Hydro-physical responses of gypseous and non-gypseous soils to livestock grazing in a semi-arid region of NE Spain

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Abstract

Pasture productivity depends on soil hydro-physical properties, which in turn are deeply affected by livestock grazing. However, the comparative response of different soil types, and particularly gypseous soil types, to grazing has hardly been studied before. This paper compares the effect of grazing on the soil hydro-physical properties of silty gypseous (Gy) and non-gypseous (NGy) soils located in a semi-arid region (Middle Ebro Valley, NE Spain). Two different soil managements were selected: ungrazed natural shrubland (N) and grazed shrubland (GR) soils. The gypsum, $CaCO_3$ and organic matter content (OM), soil texture, soil bulk density (ρ_b), penetration resistance (PR), saturated sorptivity (S), hydraulic conductivity (K), and the water retention curve (WRC) for undisturbed soil samples from the 1-10 cm depth soil layer were measured. The ρ_b and PR in NGy soils were significantly higher than those observed in the Gy ones. Soil compaction due to grazing treatment tended to increase ρ_b and decrease the K and S values. While no differences in PR were observed in the Gy soils between grazing treatments, the PR measured in the NGy soils under GR was significantly higher than the corresponding values observed under N. Differences in K and S between GR and N treatments were only significant ($p < 0.05$) in NGy soils, where K and S values under the N treatment were almost four times greater than the corresponding values measured under GR. Overall, no differences in the WRCs were observed between soil types and grazing treatments. While the WRCs of NGy soils were not significantly affected by the grazing treatment, Gy soils under N treatment present a significantly higher level of soil macropores than under GR treatment. The hydro-physical features of Gy soils tended to be less affected by grazing than those of the NGy soils. These results suggest that livestock grazing, in both Gy and NGy soils, has a negative effect on the physical soil properties, which should be taken into account by land managers of these semi-arid regions where silty gypseous and non-gypseous areas coexist.

Keywords: Water retention curve (WRC); Penetration resistance (PR); Hydraulic conductivity; Soil water infiltration; Bulk density, Ungrazed natural shrubland, Grazed shrubland.

1. Introduction

In areas with a long tradition of livestock grazing, moderate grazing pressure is beneficial to preserve rangeland productivity and biodiversity (McNaughton, 1985; Milchunas et al., 1988; Montalvo et al., 1993). In addition, livestock can act as seed dispersal agents that reduce isolation between vegetation remnants in fragmented landscapes (Collins et al., 1998; Pueyo et al., 2008). Nevertheless, the negative effects of overgrazing are well documented, including loss of plant cover and soil degradation, which can ultimately lead to desertification in arid and semi-arid regions (Heady and Child, 1994; Hary et al., 1996; UNCCD, 1994). In such regions, maintaining a high vegetation cover is essential for soil conservation (Puigdefabregas and Mendizabal, 1998).

Reduction in pasture productivity in semi-arid areas is associated with water availability (McNaughton, 1979), and plant water absorption is mediated by the soil chemical and physical properties (Gijsman and Thomas, 1996). Degradation of the soil physical properties in rangelands depends on the soil texture, type of vegetation, and soil moisture at the time of grazing (Chanasyk and Naeth, 1995), and it is mainly associated with animal trampling (da Silva et al., 2003; Quiroga et al., 2009; Hoshino et al., 2009; Kumar et al., 2010). Soil compaction due to livestock trampling reduces the pore volume and the saturated hydraulic conductivity, and modifies the water-retention characteristics (Zhao et al., 2007; Krummelbein et al., 2009). However, these general results contrast with other studies, such as those obtained by Hoshino et al. (2009), who found that the water available to plants in the ungrazed areas of the Mongolian steppe grasslands was not significantly different from that measured in the grazed areas.

Gypsum content has a significant effect on the soil hydro-physical properties. Very high gypsum content in soils reduces soil aggregation and results in a cemented layer along the soil profile (Herrero and Boixadera, 2002), increases the irregularities in moisture distribution in the soil profile (Boyadgiev, 1974), and reduces the soil water infiltration rates (Poch et al., 1998). Together with the low water retention of gypsum soils (Boukhris and Lossaint, 1975), this means that the water available for plants is very low (Poch and Verplancke, 1977).

