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# Aboveground biomass and concentration of nutrients in semiarid rangeland plant species: Influence of grazing and soil moisture

## Biomasa aérea y concentración de nutrientes en especies de pastizales naturales: Influencia del pastoreo y la humedad del suelo

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**Abstract.** Spatial and temporal patterns of aboveground biomass and nutritive value of rangeland species with respect to the influence of grazing and soil moisture were investigated. The research was conducted during two years at the Tomagh Research Station, near Sanjawi, Ziarat District, Balochistan, Pakistan. This area is protected from grazing since 1998; however, some of the area is open for grazing. Three sites were selected for research purposes: a protected plain, a protected hilly, and an unprotected plain grazed area. Sampling was carried out during the spring, summer and autumn seasons. Results revealed that soil moisture was greater at the protected than unprotected sites. The aboveground plant biomass was 66% to 76% lower at unprotected than protected sites. The biomass of annual plant species was nearly 0 at grazed sites. Species differed in their nutrient concentrations, but these were similar among protected and unprotected grazed areas. Our findings indicate lower nutrient use efficiency at grazed than ungrazed, protected sites. Eleven years of protection from grazing increased significantly plant biomass, enhanced their nutrient use efficiency and allowed growth of annual plant species.

**Keywords:** Rangeland; Biomass production; Season; Semiarid; Grazing; Grass.

**Resumen.** Se investigaron los modelos temporal y espacial de la biomasa aérea y el valor nutritivo de especies vegetales de pastizales naturales con respecto a la influencia del pastoreo y el contenido de agua del suelo. La investigación se condujo durante dos años en la Estación de Investigación Tomagh, cerca de Sanjawi, Distrito de Ziarat, Balochistan, Pakistan. Esta área está protegida del pastoreo desde 1998; sin embargo, parte del area es pastoreada. Se seleccionaron tres sitios con propósitos de investigación: dos sitios protegidos (planicie o zona de colinas), y un sitio no protegido, pastoreado. El muestreo se efectuó durante la primavera, y el verano y otoño. Los resultados revelaron que la humedad del suelo fue mayor en los sitios protegidos que en aquellos no protegidos. La biomasa vegetal aérea fue 66 a 76% más baja en los sitios no protegidos que en aquellos protegidos. La biomasa de las especies anuales fue cercana a cero en los sitios pastoreados. Las especies difirieron en sus concentraciones de nutrientes, pero estas fueron similares entre sitios protegidos y aquellos pastoreados, no protegidos. Nuestros resultados indican una menor eficiencia en el uso de nutrientes en los sitios pastoreados que en aquellos no pastoreados, protegidos. Once años de protección del pastoreo incrementaron significativamente la biomasa vegetal, mejoraron su eficiencia de uso de nutrientes y permitieron el crecimiento de especies anuales.

**Palabras clave:** Pastizales naturales; Producción de biomasa; Estación: Semiárido; Pastoreo; Gramínea.

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# INTRODUCTION

Rangelands provide many supporting, regulative and provisioning ecosystem services to mankind such as environmental health (carbon and nitrogen sequestration), recreation, livelihood, clean water, medicinal plants, etc. (Millennium Ecosystem Assessment, 2005; Teague et al., 2009; Bedunah & Angerer, 2012; Onatibia et al., 2015; Reed et al., 2015). Arid and semiarid rangelands cover ~41% of the world's land area, and support livelihood of approximately 2 billion people (Middleton et al., 2011). Rangelands are grazed by both domestic livestock and wildlife animals, and provide approximately 90% of the total feed requirements to sheep and goats; 40% to donkeys, camels, horses and mules (pack animals), and 5% to cattle and buffalo (Baloch & Tanik, 2008). However, extensive rangeland utilization for grazing purposes has determined serious threats to their degradation (Millennium Ecosystem Assessment, 2005; Bedunah and Angerer, 2012).

Above-ground plant biomass is an important indicator of rangeland productivity, and soil moisture plays an important role in the variation of biomass production in arid and semiarid rangelands (Ward et al., 2004; Yang et al., 2009; He, 2014). The interaction of heavy grazing and soil moisture hence can result in significant reductions in plant biomass production (Busso & Richards, 1995; Asner et al., 2004; Wessels et al., 2007). Moreover, since heavy grazing cause reduction in nutrient contents in soil of arid and semiarid rangelands (Xu et al., 2014), this factor may reduce the availability of nutrients to plants (Onatibia et al., 2015).

