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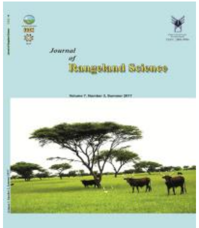

Research and Full Length Article:

Ecological Drivers of Ecosystem Diversity in Sahelian Rangeland of Niger

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Abstract. Description of vegetation patterns associated with environmental factors such as grazing, climate, landforms, substrate variables etc. are helpful for land management planning. This study used new synecological tools to investigate plants composition and to provide ecological descriptions of plants communities of communal pastures in Sahelian Ecological Zone of Niger. Vegetation and several environmental variables were recorded in 197 plots using the Braun-Blanquet cover-abundance scale. A composite soil sample of about 1 kg from each plot was collected for analysis. A total of 252 species were recorded, belonging to 148 genera from 47 families, in which the angiosperms families counting 251 species are more represented and the pteridophytes are represented by one species belonging to the family of Marsileaceae. Poaceae, Leguminosae-Papilionoideae, Convolvulaceae, Cyperaceae and Leguminosae-Mimosoideae are the largest families. High abundance of the Poaceae species reveal the great potential forage value of the Sahelian rangelands. Most of the plants species are Therophytes and widely distributed elements in the tropics, revealing therefore an arid environment with great potential forage value under high disturbance, accordingly poorly managed. Arid ecosystems under heavy disturbance are susceptible to desertification. Nine pasture vegetation communities have been discriminated, distributing along the environmental gradient. Significant abiotic factors of plants distribution and their assemblage to form communities are geomorphology, total alkalinity, magnesium, phosphorous total and the cationic exchange capacity. Significant factors as well as sand, clay, silt, calcium, organic carbon, available phosphorous contents and plants composition varied differently with the definite plants communities. Plants communities under depression have great amounts of moisture and soil factors of soil fertility, therefore more resilient. Likely, plants communities located on sandy plains and dunes slopes or summits are more vulnerable to desertification than those located in fertile depression with great water contents.

Key words: Arid flora and vegetation, Disturbance, Desertification, Rangeland, Sahel

Introduction

Rangelands worldwide have multifunctional roles, including the supporting of the production of fifty percent of the world's livestock, providing goods and services to support the livelihood and the well-being of one-fifth or over two billions of the world's human population (Reynolds and Stafford Smith, 2002; Yahdjian *et al.*, 2015), furnishing forages for both domestic and wild herbivorous consumption (Briske and Heitschmidt, 1991), inhabiting for over a third of global wildlife (Myers *et al.*, 2000) and store more than a third or 200 000–420 000 Mt of above- and below-ground carbon reserves (Allen-Diaz, 1996; Robert, 2001). Rangeland systems are also the source of many important medicinal and aromatic plants of economic importance and other non-timber forest products (Chetri and Gurung, 2004). Therefore, managing these systems is essential for continuing to provide these various services of substantial ecological, socio-economic and cultural values (Moradi *et al*., 2012).

The Sahel biogeographically zone shapes a belt, that crosses the northern Africa, approximately in a parallel direction to the equator, crossing ten countries, from Senegal in the West to Sudan in the East (Le Houérou, 1980; 1996; Hiernaux and Le Houérou, 2006; Hein and De Ridder, 2006). It forms a vast dryland area of about 2.5 million km^2 with 200–600 mm annual average rainfall, bounded by the Sahara desert in the north and the Sudanian savannah in the south. The climate of the region is tropical semiarid to arid, controlled by the West African monsoon of the Gulf of Guinea and the Harmattan (Sahara trade wind). The soils of the Sahel are sandy, with the exception of some depressions with clayey or loamy sands due to runoff deposits (Soumana *et al*., 2012). The diversity of the Sahelian vegetation is the reflectance of the steep south to north decline in rainfall and local factors such as soil surface condition and texture, topography, etc. This vegetation dominated by annual grass species, mostly C4, almost no succulents, mainly used for grazing, is characterized essentially by the poor number of plants species (about 1500 plant species) and the high seasonal variability of the quality of the biomass (Le Houérou, 1997; Hiernaux and Le Houérou, 2006). In the rainy season, the fresh fodder is abundant, tender with high quality and easy to digest. In the dry season, it loses quality by becoming dry, scarce and hard to consume by livestock (Boudet and Duverger, 1961). However, advanced studies have mentioned serious modification of Sahelian rangelands as combined effect of increasing demands of rangelands resources by growing human population, expansion of croplands area over rangelands, overgrazing because of animal number growing and substantial reduction of grazing areas, and serious deforestation mainly for firewood, all exacerbated by recurrent droughts and climate variations· (Reynolds and Stafford Smith, 2002; UNEP, 2012). Profound changes of drylands vegetation composition towards undesirable condition were known as desertification (Bestelmeyer *et al.*, 2015). Desertification threatens the livelihood and the well-being of the rural communities as rangelands provide a wide variety of services and goods, in the Sahel, it affect all aspects of daily life; health, nutrition and income of individual households (Wezel and Lykke, 2006). Therefore, detail information on rangeland condition is obviously needed for developing sustainable approaches of utilization that prevent them from desertification (Jouri *et al*., 2011). Previous data on Niger rangelands is scare even with earlier studies of CIRAD-IEMVT to inventory the flora and to analyze the effect of repeated droughts on sahelian vegetation (see de Fabregues, 1963; 1965, 1967, 1970; de Fabregues & Lebrun, 1976; Boudet, 1960, etc.). Although describing rangelands flora and understanding rangelands response to constant drought are important, plants communities descriptions associated with environmental factors such as grazing, climate, landforms, etc. are helpful for management planning. In the present study, new synecological tools using classification and ordination of phytosociological data associated with pedogeomorplological data were used to provide floristic detail information and to describe plants communities of communal pastures.

Materials and Methods

Study area

The study was conducted in the central eastern part of Niger, region of Zinder, which belongs to the Sahel Transition Zone (White, 1986). The study sites are free grazing areas, covering the south-east/north-west axis of the region, through a latitudinal gradient. The climatic conditions across the entire region are tropical arid to semi-arid, with a potential evapotranspiration estimated between 3000 mm and 3500 mm per year with a minimum in August and a maximum in April and October. The study was carried out, around two districts, Tanout (14°57'N, 8°60'E) and Gouré (13°57'N, 10°19'E) respectively in the northern and southern parts of the study area. Globally, the relief of the region is relatively flat with an average altitude ranging between 450 and 500 m, except in the Mounio Massif (Gouré) where it reaches 600 m and the southern part, where the altitudes do not exceed 320 m. The highest precipitations are recorded in July and August with respectively monthly means of rainfall of 100±42 mm and 145±76 mm at Tanout, 341±115 mm and 209±72 at Gouré between 1950 and 2000, and annual average rainfall of 100 mm in the North and 450 mm in the South, over 50 years. The natural vegetation of the study area, excepted in the depression is characterized by typical wooded grasslands which structure and composition show strong interannual and spatial variations due to severe recurrent drought, topography and latitudinal gradient of rainfall and increasing human activities like grazing. The scattered small (below 8 m) woody layer of the vegetation is dominating by thorny species like *Acacia tortilis* var. *raddiana*, *A. senegal*, *A. laeta*, *A. seyal*, *Balanites aegyptiaca*, *Commiphora africana*, etc. while the most frequent and highly palatable herbaceous species is characterizing by grass such as *Cenchrus biflorus*, *Schoenefeldia gracilis*, *Aristida adscensionis*, *A. funiculata*, *Digitaria horizontalis*, etc. In high grazing pastures, this grass species are relatively lacking and replaced by poorly palatable plants like *Boerhavia coccinea*, *Tribulus terrestris*, *Pergularia tomentosa L.*, *Calotropis procera*, etc (Figs. 1 and 2).

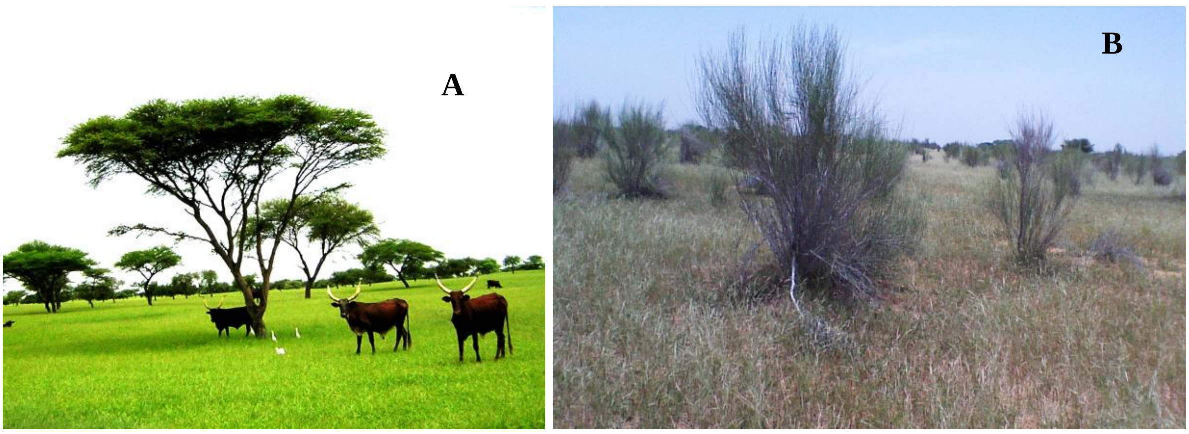

Fig. 1. Landscapes of the *Acacia tortilis- Digitaria horizontalis* (A) and *Leptadenia pyrotechnica- Aristida sieberiana* communities (B)

