Chapter

The Impacts of Soil Degradation Effects on Phytodiversity and Vegetation Structure on Atacora Mountain Chain in Benin (West Africa)

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Abstract

Atacora mountain is a particular ecosystem of West Africa where soil degradation occurs. The present study assessed the impacts of physical soil degradation on vegetation in the Beninese portion of this mountain chain. Phytosociological surveys were carried out along line transects from plain to summit within 22 plots of 30 m x 30 m. Based on indicators of physical soil degradation each plot was classified into one soil degradation class (Light, Moderate, High or Extreme). Impacts on plant diversity were assessed by comparing the floristic composition of soil degradation classes with the index of similarity of Jaccard. Variations between soil degradation classes of species richness, species chorological types, species life forms and species dispersal were also tested using a discriminant analysis combined with ANOVA. The Multi-Response Permutation Procedures analysis was used to pairwise compare the soil degradation classes based on the cover data of the species lists. All soil degradation classes were dissimilar, depending on the floristic composition. Discriminant analysis and ANOVA performed on biodiversity indicators had shown that species richness, and the number of regional species, phanerophytes and sarcochory decreased along the increasing degradation gradient in contrast to the number of species with wide distribution, therophytes and sclerochory. With regard to vegetation structure, the results had shown that only moderately and highly degraded soils presented the similar vegetation type. Physical soil degradation induced modification of floristic composition, phytodiversity loss and modification of vegetation structure. These results showed that the soil degradation gradient corresponds to a vegetation disturbance gradient.

Keywords: soil degradation, phytodiversity loss, mountain chain, West Africa

1. Introduction

Land degradation has become a global problem affecting at least a quarter of all terrestrial biomes and agro-ecologies, and occurring in many low-income as well as industrialized countries [1]. Understanding and assessing the underlying processes of land degradation is important to develop suitable land management measures and policies. Land degradation involves many interrelated processes such as soil erosion, depletion of soil nutrients, loss of biodiversity, deforestation, loss of ecosystem services etc. [2].

Many studies examined the impacts of land degradation on vegetation. In general, the methodologies used consisted in statistically testing differences in certain measures of vegetation structure, biodiversity and/or ecosystem services collected over different states or intensities of degradation of a given environmental component. Some authors examined the diversity and changing composition of plant communities of different land use and land cover types under different grazing pressure intensities [3–5]. Others have addressed the difference in species diversity between forest successional stages [6, 7] or between concretion soil, sand-clay soil and *Bowal*, (considered as the final of land degradation) [8]. *Bowa*l (plural *bowé*) comes from the *fulfulde* language spoken in Guinea and refers to degraded lands found on hardened ferruginuous soils also known as ferricretes [8]. However, we are not aware of any studies that have attempted to assess the impacts on vegetation (structure and diversity) of soil degradation defined as physical soil degradation classes.

Soil is a key resource that manages the cycle of water, cycle of carbon, plant growth and distribution, fauna and geochemicals [9–11]. Soils play an important role in mountainous areas often characterized by steep slopes and shallow soils. In Benin, the mountainous Atacora region is confronted with different soil degradation processes. Increased human activities (unsustainable agriculture, livestock grazing, fuelwood and tree cutting), combined with steep slopes, shallow soils and heavy rainfall had led to soil degradation [12–16].

Into the mountainous Atacora region, previous study in Ref. [17] had examined various indicators of land degradation and found that soils could be classified into 4 soil degradation categories i.e. light, moderate, high, and extreme degradation. However, nothing is known about the impacts of soil degradation classes on vegetation. Up to now investigations about phytodiversity into the mountainous region have mainly focused on characterization of plant communities and assessment of species diversity through phytosociological surveys [18–20]. There is need to fill a gap in scientific researches and to contribute to sustainable land management in the study area by enhancing the knowledge of land degradation processes.

For the assessment of plant diversity, different methods and indices are available, including vegetation structure, floristic composition and specific richness, chorological types, life forms and dispersal types of diapores which are good indicators of the state of vegetation health [7, 21–23]. The aim of the present study was to explore the impacts of soil degradation classes on vegetation namely vegetation structure, floristic composition, species richness, chorological types, life forms and dispersal types of diapores.