Balochistan is the largest province of Pakistan, and 93% of this area is classified as arid and semiarid rangelands, which provide ~87% livelihood to human population (Ahmad & Islam, 2011). The assessment of the interactive effects of heavy grazing and rainfall patterns on aboveground biomass and nutrient concentration of plant tissues is vital to get an insight into the productivity of these rangelands. This study aimed to evaluate the soil moisture contents, aboveground plant biomass production and concentration of nutrients [i.e., nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca)] of rangeland plant species in grazed and protected sites of the Tomagh research station at Balochistan, Pakistan.

# MATERIALS AND METHODS

**Study area.** The study was conducted at the Tomagh Range & Livestock Research Station of Arid Zone Research Centre, Quetta. The station is located near Sanjawi, Ziarat District (30° 15' 44.4" N, 68° 27' 38.36" E, 1800 m.a.s.l.). The site has a Mediterranean climate. Winters are cold at the higher altitudes, with temperatures frequently below freezing, from mid-November to the end of February. Summers are hot and usually dry. Winter rains are dominant while monsoon rains are occasional, but they provide enough moisture for vegetation and extend the vegetative growth of the grasses. Long-term average annual rainfall is 250 mm with great inter- and intra-seasonal variation (Fig. 1). Mean maximum and minimum temperatures are 32 °C and 1 °C, respectively. Dominant vegetation of the area includes *Cymbopogon jwarancusa* (Jones), *Chrysopogon aucheri* (Boiss), *Tetrapogon villosa*, *Saccharum grifithii, Poa bulbosa, Ephedra intermedia, Salvia cabulica, Convolvulus spinosus, Prunus eburnean, Perowskia atriplicifoli., Bromus tectorum, Artemisia quettensis, Astragalus stocksii, Caragana ambigua,*

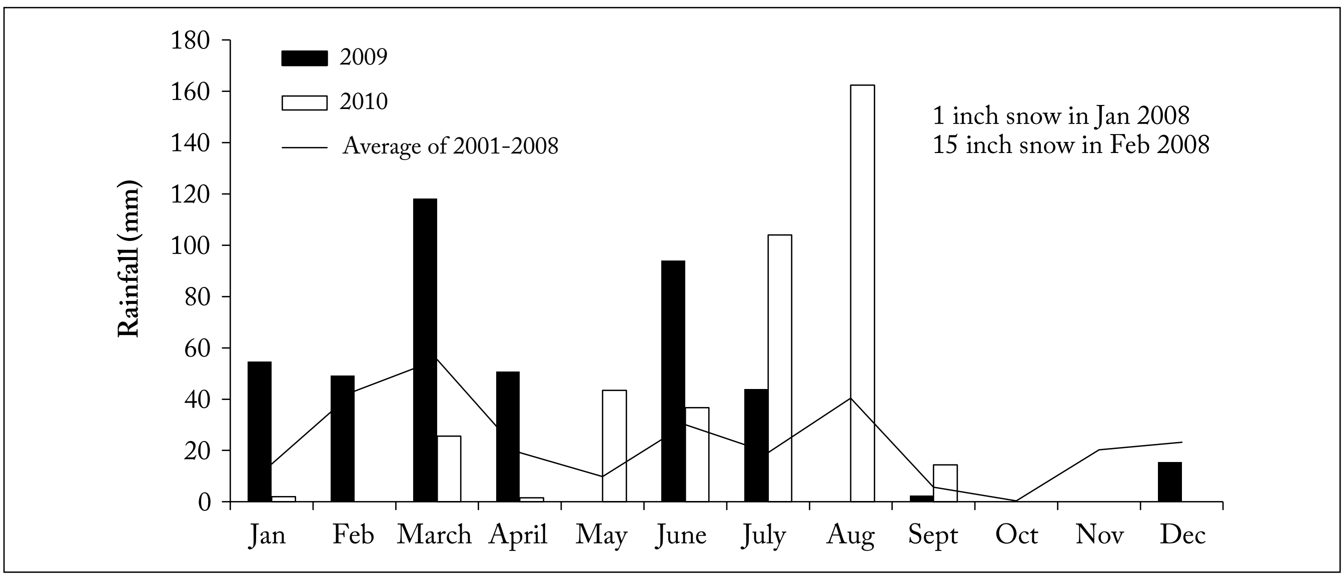


Fig. 1. Annual precipitation during 2009 and 2010 at the experimental site.
Fig. 1. Precipitación annual durante 2009 y 2010 en el sitio experimental.