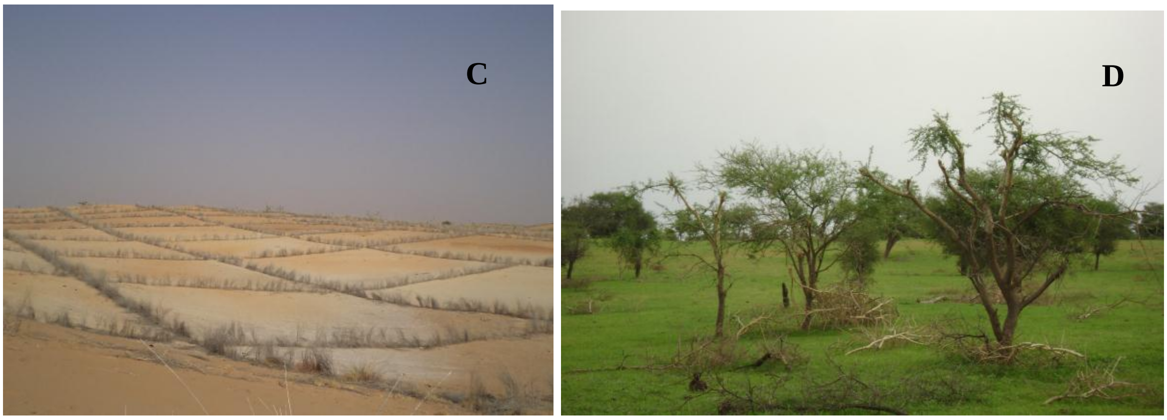

Fig. 2. Stabilizing sand dune using palisade of *Leptadenia pyrotechnica* branches (C) and pruned *Acacia* trees to supplement livestock (D)

Data collection

To analyze the composition and the structure of the plant communities of the communal rangelands, vegetation and sites characteristics were recorded in rectangular plots of 1000 m² (50 m by 20 m), from the end of August to the beginning of September when the Sahelian herbs cover was at maximal development, with grasses and forbs easily identifiable (Saadou, 1990). Stratified sampling with clustering was adopted in this study (Soumana *et al.*, 2012). The stratification was based on the topography of the communal pasturelands. Several plots were placed on each topographic unit (flat plain, dune slope and summit, and depression) based on the homogeneity of the vegetation and the soil surface feature (Guinochet, 1973; Gounot , 1969) . For each plot, GPS coordinates, soil texture, geomorphology were recorded, and then vascular plants cover were assessed using the Braun-Blanquet (1932) cover-abundance scale (+=0.5; 1=3; 2=15; 3=37.5; 4=62.5; 5=87.5). Soil samples were randomly collected from 5 points in each plot using a 5 cm diameter soil auger to a depth of 20 cm after removing surface litter. A composite soil sample of about 1 kg from each plot was collected, air-dried and sieved for analysis of soil chemical and physical characteristics (Soil Laboratory sol, Faculty of Agronomic Sciences, Abdou Moumouni University of Niamey). Soil texture was determined using the hydrometer analysis (Bouyoucos, 1962), Walkely-Black (Black, 1979); titration method was used for the determination of the soil organic carbon; electric conductivity meter was used to assess soil Electric Conductivity (EC), pH was evaluated in soil-water ratio of 1:2.5 by a glass electrode pH meter (Mathieu and Pieltain, 2003); total phosphorus and total nitrogen were determined respectively by colorimetry after wet digestion with H_2SO_4 and $HClO_4$ and Kjeldahl methods (Parkinson and Allen, 1975); available phosphorus was determined using Bray-I procedure (Olsen and Sommers, 1982); Silver-Thiourea method was used to evaluate Cation Exchange Capacity (CEC) and total alkalinity (S), finally photometer was used for estimating the cations (K, Na, Ca and Mg). Nomenclature adopted for plants is that of Lebrun and Stork (1997). Plants life forms were determined according to Raunkiaer (1934) classification which emphasizes the position of the perennating or renewal buds of plants (Stanley, 1950). The phytogeographical and syntaxonomic rank of the plant species were determined according to the most applied and accepted vegetation classification covering the whole continent, which delimitation of vegetation zones is principally based on patterns of species distributions and distinguishes regional centers of endemism (with >50% of their flora being endemic) and transition zones between them (White, 1986); chorological types used were Sudanian species (S), Wide distribution species such as Afro American species (AA), Pan tropical species (Pan), Paleotropical species (Pal), Cosmopolitan (Cos) and Continental distribution species such as Afro Malgache (AM), Afro-Tropical (AT), Guineo-Congolian (GC) Pluri regional African (PA) and Sudano-zambesian (SZ) species.

Data analysis

The analyzed data set consisted of 197 plots containing 252 species. To identify the patterns of species assemblage and to detect environmental gradients that induce those patterns, the data set was subjected to multivariate analyses. First, vegetation physiognomy types were determined using Detrended Correspondence Analysis (DCA) (Hill, 1979) based on the data set in presence/absence. Second, cluster analysis was performed with the Bray-Curtis distance and Ward's method (Ward, 1963) on the group of vegetation samples to classify plants communities of each physiognomy types (McCune and Grace, 2002). The cluster analysis (HC) was complemented by the use of an ordination based on Detrended Correspondence Analysis to observe patterns of vegetation along the Environmental gradients. DCA provides eigenvalues that can be used to estimate gradient, something that is not feasible with cluster analysis. A nonparametric test, Multi-Response Permutation Procedures (MRPP) (McCune and Grace, 2002) was used to test the difference in species composition between plants communities and the heterogeneity within each community. The data matrix for MRPP was the squared Euclidean distance between each pair of the 197 plots based on relative abundance of the 252 species. MRPP is a non-parametric multivariate procedure that tests between species composition of two or more a *priori* communities. MRPP provides three values: A (change-corrected within site agreement) tests the homogeneity within community; when all of the observations within communities are identical, then the observed delta = 0 and A = 1; T (the difference between the observed and expected deltas) tests the difference between two or more communities (groups of samples or sites), and p-value tests the difference between communities (groups of samples or sites stages). Indicator Species Analysis (ISA) (Dufrêne and Legendre, 1997) was used to identify which species were characteristic for each community. ISA has the advantage of combining both the Relative Frequency (RF) and Relative Abundance (RA) for calculating the Indicator Value (IV) of each species, and the significance is tested by the Monte Carlo test. All species with a probability less than 0.05 were accepted as more frequent and abundant species, hence as characteristic species. The Indicator Value was calculated using the following formula (Equation 1):

$$IV_{kj} = RA_{kj} \times RF_{kj} \times 100 \qquad \text{(Equation 1)}$$

Where:

IV= is Indicator Value

RA= is the relative abundance of a given species j in a given site type k and

RF= is the proportional frequency of species j in site type k (i.e., the proportion of plots in each site type with species j).

Values of IV ranged from 0 to 100 (perfect indication). A perfect indicator value means that a given species occurs only in a given site type and are always in that site type. Among the most characteristic species, two species (one woody and one grass) with high IV, low P-value were used to name plant communities (Soumana *et al.*, 2012) according to the degree of fidelity and constancy (Braun-Blanquet, 1932). Canonical Correspondence Analysis (CCA; Ter Braak, 1986) was implemented with Monte Carlo permutation test to analyze the relationship between the pattern of plants communities and the environmental variables. Monte Carlo permutation provides P-values that tested the statistical significance of each environmental variable. Cluster analysis, MRPP and ISA were done using PC-ORD (McCune and Grace, 2002) Version 5. CANOCO version 4.5 was used for DCA and CCA (Ter Braak and Smilauer, 1998). Finally, differences in soil chemical characteristics between plants community fields were analyzed using one-way Analysis of Variance (ANOVA). Before running the ANOVA test, the normality of the soil variables were tested by using the test of Kolmogorov-Smirnov. Minitab (Dytham, 2011) version 16 was used for the test of Kolmogorov-Smirnov and one way ANOVA tests.

Results

Phytodiversity

Globally, 252 species were recorded, belonging to 148 genera from 47 families in which the angiosperms families counting 251 species (183 dicotyledons and 68 monocotyledons) are more represented and the pteridophytes are represented by one species belonging to the family of Marsileaceae (Table 1). Species number per sample ranged from 17 to 42, and averaged 28. Among the 252 species, the majority are herbaceous (213 species; 85%) representing 82% of the plants cover, the other plants species are shrubs and trees (39 species) with 18% of the plants cover. Most of the species (175 species; 69%) were palatable, the most preferred by livestock (mainly goats, cow, and sheep) were herbaceous such as *Cenchrus biflorus, Dactyloctenium aegyptium, Digitaria horizontalis, Brachiaria xantholeuca, Alysicarpus ovalifolius, Zornia glochidiata, Cassia mimosoides, Crotalaria atrorubens, Andropogon gayanus, Aristida sieberiana,* etc. Some ligneous species like *A. tortilis, A. senegal, A. seyal, Balanites aegyptiaca, Faidherbia albida, Ziziphus mauritiana,* etc. were highly pruned to supplement livestock, in the dry season.

