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Vegetation dynamics regulated by grazing and soil type in arid rangelands of Southern Tunisia

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Grazing and soil type are the main drivers of plant community composition and productivity in arid land. Thus, finding an optimal balance between rangelands production and grazing impact on different soils type is important for the development of sustainable grazing systems. The current study furnishes quantitative appraises of vegetation structure and the distribution of plant communities in arid rangeland in relation to the soil type and grazing pressure. Factors affecting the species distribution and correlation between vegetation and soil type are discussed. These rangelands lie mostly on sandy, loamy, gravelly and limestone soils, and is dominated with steppe vegetation, mainly Hammada scoparia, Helianthemum kahiricum, Gymnocarpos decander, Anthyllis sericea, Stipagrostis pungens, Hammada schmittiana and Pennisetum dichotomum. In this arid land, vegetation dynamic varied significantly with grazing pressure. Grazing can reduce plant cover from 61 to 40%, Shannon-Wiener diversity index decrease from 2.63 to 0.95 and productivity was decreased from 210 to 85 Kg DM.ha\(^{-1}\).year\(^{-1}\). The magnitude of this pressure can be seen with soil type. The sandy and gravelly soils was more diversified and high more productive than limestone and loamy soil, whereas the latter were more resistant to grazing. Whereas, consumption rates of primary production by livestock was 60% on sandy soil but it does not exceed 1% on loamy soil.

Key words: Plant communities, grazing, soils type, arid zone, Tunisia.

INTRODUCTION

Landscapes of the Mediterranean region are characterized by a heterogeneous and dynamic mosaic of vegetation formations that provide diverse benefits: agropastoral products, ecosystem services, and other utilities (Koniak et al., 2009). Because livestock is the major user of primary production in arid and semi-arid regions, degradation has always been attributed to this sector (Sidahmed and Yazman, 1994). In recent times grazing by domestic herbivores, especially sheep, has had a very strong influence on the soil and vegetation. Land use change can exert a profound influence on soil and environment (Zhao et al., 2005, 2007). The combined action of these factors (grazing, clearing) is indicative of a decrease affecting the main biomass production, a shortage of the best palatable species and a proliferation of less palatable ubiquitous species (Waechter, 1982; Aidoud and Aidoud, 1991). While high spatial variability of rainfall characterizes arid regions (Noy-Meir, 1981; Dean and Milton, 1999), according to Le Houérou (1996); direct causes of land degradation in the arid sectors come from reduction of perennial species cover and ongoing simplification of vegetation structure accompanied with several serious consequences on productivity, soil structure, relationships between water and microclimate. The fodder production of plant communities, encountered in steppic zones, is variable depending on years and particularly on rainfall efficiency coefficient, the latter is frequently weak in the presaharian bioclimate (Le Houérou and Hoste, 1977; Le Houérou, 1982). These potentialities drop off an average of 20 FU/ha/year and can reach more than 50 FU/ha/year in some areas situated in depressions and stony pastures. In terms of charge, the mentioned units hold up at present a number of species which exceeds gently a normal year optimum. The resistance of floristic richness against herbivores pressure was proved through the manipulation of species diversity (Lanta, 2007). Nevertheless, the sustainable
maintain of these natural resources needs controlling desertification and land degradation (Gannry et al., 1995). Land management, used to date and were applied principally to degraded ecosystems, in order to improve nature conservation and management efficiency (Moreira et al., 2006).

In arid lands steppes, the floristic composition is dominated by therophytes and small long-lived species; also called transitory or arido-passives, Noy Meir (Noy Meir, 1973; Evenari, 1985) due to their summer physiological dormancy. The phytosociological studies realized in steppic environments have defined phytocenose, the composition of which was significantly individualized and relatively stable according to environment and steppes type (Le Houérou, 1959, 1969).

Several results concerning the natural vegetation and its relationships to protection, soil, and human use have previously been published (Floret and Pontanier, 1978; Floret et al., 1978, Gamoun et al., 2010ab, 2011, 2012ab). Whole of these results, to in particular those dealing with vegetation dynamics, describe a step towards a predictive approach to rangeland management based on ecosystem-structure and function can be very useful in the context of the rangeland management after a period of drought (Gamoun et al., 2012c). In the current paper we elucidate the relationship between species richness and plant productivity.

We asked the following questions: (1) what is the distribution of vegetation according to soil type? (2) What is the impact of grazing on vegetation? (3) What is the species richness-productivity relationship in these arid rangelands? (4) are rapid (species richness) assessments good indicators for productivity?

**MATERIALS AND METHODS**

**Study area**

Our study is localized in southern Tunisia. The studied area extends over 2000 ha of arid steppes (elevation ~ 402 - 450 at 33° 00’ 28 08”N and 10° 05‘ 24 11”E). The climate is characterized by hot dry summers and cool mild winters. It belongs actually to the Saharan superior mediterranean bioclimate according to Emberger (1954).