2. Material and methods

2.1 Sampling data and classification of plots into soil degradation classes

Data were collected in two steps. The first step consists in the identification of sampling sites (**Figure 1**). Based on vegetation, soil and administrative map, sampling sites were chosen according to the vegetation types, the proximity to hillsides and the accessibility during rainy season. Altogether four (4) sampling sites were identified at the rate of two sites per district (Natitingou and Toucountouna). The second step consists on the data collection. Local knowledge on soil erosion was

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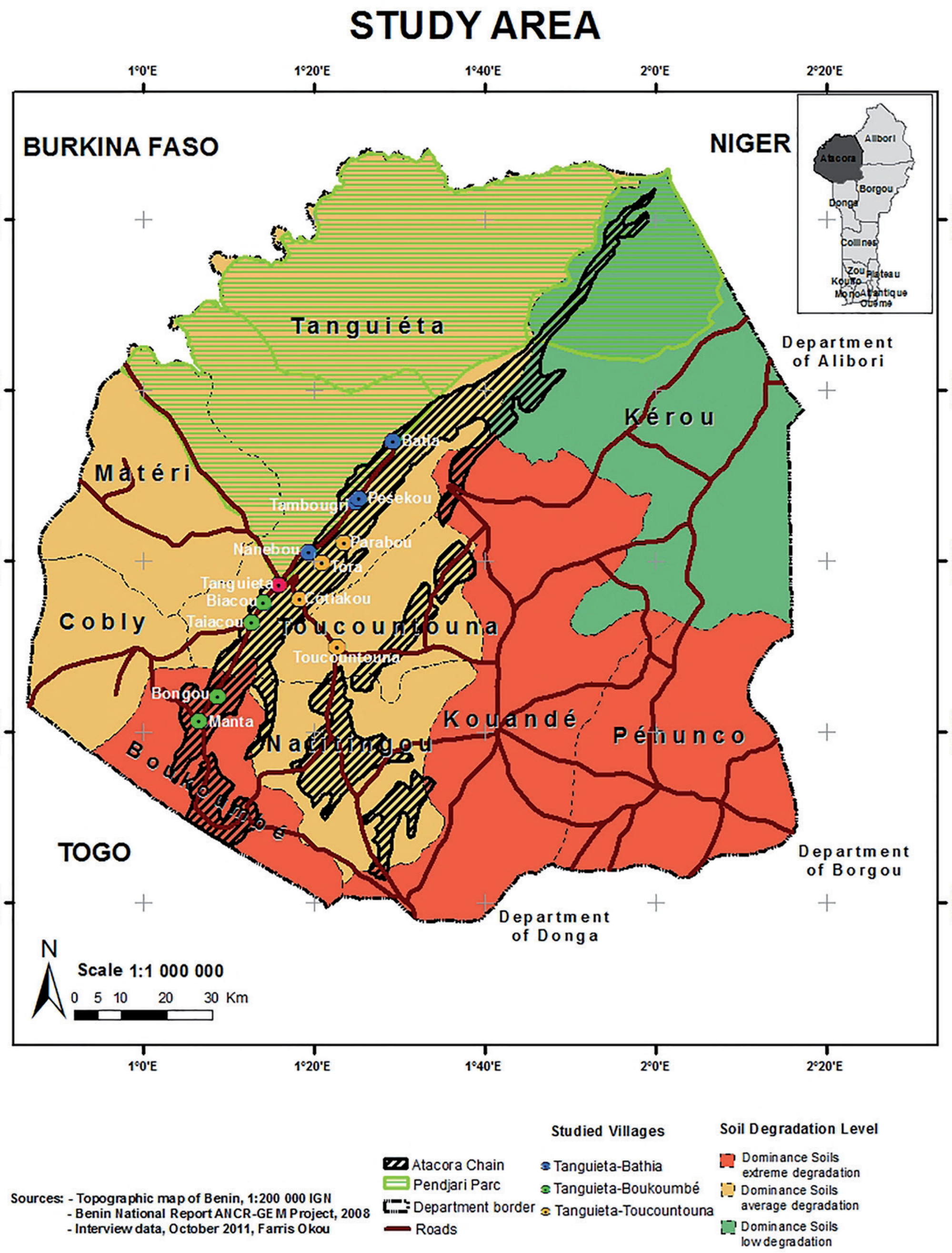

Figure 1.
Map of study area.

used in order to identify where to install the line transects. With the help of villages leaders and the guide, areas within natural vegetation, on/near mountains or hillsides where physical soil degradation occurs were identified. Within each site, one or two line transects (from plain to top) were established. At each topographical position nested sample plots (30 m x 30 m for woody layer and 10 m x 10 m for herbaceous layer) within representative and homogenous vegetation areas were installed. 22 plots of 30 m x 30 m were considered and five sub-plots each of 10 m × 10 m (four in the corner of the plot and one in its center) per plot were used.