*Ferula oopoda, Ferula costata, Sophora mollis*, *Ebenus stellata, Pistacia khinjak* and *Fraxinus xanthoxyloides*. Soil is loamy to clay loam with an average of 20.8% clay (± SD 8.3, n=6), 36.6 % silt (± SD 5.2, n=6) and 42.5% sand (± SD 6.3, n=6; data unpublished). Some of the area is protected from grazing since 1998.

**Biomass collection.** Total aboveground biomass was collected from three sites (Grazed, un-grazed and top of the hill) during spring, summer and autumn in 2009 and 2010. Four 1x5 m plots were established at regular intervals along a 35 m transect line at each study site. Whole aerial parts of plants were collected to ground level from those plots. The plant biomass samples were dried in oven at 60 ˚C for at least 48 h for constant weight and then weighed to estimate dry-matter (DM).

**Chemical analysis.** Leaves of grasses, shrubs and trees were collected from 10-15 individuals of each species from those plots, dried at 70 ˚C for 24 hours and finely ground using a ball mill. Laboratory analyses of the dried plant material included colorimetric assays of total N and P (Keeney & Nelson, 1982; Murphy & Riley, 1962) after Kjeldahl digestion. The same digest was used for the analysis of Na, K, Mg and Ca via atomic absorption spectrophotometry as described by Adams & Attiwill (1986).

**Soil moisture analysis.** Soil samples at two depths (0-10 cm and 10-20 cm) were also collected from each established block at three different places during the experiment for the determination of soil moisture content by the gravimetric method (Brown, 1995).

**Statistical analysis.** Prior to analysis of biomass production data, they were subjected to normal distribution assessment with the Shapiro-Wilk test. Differences between treatment means (biomass production in the protected either plains or hills, or grazed sites) and interactions between location, season and year were analyzed with three way ANOVA by using PROC GLM function of SAS statistical software (SAS Institute Inc. 2009). The relationship between soil moisture and aboveground biomass production was based on average values over the entire sampling season. The data for nutrient concentrations were subjected to descriptive statistics.

## RESULTS

The patterns of soil moisture content followed those of precipitation/rainfall patterns (Fig. 1, Fig. 2 a and b). The total biomass production in the two seasons sampled was significantly higher in protected than grazed areas (Fig 3). The interaction between treatments and sampling dates was significant for biomass production (Table 1). In both years, total biomass

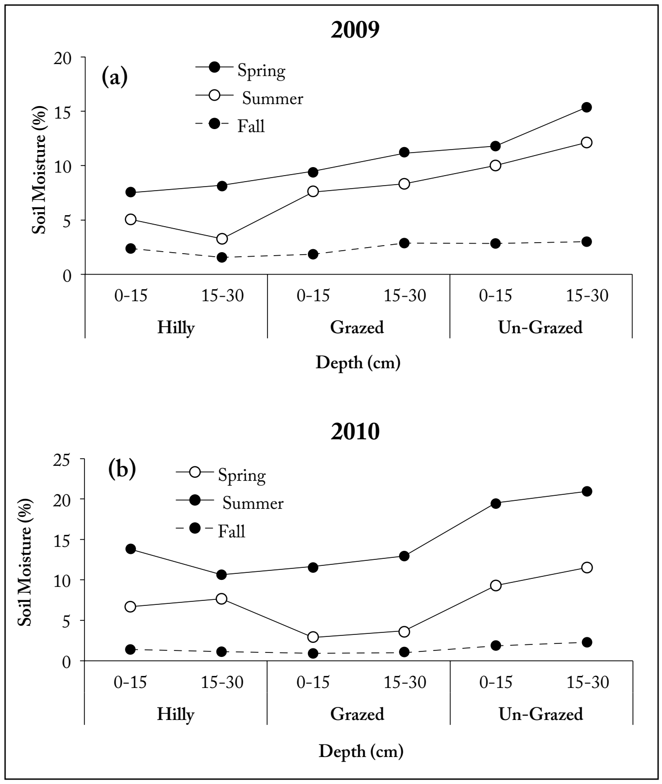


Fig. 2. Soil moisture contents at grazed, un-grazed and hilly sampling areas at 0-15 and 15-30 cm soil depth during (a) 2009 and (b) 2010.

