21	-	-	04.40
Acacia senegal	-	11.54	10.12	07.74
Acacia seyal	-	10.09	10.03	06.71
Zizyphus mauritiana	10.32	-	11.68	07.33

- = absent

Four of the species are present in all the villages of Fitri watershed with an index value of importance ≥ 10.36%: *Faidherbia albida*, *Balanites aegyptiaca*, *Prosopis juliflora* and *Mangifera indica*. Among these tree species, *Mangifera indica* is an exotic one planted by farmers.

3.3.2. Ecological Importance of Families of the Species in the Watershed of Fitri

The analysis of the ecologically important families in Fitri watershed revealed that whatever the site, the main families that exhibited Family Importance Index equal to or more than 15% are the following: Fabaceae, Balanitaceae, Mimosaceae and Arecaceae (Figure 3). The Fabaceae family is the top one with 32.04%. It regroups many species of great socio-economic and ecological importance. They are appreciated by farmers of the Fitri watershed. There is a significant difference among sites (0.0134 < 0.05).

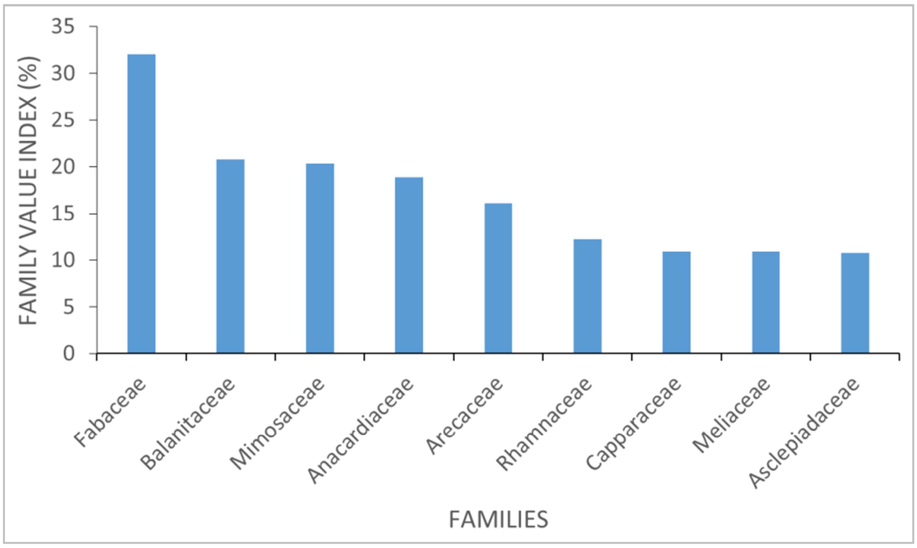

Figure 3. *Ecological families importance.*

The steady management of families with high FIV needs to be considered in view to preserve the socio-economic and ecological services that they offer. In this way, the conservation of agroforestry species and promotion of agroforestry must be encouraged in Fitri watershed.

3.3.3. Ecological Service of Agricultural Production Systems

The carbon stock of Fitri watershed agricultural production systems varies from 4.45 ± 0.9 in *Sorghum durra* fields established out to 39.41 ± 1.32 tC/ha in *F. albida* agroforestry parklands. The carbon sequestration potential of these systems oscillates between 16.1 ±1.35 tCO_2eq/ha in *S. durra* established out and 144.64±1.96 tCO_2eq/ ha in *F. albida* agroforestry parklands. The total ecological service of the agricultural production systems of the watershed of Fitri of Chad is 201.41t CO_2eq/ha (Table 5).

Table 5. *Carbon stock accumulated by agricultural production systems.*

Agricultural production systems	Biomass (t/ha)	Carbon (tC/ha)	Carbon (tCO_2eq/ha)
F. albida agroforestry parklands	82.13 ± 2.6	39.41 ± 1.32	144.64±1.96
Mixed crops	23.1 ± 1.17	11.08 ± 1.9	40.67±1.54
Sorghum durra planted out	9.28 ± 1.8	4.45 ± 0.9	16.1±1.35
Total	123.51 ± 5.57	54.94 ± 4.12	201.41±4.85

4. Discussion

4.1. Farmer Perceptions of Climate Changes

Climate changes are not perceived only by scientists, farmers are aware of their effects in the watershed of Fitri in Chad and have good pieces of knowledge on the variability in their villages through natural and physical factors such as yield decreasing, temperature growth, irregularity of precipitations, frequent floods, houses open to violent winds and dryness, etc. The high fluctuation of precipitations and temperatures registered in the Fitri watershed of Chad is similar with the findings of many researchers who study the problematics of climate changes [40-43]. The rainy season gap has been put into evidence in subsaharian Africa by various authors [44, 45]. Concerning endogenous strategies developed by farmers, *Faiderbia albida* is a multipurpose tree species valued by farmers of the area (source of fodder for animals, restoration of soil fertility, medicines, fuelwoods and charcoal, etc.). A multifunctional tree species like this one is a «worker tree» which has many functions in the field [46]. In addition, diversification of crops was evoked by 2/3 of the respondents. Farmers who have at one disposal two kinds of cereal (*sorghum durra* and *Zea mays*) and one leguminous crop (*Arachis hypogea* and/or *Vignia unguiculata*), are more resilient than others. Diversified crops can produce multiple yields in response to climate changes. The adoption of Sorghum established out has been cited by certain farmers. They reported that farmers who practice these crops of counter–season have a benefice of additional income which permits them to improve their living style.