Research into the effect of grazing on the hydro-physical properties of gypseous soils is very scarce (Meyer and García-Moya, 1989). The purpose of the present study was to compare the grazing effect on the soil hydro-physical properties for silty gypseous and non-gypseous soils. Measurements of bulk density, penetration resistance, soil hydraulic parameters at saturation, and the water retention curves sampled on the 1-10 cm depth soil layer of an ungrazed shrubland soil were compared with the corresponding values measured in grazed areas.

2. Material and methods

2.1. Study area and experimental design

The study area is located in the Middle Ebro Valley (NE Spain; 41º30'N, 0º15'W), 250 m above sea level (a.s.l.) and the largest gypsum outcrop in Europe (Fig. 1). The area is one of Europe's most arid zones (Herrero and Snyder, 1997). The climate is semi-arid Mediterranean. The mean rainfall is 353 mm/yr (average of 50 years at 250 m above sea level), and the mean annual temperature is 14.9ºC (M.A.P.A, 1987) (Table 1). The lithology is a gypsum substratum alternating with carbonate units (marls and limestone) and clays (Quirantes, 1978). The landscape is characterized by low hills and flat-bottomed valleys with altitudes ranging from 127 to around 800 m a.s.l. Hills are occupied mainly by dwarf-scrubs of *Rosmarinus officinalis* L., while uncultivated valley bottoms are occupied by *Lygeum spartum* L. steppe and scarce scrub of *Salsola vermiculata* L. and *Artemisia herba-alba* Asso (Braun-Blanquet and Bolós, 1957). Land use in the area is based on a traditional agro-pastoral system involving dry cereal croplands and extensive sheep production.

Two different soil management types (ungrazed natural shrubland, N; and grazed shrubland, GR), applying to two different types of soils (silty gypseous soils, Gy; and non-gypseous soils, NGy), were compared (Table 1). Two experimental fields per combination of soil type and grazing treatment were sampled. All fields were located in a nearly flat area. The grazing treatment consisted, in all cases, of a moderate grazing intensity (< 1 head ha^{-1} $year^{-1}$) according to the traditional use in the area (Pueyo, 2005). Measurements of physical and chemical properties were performed in May-June 2010.

2.2. Soil texture, chemical properties and organic matter content

In each experimental field, the sampling points, four per treatment, were uniformly distributed along a 50 m-long straight line. All soil samplings (for soil texture, chemical properties and organic matter content) per experimental field were taken from the 1-10 cm depth soil layer and stored in a single bag. The samples were homogenised and sieved to 2 mm-size particles in the subsequent laboratory analysis. The gypsum content was estimated from the sulphur content, calculated using a LECO 144DR elemental analyser. The carbonate content was measured with a Variomax CN elemental analyser (Hanau, Germany). The soil texture was measured using the laser diffraction technique (COULTER LS230). The organic carbon was determined by an improved chromic-acid digestion and spectrophotometric procedure (Heanes, 1984), and the results transformed to organic matter (OM) by multiplying by the factor 1.724.

2.3. Soil hydro-physical properties

All measurements of soil bulk density (ρ_b), penetration resistance (PR), saturated sorptivity (S) and hydraulic conductivity (K), and the water retention curve (WRC) for undisturbed soil samples corresponded to the 1-10 cm depth soil layer. The sampling sites, four per experimental field, were uniformly distributed along a 50 m-long straight line.

The ρ_b was determined by the core method (Grossman and Reinsch, 2002), with core dimensions of 50 mm diameter and 50 mm height. The soil samples were dried at 50ºC for 48 h and weighed in order to calculate the bulk density. This sampling was also used to determine the prior volumetric water content needed to calculate S and K. One replication of ρ_b was carried out per sampling site.