Fig. 2. Contenidos de humedad del suelo en las áreas pastoreadas, no pastoreadas y colinas a 0-15 y 15-30 cm de profundidad desde la superficie del suelo durante (a) 2009 y (b) 2010.

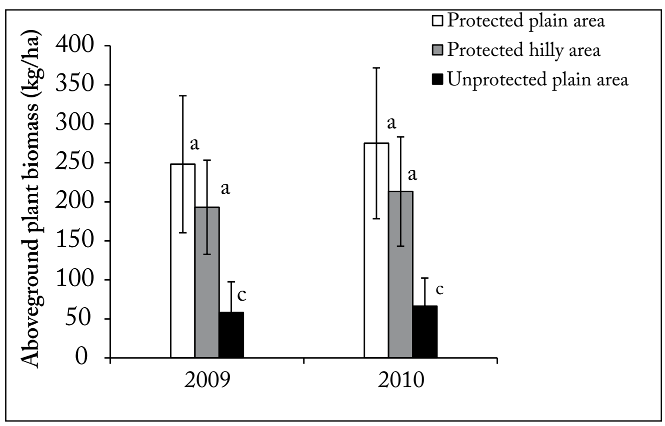


Fig. 3. Biomass production during the spring, summer and fall seasons in 2009 and 2010 at the protected plain, protected hilly and unprotected plain areas. Values are averages ± SD (n=4). Bars with different letters within either 2009 or 2010 are significantly different at P<0.05.

Fig. 3. Producción de biomasa durante la primavera, verano y otoño en 2009 y 2010 en las áreas de planicie y colinas protegidas, y de planicie pastoreadas. Los valores son promedio ± 1 D.S. de n=4. Los histogramas con letras diferentes en 2009 ó 2010 son significativamente diferentes a P<0,05.

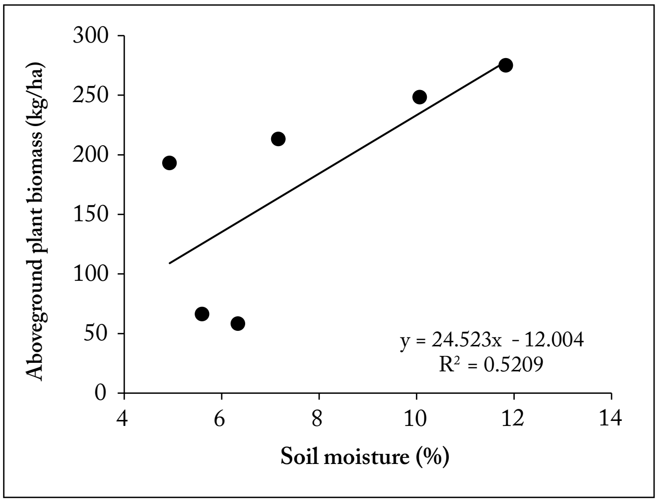


Fig. 4. Regression between aboveground plant biomass production and soil moisture content. Each symbol is the mean of n=4.
Fig. 4. Regresión entre la producción aérea de biomasa y el contenido de humedad del suelo. Cada símbolo es el promedio de n=4.

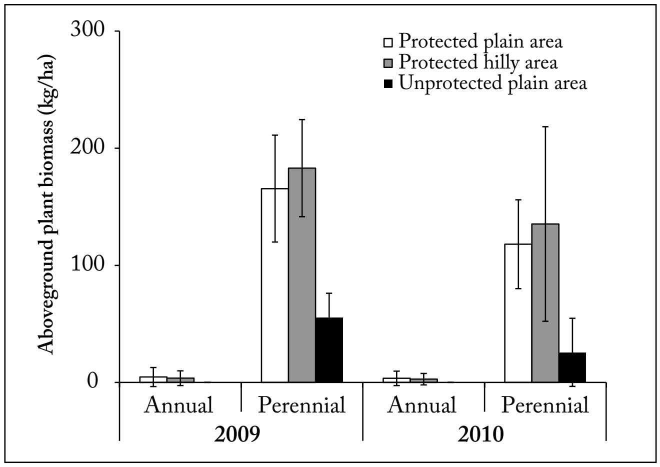


Fig 5. Biomass production (kg/ha) of annuals and perennial plant species at the protected plain and hilly sites, and the unprotected plain sites. Histograms are averages ± SD of n=4 during spring, summer and fall in 2009 and 2010.
Fig. 5. Producción de biomasa (kg/ha) de especies vegetales anuales y perennes en los sitios protegidos de planicie y colinas, y en los sitios de planicie no protegidos del pastoreo. Los histogramas son promedio ± 1 D.E. de n=4 durante la primavera, el verano y otoño en 2009 y 2010.

