Response of annual pastures to soil water variations in water-limited environments with scattered tree cover

Javier Lozano-Parrá 1, 2, Susanne Schnabel 3, Francisco Lavado Contador 3, Álvaro Gómez Gutiérrez 3, Manuel Pulido Fernández 3

1 GeoEnvironmental Research Group, University of Extremadura, web page: www.grupogiga.es
2 Department of Physical Geography, Pontifical Catholic University of Chile. Correspondence with author: jlozano@outlook.es

Introduction and Study area

Motivation and Objective

Soil moisture plays a key role in natural development of plants. Knowing soil water dynamics and how it influences plant growth is more crucial in semiarid regions with agrosilvopastoral land use than other places. This is because it can help in the management of resources and ecosystems and can have not only important ecological consequences but also a significant impact on food supply and, consequently, on regional economies. For this reason, the main objective of this study was to define the response and sensitivity of annual pastures to soil water availability in ecosystems where water is a limiting factor.

Study area

• Experimental catchment (Spain) with agro-ecological land use and 0.95 ha (Fig. 3).
• Mediterranean climate with mean temperature in January of 7.4°C and in July and August of 26.4°C.
• Annual precipitation ≥ 510 mm ± ±1.50 mm.
• Annual potential evapotranspiration is twice the precipitation.
• Soil water contents for the suction potentials at –33 kPa and –1500 kPa were calculated at 15 cm and a depth of 5 cm above the bedrock, as soils are generally very shallow (< 40 cm) and roots are concentrated in the upper layer (mainly in the top 15 cm).
• 6 profiles, covering different: i) lithology (schist and colluvial/schist) ii) topographic position (hillocks and footslopes) iii) vegetation cover (under tree canopy) (Fig. 5) and grasslands (Fig. 4).
• Pasture production was recorded by biomass cuts every season and by manual measurements of its height.

Soil moisture measurements

• Soil moisture was monitored continuously with a temporal resolution of 30 minutes by means of capacitance sensors (model EG-5, Decagon Devices, Inc., Pullman, USA), which were installed in soil profiles and gathered in Soil Moisture Stations –SMS– (Fig. 2), which were distributed in the catchment (Fig. 3).
• Sensors were installed in soil profiles at 5, 10 and 15 cm depth, and 5 cm above the bedrock, as soils are generally very shallow (< 40 cm) and roots are concentrated in the upper layer (mainly in the top 15 cm).
• 6 profiles, covering different: i) lithology (schist and colluvial/schist) ii) topographic position (hillocks and footslopes) iii) vegetation cover (under tree canopy) (Fig. 5) and grasslands (Fig. 4).
• Pasture production was recorded by biomass cuts every season and by manual measurements of its height.

Soil moisture measurements

• Soil moisture was monitored continuously with a temporal resolution of 30 minutes by means of capacitance sensors (model EG-5, Decagon Devices, Inc., Pullman, USA), which were installed in soil profiles and gathered in Soil Moisture Stations –SMS– (Fig. 2), which were distributed in the catchment (Fig. 3).
• Sensors were installed in soil profiles at 5, 10 and 15 cm depth, and 5 cm above the bedrock, as soils are generally very shallow (< 40 cm) and roots are concentrated in the upper layer (mainly in the top 15 cm).
• 6 profiles, covering different: i) lithology (schist and colluvial/schist) ii) topographic position (hillocks and footslopes) iii) vegetation cover (under tree canopy) (Fig. 5) and grasslands (Fig. 4).
• Pasture production was recorded by biomass cuts every season and by manual measurements of its height.

Soil water retention curves

• Soil water retention curves were calculated (from 0 to –1500 kPa) at 15 cm and a deeper depth under different vegetation covers (at 5 cm under trees), using a total of 74 undisturbed samples.
• 13 point soil suction curves were determined in laboratory by a desorption process, based in the porous medium method (Skidmore et al., 1969) and the pressure membrane method (Richards, 1948), both supplies by Eijkelkamp®.
• 6 profiles, covering different: i) lithology (schist and colluvial/schist) ii) topographic position (hillocks and footslopes) iii) vegetation cover (under tree canopy) (Fig. 5) and grasslands (Fig. 4).
• Pasture production was recorded by biomass cuts every season and by manual measurements of its height.

Water deficit index (WDI)

The WDI indicates the duration and intensity of different soil moisture states and establishes the necessary water amount for the vegetation development in each of its phases (Martínez-Fernández et al., 2012). The index was established as follows:

\[
\text{WDI} = \frac{0 - \theta_{33}}{\theta_{33} - \theta_{1500}} \times 100
\]

WDI - water deficit index (kPa), \( \theta_{33} \) - soil moisture content \((\mathrm{m}^3 / \mathrm{m}^3)\) at suction \( \theta_{33} \), \( \theta_{1500} \) - residual and saturated water content. (1)

\( \theta_{33} \) is related with the rain water distribution, in a constant parameter which determines the shape of the retention curve, in the case of the curve (1), both techniques were used as it was described by Skidmore et al. (2004).

Finally, the coefficient of determination \( r^2 \), the mean error (MRE) and the root mean square error (RMSE) test were applied in order to evaluate the goodness of fit, bias and the dispersion between estimated and observed curves, respectively.

Water availability for plants

The observed annual pasture growth (cm) followed the expected seasonal phenological patterns (Fig. 7). However, pasture production as well as phenological patterns of natural herbaceous may quasi-temporally vary according to environmental factors, such as temperature and precipitation distribution. The herbaceous growth only was significant when the upper soil layer was able to satisfy the water demand in the suitable time.

Results

Soil moisture retention curves

The goodness-of-fit tests observed in the adjusted curves with the Van Genuchten model showed a very satisfactory fit between observed and estimated values, with coefficients of determination \( r^2 \) always greater than 0.97 and a low statistical dispersion, as is observed in the RMSE values (Fig. 5). These results indicated the suitability of this method to be applied in this analysis.

Water deficit index (WDI)

Results showed that soils under tree canopy registered longer and more intense water deficit than those located in grasslands (Table 1). Matric potentials of –1500 kPa were reached at upper soil depth only in some occasions, particularly in summers, although some periods in spring 2012 (dry year) can also be observed (Fig. 6 A). Matric potential values lower than –1500 kPa were more variable at deeper depths (Fig. 6 B).

Table 1. Duration of the WDI with values under 0% and –100%, in two hydrological years. WDI values were calculated between the first 15 cm of all moisture stations.

Conclusions

This study highlights the importance of the upper soil layer as the main zone for water supply to annual pastures. Changes in environmental factors or management policies affecting this layer, may increase its sensitivity to external factors, compromising ecological and food resources.

References


Acknowledgements: Financed by AMID project, Spanish Ministry of Economy and Competiveness, CGL2011-23361.