Table 1. Number and percentage of taxons in Sahelian rangelands

Taxons	Number of families	% of families	Number of genera	% of genera	Number of species	% of species
Spermaphytes	46	97.87	147	99.32	251	99.60
Angiosperms	46	97.87	147	99.32	251	99.60
Monocotyledons	5	10.64	33	22.30	68	26.98
Dicotyledons	41	87.23	104	70.27	183	72.62
Pteridophytes	1	2.13	1	0.68	1	0.40
Total	47	100	148	100	252	100

The most abundant family was the Poaceae represented by 49 species (19.44%), followed by the Leguminosae-Papilionoideae (23 species; 9.13%), the Convolvulaceae (16 species; 6.35%), the Cyperaceae (14 species; 5.56%), the Leguminosae-Mimosoideae (11 species; 4.37%), the Malvaceae (3.57%), the Capparaceae (3.57%), the Asteraceae Euphorbiaceae (3.57%), representing by nine (9) species int total, etc. (Table 2). The families represented by only one species are Bombacaceae, Annonaceae, Aristolochiaceae, Balanitaceae, Colchicaceae, Pontederiaceae, Arecaceae, Marsileaceae, Caryophyllaceae, Portulacaceae, Salvadoraceae, Anacardiaceae, Scrophulariaceae, Verbenaceae, Loranthaceae, Zygophyllaceae and Sterculiaceae, each representing 0.4% of the flora.

Table 2. Number and percentage of species in each family of Sahelian rangelands vegetation of central eastern Niger

Families	Number of species	% of species	Number of genera	% of genera
Poaceae	49	19.44	25	16.89
Leguminosae-Papilionoideae	23	9.13	9	6.08
Convolvulaceae	16	6.35	4	2.70
Cyperaceae	14	5.56	5	3.38
Leguminosae-Mimosoideae	11	4.37	6	4.05
Malvaceae	9	3.57	5	3.38
Euphorbiaceae	9	3.57	5	3.38
Asteraceae = Compositae	9	3.57	9	6.08
Capparaceae	9	3.57	4	2.70
Cucurbitaceae	8	3.17	6	4.05
Amaranthaceae	7	2.78	6	4.05
Leguminosae-Caesalpinioideae	7	2.78	3	2.03
Tiliaceae	7	2.78	4	2.70
Rubiaceae	6	2.38	5	3.38
Asclepiadaceae	6	2.38	4	2.70
Borraginaceae	5	1.98	3	2.03
Solanaceae	5	1.98	5	3.38
Acanthaceae	4	1.59	3	2.03
Combretaceae	4	1.59	4	2.70
Nyctaginaceae	4	1.59	2	1.35
Molluginaceae	4	1.59	2	1.35
Commelinaceae	3	1.19	1	0.68
Burseraceae	2	0.79	2	1.35
Brassicaceae = Cruciferae	2	0.79	2	1.35
Pedaliaceae	2	0.79	1	0.68
Liliaceae	2	0.79	1	0.68
Aizoaceae	2	0.79	2	1.35
Labiatae = Lamiaceae	2	0.79	1	0.68
Polygalaceae	2	0.79	1	0.68
Rhamnaceae	2	0.79	1	0.68
Bombacaceae	1	0.40	1	0.68
Annonaceae	1	0.40	1	0.68
Aristolochiaceae	1	0.40	1	0.68
Balanitaceae	1	0.40	1	0.68
Colchicaceae	1	0.40	1	0.68
Pontederiaceae	1	0.40	1	0.68
Palmae = Arecaceae	1	0.40	1	0.68
Marsileaceae	1	0.40	1	0.68
Caryophyllaceae	1	0.40	1	0.68
Portulacaceae	1	0.40	1	0.68
Salvadoraceae	1	0.40	1	0.68
Anacardiaceae	1	0.40	1	0.68
Scrophulariaceae	1	0.40	1	0.68
Verbenaceae	1	0.40	1	0.68
Loranthaceae	1	0.40	1	0.68
Zygophyllaceae	1	0.40	1	0.68
Sterculiaceae	1	0.40	1	0.68
Total	252	100	148	100

Life forms of the flora were dominated by Therophytes (140 species; 55.56%) and Phanerophytes (59 species; 23.41%). Chamaephytes (CH: 8.73%), Hygrophytes (Hy: 4.76%), Hemicryptophytes (H: 4.37%), Geophytes (G: 2.78%) and Parasites (0.4%) represented by 22, 12, 11, 7 and 1 species, respectively (Table 3). Most of the species of the flora were widely distributed in the tropics and Africa with respectively 151 (59.92%) and 100 (39.68%) plant species (Table 4). Among the wide distribution elements in the tropics, Pantropical (Pan) and Paleotropical (Pal) species were the most abundant. In the other hand, Sudano-zambesian (SZ) and Sudanian (S) species were the most represented continental elements with respectively 29 and 26 species.

Table 3. Life forms spectrum of the species of the Sahelian rangelands vegetation of central Eastern Niger according to Raunkiaer (1934)

Life forms	Number of species	% of species
Therophytes (Th)	140	55.56
Phanerophytes (Ph)	59	23.41
Chamaephytes (Ch)	22	8.73
Hydrophytes (Hy)	12	4.76
Hemicryptophytes (H)	11	4.37
Geophytes (G)	7	2.78
Parasites	1	0.40
Total	252	100

Table 4. Chorotype spectrum of the species of Sahelian rangelands vegetation of central eastern Niger according to White (1986)

	Chorotypes	Number of species	% of species
Species widely distributed in the tropics	Pan tropical species (Pan)	78	30.95
	Paleotropical species (Pal)	56	22.22
	Cosmopolitan (Cos)	10	3.97
	Afro American species (AA)	7	2.78
	Total	151	59.92
Species widely distributed in Africa	Sudano-zambesian species (SZ)	29	11.51
	Sudanian species (S)	26	10.32
	Pluri regional African species(PA)	21	8.33
	Afro-tropical species (AT)	15	5.95
	Afro Malgache species (AM)	7	2.78
	Guineo-Congolian (GC)	2	0.79
	Total	100	39.68
Distribution not specified		1	0.40
	Total	252	100

Main vegetation types and plants communities

DCA splitted the matrix of 252 species and 197 plots into two groups of samples representing two Vegetation physiognomy (formations) (Fig. 3). Hence, Axis 1 which has the high values of variance (6.3%), eigenvalue (0.54) and lengths gradient (4.85) explains highly the distribution of the information in the diagram, it's separated at it left plots from sandy soil of wooded grasslands (132 plots and 175 species) and it right plots from woodlands of loamy and clayey moisture depressions (65 plots and 222 species), thus reflecting the underlying moisture, geomorphology and soil texture gradients. High dispersal of the plots from depressions in the DCA diagram reveals high variability of plants communities in these sites.

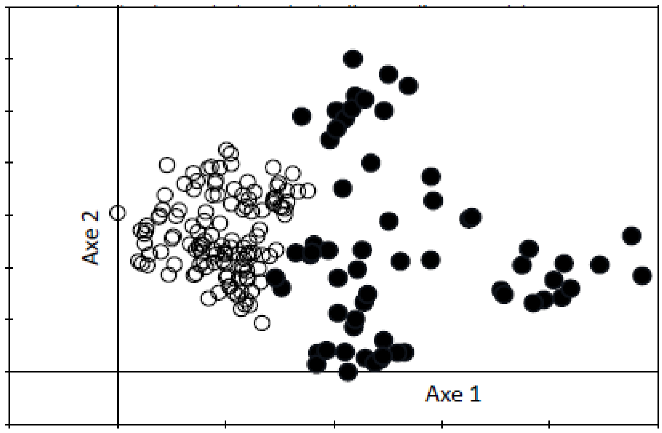

Fig. 3. Ordination by detrended correspondence analysis of the matrix of 197 plots and 252 species from the Sahelian rangelands vegetation of central eastern Niger: white circle indicates wooded grasslands formation and black circle indicates woodland formations in depression; DCA axe 1: r² =6.3%; eigenvalue= 0.54; Lengths of gradient = 4.85; DCA axe 2: r²= 3.4%; eigenvalue= 0.29; Lengths of gradient= 2.9

The group of plots from grasslands (132 plots and 175 species) and the ones from depression woodlands (65 plots and 222 species) have been separately subjected to cluster analysis and DCA. The classification of the plots based on Sorensen's similarity coefficient and cluster analysis (Dendrograms A and B) showed respectively plant communities from Sandy soil grasslands and plant communities from depression woodlands (Fig. 4) which are projected on the DCA graphs: A for plant communities from Sandy soil grasslands and B for plant communities from depression woodlands (Fig. 5). Finally, nine plants communities were discriminated on the rangelands, of which four plant communities of sandy soil grasslands and five plant communities of depression woodlands. MRPP based on plants and environmental variables revealed high differences (P<0.000; A=0.48; T=-66) of plants composition between the nine plants communities (Table 5). Each pair-wise comparison by MRPP showed that plants communities differed significantly. The small difference between the excepted (0.50) and observed delta (0.27) values confirms the strong variation in species composition between communities. The strong chance-corrected within-group agreement (A) and T test showed that the nine plants communities were distributed in different regions of the species space and relate spatial heterogeneity of the Sahelian rangelands. The average within-group distance showed that communities 2, 3, 4, 5, 7, 8, and 9 have relatively high dispersions, with an average distance of between 0.22 and 0.49, while communities 1 and 2 were relatively tight (average distance 0.10–018). The four plant communities of grassland and five plants communities from woodlands is presented in Table 5:

