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Topographic and edaphic factors determining *Chromolaena odorata* and *Hyptis suaveolens* invasion of grassland in the Guineo-Congolian / Sudanian transition zone (Benin)

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ABSTRACT

Objectives: Soil properties-invasive vegetation relationships remains uninvestigated. This study aimed at analyzing the main ecological factors, which explain the spatial distribution of two invasive species: *Chromolaena odorata* (Siam weed) and *Hyptis suaveolens* (Tea-bush).

Methodology and Results: The Data were collected in 33 plots installed randomly according to the phytosociological method. These data were submitted to the Canonical Analysis of Correspondence. The, wet grasslands contamined were distinguished from grasslands of dry plateaus. A difference was also made between establishment and invasion from the step of contamination of both plants. The relevant edaphic main factors related to grasslands on dry plateau were sandy rate, pH, potassium and carbon rate. Wet grasslands of floodplains were located on soils with a high concentration of clay and silt, phosphorus, calcium and magnesium, as well as a high cation exchange capacity.

Conclusions and application of findings: It could be concluded that the texture-moisture of the soil is the main factor, which explained the invasion intensity and the floristic composition of the investigated savannah. Dry plateau soil and oligotrophe induced the development of these alien plants. Therefore, it was suggested planning activities to prevent the expansion of these species on dry plateau grasslands.

Key words: alien plants, Canonical analysis of correspondence, dry plateau, floodplain, plant community, soil properties.

INTRODUCTION

The introduction of Alien invasive species into new habitats has serious consequences on ecological and economic systems (Wilcove *et al*., 1998; Simberloff, 2003). The biological invasions are therefore regarded as an agriculture-environmental question of first order. Invasive plants constitute, amount many others, a major constraint for the breeding of domestic ruminants. At the environmental level, some invasive alien species can threaten gravely the plant communities, which constitute a biotope with higher biological value for grasslands (Ng'weno *et al*., 2009; Oumorou *et al*., 2010). A review study suggests that African savannas are less severely invaded than those on other continents (Foxcroft *et al*., 2010). However, it needs to be borne in mind that invasions by alien species are poorly reported across Africa, besides South Africa and other localized areas (Pyšek *et al*., 2008). Recent evidence suggests that positive feedbacks between invasive plants and soils could contribute significantly to plant invasions (Corbin & D'Antonio, 2004; Ehrenfeld, 2004; Eppstein & Molofsky, 2007). In the savannah biome of South Africa, the most prominent invaders are usually only found along rivers flowing through savannas and are therefore not invaders of true savannah ecosystems (Henderson, 2007). Land use patterns can affect the sensitivity of ecosystems to plants invasion (Lozon & MacIsaac, 1997; Radosevich *et al*., 2003; Aboh *et al*., 2008). Many biotic and abiotic factors explain the invasion process of ecosystems. The climate variability affects the pattern of plant species invasion in specified ecosystems (Radosevich *et al*., 2003). In other hand, invasive plant species occur in determined ecosystems. Indeed, the studies revealed the existence of relationships between the habitat, the frequency, the prevalence and the persistence of invasive plant species and the types of soil (Radosevich *et al*., 2003; Pyšek *et al*., 2010). One of the consequences reported is the difference in taxonomic compositions between indigenous flora and alien flora (Cadotte & Lovett-Doust, 2001). In addition, variations in physiognomy may be accompanied by changes in floristic composition, structure, and productivity due to variations in chemical and physical soil characteristics (Haridasan, 2000). In the Guineo-Congolian/Sudanian transition zone of Benin, alien species, *Chromolaena odorata* and *Hyptis suaveolens* proliferate with aggressiveness (Aboh *et al*., 2008). *C. odorata* is originating of the Antilles and of equatorial America, but was introduced like a cover plant in Africa between 1920 and 1940 (Lavabre, 1988); while *H. suaveolens* is native of tropical America, now widespread in tropical Africa and Asia (Hutchinson & Daziel, 1963). In the grasslands, these alien invasive species act as non-edible plants by the ruminants (Aboh *et al*., 2008). The abundance and the dominance of edible species drop in colonized vegetation form to the advantage of inedible species (Oumorou *et al*., 2010). The spatial distribution of *Chromolaena odorata* and *Hyptis suaveolens* across grasslands vary largely. Unfortunately, there is an information gap of measurement data and experimentation as regards research on soil-invasive plant relationships in grazing system zones. The aim of this study was to analyze the physical and chemical composition of the soil in relation to the distribution of the invasive species *C. odorata* and *H. suaveolens*. Specifically, the study aims at: (i) determining soil characteristic that induces invasion of *C. odorata* and *H. suaveolens* (ii) analyzing spatial distribution of *C. odorata* and *H. suaveolens* (iii) suggesting management and use measures in order to prevent non-edible plants invasion, and to ensure a sustainable use of grasslands in the investigation area.

