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Hemicryptophytes plant species as indicator of grassland state in semi-arid region: case study of W Biosphere Reserve and its surroundings area in Benin (West Africa)

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ABSTRACT

In semi-arid region managers are facing rapid degradation of grassland. There is a need to determine indicators to be used to detect early change occurring in the grassland for their sustainable management. Thereof, in this study, we explored the reliability of the use of hemicryptophytes as indicator of grassland state in semi-arid region within W Biosphere Reserve and surrounding areas (Benin). Plots of 10 m X 10 m were installed along a land use gradient (from communal lands to the protected area via the buffer zone) in three vegetation types for plant biomass harvesting and hemicryptophytes traits measurement. The hemicryptophyte density, biovolume, tussock size, contact frequency, contribution to total plant biomass and grassland grazing value were assessed and compared between land uses. Findings showed that hemicryptopyte traits were significantly different with the land use type. Hemicryptophyte biovolume and hemicryptophyte contribution were strongly correlated, respectively, with total biomass production and grazing value. The study highlights the relevance of hemicryptophyte as indicators of grassland state that could be used by grassland managers for grassland monitoring, restoration and sustainable use.

Keywords: Grassland monitoring, hemicryptophyte traits, indicators, land use.

INTRODUCTION

Grassland represents an important ecosystem which provides multiple services such as fodder for herbivores, food, medicine and timber for human welfare (Lykke, 2000; McGilloway, 2005). Human activities affect the ecological processes in grassland through modification of its productivity, composition, functioning and structure (O'Connor, 2005; O'Connor, 2008; Nacoulma et al., 2011). This resulted in the decreasing of their carrying capacity, reduction of their surface, the invasion of unpalatable species and bush encroachment (Zarovali et al., 2007; Rakotoarimanana et al., 2008). Because of the decreasing of the grasslands carrying capacity, restoration and sustainable use of this ecosystem remain important challenge for managers. It is important to develop an appropriate knowledge of the effects of livestock grazing on grasslands characteristics in order to implement reliable management

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practices and prevent accordingly grassland degradation. There have been extensive literatures on grassland ecology of semi-arid region of West Africa grasslands ecology. Available literature focused on the assessment of the floristic composition, production potential for livestock and grazing value of grasslands (Agonyissa and Sinsin, 1998; Saidou et al., 2010; Nacoulma et al., 2011) and development of strategies to maintain their production and forage quality (McGilloway, 2005). However, these strategies will not sustain if there is not an appropriate ecological monitoring system which could inform managers on the early degradation of the grasslands. Therefore, seeking of indicators which can be used by managers to detect early change in grassland appears as a challenge.

In the semi-arid and arid region, grasslands are mainly represented by various types of savannas and woodland and are typically dominated by grasses species at the herbaceous layer (Le Houerou, 1989; Allen et al., 2011). Among the grasses plant species, perennial grasses (hemicryptophyte) represent the most dominant life form in the semi-arid region (Lejoly and Sinsin, 1991). A possibility to assess the resilience of grassland to degradation is to use hemicryptophytes since the change in their abundance and structural parameters can affect grassland functioning, productivity and quality (Sinsin, 1993). In this study, we aim at assessing whether hemicryptophytes abundance, biovolume, tussock area class distribution, contact frequency and contribution to total biomass production is affected by land use systems in semi-arid region and to explore the reliability of the hemicryptophytes as indicator of grassland state.