On the basis of physical soil degradation indicators (extent of organic layer, color of topsoil, compactness of soil, presence and extent of rills, and occurrence of sheet erosion) each plot was classified visually into specific soil degradation classes. Physical soil degradation in the study area falls into four grades, namely light, moderate, high and extreme soil degradation classes described in [17]. The characteristics of each class are summarized in **Table 1**.

Soil degradation classes	Definition
Light	Soils characterized by a low level of soil compaction, few rills and no visible sheet erosion. On the topsoils black organic layer covered the entire surface and no reddish soils were observed.
Moderate	Soils characterized by compact red soils, with a thin clay crust on the surface. Sheet erosion occurred on these soils, and rills were observed on the surface. Organic layers remained as thin patches.
High	Soils red and very compact. They looked like ferricrete but remained friable. Sheet erosion occurred. Rills covered a larger surface than on the other soils and were also deep. Organic layer remained as thin patches (less than 5 cm thick) anic layer were less extended (only 23% of rod contacts).
Extreme	Soils characterized by the presence of ferricrete (rich in iron, and hard) and red soils. The presence of the ferricrete layer reduced the depth to which roots could grow. The organic layer remained only on small patches. The thickness of the organic layer rarely exceeded 10 cm. There was no visible evidence of sheet erosion, and the presence of rills was very low because of the high level of compaction.

Table 1.
Characteristics of soil degradation classes on Atacora mountain range.

2.2 Assessing impacts of soil degradation on phytodiversity

Phytosociological surveys [24] were carried out in each sample as a mean to assess the floristic composition, discriminant species, species richness, species chorological types, species life forms and species dispersal types. Woody species were collected in the plots, while herbs were carried out on the sub-plots. All species were constituted as herbaria and were subsequently determined by the National Herbarium of the University of Abomey-Calavi.

The similarities in species composition between classes of soil degradation were assessed using the index of similarity of Jaccard (1901), which is given by the formula:

$$P_j = 100 * \frac{c}{a+b-c}; \quad (1)$$

where P_j is Jaccard community coefficient, a is the number of species present in the community A, b is the number of species in the community B, and c is the number of species shared by A and B. In the study, soil degradation classes represented communities. The computation was automatically performed with the software CAP [25] on a presence/absence matrix consisting of a number of defined soil degradation classes and 133 plant species. This index has proved to be a consistently good measure of similarity for presence/absence data [26]. The values of P_j range from 0% for an absence of similarity to 100% for a complete similarity. Plant communities are dissimilar if $P_j \leq 50\%$.

Discriminants species of each degradation class was assessed and identified based on methodology as in Ref. [27]. Discriminant species of a particular group were species devoted to that group, exclusive to that group and never occurring in others groups. Dufrêne & Legendre's method produced indicator values for species within each group. These indicator values were tested for statistical significance using a randomization (Monte Carlo) technique [28]. P value of 5% was used to retain as discriminant species. All multivariate analyses were computed with PC-ORD for Windows Version 5 [28].

The impacts of soil degradation on phytodiversity were also assessed by using species richness (S), and three indexes of diversity that were developed as part of this study: the chorological index (I_C), the life forms index (I_L) and the dispersal types (of diaspore) index (I_D). The objective was to understand how biodiversity indicators vary according to soil degradation classes, i.e. along degradation gradient.

These indexes were computed on the base of two main principles. The first one was the principle of biodiversity's indicators of disturbance. Along a gradient of disturbance, there were three major types of qualitative indicators of biodiversity (chorological types, life forms and dispersal types) which evolutions (in terms of number or cover) were negatively correlated. For example, widely distributed species, therophytes and sclerochory were assumed to be more abundant/dominant in the pioneer (more disturbed) stages and this trend decreased as less disturbed stages were reached. In the contrary, the number/cover of regional species, phanerophytes and sarcochory were assumed to increase from disturbed to stable communities [21, 29, 30]. The second principle is about the ratio or relative frequency used in Ref. [31] to calculate the phytogeographical index (I_p) which made it possible to compare and classify the different plant communities according to their level of affinity with the Sudanian or Guinea-Congolian region. On this basis, the indexes were computes as:

$$I_c = \frac{S + SZ + SG}{Pt + PAL + AA + TA + PRA}; \quad (2)$$

Where I_C is the chorological index and *S, SZ, SG, Pt, PAL, AA, TA, PRA* are respectively the frequency of Sudanian, Sudano-Zambezian, Sudano-Guinean, Pantropical, Paleotropical, Afro-American, Tropical Africa and Pluri Regional in Africa species.