MATERIEL AND METHODS

Study area: The study was carried out in the breeding ranch of Bétécoucou in Benin. This ranch is located between 2°20' and 2°28' of longitude East and 7°45' and 7°52' of Northern latitude. This corresponds to the Guineo-Congolian/ Sudanian transition zone (White, 1983) where the climate is characterized by one long rainy season (mid-March to October) and one dry season (November to March). The average annual rainfall ranges from 900 mm to 1100 mm. The annual average temperature is of 27.4°C. It was strongly observed that savannahs in the investigation area presented several physiognomies that expressed the intensity of human activities that they are suffering. In the dry season, the use of fire as a management tool of these natural grasslands is common. The main activities of local population are agriculture and cattle breeding. Grasslands play key role for the animal especially in the dry season, where the region receives transhumance herds coming from Nigeria, and North part of Benin.

Typology of grasslands: Vegetation and soil samples were collected from each vegetation form according to three steps of invasion expressed as a percentage of land covering of the invasive plant within the native range (Radosevich *et al*., 2003; Pyšek *et al*., 2004; Aboh *et al*., 2008). Step 1: contamination or non-invasive corresponds to the step during which the invasive plant has a covering varying from 0 to 10%. Step 2: establishment is a starting of the invasion, during which the invasive plant has a covering varying from 10 to 40%. Step 3: invasion is reached when the invasive plant becomes abundant and dominant, presenting a covering over than 40%. The sampling of species was carried out inside of each vegetation form according to the phytosociological method (Braun-Blanquet, 1932). Botanical materials were taken inside 33 plots of 20 m x 20 m installed randomly during the period of maturation of the herbaceous species. All plants were recorded and identified to species level at the Laboratory of Applied Ecology of the University of Abomey-Calavi (Benin). For each plot, the list of the inventoried species and their coefficients of abundance-dominance were recorded.

Soil sampling and chemical analysis: In the field, soil samples were taken in each plot at a depth of 0 - 20 cm for chemical and granulometric analyses. In each plot, 12 soil samples were taken at 12 points of the diagonals and the medians of the plot. Samples from each plot were then mixed to obtain one sample per plot. The analyses were realized at the Laboratory of Soil Sciences, Water and Environment of the National Institute of Agricultural Research of Benin. Soil samples were spread out and dried sheltered from dust in a room with ambient air during 5 days. Air-dried soil samples were sieved in 2.0 mm. For total N analyses, the samples were digested with sulphuric acid, distilled in boric acid and determined by titration with 0.1 M sulphuric acid (the Kjeldahl method). The total organic matter (OM) was determined by spectrophotometry after oxidation with sodium dichromate in the presence of sulfuric acid and a subsequent titration with ammonic ferrous sulfate; available phosphorus (P) by Bray-II method; and basic cations potassium (K), magnesium (Mg), calcium (Ca) were extracted with 1molc l^{-1} KCl; cation exchange capacity (CEC) was determined based on the sum of K, Ca, and Mg. The pH was determined in H_2O (1:2.5) and in a 1 M KCl (1:2.5) solution. The commonly applied particle size class limits are used: clay < 2 µm < silt < 50 µm < sand < 2000 µm. All these procedures are described by (FAO, 1984)