The soil penetration resistance (PR) was automatically recorded in the field using a commercial penetrometer (CP40II Penetrometer). In this case, five replications, close to the infiltration measurements, were performed per sampling site.

The soil hydraulic properties were measured in the field using a tension disc infiltrometer (Perroux and White, 1988) with a base radius of 50 mm. Infiltration measurements were performed after removing the crust surface. The base of the disc was covered with a nylon cloth of 20 µm mesh size, and a thin layer of commercial sand (80–160 µm grain size) was used to ensure good hydraulic contact between the base of the disc and the soil surface. Only infiltration measurements at soil saturation conditions, which last up to 15 min, were conducted. Flow readings were automatically recorded every 5 s from the drop in water level of the water supply reservoir, using a ± 0.5 psi pressure transducer that, connected to a datalogger (CR1000, Campbell Sci,), was installed at the bottom of the water supply reservoir (Casey and Derby, 2002). The method of Vandervaere et al. (2000), which analyses the transient cumulative infiltration curve, was used to calculate the sorptivity and soil hydraulic conductivity. The final soil water content, needed to calculate the hydraulic conductivity, was sampled from the upper centimetres of the soil just after removing the disc infiltrometer from the soil surface. Two replications were performed per sampling site.

The water retention curve (WRC) for undisturbed soil samples was measured in the laboratory using a pressure head TDR-cell (Moret-Fernández et al., 2011). The undisturbed soil samples were taken with a 50 mm-diameter and 50 mm-high stainless steel core. The volumetric water content (θ) was measured by TDR in air-dry soil, which corresponds to a soil suction head of about 166 MPa (Munkholm and Kay, 2002), at soil water saturation and at suction heads of 1.7, 3, 5, 10, 50, 100, 500, and 1500 kPa. Assuming a residual water content equal to zero, the WRCs were fitted to the bimodal function proposed by Durner (1992) using the SWRC Fit Version 1.2. software (Seki, 2007) (http://seki.webmasters.gr.jp/swrc/), according to

$$\theta = \left(\theta_{sat}\right)\left[w\left[\frac{1}{1+\left(\alpha_1\psi\right)^{n1}}\right]^{m_1} + \left(1-w\right)\left[\frac{1}{1+\left(\alpha_2\psi\right)^{n_2}}\right]^{m_2}\right] \quad (1)$$

$$0 < w < 1$$

$$\sum w_i = 1$$

$$\alpha_i > 0,\ m_i > 0,\ n_i > 1$$

where n_i is the pore-size distribution parameter, $m_i = 1\text{-}(1/n_i)$, α_i is the scale factor, θ_{sat} is the saturated volumetric water content, and w is a weighting factor for the sub-curves. One replication of the WRC was performed per sampling site. The same soil cores used to calculate the WRC were subsequently dried at 50ºC for 48 h and employed to calculate the soil bulk density, which allowed additional ρ_b values to be obtained for each sampling site.

To compare the effects of the soil management system on the soil hydro-physical properties, an analysis of variance (ANOVA) for a completely randomized design was conducted using SPSS (V. 13.0) statistical software. The PR and θ_{sat}, and the n_1 variables needed to be normalized using the root square and the inverse transformations, respectively. The treatment means were compared using Duncan's multiple range test.

3. Results and discussion

The soils were grouped as gypseous (Gy) (Lomaza and Leciñena) and non-gypseous (NGy) (Planerón and Sariñena), with high and low silty gypsum content, respectively. The taxonomy of the different soils is summarized in Table 2. Soil analysis confirmed that soils of Lomaza and Leciñena had a high content of silty gypsum (Table 2). Soils from the Planerón experimental field, which also had a high gypsum content, were considered non-gypseous since the soil physical properties conferred by the gypsum found in these soils, which crystals were arranged in nodules (up to 2-3 cm diameter), were completely different from the "flour-like" texture observed for the silty gypsum found in Lomaza and Leciñena. The soil texture was sandy loam and loam for the Gy and NGy soils, respectively (Table 2). A qualitative interaction was found in the OM between the soil type and the management. While the N treatment in Gy soils presented 43.3% more OM than the GR treatment, the opposite was found in the NGy soils, where OM under GR was 38.4% higher than under N (Table 2). These results would indicate that, unlike NGy, grazing management in Gy soils has a negative influence on the OM storage.