Table 5. The classification of the 197 plots and 252 species into 9 plant communities based on cluster analysis

Communities	Code	Community type	Abbreviation	Number of plots	Number of species
Grasslands	1	*Leptadenia pyrotechnica- Aristida sieberiana*	Lp_As	16	55
	2	*Sclerocarya birrea- Brachiaria xantholeuca*	Sb_Bx	48	127
	3	*Acacia tortilis- Digitaria horizontalis*	At_Dh	26	51
	4	*Boscia senegalensis-Cenchrus biflorus*	Bs_Cb	46	124
Woodlands	5	*Balanites aegyptiaca- Setaria pallide fusca*	Ba_Sp	15	120
	6	*Salvadora persica-Brachiaria ramosa*	Sp_Br	11	64
	7	*Grewia tenax-Cymbopogon schoenanthus*	Gt_Cs	12	89
	8	*Acacia ehrenbergiana-Sesbania leptocarpa*	Ae_Sl	15	128
	9	*Acacia nilotica- Echinochloa colona*	An_Ec	13	68

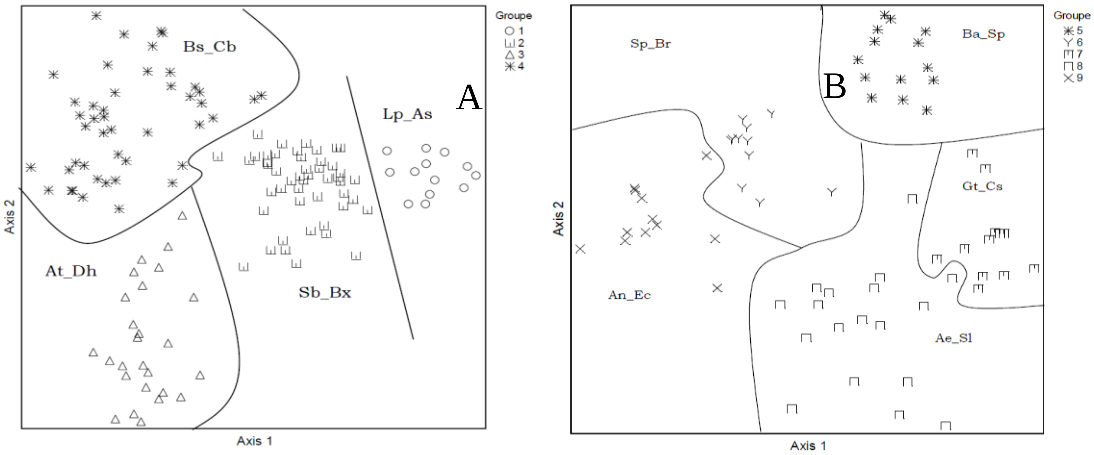

Fig. 4. Ordination by Detrended Correspondence Analysis (DCA) of the matrix of 132 plots and 175 species from sandy soil grasslands, dividing into four plants communities (graph A) and the matrix of 65 plots and 222 species from depression woodlands, dividing into five plants communities (See Table 5 for plant community abbreviation)

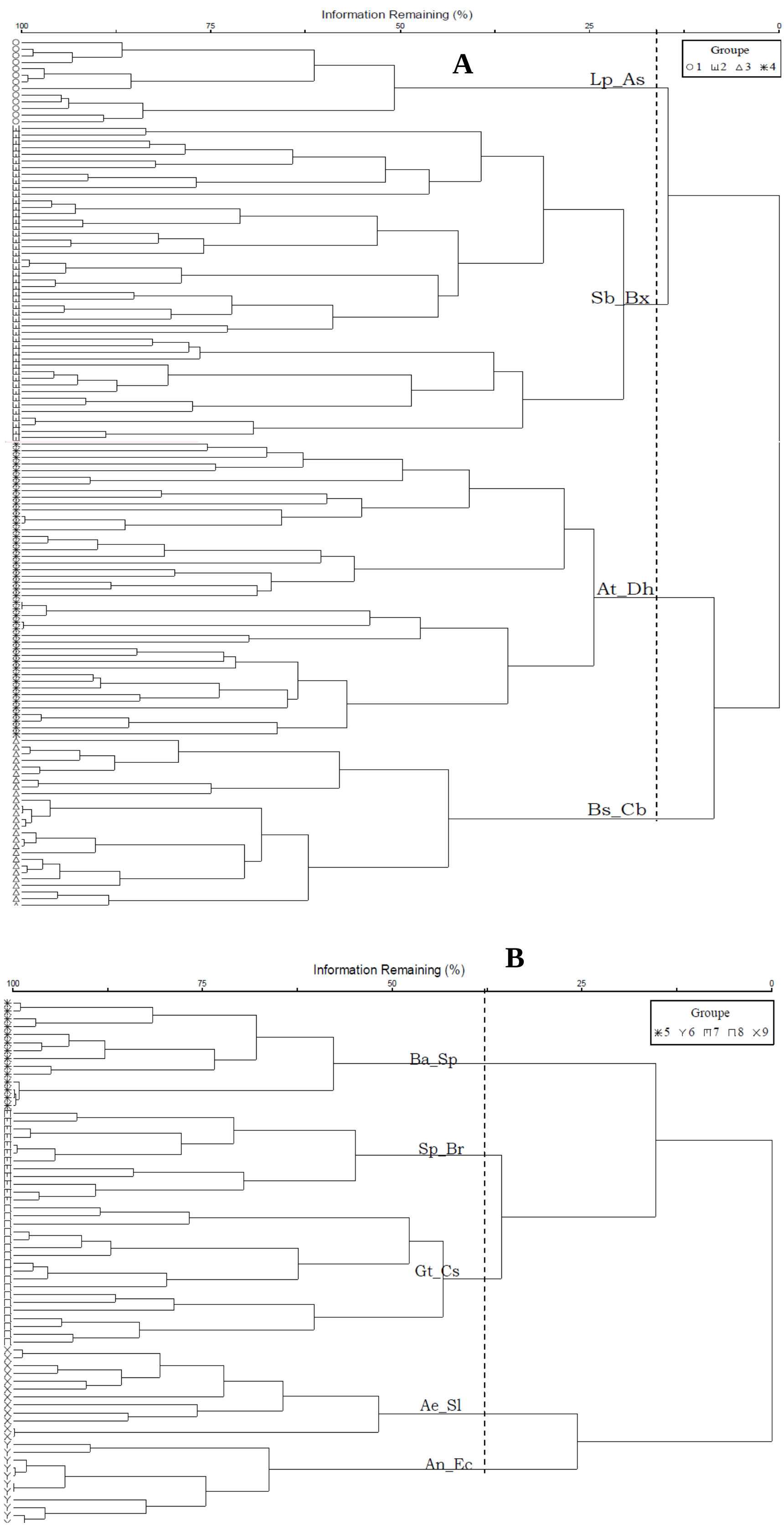

Fig. 5. Hierarchical Classification of the matrix of 132 plots and 175 species from sandy soil grasslands, dividing into four plants communities (Dendogram A) and the matrix of 65 plots and 222 species from depression woodlands, dividing into five plants communities (Dendogram B) (See Table 5 for plant community abbreviations)

Description of main plants communities

Grassland communities

***Leptadenia pyrotechnica- Aristida sieberiana* community**

The community was described from 16 plots and 55 species, with an average of 27.69±3.37 per plot, ranged from 19 to 31 species. Among the total plants species, Indicator Species Analyisis (ISA) based on the species relative frequency and relative abundance has distinguished 19 characteristics species mainly phorbes *Spermacoce ruelliae, Amaranthus spinosus, Commelina forskaolii, Cyperus conglomeratus, C. esculentus, C rotundus, Cleome gynandra, Ipomoea coscinosperma, I. kotschyana, I. pes-tigridis, Citrullus lanatus, C. colocynthis, Limeum pterocarpum, L. viscosum, Phyllanthus pentandrus, Sesamum alatum,* few grasses like *Aristida sieberiana, A. stipoides, Andropogon gayanus, Cenchrus prieurii* and two Phanerophytes species *Euphorbia balsamifera* and *Leptadenia pyrotechnica.* The community was founded on deeper sandy dunes and versants, near localities, using for free grazing by sedentary herders. It's characterized by high covers of *Leptadenia pyrotechnica*, which is very important for camel grazing, during the dry season when grasses and other woody plants fodder were not available, It also provides wood for fire and palissade in stabilizing and restoring mobile sandy dunes. Among the phorbes species, the high frequency of nitrophytes species like *Amaranthus spinosus*, *Tribulus terrestris*, *Cyperus rotundus* and *Cleome gynandra*, due to livestocks urine and faeces; and *Cyperus conglomeratus* that tolerates high disturbed and cleaned sandy ground in the community reflect high grazing intensity.

The soil of the plants community has sandy texture with (90% of sand) with high water infiltration (Table 6). Soil chemical analysis indicates slightly acid soil (pH= 6.73±0.28) with very low soil organic matter (C= 0.35%) and cation exchange capacity (10.05 meq/100 g) and high content of available phosphorus (41.31±3.52 ppm (Table 6).