4.2. Characteristics of Agricultural Production Systems in Fitri Watershed of Chad

Among the various agricultural systems, three linked to agroforestry systems present large areas (More than 3ha per Household). According to households, the ratio of crops associated with *F. albida* is bigger than that of the *S. durra* planted out in production systems. *F. albida* is a nitrogenous species that contributes to soil fertility. The species softens the light infiltration and its roots spread deep in the soil. These systems use litter and biomass easily decomposable permitting accommodation to the variability of climatic conditions. These findings are similar to those demonstrated in Kiki in Niger that fertility under *F. albida* is high. In the Sudano-sahelian zone of Cameroon, farmers claim that *Zea mays* growing under the species during the dry season withers latter than that which is far from it [46]. In addition, fruits of this species hold a high fodder value. They are particularly rich in the nitrogenous digestive matter [47]. Diversified Mixed crops reduce risks of crop yields and increase their ductibility [48].

For the flora in these systems, the following species present ecological importance: *Faiderbia albida* (23.80%), *Balanites aegyptiaca* (22.10%), *Prosopis africana* (16.94%) and *Mangifera indica* (11.39%). These plant species are important species of great socio-economic and ecological importance. They play an additional function of windbreak, by reducing the velocity of winds [49]. They said that they contribute to reinforcing resilience and mitigating climate changes. These findings are similar to those reported in Benin [50, 51] and Wofo (2008) in Cameroon [52]. Nevertheless, they are in another hand some findings which constrast with the previous in Northern Cameroon [53].

Concerning plant families, eight exhibited an important family index among which, the family of Fabaceae leads. Some studies in Africa reported the importance of this family in agroforestry systems [34, 54-56]. Meanwhile, the index of family importance is useful in the biodiversity conservation programm. Families with weak indexes are among the priorities for conservation [57] whereas those with high indexes to be well-managed and followed [58].

4.3. Ecological Service of Agricultural Production Systems in Fitri Watershed of Chad

The total ecological service of the agricultural production systems of Fitri watershed is 201.41t CO_2eq/ha. The two traditional agroforestry systems (*F. albida* agroforestry parklands, Mixed crops systems) store significant amounts of carbon in their biomass. The ecological service of *F. albida* agroforestry parklands is 1.4 whereas that of *S. durra* planted out is 0.07 times compared to the total ecological service. The superiority of the *F. albida* agroforestry parklands in sequestering carbon in other systems was reported in West African Sahel [54]. These values concerning the carbon stock are higher than 24tC/ha reported in Parklands of Mali [59] and at the same time, fit in the interval (40-60 tC/ha) reported [60]. It is also higher than 5.046 tC/ha obtained in *Vitellaria paradoxa* agroforestry parklands in Cameroon [61]. Based on these findings, they can say that agroforestry systems are excellent carbon shafts.

5. Conclusion

Farmers have good knowledge of climate changes in their area. This study carried out in three villages of the watershed of Fitri permits to identify three agricultural production systems among which *F. albida* agroforestry parklands are the most important in increasing water infiltration, soil fertility and biodiversity conservation, thus limiting consequences of climate changes. Diversification of mixed crops reduces considerably risk of failure linked to climate changes. Ecological importance species are *Faidherbia albida*, *Balanites aegyptiaca*, *Prosopis juliflora* and *Mangifera indica*. Fabaceae, Balanitaceae, Mimosaceae, Arecaceae, Rhamnaceae, Capparaceae, Meliaceae and Asclepiadaceae are the main top families with an importance value index equal to or more than 10%. Plant diversity blooms better in Zegue than elsewhere in Fitri watershed. Agroforestry represents alternatives which can reverse actual trends of degraded natural ecosystems in the area. The high density of woody species shows that they abound in seeds which can permit their renewal. The development of an agroforestry system developed by farmers to enhance resilience against Climate changes could be encouraged in the broader context of sustainable development in the area of the watershed of Fitri of Chad. Agroforestry is an agro-ecological and climate-smart practice with huge potentials to reduce smallholder farmers' vulnerability and enhance their resilience faced with the predominantly negative effects of climate change. The next step will be focused on biodiversity conservation in the area.

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