MATERIALS AND METHODS

Study area

The study was conducted in the W Biosphere Reserve in Benin (WBR) (11°26'-12°26' N; 2°17'-3°05' E). It is part of the trans-boundary (Benin, Niger and Burkina Faso) Biosphere Reserve of UNESCO-MAB (Man and the Biosphere Programme, November 2002). The WBR is composed of the park and its adjacent hunting zones and is under the administration of the National Centre for Wildlife Reserves Management (CENAGREF) which outlined and implemented management and conservation actions of the reserve (Clerici et al., 2007). The region is located in the Sudanian region centre of endemism (White, 1983), where climate is characterized by one rainy season (May to October) and a dry season (November to April). The mean annual rainfall ranges from 900 mm to 1100 mm. The mean monthly temperature ranges from 25 to 35 °C and values of the relative air humidity range from 81% in August to 26% in February (ASECNA, Unpubl. data). Overall, soils are tropical ferruginous type and characterized by moderate fertility (CENAGREF, 2002). Anthropogenic activities (livestock grazing, cropping, uncontrolled fire and logging) are strictly prohibited inside the reserve. At the periphery of the reserve, a 5 km land belt (buffer zone) is devoted to alter anthropogenic pressure from communal lands on the reserve. In the buffer zone, although crops growing, Non-timber Product Forests (NTFPs) harvesting and livestock grazing are allowed, they are subjected to restrictions. In theory, the use chemical pesticides is banned; the livestock carrying capacity should be ecological acceptable and the overharvesting of NTFPs none tolerated. However, the buffer zone is not functioning as envisioned. For instance, it is frequent to find in the buffer zone, cotton crops cultivation which involves chemical pesticides use. In contrast to the park and buffer zone, there is no restriction with respect to human activities in the communal lands. Thus this latter are subject to high anthropogenic disturbance. Cropping based on shifting cultivation and livestock breeding based on extensive use of grassland represent the most important socio-economic activities of the local populations. The main crops cultivated are cotton, sorghum, corn and millet. Cattle, sheep and goat are the main livestock farmed. Uncontrolled fires are frequently applied by the local populations in order to favour perennial grasses regrowth, for poaching and for land cleaning according to local perception. The population density in the peripheral WBR is about 20.0 inhabitants km^{-2} and the most dominant ethnic groups are Batonou (32.6%), Fulani (22.1%), Dendi (18.2%) and Monkollé (8.5%) (INSAE, 2003).

Methods

Data collection

27 Plots of 10 m X 10 m were installed along a gradient of land use going from communal land, through buffer zone to the protected area. In each land use, three main vegetation types have been selected: woodland, tree savanna and shrub savanna. Three plots were randomly laid out in each selected vegetation type per land use. Within each plot, seven quadrats (1m X 1m) were randomly sampled for biomass quantification. Inside each plot the coverage percentage of hemicryptophyte has been visually estimated following Braun-Blanquet approach: +: coverage less than 1%; 1: coverage ranging from 1 - 5%; 2: coverage ranging from 5 - 25%; 3: coverage ranging from 25 - 50%; 4: coverage ranging from 50 - 75% and 5: coverage ranging from 75 - 100%. In each quadrat, the height of the hemicryptophytes species was measured. Hemicryptophytes and other herbaceous (i.e., annual grasses and dicotyledons) plant species were separately clipped closed to the soil in the quadrats for biomass estimation. Representative samples (100 g) of the so harvested fresh biomass for each group of species were then taken in envelop for oven-drying at 105 °C for 48 hours i.e. until constant weight in order to determine the dry matter.

Thereafter, the number of grass tussock in the quadrat was counted. A Grid of 1.2 cm X 1.2 cm pixel was laid on grass tussocks and the number of pixel was counted for the area determination.

In addition to hemicryptophytes coverage estimation and biomass harvesting, point quadrat relevés of the vegetation (Daget and Godron, 1995) was carried out in the same vegetation type where the herbaceous biomass was harvested to assess the hemicryptophytes contact frequency and the grassland grazing value. Plant species presence was recorded every 20 cm along four linear segments of 5 m length established near each plot. The relevé consisted of listing all the plant species in contact with a metallic bar at each 20 cm position along the line. A species was counted only once at a given position. Livestock follow up to pasture was done to determine the forage quality index of the plant species.

Data analysis

Hemicryptophyte biovolume

Mean biovolume of hemicryptophytes (Bv, in $m^3.ha^{-1}$) was estimated per plot as

$\mathbf{Bvi = Hi \times (R_{vi} \times S) \times 10^2}$, Where Hi (expressed in meter) was the mean height of hemicryptophytes in the plot of 10 m X 10 m. Hi was estimated by computing the average height of hemicryptophytes in the 7 subplots of 1m² per plot of 10 m X 10 m. Rvi (expressed in %) was the mean coverage of hemicryptophytes in the plot of 10 m X 10 m following the Braun-Blanquet scaling. S is the plot area (100 m²).

Hemicryptophyte abundance and area size class distribution

We estimated the mean density of hemicryptophytes as follow:

D = n/S, where *n* is the number of grass tussock counted per quadrat and *S* the unit area of quadrat (1m²).

Size class area distribution of 20 cm² width was computed for hemicryptophytes per vegetation type and land use type.