Table 1. Summary of analysis of variance of aboveground biomass production.
Tabla 1. Análisis de varianza de la producción de biomasa aérea.

| Source | Degrees of freedom | Sum of Squares | Mean Square | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 6508.700 | 2169.567 | 3.5881 | 0.0198 |
| Factor A | 2 | 503950.509 | 251975.254 | 416.7196 | 0.0000* |
| Factor B | 2 | 195380.106 | 97690.053 | 161.5609 | 0.0000* |
| AB | 4 | 46606.700 | 11651.675 | 19.2697 | 0.0000 |
| Factor C | 1 | 6060.730 | 6060.730 | 10.0233 | 0.0026* |
| AC | 2 | 1094.691 | 547.346 | 0.9052 | NS |
| BC | 2 | 31921.165 | 15960.582 | 26.3958 | 0.0000* |
| ABC | 4 | 1647.591 | 411.898 | 0.6812 | NS |
| Error | 51 | 30837.853 | 604.664 | | |

Values with * are significant at P≤0.05; NS represents non-significant results at P≥0.05. A: Location, B: Season, C: Year.
Los valores con * son significativos a P≤0,05; NS representa resultados no significativos a P≥0,05. A: Tratamientos, B: Estación de crecimiento, C: Año.

production was significantly different between treatments (df = 2 F= 416.7196; P=0.000) and within the study season (df=2, F=161.5609, P=0.000, Table 1). There was a positive linear regression between aboveground plant biomass production and soil moisture content (Fig. 4).

The perennial grasses showed the major contribution to above ground biomass production, while the biomass of annual plants was negligible (Fig. 5).

Analysis of nutrients in aboveground plant biomass revealed high variability among species (Table 2).

# DISCUSSION

Grazing reduced the total biomass production of plants at the Tomagh semiarid rangeland. The soil moisture content was also low at the grazed site, and it displayed a positive relation with aboveground plant biomass production. This study provides an important indication that plant biomass is an important factor in maintaining soil moisture content, which helps to increase their growth. Although not quantified experimentally in this study, the possible explanation for high soil moisture contents in protected sites is a lower wa-

Table 2. Concentration of nitrogen and phosphorus (µg/g oven dry weight), and potassium, magnesium and calcium (% oven dry weight) in the foliage of perennial shrubs, and perennial and annual grasses at the study treatments (un-grazed, hilly or grazed sites). Each value is the mean ± S.D. of n=10-15.
Tabla 2. Concentración de nitrógeno y fósforo (µg/g peso seco en estufa), y de potasio, magnesio y calcio (% peso seco en estufa) en el follaje de arbustos perennes, y gramíneas anuales y perennes en los tratamientos estudiados (No pastoreado, zonas de colinas y sitios pastoreados). Cada valor es el promedio ± 1.D.S. de n=10-15.