Statistical Analysis

The analysis of variance (ANOVA) using STATISTICA (1998) is used to compare the means of environmental data: Sand, clay, silt, organic matter (OM), pH(H2O), pH(KCl), carbon (C), pH, nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), Cation Exchange Capacity (CEC), sum of the cations (Sc), ratio C/N of the dry plateau invaded by *C. odorata*; *H. suaveolens* and non-invaded. The test of student Newman-Keuls is used to separate the homogeneous groups if there was any significant difference. The ecological interpretation of the principal types of grassland was made via a simultaneous treatment of two matrices, one consisted of 33 plots and 199 plant species and the second consisted of the same number of plots (33) and 15 environmental variables (soil chemical elements and granulometric variables). A canonical correspondence analysis (CCA) (Jongman *et al*., 1995) was performed to investigate the relationships between species abundance and soil variables in the 33 plots. These variables were ordinated by direct gradient analysis using CANOCO for Windows 4.5.

RESULTS

Floristic characteristics: In the present study, 199 species were sampled and gathered in 53 families. The richest families were Fabaceae (18.59%), Poaceae (15.08%), Combretaceae (5.03%), Euphorbiaceae (5.03%) and Rubiaceae (4.52%). In flood plain, 56 species were sampled and gathered in 21 families. The richest families were poaceae (14 species, dominated by *Andropogon gayanus* Kunth var. gayanus), fabaceae (11 species, dominated by *Desmodium hirtum* Guill. & Perr.), rubiaceae (4 species, dominated by *Gardenia ternifolia* Schumach. & Thonn.). A total of 188 species were sampled and gathered in 52 families in dry plateau. The richest families of dry plateau were Fabaceae (36 species, dominated by *Desmodium hirtum* Guill. & Perr.), Poaceae (22 species, dominated by *Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.), Euphorbiaceae (10 species, dominated by *Flueggea virosa* (Roxb. ex Willd.) Voigt).

Soil property: Variables of average soil characteristics of invasive grasslands or non-invasive grasslands studied are presented in table 1. results of this study showed that *H. suaveolens* and *C. odorata* sometimes germinated without being established (invasion step 1) on the vertisol and the gleysol. However, these invasive plants became abundant and dominant (invasion steps 2 and 3) on luvisol of the dry plateau. The luvisol presented a high level in sand. This type of soil under invasive grassland (i.e. at invasion steps 2 and 3) presented a neutral pH (H_2O), vs an acid pH (H_2O) for the same type of soil under grassland at invasion step 1. In general, vertisol and gleysol of floodplains at invasion step 1 have an acid pH with high levels of clay, silt, CEC and Ca.

Table 1: Average of soil properties according to grassland, ecology and invasion intensity

Parameters	Soil of non-invasive Savannah		ferrics Luvisol of savannah/invasive Fallow	
	Eutric Vertisol/gleysol	Ferric Luvisol	*C. odorata*	*H. suaveolens*
Step of invasion	Invasion step 1	Step 1	Steps 2 and 3	Steps 2 and 3
Clay ($g.kg^{-1}$)	18.02 ± 18.31	4.52 ± 1.09 b[1]	7.845 ± 3.36 a	3.43 ± 0.36 b
Silt ($g.kg^{-1}$)	17.99 ± 7.25	10.94 ± 4.22 ab	13.45 ± 5.63 a	7.07 ± 3.03 b
Sand ($g.kg^{-1}$)	61.59 ± 26.46	83.30 ± 5.60 a	76.27 ± 9.82 b	88.30 ± 3.89 a
C ($g.kg^{-1}$)	1.90 ± 1.49	1.38 ± 0.19 a	1.87 ± 0.21 a	2.05 ± 0.8 a
N ($g.kg^{-1}$)	0.11 ± 0.06	0.09 ± 0.02 c	0.14 ± 0.02 a	0.14 ± 0.05 ab
C/N	14.53 ± 4.92	15.25 ± 1.97 a	13.89 ± 0.80 a	14.22 ± 1.41 a
O. M. ($g.kg^{-1}$)	3.03 ± 2.22	2.39 ± 0.39 a	3.28 ± 0.37 a	3.49 ± 1.26 a
pH(H_2O)	6.35 ± 0.53	6.79 ± 0.39 a	7.12 ± 0.48 a	7.11 ± 0.22 a
pH(KCl)	5.050±0.63	6.01±0.58 b	6.43 ±0.71 a	6.54 ±0.16 a
Ca ($cmol.kg^{-1}$)	12.35 ± 10.08	5.66 ± 0.45 b	7.47± 1.11 a	6.34 ± 1.27 b
Mg ($cmol.kg^{-1}$)	9.88 ± 7.86	4.51 ± 0.56 b	5.94± 1.12 a	4.42 ± 0.69 b
K ($cmol.kg^{-1}$)	0.18 ± 0.20	0.13 ± 0.06 b	0.34± 0.22 a	0.18 ± 0.07 b
Cationic sum	22.41 ± 18.14	10.30 ± 0.94 b	13.75 ± 2.19 a	11.00 ± 1.91 b
CEC ($cmol.kg^{-1}$)	39.20 ± 36.81	8.68 ± 1.02 b	12.31 ± 2.69 a	9.19 ± 0.42 b
P assimilated ($mg.kg^{-1}$)	19.10 ± 17.31	8.89 ± 3.70 a	9.73 ± 1.09 a	10.94 ± 4.52 a