Biomass production estimation

Data were computed per land use (communal land, buffer zone and protected area) and per vegetation type. Herbaceous biomass at plot level was estimated as:

$$\mathbf{P_{plot}} = \sum_{i=1}^{7} \mathbf{TS_i \times BF_i} \ \ (\mathbf{g\,DM.m^{-2}})$$

where **Bfi** is the weight of fresh herbaceous biomass for each harvested category (hemicryptophyte/annual grasses/ dicotyledons), and **Tsi** the proportion of dry matter in 100 g of fresh sampled herbaceous biomass per category. Seven (**7**) represented the number of harvested quadrats. Finally, herbaceous biomass at vegetation type level was computed as the average of the herbaceous biomass in the three plots designed in each vegetation type.

$$P_{vegetation} = \sum_{i=1}^{3} \frac{P_{plot}}{3} \; (g\,DM.m^{-2})$$

where $P_{vegetation}$ represented standing herbaceous biomass at plot level and 3, the number of plot designed per vegetation type in a given land use.

Species Contact Frequency (CF)

Species contact frequency (CFi, in percentage) was computed as

$$CF_i = \frac{FR_i}{\sum_{i=1}^{k} FR_i} \; x\,100$$

with **Fri = n_i/N**

FR_i represents the relative frequency of the species ***i*** in the vegetation type; n_i was the number of contact point of the species **i** and **N** = total number of contact point recorded in a given vegetation type.

$\sum_{i=1}^{k} FR_i$ is the sum of the relative frequency of the ***k*** species recorded in a vegetation type.

The hemicryptophytes contact frequency (**CF_h**) was thereafter derived as

$$CF_h = \frac{FR_h}{\sum_{i=1}^{k} FR_h} \; x\,100$$

with FR_h = the relative frequency of hemicryptophytes.

Grazing value

The grazing value (GV) is a field-based index of grassland quality. It gave a view of the quality of the grassland based on species frequencies and their forage quality indices. The grazing value was estimated following Sinsin (1993) as:

$$GV = 0.25\; x\; R_v\; x \sum_{i=1}^{k} CF_i\; x\; IS_i$$

Where **Rv** represented soil cover percentage for herbaceous strata in a given grassland. It was visually estimated. **CFi** = Contact frequency of the species (i) and **ISi** = Forage quality index of the species i, appreciated using the scale of 0 to 4 (Sinsin, 1993). 0 = non palatable species; 1 = weakly grazed species; 2 = fairly grazed species; 3 = well grazed species, 4 = highly grazed species.

Statistical analysis

Collected data were log-transformed to meet the assumptions of normality and homogeneity of variance for the estimated parameters (Dagnelie, 2011). One-way Anova tests were performed to check if there were significant differences between hemicryptophyte biovolumes, densities, productivities and contact frequencies along the land use gradient. Log linear analysis was performed to test whether the abundance and size class distribution of hemicryptophytes tussock area was related or not to the land use. We finally assessed correlation between grassland characteristics (biomass production, grazing value) and hemicryptophyte traits. MINITAB Release 14.1 software was used for statistical Analysis.

RESULTS

Hemicrypotophyte density

Overall, the mean density of hemicryptophytes was 3.8±0.9 m^{-2}; 3.2±1.1 m^{-2} and 0.9±0.6 m^{-2} respectively in the protected area, buffer zone and communal land. With respect to the vegetation type, the mean density of hemicryptophytes was 2.95±1.51 m^{-2}; 2.67±1.40 m^{-2} and 2.49±1.63 m^{-2}respectively for woodland, tree savanna and shrub savanna. However the vegetation type, the mean number of hemicryptophytes per square meter differed significantly between land use types (Figure 1).

Hemicryptophyte biovolume

With respect to land use type, the protected area had significantly higher biovolume in hemicryptophytes comparatively to the buffer zone and communal land ($p < 0.05$ irrespective of land use type, (Table 1). Hemicryptophyte biovolume was generally higher in woodland comparatively to shrub savanna and tree savanna however the land uses type. However, no significant difference was found between hemicryptophyte biovolume with respect to vegetation type in the protected area (F = 0.84; P = 0.477); buffer zone (F = 1.13; P = 0.384) and communal land (F = 1.09; P = 0.394).

Area size class distribution of hemicryptopyte tussocks

Hemicryptophyte tussock area distributions showed significant differences in all vegetation type across the different land use (Figure 2). Regardless of the vegetation type, grass tussock area distribution were mostly closed to the normality in the protected area (skewness = 0.26 - 0.86) and in the buffer zone (skewness = 0.69 - 1.04). In contrast, grass tussocks area size class distribution was right skewed in all vegetation in the communal lands. Almost 100% of the hemicryptophytes stands were inside the smaller size class area ranging from 0 to 20 cm² showing the weak area of the grass tussock in the communal land.