On average, Gy soils present a significantly lower bulk density (ρ_b = 1.13 g cm^{-3}) than NGy soils (1.39 g cm^{-3}) (Fig. 2a). These differences can be attributed to the lower particle density of gypsum (2.30 g cm^{-3}) when compared to the average 2.62 g cm^{-3} particle density typically assigned to mineral soils (Hillel, 1998). The ρ_b measured in both Gy and NGy soils under the GR treatment was significantly higher than the corresponding ρ_b measured under the N management (Fig. 3a). No significant interaction (p = 0.32) was observed in ρ_b between the soil type and grazing treatment. The lowest ρ_b value corresponded to the Gy soils under N treatment. As observed by da Silva et al. (2003) and Quiroga et al. (2009), these results indicate that livestock trampling tends to increase the soil bulk density, with consequences for water infiltration, plant root development and seed establishment (Heady and Child, 1994).

The volumetric water content in the 1-10 cm soil layer during the PR samplings, calculated from the soil bulk density measurements, was on average 0.09, 0.07, 0.04, 0.04 $m^3 m^{-3}$ for the Gy-N, Gy-GR, NGy-N and NGy-GR treatments, respectively. The soil penetration resistance (PR) was significantly higher for NGy soils than the corresponding value measured in Gy soils (Fig. 2b). A significant interaction was observed between the soil type and grazing treatment ($p < 0.01$). While no statistical differences in PR were observed in the Gy soils between the GR and N treatments, the PR measured in the NGy soils under GR management was significantly higher than the corresponding value observed in N (Fig. 3b). The highest PR corresponded to the NGy soils under the GR treatment. These results indicate that the PR in Gy soils is little affected by livestock trampling.

The average values of saturated hydraulic conductivity (K) and sorptivity (S) measured in Gy soils were not statistically different from those calculated for NGy soils (Fig. 2c and d). However, a significant interaction ($p < 0.01$) was found between the soil type and grazing treatment in both K and S parameters. While no differences in K and S were observed between the N and GR treatments in Gy soils, the grazing treatment was observed to exert a significant influence in the NGy soils (Fig. 3c and d). This difference can be attributed to the inherent characteristics of wetted gypsum, which shows a completely different soil structural behaviour from that observed in NGy soils. During soil wetting, the gypsum that coats the soil macropores dissolves, and subsequently new gypsum crystals grow, obstructing pre-existing conductive pores (Poch and Verplancke, 1997). This phenomenon results in a reduction of the water infiltration rate. This process, which does not take place in many mineral soils, may explain why Gy soil compaction due to livestock trampling (Fig. 3a and b) does not significantly affect the infiltration parameters. For the NGy soils, the K and S values under the N treatment were almost four times greater than the corresponding values measured under the GR management. These results indicate that grazing on NGy soils tends to collapse the soil water conductive macropores of the upper soil layers (Zhao et al., 2007), and consequently reduce the soil water infiltration.

A typical bimodal WRC curve (Eq. 1), which indicates that the studied soils present a clear double porosity system, was found in all soils and grazing treatments (Fig. 4). Differences between Gy and NGy were only significant ($p < 0.05$) for the θ_{sat} and the weighting factor w. The w was the only WRC parameter that showed significant differences between grazing treatments and a significant interaction between soil type and grazing treatment. The w parameter estimated in the Gy soils under N management was significantly higher than the corresponding value observed under GR (Table 3).

All these results suggest that livestock grazing, in both Gy and NGy soils, has a negative effect on the soil hydro-physical properties. The higher soil compaction due to livestock grazing tends to slow down the soil water movement through the soil profile. This phenomenon, which leads to soil water being stored in the upper soil horizons, increases the risk of water loss by evaporation, and consequently reduces the water available to plant production.

