



## Soil water dynamics, root systems, and plant responses in a semiarid grassland of Southern Patagonia



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### ABSTRACT

Distribution of water enables different ecological niches and the coexistence of species. This separation may be in space: vertically in the soil profile or horizontally by lateral root exploration; and in time, as plants may use water at different periods. This study focused on the soil-plant water relation in semiarid Patagonia. Water potential at three depths: 10, 25 and 60 cm, and water content beneath vegetated and bare patches were measured. Access to water in the soil profile was studied in two grasses and a dwarf shrub based on the root biomass. Soil was usually dry at 10 cm ( $-1.22 \text{ MPa} \pm 0.25$ ) and 25 cm ( $-1.00 \text{ MPa} \pm 0.14$ ) during summer. In dry years, it was also dry during autumn ( $-1.17 \text{ MPa} \pm 0.32$ ) at 10 cm depth). At 60-cm depth, soil was moist year-round ( $-0.38 \text{ MPa} \pm 0.05$ ). Soil conditions were not spatially homogeneous, as bare soil patches showed higher water content than vegetated patches. Dwarf shrubs presented both shallow and long roots, that extended laterally instead of exploring deep soil. It is hypothesized that this lateral expansion may give access to water under the bare soil patches, a resource that is not available to the other life forms.

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### 1. Introduction

In arid and semiarid ecosystems, soil water determines important functional aspects of the ecosystems including the dominance of plant functional types, phenology, and primary production. It exerts the main control over biological processes (Noy-Meir, 1973), and induces different physiological and anatomical adaptations and “trade-offs” in plants that enable them to use different soil water sources (Abbott and Roundy, 2003; Schwinning and Ehleringer, 2001). These differences may lead to niche differentiation and coexistence of species (Chesson et al., 2004).

Soil water availability for plants is associated with the seasonality, frequency and size of rainfall (Loik et al., 2004). In the topsoil water is available for short periods, generated by small rainfalls, the predominant type of rainfall in deserts and semiarid systems (Loik et al., 2004; Reynolds et al., 2004; Sala and Lauenroth, 1982). These small events do not infiltrate deeply in the soil, and the water stored shallow in the soil is lost quickly in the warm season, when

potential evapotranspiration is intense. The plants with shallow root systems can make use of these water pulses (Jobbágy and Sala, 2000; Schwinning et al., 2005) adopting an “opportunistic” strategy (Soriano and Sala, 1983). Leaves of these plants have to tolerate a wide range of water potentials (Schwinning et al., 2005), and maintain partially developed leaf meristems or buds that can be rapidly activated to replace senescent foliage and take advantage of the pulses (Soriano and Sala, 1983).

Water that reaches the deep layers of the soil is a more stable resource. It is not subject to evaporation (Pardue and Sala, 1995), and therefore has a longer residence time. The recharge of these layers usually coincides with the rainy season, but it may also take place at any time of the year by the occurrence of large rainfall events. Mediterranean (winter) type rain distributions and permeable soils facilitate infiltration and deep soil recharge (Sala et al., 1997). Water in deep layers is utilized mostly by plants that can develop long, thick roots with secondary growth that are capable to explore the entire soil profile. These plants usually bear long-lived and slow-growing foliage (Bucci et al., 2009), and their leaf water potentials are less variable in the year (Schwinning et al., 2005).

A third type of resource that is often overlooked in arid and semiarid system studies are the water pockets under bare soil patches. They are generated in systems that show incomplete

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vegetative cover (Soriano, 1990), because direct evaporation from the soil surface can only draw superficial water as capillary forces loose strength in coarse-textured soils (Noy-Meir, 1973). Low or nil vegetative cover means that they are not subject to transpiration. Annuals that complete development in the interspaces of perennial vegetation may use this resource.