Contribution of hemicryptophytes to total biomass production

Irrespective of vegetation type, the contribution of hemicryptophytes to biomass production decreased from the protected area to the communal (Figure 3). The mean contribution of hemicryptophytes to biomass production was respectively 83.49±6.22%; 61.38±2.77% and 11.28±5.10% in the protected area, buffer zone and communal land. Significant differences were found for hemicryptophytes contribution to biomass production according to the land use in all the vegetation type ($p < 0.001$).

Hemicryptophytes contact frequency

The hemicrytophytes contact frequency was in general lower in the communal land, higher in the protected area and intermediate in the buffer zone. The mean hemicryptophytes contact frequency was respectively 37.7±10.4%; 18.73±7.63% and 3.14±2.08% in the protected area, buffer zone and communal land. However the vegetation type, significant differences were observed for the hemicryptophytes contact frequency with respect to land use type (Table 2).

Relationship between biomass production, grazing value and hemicryptophyte traits

Overall, hemicryptophyte traits were found to be correlated with land use types (Table 3). There was a significant correlation between total biomass production, hemicryptophyte density, biovolume and contact frequency. The correlation was strongly higher between biomass and hemicryptophyte biovolume while biomass was weakly correlated with hemicryptophyte density and contact frequency.

The grazing value was significantly correlated with hemicryptophyte density, contact frequency and hemicryptophytes contribution to biomass production. The correlation was higher between the grazing value and hemicryptophytes contribution to biomass and contact frequency while the correlation was weak with hemicryptophyte density.

Table 1: Hemicryptophyte biovolume across the different land use types.

	Protected area (Mean ± SE)	Buffer Zone (Mean ± SE)	Communal Land (Mean ± SE)	F	P
Woodland	13845.1±2930.5	6383.7±2559.2	259.4±74.4	27.72	0.001
Tree savanna	10620.3±3776.4	3178.3±1421.1	227.2±97.5	15.85	0.004
Shrub savanna	11134.2±3055.8	5228.3±3535.8	170.6±43.1	12.41	0.007
Mean value	11866.2±1732.6	4930.5±1623.4	219.5±45.2		

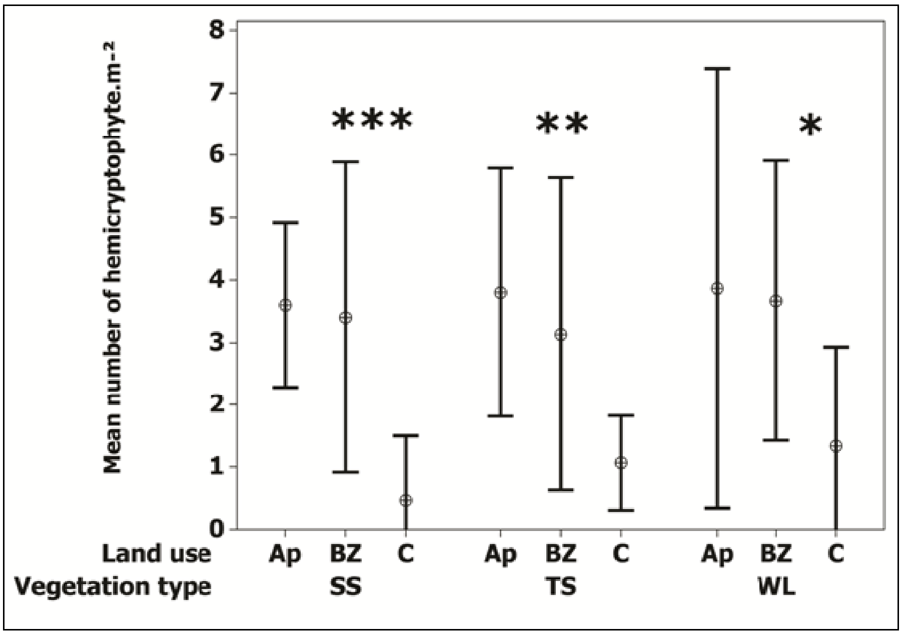
Table 2: Hemicryptophyte contact frequency (%) across the different land use types.