[1] = The numbers followed by the different letters on the same line are statistically different ($P < 0.05$)

Step 1 = contamination/non-invasive; Step 2 = Establishment; Step 3 = Invasion

Relationship between soil and vegetation of invasive grassland: The summary of the Canonical Correspondence Analysis (CCA) outputs for the first four axes is presented in the table 2. The factorial chart and the correlation coefficients of the CCA show that the various environmental variables are significantly linked to the vegetation form. The sum of all unconstrained eigenvalues was 7.023, and the sum of canonical eigenvalues was 4.109. Concerning the relation between species and environmental variables, a correlation is shown by the CCA, which explained about 47.9 % of the original variance in terms of relation for the first four axes. The cumulative percentages of variance of the species in the first four axes were respectively 8.9%, 16.2%, 22.3%, and 28.0%. Those of the relations species-environment in the first four axes were respectively 15.1%, 27.7%, 38.1%, and 47.9%. The correlations between species-environmental variables were respectively 0.988, 0.978, 0.974, and 0.957 for the first four axes.

Table 2 Eigenvalues and percentage of variance explained by the 4 axes of ordination of CCA.

Axis	Axis 1	Axis 2	Axis 3	Axis 4	Total Inertia
Eigenvalues :	0.622	0.516	0.427	0.403	7.023
Species-environment correlations :	0.988	0.978	0.974	0.957	
Cumulative percentage variance					
of species data :	8.9	16.2	22.3	28.0	
of species-environment relation :	15.1	27.7	38.1	47.9	
Sum of all canonical eigenvalues					4.109
Correlation coefficients					
Clay ($g.kg^{-1}$)	0.483	-0.038	-0.801	0.162	
silt ($g.kg^{-1}$)	0.501	0.049	-0.553	0.306	
Sand ($g.kg^{-1}$)	-0.512	-0.011	0.721	-0.236	
C ($g.kg^{-1}$)	0.021	0.153	-0.657	-0.051	
N ($g.kg^{-1}$)	-0.088	0.282	-0.478	-0.181	
C/N	-0.084	-0.298	-0.724	0.258	
O.M. ($g.kg^{-1}$)	-0.054	0.144	-0.631	-0.059	
pH (H_2O)	-0.554	0.432	-0.399	-0.077	
pH (KCl)	-0.696	0.327	-0.212	-0.107	
Ca ($cmol.kg^{-1}$)	0.428	0.023	-0.828	0.050	
Mg ($cmol.kg^{-1}$)	0.450	-0.015	-0.823	0.059	
K ($cmol.kg^{-1}$)	0.014	0.573	-0.623	0.277	
Cationic sum ($cmol.kg^{-1}$)	0.435	0.013	-0.830	0.058	
CEC ($cmol.kg^{-1}$)	0.542	-0.041	-0.789	0.087	
P assimilated ($mg. kg^{-1}$)	0.424	0.023	-0.789	0.117	