$$I_L = \frac{Ph}{Th} \quad (3)$$

where I_L is the life forms index, *Ph* is the frequency of Phanerophytes and *Th* is the frequency of Therophytes.

$$I_D = \frac{Sarco}{Sclero} \quad (4)$$

where I_D is the dispersal types index, *Sarco* is the frequency of Sarcochory and *Sclero* is the frequency of Sclerochory.

These indices calculated for each plot, compared the relative evolution of each pair of indicators between the different soil degradation classes. The higher the index, the greater the relative abundance of the biodiversity indicator in the numerator. The lower the index, the greater the relative abundance of biodiversity indicators at the denominator. Thereafter, the species richness (S), the chorological index (I_C), the life forms index (I_L) and the dispersal types index (I_D) were submitted to discriminant analysis and ANOVA using R software [32].

2.3 Assessing impacts of soil degradation on vegetation structure

The cover of each species was visually estimated within each plot. Braun Blanquet cover/abundance scale [33] was used: +: rare, less than 1% cover, 1: 1–5% cover, 2: 5–25% cover, 3: 25–50% cover, 4: 50–75% cover, and 5: 75–100% cover. The cover data of all inventoried species through the phytosociological surveys were grouped into an abundance matrix of 22 plots x 133 species and submitted to the Multi Response Permutation Procedures (MRPP). MRPP is a nonparametric procedure for testing the hypothesis of no difference between two or more groups of entities [34]. This procedure was used to pairwise compare the described soil degradation classes based on the cover data of their species lists. The analysis was computed with PC-ORD for Windows Version 5 [28].

3. Results

3.1 Impacts of soil degradation on phytodiversity

3.1.1 Floristic composition

Table 2 presents the pairwise comparison of soil degradation classes based on the index of similarity of Jaccard. On this basis, none of the soil degradation classes was similar to another. Given that the analysis was performed on the presence/absence matrix, we were able to conclude that all soil degradation classes were dissimilar, according to the floristic list. However, we noticed that the floristic composition of the vegetation in slightly and moderately degraded soils, although dissimilar, was closest (index of similarity of Jaccard equals to 0.434). Considering the discriminant species of each degradation class, the greatest number of discriminant species were found on slightly and moderately degraded soils (5 plants species) while the lowest were found on highly degraded soils (2 plant species) (**Table 3**).

3.1.2 Species richness, chorological types, life forms and dispersal types

The first two canonical axes obtained from the discriminant analysis on indicators of biodiversity were significant because they explained 97.59% of the initial information. The correlation between the two axes and the indicators of biodiversity showed that all the indicators (species richness, chorological, life forms and dispersal types indexes) were well and positively correlated with the first axis (0.91, 0.99, 0.99, 0.98 respectively) (**Table 4**). Thus, the first axis described high values of species richness and high values of chorological, life forms and dispersal type indexes. None of the indicators of biodiversity were well correlated with the second axis (**Table 4**).

The **Figure 2** showed that slightly and moderately degraded soils were positively correlated with the first axis while high and extreme degraded soils were well negatively correlated with the same axis. Based on the information gathered on this axis we could conclude that slightly and moderately degraded soil showed the highest species richness and were characterized by the highest relative abundance of regional species, phanerophytes and sarcochory. On the other hand, highly and extremely degraded soils showed lower species richness and highest relative abundance of species with wide distribution, therophytes

Soil classes	Light	Moderate	High	Extreme
Light	—	—	—	—
Moderate	0.434	—	—	—
High	0.149	0.19	—	—
Extreme	0.143	0.184	0.088	—

Table 2.
Index of similarity of Jaccard.