***Sclerocarya birrea- Brachiaria xantholeuca* community**

This community is typically the vegetation of sandy flat plains in the southern part of the study area. Within 48 plots, 127 species were recorded, averaged 27.37±4.42 species per plot and ranged from 17 to 38 species. Based on ISA, 11 characteristic species were distinguished: *Sclerocarya birrea, Brachiaria xantholeuca, Achyranthes aspera, Alysicarpus ovalifolius, Boerhavia erecta, Dactyloctenium aegyptium, Indigofera aspera, Leptadenia hastata, Mitracarpus scaber, Polygala erioptera, Zornia glochidiata.* This community is the typical a steppe wherein the woody species include mainly *Sclerocarya birrea, Acacia tortilis, A. senegal, A. seyal, A. nilotica, Boswellia papyrifera, Boscia salicifolia, Adansonia digitata*. Although the physiognomy of vegetation was different to *Leptadenia pyrotechnica- Aristida sieberiana* community.

The soil of the plants community were close with slightly deep sandy neutral soil pH (pH= 7.27±0.48; Sand= 82.32%), with low soil organic matter (C= 0.40%) and cation exchange capacity (10.75 meq/100 g) et high content of available phosphorus (41.31±3.52 ppm) (Table 6).

***Acacia tortilis- Digitaria horizontalis* community**

This community was described from 26 plots and 51 species, recorded in the vegetation of the rangelands of the northern and the central parts of the study area, generally on sandy dunes, versants and plains. Average number of species was 16.23±2.40 species per plot, ranged fron 10 to 20.This rangeland was used as common pasture by both sedentary *Kanury* and *Hausa* farmers of the area and also by several pastoral groups such *Uda'en, bornanko'en*, *Woodabes yamanko'en* etc. According to ISA, the community is mainly structured by *Acacia tortilis, Digitaria horizontalis, Amaranthus graecizans, Boerhavia diffusa, Cyperus bulbosus, Tragus racemosus, Tribulus terrestris,* which's physiognomy and composition reflected the high grazing intensity. The very scarce woody layer, with lower cover (<10%) generally comprise thorny species like *Acacia tortilis, A. senegal, Balanites aegyptiaca* excepted *Leptadenia pyrotechnica. Acacia tortilis* is common and widely widespreads in all the rangelands of the study area, it is a great fodder for camel and other livestock, greatly pruned in the dry season for it pods, young leaves and buds.

The substrate was also sandy neutral soil pH (pH= 7.28±0.12 ; 86% of sands), with poorly soil organic carbon (0.55%), cations exchange capacity (11.33±0.14 meq/100g). Nevertheless total alkalinity (10.17±0.13 meq/100 g) and available phosphorous content (41.31±3.52ppm) are relatively high (Table 6).

***Boscia senegalensis- Cenchrus biflorus* community**

The community was recognized from 46 plots and 124 species, with an average number of 27.82±5.49 species, ranged from 13 to 35 species, all of which recorded in the extreme northern part of the study area, at Tanout district, on relatively flat sandy plains. The community was only used by mobile herders in the rainy season when pounds can afford drinking to herders and their livestock. In the dry season, the pounds dry up and force the herders to abandon this community for the southern part, where water is available. Most of the characteristic species revealed by ISA were Therophytes mainly *Cenchrus biflorus, Ceratotheca sesamoides, Chrozophora brocchiana, Geigeria acaulis, Farsetia aegyptiaca, Senna italica* and *Cassia mimosoides,* and only one dominant Phanerophyte *Boscia senegalensis.*

The flat sandy plains soil are neutral soil pH (pH= 7.08±0.2) with lower organic carbon (0.51±0.01%), cations exchange capacity (10.25±0.00 meq/100g). However, high contents of total alkalinity (8.80±0.15 meq/100g) and available phosphorous (50.64±6.00 ppm) were recorded in these soil (Table 6).

Woodland communities

***Balanites aegyptiaca- Setaria pallide fusca* community**

This community was founded from 15 plots and 120 species, with an average number of 36.21±5.67 species, ranged from 38 to 40 species, recorded in depressions, between adjacent downslops of sandy dunes associated with water stockages, in the southern part of the study area. The community had more mesic species, recorded in slight depressions in which water flow occasionally. This community was grazed as soon as sandy plains and dunes communities such as *Sclerocarya birrea- Brachiaria xantholeuca* community and *Acacia tortilis- Digitaria horizontalis* community were grazed. Significant indicator plants included *Acacia senegal, A. seyal, Aristida funiculata, Balanites aegyptiaca, Setaria pallide fusca, Bidens biternata, Blainvillea gayana, Brachiaria lata, Commelina benghalensis, Hibiscus hasirikus, Hyphaene thebaica, Indigofera tinctoria, Ipomoea stolonifera, Leucas martinicensis, Sida ovata, Withania somnifera, Tapinanthus globiferus.* Woody charactersistic species like *Acacia senegal, A. seyal, Balanites aegyptiaca* received high grazing pression from camel and also greatly pruned to supplement livestock, in the dry season.

These depressions have sandy loam soil (sand= 47.57% and silt= 45.04%), acid pH (pH=5.05) with low contents of soil organic carbon (0.52±0.00%), and cation exchanges capacity (12.75 meq/100g). However, the reserve in exchangeable bases and contents of available phosphorus were relatively high

(12.12±0.51 meq/100g, 83.11±5.14 ppm respectively) (Table 6).

***Salvadora persica- Brachiaria ramosa* community**

This vegetation type was described from 11 plots and 64 species, with an average number of 21.54±2.33 per plot, ranged from 19 to 26 species. The community characterized the vegetation of the depressions of the rangelands located at the central part of the study area. This community was used as early grazing pasture due to the high growth of *Amaranthus spinosus* and *Amaranthus graecizans* which were among the most dominant herbaceous layer. Significant indicator plants that structured the community included *Salvadora persica, Brachiaria deflexa, Brachiaria ramosa, Calotropis procera, Chloris prieurii* and *Eragrostis tenella*. In the area, *Calotropis procera* was conidered by the herders, as indicator of grazing pression. *Salvadora persica* is a common species mainly found in the depression and around riparian vegetation of the extremely northern part of the Sahel. It is an important grazing evergreen plant during the dry season, pruned for both fodder and toothbrush.

The sandy loam slightly acid soil (pH=6.05) of these depressions, has low soil organic carbon (0.6±0.2%) and cation exchange capacity (12.75 meq/100g) but they have great potential of total alkalinity (12.75 meq/100g) and available phosphorous (88.77±2.51 ppm) (Table 6).

***Grewia tenax- Cymbopogon schoenanthus* community**

This community was characterized from 12 plots and 89 species, with an average number of 27, 69±3, 37 species per plots, ranged from 20 to 39 species, recorded on the downhill of the limestone plateau, around relatively short, narrow stream, without standing or permanently running water, in the central and northern parts of the study area. According to the herders, these temporarily wet locations and runnels rangelands of downhill were good pasture at high rain fall periods (August), due to the loamy and gravel substrates, and the slopes range from 5 to 10% that allow rapid water evaporation and drainage after rain fall. Significant frequent and dominant species that structured the community comprise mainly these Phanerophytes: *Grewia tenax, Acacia macrostachya, Aristida adscensionis, A. mutabilis, Bauhinia rufescens, Commiphora africana, Cordia sinensis, Guiera senegalensis, Rhynchosia minima,* and *Ziziphus mauritiana;* and in the ground layer was developped sparsly Chamephytes: *Caralluma dalzielii;* Hemichryptophytes: *Cymbopogon schoenanthus*; and Therophytes: *Cienfuegosia digitata, Enteropogon rupestris, Eragrostis cilianensis, Ipomoea vagans, Pennisetum divisum, Pupalia lappacea, Sporobolus ioclados, Stylosanthes erecta* and *Urochloa trichopus.*

The soil crusted substrate was sandy loam with hight contents of sand (73.37±4.78%) and silt (22±2.40%). It has low contents of soil oragnic carbon (0.33±0.02%), cation exchange capacity (11.00±0.00 meq/100g), and high contents of available phosphorous (54.32±2.00 ppm) and total exchangeable bases (10.15±0.06 meq/100g) (Table 6). The nitrogen content is also low (0.03 ± 0.00%), although the C/N ratio (9.43 ± 0.28) shows good mineralization of organic matter.

***Acacia ehrenbergiana- Sesbania leptocarpa* community**

The community is the vegetation of the flooding plains and riparian streams of the extreme northern part of the study area, founded from 15 plots and 128 species, with an average of 28, 06±5, 41 species, ranged from 19 to 36. After the high rainfalls period, the progressive evaporation of the water induces great meadows cover preffered for grazing by herders at the dry season. In these temporally stream environment, shrubs and trees cover was well developed particularly at the bottom of the valley that look like an open forest, with cover of up to 70 %, dominated by *Acacia ehrenbergiana, Acacia nilotica, A. laeta, A. tortilis, A. senegal, A. seyal, Balanites aegyptiaca, Bauhinia rufescens, Boscia angustifolia, Boscia senegalensis, Calotropis procera, Cordia sinensis, Grewia cissoides, G. tenax, G. villosa, Leptadenia heterophylla, Maerua crassifolia, Prosopis juliflora, Ricinus communis, Salvadora persica*. Significant frequent and dominant herbaceous and woody species were *Acacia ehrenbergiana, Aristida hordeacea, Aristolochia bracteolata, Spermacoce filifolia, Schouwia thebaica, Cleome amblyocarpa, Crinum ornatum, Chrysanthellum procumbens, Cynodon dactylon, Cyperus amabilis, Eragrostis pilosa, Indigofera senegalensis, Lasiurus scindicus, Maerua crassifolia, Morettia canescens, Mukia maderaspatana, Pennisetum violaceum, Peristrophe bicalyculata, Phyllanthus maderaspatensis, Sesbania leptocarpa* and *Striga hermonthica.*

The soil was sandy loam with high contents of sands (67.05±4.11%), silt (24.33±51%) and relatively clay content (8.61±1.00%). Soil pH is around neutrality (pH= 7.30±0.17), with relatively low contents of soil oragnic carbon (0.43±0.00%), Nitrogen (0.04±0.00%) and cation exchange capacity (12.75 meq/100g). (Table 6). Nevertheless, content of available phosphorus (73.59±5.72 ppm) and total alkalinity (12.18±0.27 meq/100g) was relatively high.