Vegetation type	Protected area Mean ± SE	Buffer zone Mean ± SE	Communal land Mean ± SE	F	P
Woodland	44.8±2.7	22.5±10.8	2.9±2.5	30.2	0.001
Tree savanna	29.4±14.7	19.7±5.8	3.8±2.5	5.8	0.039
Shrub savanna	38.9±5.4	14.0±5.2	2.8±2.0	51.5	0.000

Table 3: Correlation matrix between biomass, grazing value and hemicryptophyte traits.

	Biovolume	Density	ContactFreq	GrazValue	ContriProdu
Density	0.87				
ContactFreq	0.79	0.74			
GrazValue	NS	0.52	0.91		
ContriProdu	0.58	0.63	0.54	0.75	
Biomass	0.81	0.56	0.42	NS	0.97

Biovolume = Hemicryptophyte biovolume; Density = Hemicryptophyte density; ContactFreq = Hemicryptophyte contact frequency; GrazValue = Grassland Grazing value; ContriProdu = Hemicryptophyte contribution to biomass; Biomass = Grassland total biomass production.



Ap = Protected area; B = Buffer zone; C = Communal land; SS= Shrub savanna; TS = Tree savanna and WL = Woodland. Asterisks on the figure showed significant differences between hemicryptohyte density; *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$.

Figure 1: Hemicryptophyte density across the different land use types.

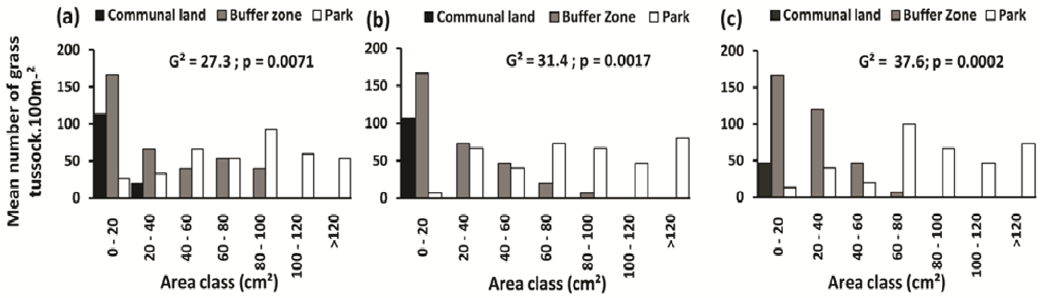


Figure 2: Size class distribution of hemicryptopyte tussocks among land use.

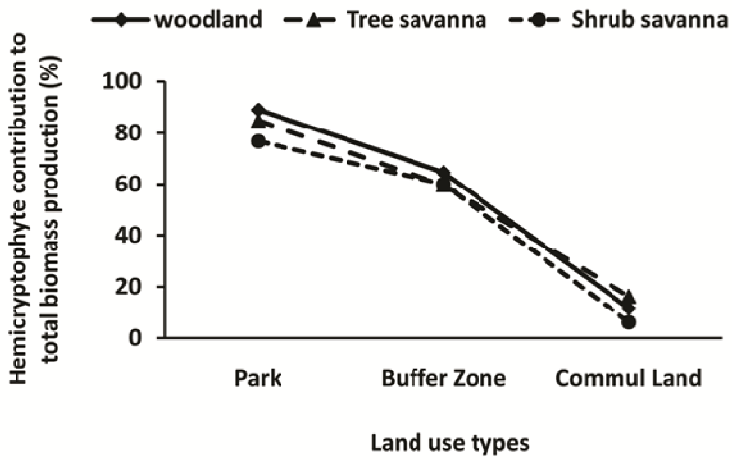


Figure 3: Hemicryptophytes contribution to total biomass production.