Species	Soil classes	Probability
Cochlospermum planchonii Hook.f.	Light	0.0062
Crossopteryx febrifuga (G. Don)Benth.	Light	0.0148
Indigofera nigritana Hook. f.	Light	0.0202
Strychnos spinosa Lam.	Light	0.0302
Hexalobus monopetalus (A.Rich.)Engl. & Diels	Light	0.0374
Basilicum polystachion (L.) Moench.	Moderate	0.0012
Blumea crispata Merxm. & Roessler var. cripata	Moderate	0.0012
Elephantopus mollis Kunth	Moderate	0.0032
Andropogon pseudapricus Stapf	Moderate	0.0230
Cissus corylifolia (Baker) Planch.	Moderate	0.0230
Stylosanthes fruticosa (Retz.)Alston	High	0.0010
Polygala multiflora Poir.	High	0.0084
Spermacoce filifolia (Schmach. & Thonn.) J.-P.Lebrun & Stork	Extreme	0.0002
Cochlospermum tinctorium Perr. ex A.Rich	Extreme	0.0134
Chamaecrista mimosoides (L.) Greene	Extreme	0.0198

Table 3.
Discriminant species of each soil degradation class.

Variables	Can 1	Can 2
Species richness (S)	0.91	−0.34
Chorological index of disturbance (I_C)	0.99	0.02
Life forms index of disturbance (I_L)	0.99	0.14
Dispersal types index of disturbance (I_D)	0.98	0.13

Table 4.
Correlation between biodiversity indicators and the two canonical axes.

and sclerochory (or lower relative abundance of regional species, phanerophytes and sarcochory).

Simple statistics and ANOVA were summarized in **Table 5** and demonstrated that the between soil degradation classes based on biodiversity indicators were significant. Weighted spectrums of chorological types, life forms and dispersal types of diaspores were illustrated in **Figure 3(a–c)**. The highest species richness was found on slightly and moderately degraded soils (30.5 ± 7.2; 31.33 ± 4.93) and the lower values of this variable were found on highly (11.33 ± 3.21) and extremely degraded soils (16.5 ± 12.08). The high values of chorological index, life forms index and dispersal types index characterized light degraded soils (respectively 5.83 ± 1.64; 6.21 ± 3.82; 2.20 ± 0.76) and these values decreased gradually on moderately degraded soils (3.45 ± 0.40; 2.73 ± 1.70; 1.70 ± 0.91) and highly degraded soils (2.44 ± 0.096; 0.89 ± 1.54; 1.08 ± 0.38) and reached the lowest values on extreme degraded soils (1.51 ± 0.62; 0.78 ± 0.38; 0.62 ± 0.79). In other words, regional species, phanerophytes and sarcochory presented a regressive trend from light to extreme degraded soils through moderate and high soil degradation classes while species with wide distribution, therophytes and sclerochory followed a contrary trend.