Acacia nilotica- Echinochloa colona community

This community was recognized from 13 plots and 68 species, with an average of 20.61±4.36 species, ranged from 13 to 29. It was located all over the study area and characterized the vegetation of seasonal water beds, determined by the depth of the water table, the frequency of overflows and the variability of the rainfall. The cover of the wooded species was relatively important due to the proximity of watercourses; it were included *Acacia ehrenbergiana, A. nilotica, A. laeta, A. tortilis, A. seyal, Anogeissus leiocarpa, Balanites aegyptiaca, Bauhinia rufescens, Boscia senegalensis, Commiphora africana, Cordia sinensis, Grewia villosa, Faidherbia albida* and *Ziziphus mauritiana.* Progressive retirement of the water, induce above the establishment of a meadow, dominated by *Echinochloa* spp genus species, including *Echinochloa pyramidalis, E. stagnina, E. colona*, which were preferred by herders for dry season grazing. Significant frequent and dominant species included *Acacia nilotica, Anogeissus leiocarpa, Aeschynomene indica, Corchorus olitorius, Cyperus iria, Echinochloa pyramidalis, E. stagnina, E. colona, Heteranthera callifolia, Hygrophila senegalensis, Ipomoea aquatica, I. asarifolia, I. blepharophylla, I. dichroa, I. ochracea, Mariscus cylindristachyus, Marsilea minuta, Nothosaerva brachiata, Brachiaria villosa, Panicum repens, P. subalbidum, Pycreus macrostachyos, Rhamphicarpa fistulosa, Schoenoplectus senegalensis, Sphaeranthus suaveolens, Sporobolus helvolus, S. pyramidalis* and *Sesbania pachycarpa.*

The substrate is waterlogged sandy loam soil that with 65, 17±4.18% of sand, 35.56± 4.75% of silt and 4.28±1.53% of clay. An alkaline pH (pH= 8.16±0.08), with low content of soil organic carbon (0.58±0.03%), nitrogen (0.05±0.00%), cation exchange capacity (13.00±0.00 meq/100g) and great available phosphorous content (84.25±6.41 ppm) (Table 6). The reserve of exchangeable bases is relatively high (12.87±0.10 meq/100g) associated to the high contents of Ca^{2+} and Mg^{2+} (7.24±0.08 meq/100g ; 5.38±0.20 meq/100g).

Table 6. Mean and standard deviation of the soil variables in the nine community types

Vegetation type	Sandy soil grasslands				Depression woodlands				
Parameters	Lp_As	Sb_Bx	At_Dh	BS_Cb	Ba_Sp	Sp_Br	Gt_Cs	Ae_Sl	An_Ec
Clay (%)***	1.60±0.02	2.13±0.24	2.60±0.02	3.60±1.01	7.39±0.62	6.62±0.05	4.62±0.06	8.61±1.00	4.28±1.53
Fine silt (%)***	3.15±0.54	8.06±0.73	5.27±0.44	7.48±1.11	26.30±0.52	20.89±1.20	14.56±1.05	11.26±1.39	15.39±2.01
Coarse silt (%)***	5.32±1.24	7.57±1.29	6.71±0.34	7.83±1.28	18.74±0.42	15.45±2.56	7.46±1.35	13.07±1.12	15.17±2.74
Very fine Sand (%)***	43.51±0.84	30.05±2.11	32.04±6.77	29.71±4.30	12.45±1.62	24.21±2.87	33.87±1.16	27.99±2.51	27.72±1.78
Fine Sand (%)***	36.22±2.65	40.64±1.37	41.14±2.28	41.48±2.38	26.52±1.59	19.86±2.65	25.86±1.88	29.25±0.38	27.63±1.86
Coarse Sand (%)***	10.20±0.74	11.54±1.63	12.23±5.67	9.90±1.49	8.60±1.01	12.97±1.65	13.64±1.74	9.81±1.12	9.81±1.33
Soil pH (H_2O)***	6.73±0.28	7.27±0.48	7.28±0.12	7.08±0.21	5.05±0.1	6.05±0.05	6.97±0.38	7.30±0.17	8.16±0.08
Organic Carbon (%)***	0.35±0.01	0.40±0.00	0.51±0.01	0.51±0.01	0.52±0.00	0.56±0.02	0.33±0.02	0.43±0.00	0.58±0.03
Total Nitrogen (%)**	0.03±0.00	0.04±0.00	0.04±0.00	0.05±0.00	0.05±0.00	0.05±0.00	0.03±0.00	0.04±0.00	0.05±0.00
Carbon/Nitrogen (C/N)***	9.33±0.17	11.42±0.33	12.03±0.38	10.92±0.12	10.83±0.00	10.31±0.10	9.43±0.28	10.06±0.25	10.42±0.37
Total Phosphorus (ppm)***	72.82±3.45	67.85±4.80	68.32±3.33	85.25±7.87	125.22±8.20	148.58±8.03	73.71±4.00	95.68±8.66	146.51±7.50
Available Phosphorus (ppm)***	48.97±1.91	42.25±5.23	41.31±3.52	50.64±6.00	83.11±5.14	88.77±2.51	54.32±2.00	73.59±5.72	84.25±6.41
Ca^{++} (meq/100g)***	5.60±0.13	5.31±0.09	5.64±0.09	4.61±0.13	6.97±0.20	6.81±0.08	5.58±0.06	6.81±0.08	7.24±0.08
Mg^{++} (meq/100g)***	4.14±0.09	4.38±0.20	4.28±0.08	3.94±0.14	4.90±0.28	4.90±0.28	4.32±0.05	5.12±0.28	5.38±0.20
Na^{+} (meq/100g)	0.17±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.01	0.12±0.01
Total Potassium K^{+} (meq/100g)	0.13±0.01	0.13±0.01	0.13±0.02	0.13±0.02	0.13±0.01	0.13±0.02	0.13±0.02	0.13±0.02	0.13±0.02
Total alkalinity S (meq /100g)***	10.00±0.17	9.94±0.25	10.17±0.13	8.80±0.15	12.12±0.51	11.96±0.25	10.15±0.06	12.18±0.27	12.87±0.10
Cation exchange capacity (meq /100g)***	10.50±0.00	10.75±0.00	11.33±0.14	10.25±0.00	12.75±0.00	12.75±0.00	11.00±0.00	12.75±0.00	13.00±0.00
S /T***	0.95±0.02	0.924±0.02	0.89±0.02	0.86±0.01	0.95±0.04	0.94±0.02	0.92±0.00	0.96±0.02	0.99±0.01
Electric Conductivity EC***	8.67±1.15	11.33±1.53	12.33±1.15	10.67±1.15	27.00±10.44	44.67±1.53	24.67±12.85	25.67±8.08	33, 00±8, 54

Differences between means of nine plants communities tested using analysis of variance (ANOVA):* indicates significant at P<0.05, ** indicates significant at P<0.01, *** indicates significant at P<0.001, (See Table 5 for plant community abbreviations)

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Main environmental variables

Relationships between environmental factors and plant communities are illustrated using CCA graps (Fig. 6) in which each point represents a plants community and each narrow an enviromental variables.The species–environment correlation for axis 1 and 2 was respectively 0.99 and 0.97, these indicates a strong relationship between the species and the ecological traits of the plants communities. Axis 1 of the CCA which has 21% of the total variance, explained highly the distribution of the information in the CCA graph. Correlations between environmental factors land form, soil moisture, soil physical and chemical characteristics and the CCA axis are given in Table 7. Trends shown in the CCA ordination graph are quantitatively confirmed by the values of Pearson correlation. Hence, axis 1 of the CCA was negatively correlated with soil content of sand and C:N ratio and positively correlated with depression (geom), clay, silt, and flood condition (Moisture), pH, soil contents of calcium (Ca^{2+}), Cation Exchange Capacity (CEC), total alkalinity (S), available phosphorus (Pav), electrical conductivity (CE), total phosphorus (Ptot), Soil organic carbon (C), and Magnesim (Mg^{2+}). At the negative end of axis1 were plotted sandy grasslands communities like *Leptadenia pyrotechnica- Aristida sieberiana* community, *Sclerocarya birrea- Brachiaria xantholeuca* community, *Acacia tortilis- Digitaria horizontalis* community and *Boscia senegalensis- Cenchrus biflorus* community, which have relatively high C:N ratio, deep soil and moderate elements of soil fertility. At the positive end of the axis were discriminated wooded plants communities depressions like *Salvadora persica- Brachiaria ramosa* community, *Acacia ehrenbergiana- Sesbania leptocarpa* community and *Acacia nilotica- Echinochloa colona* community, which were associated with depression (geom), clay, silt, flood conditions (Moisture), pH, soil contents of calcium (Ca^{2+}), Cation exchange capacity (CEC), total alkalinity (S), available phosphorus (Pav), electrical conductivity (CE), total phosphorus (Ptot), Soil organic carbon (C), and Magnesim (Mg^{2+}). Between these two groups of plants communities were contrasted *Grewia tenax- Cymbopogon schoenanthus* and *Balanites aegyptiaca- Setaria pallide fusca* communities recorded in intermediate condition of these extreme gradients.