The ordination diagram (Fig. 1) showed two distinct groups, each one corresponding to one of the sampled vegetation forms. Axis 1 separated the dry grassland at invasion steps 1, 2 and 3 related to luvisol of the dry plateau from the wet grassland at invasion step 1 related to gleysol and vertisol of floodplains. The dry grassland at the invasion steps 1, 2 and 3 presented negative scores in the first axis, due to higher values of sand, organic matter, nitrogen, ratio C/N, pH (H_2O) and pH (KCl); while the wet grassland presented positive scores in the first axis, due to larger amounts of clay, silt, CEC, Mg, sum of cations and P. Thus, dry grassland at invasion steps 1, 2 and 3; dominated by *A. tectorum* and *Anogeissus leiocarpa; H. contortus* and *Pseudocedrela kotschyi; H. involucrata* and *Combretum collinum; A. tectorum* and *H. suaveolens; A. tectorum* and *C. odorata; H. contortus* and *C. odorata; H. contortus* and *H. suaveolens; C. odorata* and *H. suaveolens* are concentrated on sandy soil, an indicator of poor soil fertility. While wet grassland at invasion step 1, dominated by *Brachiaria jubata* and *Desmodium hirtum; Andropogon schirensis* and *Terminalia macroptera* is concentrated on soil containing high clay, silt, CEC, Mg and Ca. Within the dry grassland on the plateau, the axis 2 separated grassland at invasion step 1 from most grassland at invasion steps 2 and 3. The dry grassland at invasion steps 2 and 3 presented positive scores in the second axis, being related to larger amounts of K, N, organic matter, C and pH. Whereas, the dry grassland at invasion step 1, presented negative scores in the second axis, being related to larger amounts of the ratio C/N; but a low value in K, N, organic matter, C and pH.