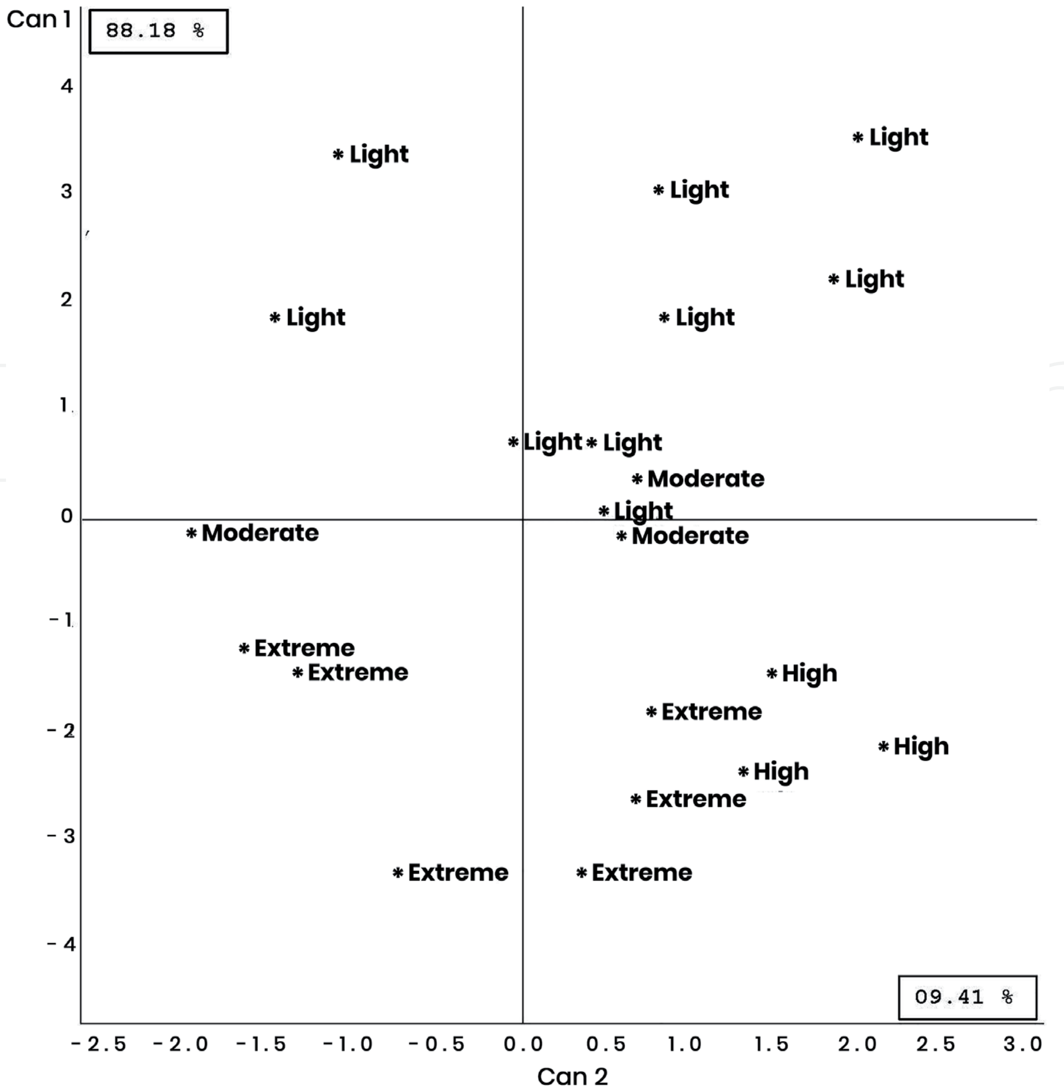

Figure 2.
Projection of soil degradation classes in the canonical system axis based on biodiversity indicators.

3.2 Impacts of soil degradation on vegetation structure

Tables 6 and **7** summarize the results of MRPP computed on cover data of each plots. First, all the degradation soil classes were considered together (**Table 6**). Thereafter, the degradation soil classes were considered two by two (**Table 7**). Considering all soil degradation classes, the results showed that the vegetation cover data for the four soil degradation classes were significantly different (**Tables 5** and **6**). However, the pairwise comparison (**Table 7**) gave more details and showed that the vegetation cover data of moderately and highly degraded soils were broadly overlapping ($p > 0.05$). Moderate and high degraded soils presented a relative similar vegetation type i.e. shrub savannas.

4. Discussion

4.1 Impacts of soil degradation on phytodiversity

The similarity index of Jaccard was significantly different on all the soil degradation classes and revealed that all soil degradation classes were dissimilar, depending on the floristic composition. The results allowed us to conclude that soil degradation induced modification of the floristic composition of vegetation. This finding

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Degradation degree	Light		Moderate		High		Extreme		F value	Pr (>F)
	m	**s**	**m**	**s**	**m**	**s**	**m**	**s**	**—**	**—**
Biodiversity indicators										
Species richness (S)	30.5	7.2	31.33	4.93	11.33	3.21	16.5	12.08	6.648	0.00324**
Chorological index (I_C)	5.83	1.64	3.45	0.40	2.44	0.096	1.51	0.62	17.73	1.31e-05***
Life forms index (I_L)	6.21	3.82	2.73	1.70	0.89	1.54	0.78	0.38	5.898	0.00549**
Dispersal types index (I_D)	2.20	0.76	1.70	0.91	1.08	0.38	0.62	0.79	5.956	0.00526**

m: mean; s: standard of deviation ns: not significant difference.
**Significant at 0.01.*
***Significant at 0.001.*

Table 5.
Mean, standard deviation and ANOVA of biodiversity indicators soil on each soil degradation classes.