The Monte Carlo permutation test indicates which of the environmental variables have significant effect on plants distributions and their assemblage to form communities. Among the fifteen environmental variables tested with the Monte-Carlo permutation procedure, land form (geomorphology), soil contents of clay, magnesium (M^{2+}), total phosphorous (Ptot) and total basic cations (S) were determinants ($P<0.05$) on plants distribution and their assemblage to form plants communities.

All environmental variables except sodium and potassuim were significantly different among the rangelands plants communities (Table 6). *Balanites aegyptiaca- Setaria pallide fusca* and *Salvadora persica- Brachiaria ramosa* communities have the highest amounts of silt while the lowest was successively recorded in *Leptadenia pyrotechnica- Aristida sieberiana* and *Acacia tortilis- Digitaria horizontalis* communities, the other communities have the intermediate amount of silt (Fig. 6). The highest content of sand was recorded in *Leptadenia pyrotechnica- Aristida sieberiana* community, followed successively by *Boscia senegalensis- Cenchrus biflorus* community and *Sclerocarya birrea- Brachiaria xantholeuca* community and the lowest in *Balanites aegyptiaca- Setaria pallide fusca* community. *Acacia ehrenbergiana- Sesbania leptocarpa* and *Balanites aegyptiaca- Setaria pallide fusca* communities have successively the highest contents of clay while the lowest values were recorded in *Leptadenia pyrotechnica- Aristida sieberiana* and *Sclerocarya birrea- Brachiaria xantholeuca* communities.

Regarding chemical characteristics, globaly, high values of total phosphorus (Ptot.=98.22±32.39 ppm) were recorded in all the Sahelian rangelands, but the highest and the lowest total phosphorus contents were respectively recorded in *Salvadora persica-Brachiaria ramosa* and *Acacia tortilis- Digitaria horizontalis* with an average value of 148.58±8.03 ppm ranged from 142 to 157 ppm and 68.32±3.33 ppm ranged from 65 to 69 ppm.

Acacia nilotica- Echinochloa colona community has the highest contents of calcium (Ca^{2+}), Cation Exchange Capacity (CEC) and total alkalinity (S) with respectively an average mean of 5, 38±0, 20 meq/100 g, 7, 24±0, 08 meq/100 g et 12, 87±0, 10 meq/100 g. While the lowest values of these variables were recorded in *Boscia senegalensis- Cenchrus biflorus* (Bs_Cb) with respectively mean values of 3, 94±0, 14 meq/100 g, 4, 61±0, 13 meq/100 g et 8, 80±0, 15 meq/100 g. Similar pattern has been observed with Cation exchange capacity (CEC) (Fig. 6). Highest value of pH and contents of Nitrogen (N) and soil organic carbon (C) were also observed in *Acacia nilotica- Echinochloa colona* community, when lowest values were observed in *Balanites aegyptiaca- Setaria pallide fusca* community for pH, in *Grewia tenax- Cymbopogon schoenanthus* for Nitrogen (N) and carbon (C). *Acacia tortilis- Digitaria horizontalis* community has the highest rate of C:N ration and *Leptadenia pyrotechnica- Aristida sieberiana* community the lowest.

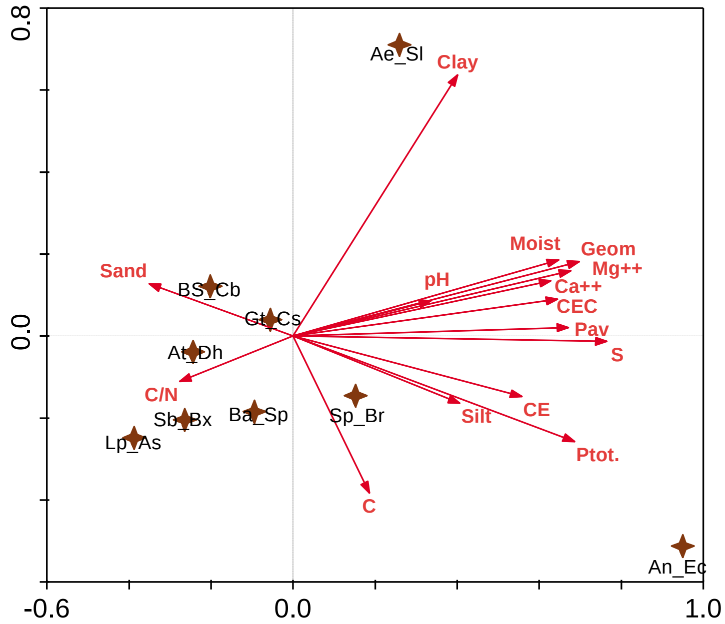

Fig. 6. Canonical Correspondence Analysis (CCA) result showing relationship between sahelian rangelands plants communities and environmental variables;
CCA axis 1: Eigenvalue= 0.36; variance of species-environment relation= 31%;
CCA axis 2: Eigenvalue= 0.30; variance of species-environment relation= 26%, (see table 7 for environmental variables abbreviation and table 5 for plant community abbreviation)

Table 7. Correlations of Pearson between canonical axis and environmental variables, F-ratios and P-values from Monte-Carlo permutation test

Environnemental variables	Abbreviation	Axis 1	Axis 2	Axis 3	P-value	F-ratio
pH	pH	0.34	0.09	0.29	0.58	0.91
Electric conductivity	EC	0.56	-0.15	-0.32	1.17	0.24
Soil organic carbon	C	0.19	-0.38	0.17	0.78	0.91
Carbon/ Nitrogen ratio	C/N	-0.28	-0.11	-0.34	0.79	0.91
Total phosphorous	Ptot.	0.69*	-0.26	-0.08	0.05	1.36
Available phosphorus	Pav	0.67	0.02	-0.15	0.11	1.28
Calcium	Ca^{++}	0.63	0.14	-0.05	0.17	1.26
Magnesium	Mg^{++}	0.68*	0.16	-0.32	0.05	1.39
Total alkalinity	S	0.77**	-0.01	-0.3	0.006	1.57
Cation exchange capacity	CEC	0.64	0.09	-0.33	0.09	1.36
Clay	Clay	0.40*	0.64	-0.1	0.03	1.58
Silt	Silt	0.41	-0.16	-0.29	0.17	1.32
Sand	Sand	-0.35	0.13	0.32	0.73	0.65
Moisture	Moisture	0.65	0.19	0.01	0.49	1.13
Geomorphology	Geomorphology	0.70*	0.18	-0.17	0.02	1.41

*Significant at p<0.05, **: significant at p<0.01 using CCA Monte-Carlo permutation test

Discussion

Taxonomic diversity

The number of species recorded in this study is similar to many studies carried on sahelian rangelands, but lower than sudanian rangelands (Table 8). Furthermore, 584 species were recorded in the sudanian rangelands of Bénin (Houinato, 2001); while 230, 227 and 252, species were respectively recorded in the sahelian rangelands of Kaarta (Togola, 1982), Niono (Djiteye, 1984), and in this study. This flora sahelian rangelands including Kaarta and Niono were characterized by the abundance of the following successively families: Poaceae, Leguminosae-Papilionoideae and the Convolvulaceae, but in the sudanian rangelands were dominated successively the families of Poaceae, Leguminosae-Papilionoideae and Asteraceae.

According to herders, rangelands with high cover of Poaceae (grass) species have great potential forage value (Soumana *et al.*, 2012). The life forms and the chorological types spectrums in the study area are in accordance with earlier description of sahelian rangelands (Togola, 1982; Djiteye, 1984; Boudet & Duverger, 1961). Therophytes that dominated the life forms spectrum were known to be the major life form in dryland ecosystems such as sahelian rangelands (Saadou, 1990), but in the sudanian rangelands, Houinato (2001) found similar proportion of Phanerophytes and Therophytes with respectively 36% and 34% of species. High abundance of wide distribution elements in tropics such Pantropical and Paleotropical species were found in the study area, consistent with White (1986) and Poilecot (1999). Abundance of wide distribution chorotypes have been related to disturbance events (Mbayngone, 2009). In the study area, data from several studies manly indicates that the major factors of disturbances were land encroachment, overgrazing, deforestation, episodic droughts, climate changes, etc. Analysis based on plants species indicated clearly arid ecosystems (sahelian rangelands) with great potential forage value (Poaceae) under heavy pressure (land encroachment, deforestation, overgrazing, droughts, climate changes). Arid ecosystems with heavy disturbances resulting from anthropic actions (e.g. land encroachment, deforestation and overgrazing due to respectively increasing demand of farming lands and animal number increasing) and climate changes are subjected to desertification.