DISCUSSION

Sustainable management and conservation of pastures are regarded as an important ecological issue in grassland management. In sub-Saharan Africa, livestock herders as well as grassland managers are facing daily degradation of pasture which results in reduction of the grassland productivity and the increasing rate of non palatable and invasive species. However, the early detection of the grassland degradation through an appropriate ecological alerts 'Indicator' could help in avoiding such degradation whose ecological costs of restoration may be very perilous and expensive. We therefore, determined hemicryptophyte patterns along a land use gradient in order to assess its effectiveness as indicator of grassland state in and around the W Biosphere Reserve. Findings showed that hemicryptophytes' traits (biovolume, density and area size class distribution of hemicryptopyte tussock) were significantly affected by land use types however the vegetation type. This result might be explained by the fact that disturbance occurring in the communal land involved important reduction of the perennial grasses as revealed by previous studies (Houessou, 2001; Nacoulma et al., 2011). Three main factors could be highlighted as factors affecting hemicryptophyte traits: soil tillage for crop production, grazing and trampling by cattle and fire. The soil ploughing for crop cultivation in communal lands is accompanied by the uprooting of the vegetative organs of the perennial grasses. Thus this situation may lead to decreasing of hemicryptophytes density in the communal land as their regeneration organs are mostly removed. Moreover the regular passage and trampling of livestock may limit the grass tussock regeneration and contributed to their progressive regression (Plumptre, 1993). As results, one assists to patches of bare soil in grassland, high occurrence of dicotyledons herbaceous species and an increasing rate of unpalatable species at the expense of perennial grasses preferentially sought after by cattle (Roques et al., 2001; Wigley et al., 2009). In addition to hemicryptophyte density reduction, regular and repetitive grazing of the grasslands in the communal lands might contribute to limiting the growth in height of the hemicryptophytes plant species. Indeed, in the communal land after repetitive season of grazing, hemicryptophytes appeared as affected in their development in height and cover. They are unable to reach their maximum height growth because of stress induced by the grazing pressure. This situation could explain the significant lower hemicryptophyte biovolume observed in the communal lands comparatively to the buffer zone and the protected area where stress induced by grazing might be low. One other hemicryptophyte trait affected by land use was the area size class distribution of the grass tussock. Findings also indicated that grass tussocks area distribution was mostly closed to the normality in the protected area and buffer zone while it was right skewed in the communal land. This suggests the presence of hemicryptophyte tussocks with relatively small size in the communal land comparatively to the protected area. Pressure on hemicryptophyte tussock induced by cattle trampling occurring in the communal land might result in fragmentation of the large tussocks in small ones or jeopardize the evolution of young tussocks to large tussock which are able to support a heavy animal capacity.

Although vegetation fires are seen as natural factors structuring savanna area for long times, its effects on grassland functional group had largely been discussed. The effect of fire on grassland functional group may depend on the fire regime (van Wilgen et al., 2007). Late fire application was found to jeopardize the perennial grasses development and consequently their productivity (Teka et al., 2011, Gittins et al., 2011). In contrast, early fire application in savanna was found to stimulate perennial grasses regeneration and impact positively in their productivity (Teka et al., 2011). In our study area, it is a common practice that villagers applied late fire in the communal land for various purposes while early fire is applied by managers to facilitate animal visibility for ecotourism and avoid the late fire which was thought to be destructive for vegetation (CENAGREF, 2004). In consequence, it is not surprising to find high contribution of hemicryptophytes to biomass production in the protected area where early fire are applied and low contribution of hemicryptophytes in the communal where late fire is common practice.

Grassland state indicators should allow informing on the current trend of investigated phenomenon and should help for designing future management actions to be done for sustainable natural resource use. Our results revealed that hemicryptophyte density, contact frequency and biovolume were positively correlated with grassland biomass production while hemicryptophytes contribution to biomass production was correlated with grazing value. We deduced that hemicryptophyte traits could be used as indicators for grassland productivity and quality state. Indeed when hemicryptophyte density or biovolume increase, the biomass production of the grassland is higher. In the same time, when the hemicryptophyte contribution to biomass production increase the grazing value of the grassland is higher. The relative importance of hemicryptophytes in the grassland may contribute to avoid wind and water erosion of topsoil reducing the risk of soil degradation. Thereof hemicryptophytes dominance in grassland may increase the stability and increase its resilience to degradation. Managers might then pay attention to hemicryptophytes trend in the grassland for its sustainable use. Hemicryptophytes decline may increase the risk of grassland exposure to degradation and similarly hemicryptophytes increase may increase stability and resilience of grassland.

Conclusion

This study highlights effects of land use types on hemicryptophyte traits. Hemcryptophytes may be use as relevant indicators to inform on the pressure faced by grasslands. Results from this study may be used by grassland managers who, once knowing hemicryptophyte density, biovolume, and contribution of hemicryptophytes to total biomass could get reliable information on the current and future productivities as well as on the available forage quality over time. Grassland managers will then be able to make technically feasible, ecologically sustainable and economically profitable decisions. Integration of the different types of hemicryptophytes (i.e. "basiphylous" and "cauliphylous") in such a study may increase the effectiveness of hemicryptophytes as bio-indicator of trends in grasslands dynamics.

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