The mean annual rainfall during 1987-2007 is, with large interannual fluctuations. Drought cycles occur frequently, often broken by significant rainfall.

The vegetation measurements presented here taken in March 2007 and in September 2007, that is, the first measurement was taken during protection (March 2007), the other measurement was taken after protection (September 2007). Therefore, the objectives of our study were to determine the behaviour of dry land vegetation after the introduction of a heavy grazing regime during short grazing periods for four soil type.

Four parameters related to vegetation were analyzed before and after grazing: (1) plant cover; (2) diversity; (3) species richness; and (4) productivity.

At each soil type, vegetation was sampled along three permanent linear transect. In each measurement, the vegetation was surveyed using the permanent transect method (Daget and Poissonet, 1971). Species frequency and cover was measured for each sample by noting presence-absence at 100 point-quadrats, at 20 cm intervals along the 20 m long transect. The vegetation cover was calculated as follow:

\[ R = (n/N)\times100 \]

where \( R \) is the percentage abundance of species, \( n \) the number of species present, and \( N \) the number of quadrats sampled.

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\[ H' = \log \frac{S}{S-1} \]

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\[ R = \frac{n}{N} \times 100 \]

With \( f_i \) the number of i species in the samples, and \( N \) the overall number of species.

\[ H' = \frac{\text{Shannon's index of diversity}}{\text{Shannon, 1948}} \]

\[ H' \text{ varies between:} \]

- \( H' = 0 \), where the population consists of a single specie;
- \( H' = \text{log}_2 S \), where the existing species have an equivalent abundance.

To determine aboveground plant community productivity, three sub-samples of 2 x 2 m quadrant were taken in each soil type. Fresh consumable vegetation parts of the encountered plant species was cut and dried at 70°C for

**Methods**

Experiments were located on a 3-year-old enclosure of a native rangelands community (2000 ha). We selected this enclosure because it is one of the few sites in the region resembling the protected natural rangelands which was then subjected to intensive grazing by 1700 sheep during two months (July and August). The studied vegetation was made up of four soil type being protected from grazing since three years.

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Figure 1. The mean (±SE) relative cover of each soil type on before and after grazed rangeland. Cover is significantly different among soil types and grazing (P < 0.001).

48 h and weighed.

Statistical analyses

Effects of grazing on cover, species richness, diversity and productivity for four functional groups were analyzed with two-way ANOVA with an experimental wise error of 0.05. Significant differences for all statistical tests were evaluated at the level of P ≤ 0.05. The analysis of correlation elaborated with Pearson’s bivariate was used to examine interaction among the variables. All data analyses were conducted with the SPSS 16.0.

RESULTS

Plant cover

Regarding cover, statistically significant effects of treatment were found (F = 1087.736; P < 0.001; df = 1) with observed higher values were reported for protected area (mean = 61%) and lower values were observed in grazed area (mean = 40.25%). There were also significant effect that was occurred for soil type (F = 341.912; P < 0.001; df = 3) with higher value on sandy soil (mean = 61%) followed by gravelly soil (mean = 59.67%) then the limestone soil (mean = 44.67%) and finally loamy soil (mean = 37.17%). For plan cover, there was also a statistically significant treatment*soil type interaction (F = 44.368; P < 0.001; df = 3).

In the protected area, the rate covers is more important on the sandy soil (mean = 76.66%) followed by gravelly soil (mean = 68.33%) then the limestone soil (mean = 50.33%) and finally loamy soil (mean = 48.33%). On the other hand after grazing the rate covers remain more important on the gravelly soil (mean = 50.66%) followed by sandy soil (mean = 46.33%) then the limestone soil (mean = 39%) and finally loamy soil (mean = 26%) (Figure 1).

Floristic diversity

Shannon-Wiener diversity index was significantly affected by grazing pressure (F = 952.901; P < 0.001; df = 1). Protected area had higher diversity index values (mean = 2.63) as compared to the grazed area (mean = 0.95). Likewise, Shannon-Wiener diversity index was significantly affected by soil type (F = 96.193; P < 0.001; df = 3) with the highest value on sandy soil (mean = 2.285) followed by gravelly soil (mean = 1.985) then the limestone soil (mean = 1.853) and afterward loamy soil (mean = 1.036). Interaction between these two factors (treatment*soil type) had an effect on Shannon-Wiener diversity (F = 8.605; P < 0.001; df = 3). Under protection, vegetation is most diversified on sandy soil with 3.226 followed by gravelly soil with 2.965 then the limestone soil (mean = 2.667) and finally loamy soil (mean = 1.662). This diversity decreases with grazing more than 60% (Figure 2).