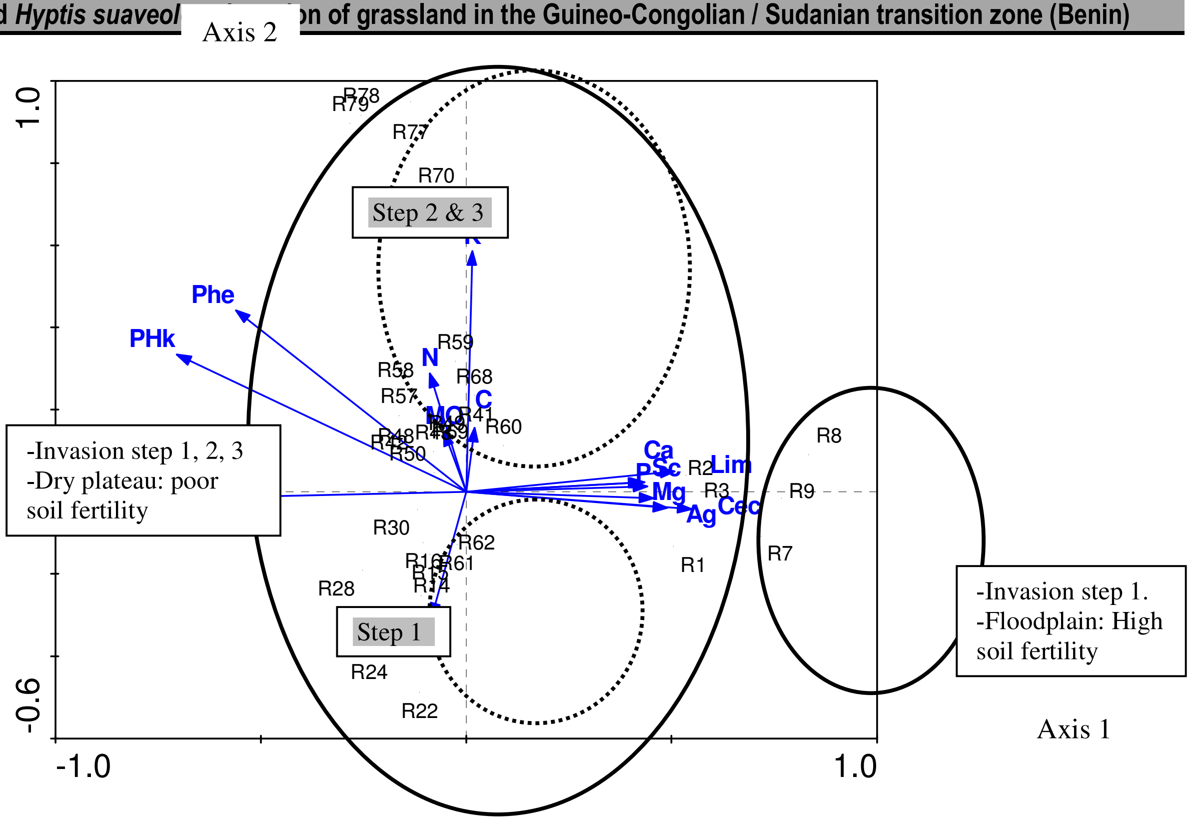

Fig 1 Projection on axes 1 and 2 of the CCA applied to the 33 plots and the fifteen environmental variables

Sands (sab), clay (Ag), silt (Lim), carbon (C), organic matter (O.M.), calcium (Ca), magnesium (Mg), sum of the cations (Sc), cation exchange capacity (CEC), phosphorus (P), potasium (K), Nitrogen (N), ratio C/N (CN), pH(H_2O) (Phe), pH(KCl) (PHk).

- R1, R2, R3, R4, R5, R6 and R7: Plot of savannah: (invasion step 1) of eutric vertisol and eutric gleysol of *B. jubata* et *Desmodium hirtum* and of *Andropogon schirensis* and *Terminalia macroptera;*
- R22, R23 and R24: Plot of shrub and tree savannah: (invasion step 1) in ferric luvisol of *A. tectorum* and *Anogeisus leiocarpa H. involucrata*;
- R41, R42 and R43: Plot of shrub and tree savannah: (invasion step 1) of ferric luvisol of *H. contortus* and *Pseudocedrela kotschyi*;
- R60, R61 and R62: Plot of shrub and tree savannah: (invasion step 1) of ferric luvisol of *H. involucrata* and *Combretum collinum*;
- R14, R15 and R16: Plot of Shrub and tree savannah (invasion step 2) of ferric luvisol at *A. tectorum* and *H. involucrata/ H. suaveolens*;
- R28, R29 and R30: Plot of Shrub and tree savannah (invasion step 2) of ferric luvisol at *A. tectorum* and *H. involucrata/ C. odorata*;
- R57, R58 and R59: Plot of shrub and tree savannah (invasion step 2) of ferric luvisol at *H. contortus* and *C. odorata*;
- R48, R49 and R50: Plot of Shrub and tree savannah (invasion step 2) of ferric luvisol at *H. contortus* and *H. suaveolens*;
- R68, R69 and R70: Plot of fallow (invasion step 3) of ferric luvisol at *H. suaveolens*;
- R77, R78 and R79: Plot of fallow (invasion step 3) of ferric luvisol at *C. odorata*.

DISCUSSION

Topographic key factors of process of grassland invasion: The Canonical correspondence analysis shows that the edaphic variables measured, explain only part of the gradient variation, as pointed out by the low cumulative percentages of variance and by the difference between the eigenvalues and the canonical eigenvalues. Nevertheless, this fact did not invalidate the relationships, since they were statistically significant. Species–environment correlations were high, showing a high degree of association between plant species and measured soil characteristics. There is an intimate relationship between soil characteristics and plant community (Amorim & Batalha, 2007) as demonstrate this study results. The two topographical environments floodplains and dry plateau constitute distinct groups in the ordination diagram as a consequence of different floristic composition, abundance and dominance of invasive species *C. odorata* and *H. suaveolens*. In the area of permanent or temporal floodplains, floristic composition is structured mainly by abiotic factors (Lenssen *et al*., 1999), as shown by the high correlation of species-environment recorded in the present study. Wet grassland also appeared on soils with increased amounts of clay (Bridgewater *et al*., 2002) and silt as confirmed by our result.