4. Conclusions

This paper compared the effect of livestock grazing on the soil hydro-physical properties for silty gypseous (Gy) and non-gypseous (NGy) soils. Soil compaction due to grazing treatment tended to increase ρ_b and decrease the K and S values, resulting in a deterioration of soil hydro-physical properties. Small differences in the WRCs were observed between soil types and grazing treatments. In general, the hydro-physical features of Gy soils tend to be less affected by grazing treatment.

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Figure captions

Figure 1. Location of the experimental fields in the study area: (A), Lomaza; (B), Planerón; (C), Leciñena; (D), Sariñena. The two dots per experimental field represent the grazed and ungrazed treatments, respectively.

Figure 2. Average (a) soil bulk density, (b) penetration resistance, (c) saturated sorptivity (*S*), and (d) saturated hydraulic conductivity (*K*), measured on the 1-10 cm depth soil layers for silty gypseous and non-gypseous soil. Columns within the same soil type with the same letter indicate no significant differences ($p < 0.05$) between treatments. Vertical lines indicate the standard deviation within each treatment.

Figure 3. Average (a) soil bulk density, (b) penetration resistance, (c) saturated sorptivity (*S*), and (d) saturated hydraulic conductivity (*K*), measured on the 1-10 cm depth soil layers for silty gypseous and non-gypseous soil under grazed and ungrazed treatments. Columns within the same soil type with the same letter indicate no significant differences ($p < 0.05$) between treatments. Vertical lines indicate the standard deviation within each treatment.

Figure 4. Average measured and modelled water retention curves estimated for the 1-10 cm depth soil layers for (a) silty gypseous and (b) non-gypseous soils under grazed and ungrazed treatments. White and grey points denote the average values of the water content-suction head pair of points measured in the grazed and ungrazed treatments. Vertical lines indicate the standard deviation within each suction head.

Figure 1_Moret-Fernndez et al_AGWAT3661R2

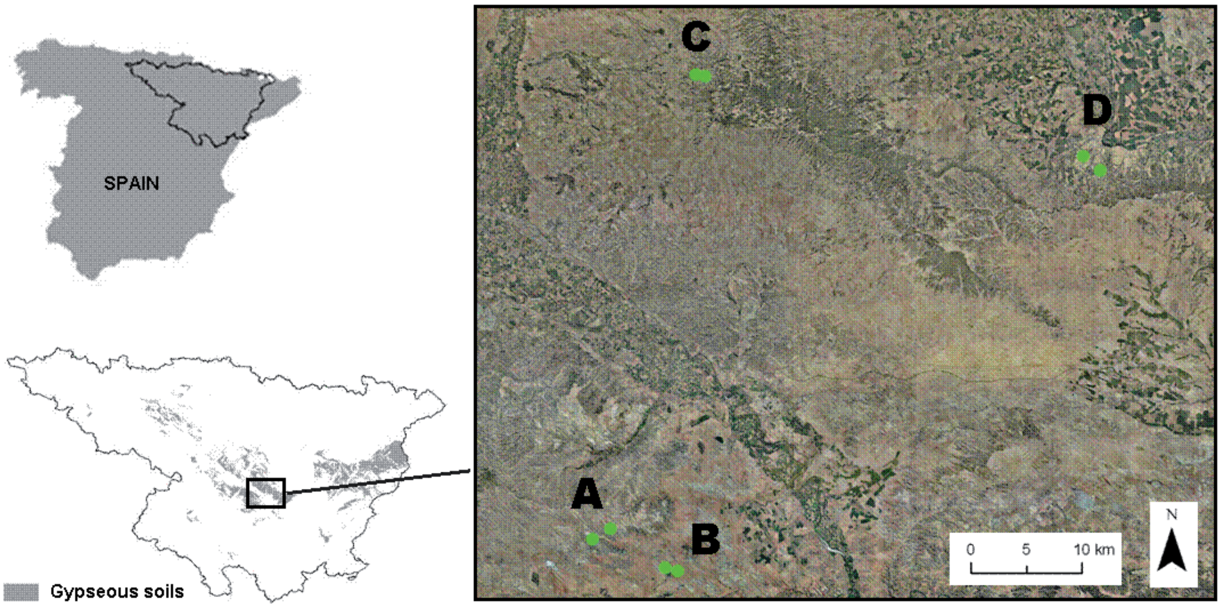

Figure 1.