Plant species composition

Figure 3 summarizes the species composition during before and after grazing. The species composition differed greatly according to the different soils and grazing. Significant differences between protected and grazed areas were detected, in the same way significant
The effect of soil type on the species richness was revealed. The species richness strongly decreased under grazing treatment. The most remarkable result was the increase of annual species that become null on the limestone soil and on loamy soil. Under protection the annuals was more important on sandy, gravelly and limestone soil than on the loamy soil.

The number of species declined significantly with grazing pressure, whereas, the annual species was almost completely disappeared and only the perennial ones remain. This is strongly explained by the non significant effect of grazing on perennial richness ($P > 0.05$) (Figure 3).

**Productivity**

Productivity was significantly affected by grazing pressure, ($F = 22147.147; P < 0.001; df = 1$). Our results showed that fencing improved productivity (mean = 210 kg DM.ha$^{-1}$.year$^{-1}$). In contract, grazing can reduce productivity (mean = 85 Kg DM.ha$^{-1}$.year$^{-1}$). There were also significant effects of soil type ($F = 32629.656; P < 0.001; df = 3$) with a higher mean for sandy soil (mean = 287 Kg DM.ha$^{-1}$.year$^{-1}$) than the gravelly soil (mean = 272 Kg DM.ha$^{-1}$.year$^{-1}$) then the limestone soil (mean = 24 Kg DM.ha$^{-1}$.year$^{-1}$) and finally loamy soil (mean = 9 Kg DM.ha$^{-1}$.year$^{-1}$). Interactions between the two effects

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*Figure 2. Mean (±SE) of diversity (H') of the four soils types of the Southern Tunisia according to grazing. The effect of soil type and grazing are highly significant ($P < 0.05$).*

*Figure 3. Variability of plant species richness of four soils types in southern Tunisia according to grazing treatment ($P < 0.05$).*
were significant: soil and treatment (F = 7223.016; P < 0.001; df = 3). Before grazing in the protected area the productivity is more important on sandy soil with 407 Kg DM.ha⁻¹.year⁻¹, with 400 Kg DM.ha⁻¹.year⁻¹ on gravelly soil, low on limestone soil 24.666 and lowest on loamy soil. This productivity decrease with grazing, this reduction reached 65% on sandy soil, 68% on gravelly soil, 16% on limestone soil and only 10% on loamy soil. Figure 4 show that fencing improves primary production by excluding grazing.

**Relationship between productivity and species richness**

Most authors agree that diversity is influenced by productivity (Huston, 1997; Tilman et al., 1996). Conversely, the number of species influences productivity is also more general. While there is evidence that species richness is important for maintaining ecosystem functioning, it is obvious to observe a linear relationship between species richness and productivity (r² = 0.818; P=0.0001) (Figure 5). When species richness is low, increased species richness is accompanied by increased productivity.

Regarding at each soil type, Figure 6 show a significant linear relationship between species richness and productivity on sandy soil (r² = 0.991; P < 0.001) and on the gravelly soil (r² = 0.973; P < 0.001). There were no significant difference between species richness and productivity on limestone soil and loamy soil, significant (r² = 0.342; P = 0.505 and r² = 0.461; P = 0.359 respectively). Productivity all tended to increase with
species richness, both with and without grazing. Thus, in the ungrazed rangelands the correlation is more significant than grazed rangelands ($r^2 = 0.763$; $P < 0.001$ and $r^2 = 0.505$; $P = 0.01$ respectively) (Figure 7).

**DISCUSSION**

Several authors view heavy grazing as the major cause of rangelands degradation in southern Tunisia (Le Houérou, 2001; Jauffret and Lavorel, 2003). Whereas, as it was indicated by Whitford (2002), the most important factor affecting the structure of vegetation in an ecosystem is soil. This distribution of plant communities in our rangelands seems to reflect the combined influence of grazing and soils type. Vegetation is sparsely distributed in space resulting in a heterogeneous horizontal pattern of vegetation patches alternating with areas of bare soil (Noy-Meir, 1973).

Our study has demonstrated significant relationships between grazing intensity and soil type in arid lands. These results were demonstrated by previous studies in the southern Tunisia (Floret and Pontanier, 1982; Gamoun et al., 2010ab, 2011, 2012a).

Two months of livestock grazing significantly decreased cover, species richness, diversity and primary production.
of four plants community types. Additionally, there is a significant difference for cover, species richness, diversity and primary production among the four soil types.