Edaphic key factors of process of grassland invasion: From an ecological point of view, the invasion by *H. suaveolens* and *C. odorata* steps 2 and 3 is observed only on the sandy soil of the dry plateau, poor in fertility elements. Thus, the luvisols of the well-drained, acid and oligotrophic plateau, seem to induce the expansion of *H. suaveolens* and *C. odorata*; whereas the floodplains seem to be pedological barriers to their invasion. Our results revealed that invasive species *C. odorata* and *H. suaveolens* are presented, but did not reach steps 2 and 3 on seasonal floodplains and clayed soil. This less abundant and poor development on floodplains by *H. suaveolens* and *C. odorata*, is probably because of their physiological incapacity of tolerating temporary flooding. This also reflects the physiological incapacity of the majority of wet grassland species in tolerating dryness as reported by Batalha *et al*. (2005). Soil texture and temporary flooding of the vegetation seem to constitute a principal factor reducing the aerobic breathing of roots, as well as the mineral and water absorption of *H. suaveolens* and *C. odorata*. this excess of permanent or seasonal water is one of the principal factors to distinguish the two forms of vegetation, which have different floristic compositions, abundance and dominance of invasion species. The main edaphic variables influencing site segregation related to soil fertility are CEC, P and Mg levels content and clay (Vincent & Meguro, 2008) as indicated our results. In particular, the availability in K, Mg, Ca, CEC, N, clay and silt is significantly higher in the soil under *C. odorata* (invasion step 3) than that in the soil of non-invaded pastures (invasion step 1). This impact could be explained by a more intense flow of biogenic mineral, consecutive either to a higher primary productivity or with a higher nutriments content of the organic waste restored by *C. odorata*, or both (Ruggiero *et al*., 2002). The improvement of the chemical properties of the soil under *C. odorata,* in particular Ca, pH and Mg, and biological activity has been reported (De Foresta & Schwarts, 1991; Akobundu & Ekeleme, 1996; Ngobo *et al*., 2004). In northern Cameroon, *H. suaveolens* in the field is used by farmers as indicator of the fertile soil (M'biandoun & Bassala, 2007). A bias of this study is that, our soil analysis is limited in time and there may be variations in soil characteristics throughout the year in all vegetation forms. Moreover, flooding and fire frequency may also alter soil characteristics (Coutinho, 1990).

Implications for sustainable grassland management: In the pastoral way, the tropical grassland constitutes the base and generally the totality of ruminant feed resources in extensive breeding. This grassland provides the main energy consumed by the cattle. Its evidence, that invasion grassland by non edible plants such as *H. suaveolens* and *C. odorata,* impact negatively cattle production enterprises through the reduction of forage production and livestock carrying capacity (Huntsinger *et al*., 2007; Ng'weno *et al*., 2009; Oumorou *et al*., 2010). The implications for sustainable grassland management, is that grazing management must be integrated into the restoration of the plateau ecosystem. Therefore, to ensure success, the use of the traditional vegetation fire can continue as a management tool in savannas of plateau to increase pasture and combat bush encroachment. In addition, the control of the grazing intensity and the rest from grazing can be used to restore invasive ecosystem functions and services.

CONCLUSION

This study has highlighted that plant communities are structured predominantly by abiotic factors, as pointed out by the high species-environment correlation. This study results show that *H. suaveolens* and *C. odorata* are invasive species particularly powerful on the dry plateau, poor soil, well-drained soil and developing on a permeable soil. The soil properties most favourable to abundance and high covering of *H. suaveolens* and *C. odorata* are the sandy soil, with high pH, high potassium and high organic matter. The implication of the finding is that the soil of the area, mainly the plateau soil, is pre-disposed or susceptible to invasion. If in the case of pastoralism it becomes illusory to want to eliminate the two invasive species, it is significant to firstly supervise these types of soil, so as to be able to intervene quickly in the event of establishment of the species, and to thus limit its propagation to a regional scale.

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