Figure 2_Moret-Fernndez et al_AGWAT3661R2

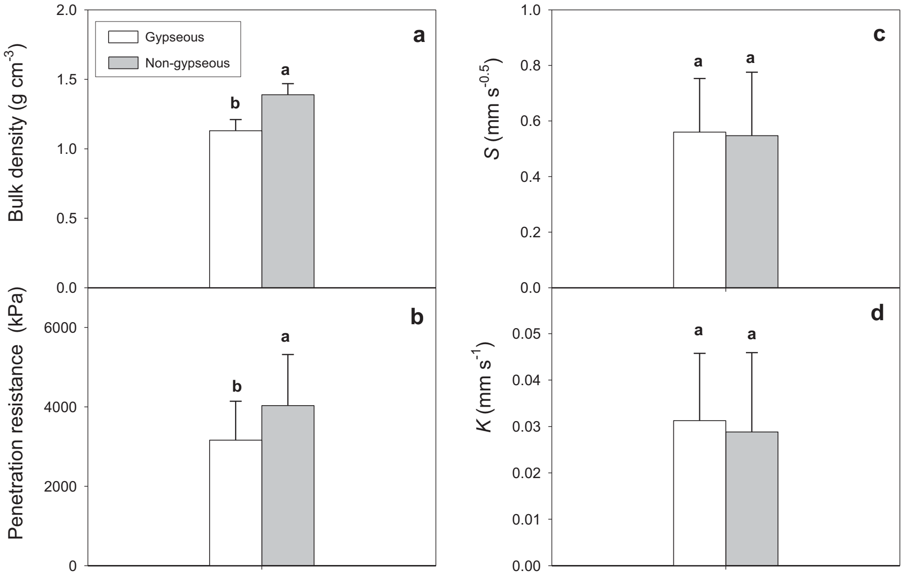

Figure 2.

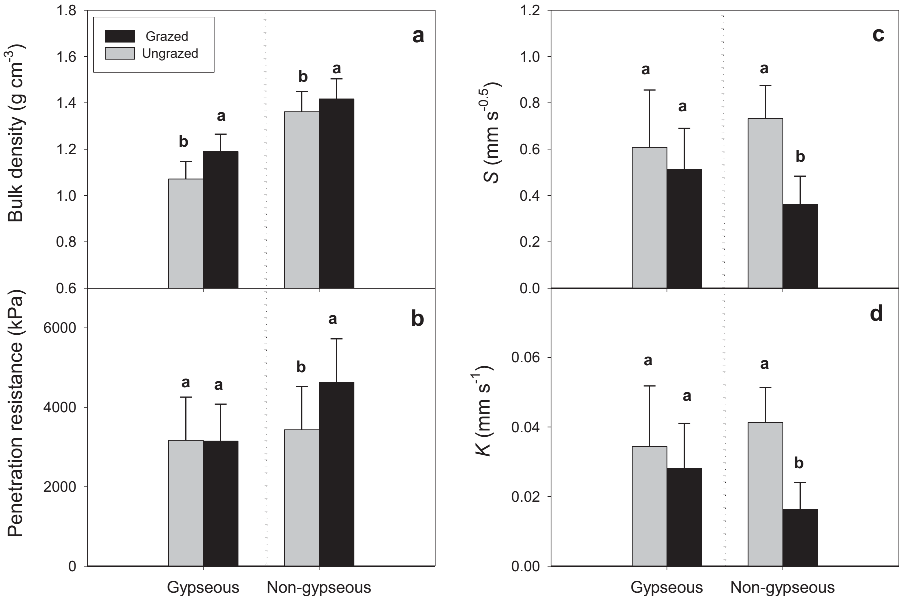
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Bulk density (g cm-3)
Grazed
Ungrazed
a
b
a
b
a
6000
4000
2000
0
Penetration resistance (kPa)
b
a
a
b
a
Gypseous
Non-gypseous
1.2
1.0
0.8
0.6
0.4
0.2
0.0
S (mm s-0.5)
c
a
a
a
b
0.06
0.04
0.02
0.00
K (mm s-1)
d
a
a
a
b
Gypseous
Non-gypseous

Figure 3.