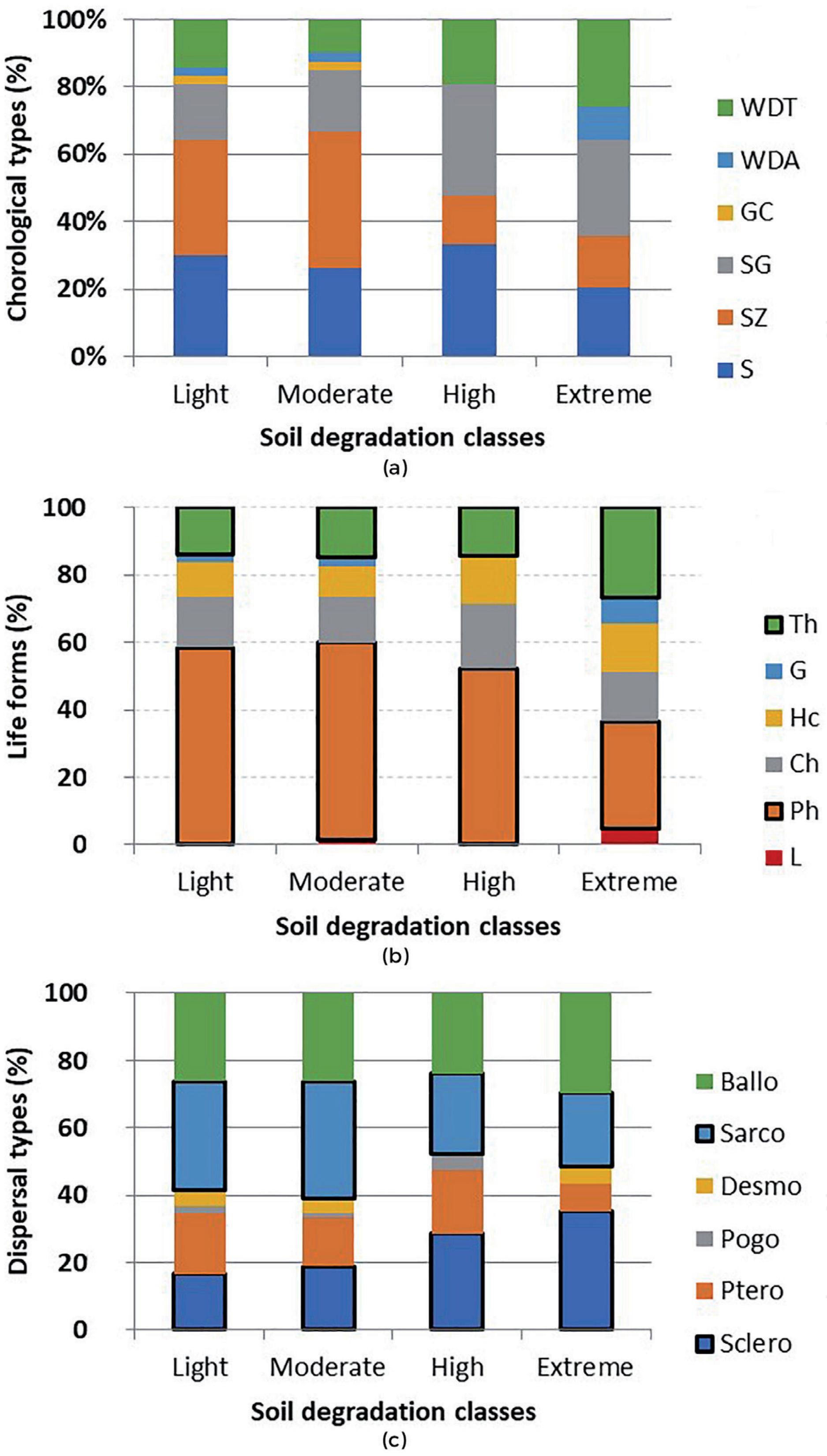

Figure 3.
(a) Weighted spectrum of chorological types, (b) life forms and (c) dispersal types on soil degradation classes. SG: Sudano-Guinean, SZ: Sudano-Zambezian, S: Sudanian/Th: Therophytes, G: Geophytes, Hc: Hemicryptophytes, Ch: Chamephytes, Ph: Phanerophytes, L: Lianas / Ballo: Ballochory, Sarco: Sarcochory, Desmo: Desmochory, pogo: Pogonochory, Ptero: Pterochory, Sclero: Sclerochory.

could be explained by the fact that the soil aggregate stability is closely related to soil organic matter composition [35], biological activity [36], infiltration capacity [37], water absorption and retention in the biomass and upper rhizosphere [38, 39] and erosion resistance [37]. Physical soil degradation on the hillsides of Atacora

Soil classes	Size	Average distance	A	T	P
Light	10	0.12	0.42486681	−6.7528582***	0.00000064
Moderate	3	0.14			
High	3	0.29			
Extreme	6	0.15			

A: Chance-corrected within-group agreement P: Probability of a smaller or equal delta T: Test statistic.
****Significant at 0.001.*

Table 6.
Global comparison with multi response permutation procedures.