Table 8. Most dominant families of different rangelands and the present study

Sources	Togola (1982)	Djiteye (1984)	Houinato (2001)	Present study
Phytochoria according to White (1986)	Sahelian regional transition zone	Sahelian regional transition zone	Sudanian regional center of endemism	Sahelian regional transition zone
Countries	Mali (Kaarta)	Mali (Niono)	Bénin (Monts Kouffé)	Niger (Zinder)
Number of species	230	227	584	252
Number of families	56	48	98	47
% number species of dominant families	Poaceae (21%) Papilionoideae(11%) Convolvulaceae(4%) Mimosoideae (4%)	Poaceae (23%) Papilionoideae(11%) Convovulaceae (4%) Cyperaceae (4%) Capparidaceae (4%)	Poaceae (15, 6%) Papilionoideae(15,4%) Asteraceae (6, 9%) Rubiaceae (4%)	Poaceae (19, 44%) Papilionoideae (9, 13%) Convolvulaceae(6,35%) Cyperaceae (5, 56%) Mimosoideae (4, 37%)

Relationship between plants communities and environmental factors

Following Detrened Correspondence Analysis (DCA) and Hierarchical Classification, nine plants communities with significantly different plants composition have been identified, distributing differently along the environmental gradients. This may be linked to the heterogeneity of the study area attested by the MRPP test among species composition of the plants communities and the ANOVA test among soil variables. According to Canonical Correspondence Analysis (CCA) associated with Monte-Carlo permutation tests, the environmental factors such as depression (geomorphology), total alkalinity (S), magnesium (Mg^{++}), total phosphorous and the Cationic Exchange Capacity (CEC) have major effect in distributing plants species and their assembling to form communities. Although, theses parameters have significant effect in structuring communities in these rangelands, they can have less important in other ecosystems. Contents of Magnesium and calcium, soil texture, pH and depth have been observed as significant determinants in structuring rangeland vegetations in Arly Park in the Sudanian zone of Burkina Faso (Oumorou, 2009). Abd El-Ghani and Amer (2003) have clearly shown that soil surface sediments, calcium carbonate, soil reaction, organic matter and soil saturation percentage as the most important factors for the distribution of the vegetation pattern in El-Qaa plain.

Results from the CCA reveal strong positive correlation between significant variables, and among these variables and soil moisture (water contents), soil contents of clay, silt, calcium, organic carbon and available phosphorous. Correlation among environmental variables does not necessary mean that a cause-effect relationship exists between them (Lei, 1999). Although these variables have been distributed differently in the plants communities, they have their greatest amounts in communities of depression while sand contents and the C:N ratio have their greatest values in communities recorded on depth sandy soil such as sandy plains, dune slopes and dune summits. In accordance with Liu *et al.* (2006) observations in the Loess Plateau in China, water content and soil nutrient levels correlate negatively with elevation (slope). Several studies have related water and nutrients distributions in arid ecosystems to land heterogeneity due to elevation through the relief and the land form, and land surface conditions through soil surface physical and biological crusts. Soil surface crusts may have important roles in controlling soil water balance through infiltration and water loss by runoff and evaporation (Casenave and Valentin, 1989; d'Herbès and Valentin, 1997; Peugeot *et al.,* 1997). Elevation acts via land slopes and accumulates water, nutrients and sediments at down slope, in the depressions which have the high amounts of phosphorous, calcium, magnesium, total alkalinity, organic carbon, nitrogen, clay, silt and moisture. Soil with high contents of nutrients, organic matter and clay are fertile soil. In our study area, soil under plants communities located in depression may be more fertile than those located on sandy plains, dunes slopes and summits, consistent with Pierson & Mulla (1990) that observed soils on down slopes with higher content of SOM and greater aggregate stability than those located at the summit positions. Ecosystems with great aggregate stability are resilient, therefore communities located on summit positions may be more susceptible to desertification than those in depression, which may be more resilient.

Conclusion and implication to rangeland management

This study of the flora and the pasture plants communities associated with topography and substrate variables of the sahelian rangelands, recorded a total of 252 taxa belonging to 148 genera from 47 families in which the angiosperms families counting 251 species (183 dicots and 68 monocots). The most dominated family, life form and geoelements indicated arid ecosystem with great potential pasture value under high disturbance related to anthropic actions and climate changes, accordingly poorly managed. Ecosystem under such conditions are prone to desertification. Nine plants communities were identified using classification and ordination of the matrix data of 197 plots and 252 species, distributing along the environmental gradients: the *Leptadenia pyrotechnica-Aristida sieberiana* community, *Sclerocarya birrea- Brachiaria xantholeuca* community, *Acacia tortilis-Digitaria horizontalis* community and *Boscia senegalensis- Cenchrus biflorus* community in sandy falt plains, dune slopes and summits; and the *Balanites aegyptiaca- Setaria pallide fusca* community, *Salvadora persica-Brachiaria ramosa* community, *Grewia tenax- Cymbopogon schoenanthus* community, *Acacia ehrenbergiana-Sesbania leptocarpa* community and *Acacia nilotica- Echinochloa colona* community in moisture depressions. Each plants community was characterized by specific plants species by using Indicator Species Analysis (ISA). The MRPP test confirms the clearly differences between the nine plants communities revealed by the ordination and the classification. Among the 15 variables tested by Monte-Carlo test, depression (geomorphology), total alkalinity (S), magnesium ($Mg^{++)}$, phosphorous total and the Cationic Exchange Capacity (CEC) have significant determinant effect in distributing plants species and their assembling to form communities. The high contents of significant soil variables as well as high contents of phosphorous, calcium, magnesium, total alkalinity, organic carbon, nitrogen, clay, silt and moisture have been located in plants communities recorded in depression positions. Ecosystem with great contents of these variables have more aggregate contents, therefore more resilient. Thus, plants communities located in sandy falt plains, dune slopes and summits positions are more susceptible to desertification than those located in depression with high nutrients and moisture content. The results obtained with the current study will surely help defining scientific bases of management and secure of Sahelian rangelands.

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عوامل اکولوژیکی ایجاد کننده تنوع در اکوسیستم‌های مراتع ساحلی منطقه نیجر

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چکیده. شرح الگوهای پوشش گیاهی در ارتباط با عوامل محیطی مانند چرا، آب و هوا، اشکال مختلف زمین، متغیرهای اصلی و غیره برای برنامه ریزی مدیریت زمین مفید است. این مطالعه با استفاده از ابزار جدید همگرایی‌بومشناسی به بررسی ترکیب گیاهان و ارایه توصیف زیست محیطی از جوامع گیاهی مراتع ساحلی نیجر پرداخته است. پوشش گیاهی و متغییرهای محیط زیستی در ۱۹۷ پلات با استفاده از روش براون-بلانکه با مقیاس پوشش-فراوانی ثبت شدند. نمونه‌های خاک در حدود ۱ کیلوگرم از هر پلات برای تجزیه و تحلیل جمع آوری شدند. نتایج نشان دادند که در این منطقه ۲۵۲ گونه از ۱۴۸ جنس متعلق به ۴۷ خانواده وجود دارد. از این تعداد، ۲۵۱ گونه از خانواده نهاندانگان می‌باشند و یک گونه مربوط به خانواده Marsileaceae می‌باشد. همچنین نتایج نشان داد که خانواده‌های غلات، بقولات- پروانه آساها، پیچکیان، جگن، بقولات-کهوریان بزرگترین خانواده‌ها هستند. فراوانی بالای گونه‌های مربوط به خانواده غلات، ارزش زیاد بالقوه علوفه آنها را در مراتع ساحلی نشان می‌دهد. باید گفت که بیشتر گونه‌ها تروفیت (یکساله) هستند و توزیع گسترده‌ای از عناصر در مناطق استوایی وجود دارد، بنابراین واضح است، محیطی شکننده و با ارزش بالای بالقوه علوفه وجود دارد که با اختلال زیاد مواجه و از مدیریتی ضعیف برخوردار هستند. اکوسیستم‌های خشک تحت اختلال سنگین مستعد بیان زایی می‌باشند. این مطالعه براساس پوشش گیاهی نشان داد که ۹ جامعه گیاهی قابل تشخیص و تمایز با توزیع در امتداد شیب زیست محیطی وجود دارد. در توزیع گیاهان و جمع شدن آنها به شکل جوامع، عوامل غیر زنده قابل توجه نظیر ژئومورفولوژی، قلیاییت کل، منیزیم، فسفر کل و ظرفیت تبادل کاتیونی نقش دارند. عوامل ویژه همچنین مانند شن و ماسه، رس، سیلت، کلسیم، کربن آلی، فسفر موجود و ترکیب گیاهان متنوع، باعث تفاوت جوامع گیاهی می‌باشد. جوامع گیاهی تحت فشار و رکود دارای مقادیر زیادی از رطوبت و عوامل حاصلخیزی خاک می‌باشند، بنابرین مقاوم‌تر هستند. احتمالا، جوامع گیاهی واقع در دشت‌های شنی و دامنه تپه‌ها، از مناطق با حاصلخیزی و رطوبت بالا، آسیب پذیری و استعداد بیشتری جهت تبدیل شدن به مناطق بیابانی دارند.

کلمات کلیدی: فلور و پوشش گیاهی مناطق خشک، اختلال، بیابان زایی، مرتع، ساحل