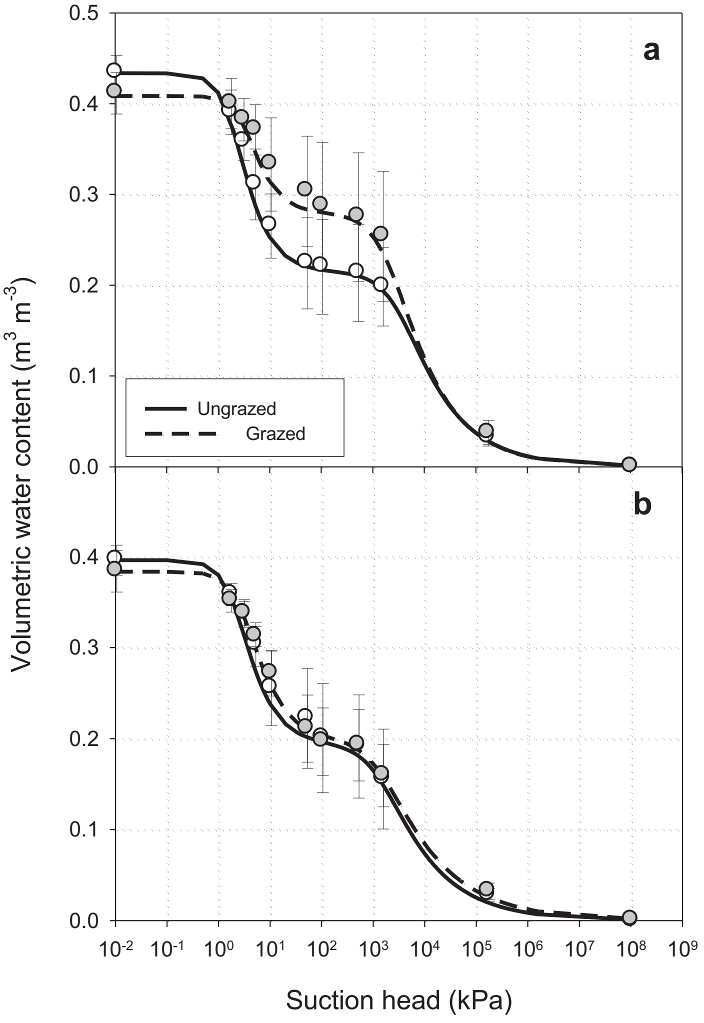
a
b
Ungrazed
Grazed
Volumetric water content (m^3 m^{-3})
Suction head (kPa)
0.0
0.1
0.2
0.3
0.4
0.5
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Figure 4

Table 1.Experimental fields, soil type, grazing treatments, annual cumulative rainfall, and maximal, minimal and average annual temperature for each experimental field.

Experimental field	Soil type	Grazing treatment	Annual Rainfall (mm)[1]	Average annual temperature (^{o}C) [1]		
				Maximal	Minimal	Average
Lomaza	Gypseous	Grazed / Ungrazed	341.8	20.5	9.3	14.9
Planerón	Non-gypseous	Grazed / Ungrazed	319.3	21.1	9.7	15.4
Leciñena	Gypseous	Grazed / Ungrazed	465.6	19.0	8.3	13.6
Sariñena	Non-gypseous	Grazed / Ungrazed	376.2	20.4	9.1	14.7

[1] Atlas Climático de Aragón; http://anciles.aragon.es/AtlasClimatico