Soil classes compared	A	T	P
High vs. Moderate	0.17460317	−1.68534137*	0.05423789
High vs. Light	0.21250178	−3.18865435**	0.00515585
High vs. Extreme	0.37185184	−3.98260352**	0.00360514
Moderate vs. Light	0.14571143	−2.20526374**	0.02559057
Moderate vs. Extreme	0.30172839	−3.95512754**	0.00298946
Light vs. Extreme	0.30594002	−6.68470594***	0.00005983

Chance-corrected within-group agreement P: Probability of a smaller or equal delta T: Test statistic.
**Significant at 0.1.*
***Significant at 0.05.*
****Significant at 0.001.*

Table 7.
Pairwise comparisons with multi response permutation procedures.

mountain was characterized by the removal of the organic layer and the modification of soil structure leading to the occurrence of ferricrete (extremely degraded soils) [17]. Soil degradation had resulted in soil loss, nutrient depletion, changes in soil structure, and soil hardening that limited plant root system penetration. Thus, only the most adapted species to the soil conditions were found on each soil degradation classes.

Moreover, the changes in species lists have been accompanied by a decrease of species richness and the number of regional species, phanerophytes and sarcochory as opposed to the number of species with wide distribution, therophytes and sclerochory. Many studies about post crop plant succession in Africa, United States and Europe [18, 21, 40, 41], or forest regeneration [7, 42] had shown that therophytes and sclerochory were pioneer species, which well-developed on disturbed areas, while phanerophytes and sarcochory colonized less disturbed areas. Moreover, according to references [23, 43, 44], therophytes and sclerochory developed a "ruderal" life strategy (habitat with high disturbance) and were submitted to a reproductive strategy of type r (rapid growth, effective dispersal and great invest in reproduction) while phanerophytes and sarcochory developed "competitive" or "stress-tolerant" strategies (habitat with low disturbance) and were submitted to a reproductive strategy type K (slow growth, effective use of resources and low invest in reproduction). The results then suggest that soil degradation leads to a loss of biodiversity and disturbance of vegetation.

As far as chorological types are concerned, we have reached the same conclusion of disturbance gradient. Indeed, regional species considered as indigenous or native species are found in great number in undisturbed areas and their number decrease along the gradient while species with wide distribution or immigrant species increase in number and are numerous on very disturbed areas [21, 45]. Thus, the vegetation trend over the different soil degradation classes followed a retrograde succession from the least disturbed soils (slightly degraded soils) to the most disturbed soils (extremely degraded soils) through intermediate stages (moderately and highly degraded soils).

4.2 Impacts of soil degradation on vegetation structure

Vegetation cover was used in the study as a measure of vegetation structure. With respect to vegetation cover data, the results showed that only moderately and highly degraded soil vegetation cover data were significantly similar ($p > 0.05$). Vegetation cover data provide information on vegetation type and may be used in gradients studies to investigate the effects of environmental factors on plant abundance [46, 47]. These results could be explained by the vegetation type found on each soil degradation class. Shrub savannas were the vegetation type found both on moderately and highly degraded soils. The types of vegetation observed on slightly and extremely degraded soils are tree/shrub savannas and herbaceous savannas respectively. The results of the impacts of soil degradation on vegetation structure namely vegetation type demonstrated the abundance of phanerophytes on slightly degraded soils, a decrease of the abundance of phanerophytes to the profit of therophytes on intermediate degradation classes and an abundance of therophytes on extremely degraded soils.

5. Conclusion

Soil degradation impacts vegetation in various ways. Floristic composition (presence/absence of species), species richness, chorological, life forms, dispersal types and vegetation type (tree and shrub savannas on light degraded soils, shrub savannas on high degraded soils and grass savannas on extreme degraded soils) were the different aspects of vegetation which were modified along the gradient of soil degradation. The overall trend observed, showed the degradation of vegetation along the gradient of degradation of soils. The findings confirmed the negative impact of land degradation on vegetation and plant diversity. The results provided a good overview of the relationship between soil degradation and vegetation, useful for management policies. The study did not attempt to characterize the vegetation found on each degradation class, but rather to test the effects of soil degradation gradients on some measures of phytodiversity and vegetation structure. However, one limitation of this evaluation could be the low number of plots considered, which makes it difficult to generalize the results at the level of the whole study area. Further researches should be conducted in order to eliminate the limitation.

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