Our results suggest that, under protection, the maximum cover, diversity, species richness and productivity are reached on sandy and gravelly soil. On these soils, the considerable heterogeneity of the substrate determines the coexistence of a larger number of species than on the other two soil type (limestone and loamy soil). From the special point of view, the productivity obtained for the various studied rangelands are very variable. Indeed, one notice that the best productivity is recorded for the rangelands of the sandy and those of the gravelly soil, with values exceeding 40 times more those of the other soil types. It can be explained by that in deep sandy and gravelly soils, water percolates deeper into the ground following rainfall than in loamy and limestone soil, where water is trapped close to the soil surface. Thus, less rainfall is required on the latter substrate to facilitate germination of seeds following heavy grazing.

As a group, annual species were most abundant in the sandy soil, locations with intermediate amounts of available water. They were least abundant in limestone and loamy soil with the least available water.

Our experiment demonstrated that grazing by livestock introduction had significant effect on decreased of cover vegetation, species richness, diversity and productivity. This vegetation structure was mainly due to soil structure (Noy-Meir, 1981; Le Houérou, 1993). As under protection, they were more important on sandy and gravelly soils that on the others soil types. Our results show that the relationship between grazing system and rangelands function is an example of a high-complexity problem. In both cases the vegetation structures are important on sandy and gravelly soils and it was very weak on loamy and limestone soils, but the consumption rates differ between soils types. Heavy grazing can affect the structure and organization of vegetation in different ways (Noy-Meir et al., 1989). One estimate of consumption rates of primary production by livestock was 60% on sandy soil but it does not exceed 1% on loamy soil. High consumption rates have resulted in loss of vegetation cover. In improved rangelands, most grazing animals are selective, and some plants are not palatable or are only eaten when at their most tender in early growth stages. Otherwise, grazing acts on rangelands structure and ecosystem processes by imposing selective pressure on vegetation quantity and quality. Species diversity of the annual plants, which are the keystone-process species, is much higher than species diversity of the ecosystem-resilience component the shrubs. It may be related to the selective pressure on the vegetation due to thousands of years of human activity and livestock grazing (Perevolotsky, 1999).

Also, animals’ selection between species depends on soil types. 17 species were completely grazed in sandy soil, 12 species in the gravelly soil, 9 species in limestone soil and 7 species in loamy soil. The majority of these species are annuals with some perennial such as *Echiochilon fruticosum* Desf., *Nolletia chrysocomoides* (Desf.) Cass. ex Less. and *Stipagrostis ciliata* (Desf.) de Winter, who are more available on sandy soil. Thus, grazing is essential to the maintenance of perennials species. At all sites, under grazed conditions, the vegetation was dominated by a perennials species, these species, are generally present in the ungrazed rangelands. These perennials species may have benefited from an adaptation caused by drought and grazing. The absence of perennial species such as *Echiochilon fruticosum*, *Nolletia chrysocomoides* and *Stipagrostis ciliata* is due to their high palatability. On the other hand, they may have suffered from grazing, and that sandy and gravelly soils also suffer from trampling and grazing. Otherwise, on good condition grazing land, there is a greater variety of plant species available for selective grazing and that grazing animals are highly selective when given the opportunity. Thus we can say that the positive manipulation of the soil-forage plant-grazing animal complex is a central role of the grazing manager.

Land use affected the relationship between species richness and productivity (Zhou et al., 2006). In our results the relationship between species richness and productivity was more significant within the enclosure and less significant within grazed area. Moreover, the relationship between species richness and productivity showed a positive trend on sandy and gravelly soil and no trend within loamy and limestone soils. They show that assumptions about the grazing and soil type of variance to the mean abundance of a species can affect the relationship between the species diversity and productivity.

**Conclusion**

The interactions between soil types and domestic grazers are examined and discussed in this paper, with particular focus on the sustainable management of both the rangelands and the livestock.

In arid land it is useful to say that edaphic factor availability strongly determines vegetation. Soil type has been found to limit arid plant dynamics within rangelands by affecting grazing regimes. Each soil type is characterized by specific vegetation. Range production, cover and species richness are low and most irregular in the arid zones, and always spatially limited to sandy and gravelly soils. This richness is primarily due to the fact that the sandy and gravelly soils constitute a favorable medium.

The introduction of herbivores is generally believed to reduce plant diversity. Selective grazing by livestock has shown large effects on plant diversity and species
composition in arid ecosystems. The heavy grazing of natural rangelands leads to loss of several highly palatable species. However, the soil type has influences on response to grazing. Vegetation on sandy and gravelly soils was more diversified and more productive than the limestone and loamy soil, whereas the latter was more adapted to grazing pressure. On the whole, grazing caused a spatial homogenization of the plant community in areas with predominance of chamaephytes.

In this study we found that species richness was an adequate predictor to productivity, and that the relationship between species richness and productivity were dependant to soil type. Overall, we found that productivity increases linearly with increasing species richness. It was suggest that the relationship between species richness and productivity showed a positive trend on sandy and gravelly soils. In opposition, species richness was not correlated with productivity on loamy and limestone soils.

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