| Species | N | P | K | Mg | Ca |
|---|---|---|---|---|---|
| ***Un-Grazed*** | | | | | |
| *Caragana ambigva* | 26.07 ± 3.5 | 1.52 ± 1.8 | 0.55 ± 2.1 | 0.20 ± 0.8 | 0.89 ± 0.5 |
| *Ephedra intermedia* | 11.21 ± 2.1 | 0.85 ± 2.1 | 0.34 ± 1.6 | 0.41 ± 1.1 | 2.48 ± 0.4 |
| *Salvia cabulica* | 22.75 ± 1.8 | 1.62 ± 2.1 | 0.54 ± 1.4 | 0.42 ± 0.4 | 4.41 ± 0.5 |
| *Prunus eburnea* | 17.68 ± 3.1 | 1.39 ± 1.4 | 0.59 ± 0,9 | 0.39 ± 0.6 | 1.22 ± 0.7 |
| *Convolvulus spinosus* | 17.33 ± 0.9 | 1.55 ± 1.3 | 0.34 ± 2.3 | 0.22 ± 0.6 | 1.42 ± 0.9 |
| *Perowskia atriplicifolia* | 21.35 ± 1.7 | 1.74 ± 2.1 | 0.44 ± 0.5 | 0.28 ± 0.7 | 0.53 ± 0.7 |
| *Bromus* spp | 12.79 ± 2.4 | 2.00 ± 1.6 | 0.27 ± 0.6 | 0.75 ± 0.2 | 1.32 ± 0.3 |
| *Poa bulbosa* | 14.01 ± 2.9 | 1.49 ± 1.9 | 0.22 ± 0.4 | 0.17 ± 0.3 | 3.26 ± 0.1 |
| *Chrysopogon auncheris* | 16.25 ± 2.6 | 2.20 ± 1.4 | 0.36 ± 0.2 | 0.13 ± 0.1 | 1.28 ± 0.3 |
| *Cymbopogan jwarancusa* | 15.68 ± 1.8 | 2.13 ± 3.1 | 0.24 ± 0.4 | 0.12 ± 0.3 | 0.68 ± 0.5 |
| ***Hilly*** | | | | | |
| *Caragana ambigva* | 24.28 ± 2.3 | 0.98 ± 0.4 | 0.45 ± 0.4 | 0.19 ± 1.4 | 0.65 ± 0.5 |
| *Ephedra intermedia* | 12.34 ± 2.8 | 0.78 ± 0.5 | 0.32 ± 0.2 | 0.34 ± 1.4 | 1.98 ± 0.5 |
| *Prunus eburnea* | 15.34 ± 1.9 | 1.12 ± 0.7 | 0.51 ± 0.5 | 0.33 ± 1.4 | 1.03 ± 0.6 |
| *Convolvulus spinosus* | 15.67 ± 1.5 | 1.08 ± 0.9 | 0.27 ± 0.3 | 0.18 ± 1.4 | 1.12 ± 0.2 |
| *Chrysopogon auncheris* | 13.23 ± 3.1 | 1.87 ± 0.6 | 0.32 ± 0.2 | 0.10 ± 1.4 | 1.11 ± 0.6 |
| *Cymbopogan jwarancusa* | 12.34 ± 2.3 | 1.67 ± 0.7 | 0.26 ± 0.1 | 0.09 ± 1.4 | 0.56 ± 0.2 |
| ***Grazed*** | | | | | |
| *Convolvulus spinosus* | 19.22 ± 1.4 | 1.23 ± 0.9 | 0.30 ± 0.1 | 0.22 ± 0.1 | 1.78 ± 0.9 |
| *Perowskia atriplicifolia* | 22.45 ± 2.8 | 1.45 ± 0.6 | 0.35 ± 0.4 | 0.28 ± 0.2 | 0.83 ± 0.4 |
| *Chrysopogon auncheris* | 18.34 ± 3.2 | 2.12 ± 1.3 | 0.34 ± 0.2 | 0.16 ± 0.2 | 1.78 ± 0.3 |
| *Cymbopogan jwarancusa* | 17.23 ± 2.9 | 1.98 ± 0.8 | 0.28 ± 0.2 | 0.14 ± 0.1 | 0.88 ± 0.3 |

ter evaporation at these sites. This might be due to more soil shading by the plant canopies (Harper, 1977), and a greater residue- and root-derived organic matter input to soil (e.g. Raiesi & Riahi, 2014), which increases soil aggregation (Gul et al., 2014a,b). There was also a negligible biomass of annual plants at the grazed site. This low biomass can cause a severe threat to their population existence at the grazed sites. The high biomass of annuals at the protected sites suggests that protection from grazing can provide an opportunity to these plants for sustaining their population in the community.

High variability in tissue nutrient concentration was found among plant species exposed to the different treatments. Factors such as soil texture (Gul et al., 2014a,b), climatic conditions (i.e. temperature, precipitation/rainfall pattern) and grazing intensity can contribute to the acquisition of nutrients by plants. Information about climatic conditions and soil texture at the research site were not mentioned in Onatibia et al. (2015), but these factors might help to explain the differences found in our study. Our findings also indicated that grazed plants replaced nutrients in greater amounts as compared to the other two sites, which shows their low nutrient use efficiency (NUE, defined as plant biomass concentration of nutrients: Zheng et al., 2013), while 11 years of protection from grazing caused increased NUE. Further studies are required to link the grazing-induced decreases in NUE of plants to soil quality such as organic matter contents, concentration of nutrients, pH and aggregation.

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