In Patagonia, the dominance of summer or winter rains determines the seasonal pattern of soil water and explains the dominance of different functional types (Sala et al., 1997). Soil-plant water relations studies have so far mostly focused on shrub–grass steppes with winter rain of North and Central Patagonia (Bucci et al., 2009; Paruelo and Sala, 1995; Schulze et al., 1996; Soriano et al., 1987). In these areas grasses use water available in the 0–30 cm layer, while shrubs obtain water mostly from deeper layers. Some woody plants, nevertheless, show dimorphic root systems and can make use of both resources (Bucci et al., 2009; Kowaljow and Fernández, 2011; Rodríguez et al., 2007). Plants with an annual strategy that could use the water available under bare soil patches are missing (Soriano, 1990).

Southern Patagonia has a uniform seasonal distribution of rainfall (Burgos, 1985), and is dominated by grass steppes (Roig, 1998; Soriano, 1956). Soil water dynamics in these areas has received little attention, but the increased dominance of grasses, both in cover (Humano et al., 2005) and productivity (Cibils et al., 2005) points to a different water balance. The present study focuses on the spatial soil water distribution and its relation with root system structure in two grasses and a dwarf shrub in the Magellanic Steppe. The main hypothesis was that the pattern of rainfall distribution reduces the availability of deep soil water. Grasses and shrubs consequently will develop shallow root systems, with high competition potential for the shallow water and similar leaf water potential patterns.

## 2. Methods

### 2.1. Study area

Study area was Potrok Aike station, an experimental field of National Institute of Agricultural Technology (INTA) Santa Cruz, at 51° 36' S and 69° 14' W. It is located at 150 m a.s.l., 100 km west from the city of Río Gallegos and 30 km away from the Magellanic Strait shores. Climate is Temperate-cold and semiarid, with a mean rainfall of 200 mm, distributed evenly throughout the year (De Fina et al., 1968). Predominant winds from the SW, show a mean annual intensity of 27 km/h.

Soils are entisols, with Typic Torriorthents and Typic Torripsaments, that show a A-C and A-AC-C sequence. They are relatively deep, sandy loam in texture (85% total sands 0–20 cm depth), with reduced stone content in the surface and abundant fine, medium and thick gravels and stones in the deep horizons. Soil pH is slightly acidic (6.2), and reaches 6.8 deeper in the soil profile. They show higher values of organic matter (2.64%) and nitrogen (0.16%) close to the surface, but these values fall to 0.98% and 0.06% respectively in the A2 horizon (Lamoreaux et al., 2005). Soil water content in the A horizon at field capacity (–0.03 MPa) is 12% weight/weight (Ferrante, 2011). Vegetation is a 60%-cover perennial grass steppe with three strata: tussock grasses, mainly *Festuca gracillima*, with 25% relative cover. Prostrate, dwarf shrubs including *Nardophyllum bryoides* and other species cover 23%. Short grasses and herbaceous forbs constitute the remaining 52% of the vegetative cover, with *Poa spiciformis* as dominant. Ephemeral and annual plant cover is negligible (Humano et al., 2005).

Soil and vegetation variables were analyzed in three experimental plots within one-ha enclosures established in 1999. The sites reflect the environmental variability of the study area in terms

of topography, two of them in 5–10% slopes with N and S aspect and the remaining one in a flat area. Differential insolation patterns between slopes resulted in small differences in the temperature of the soil surface of ca. 1 °C (Ferrante, 2011), but soils and vegetation are otherwise similar.

### 2.2. Climate

Rainfall and temperature were recorded with an automated meteorological station (Davis Weatherlink 4.04 s, California) between 2001 and 2007. The size of rainfall events was classified using the intervals: 0–5, 5.1–10, 10.1–15, 15.1–20, >20 mm. Dry spells (time between two successive rainfalls) were recorded. Potential daily evapotranspiration ( $E_{t0}$ ) was estimated from daily temperature and relative humidity values using the Penman–Monteith algorithm (Monteith, 1973).

### 2.3. Soil water

Three sites in vegetated patches within each experimental plot ( $n = 9$ ) were selected for soil water potential measurements. At each site, a 1-m deep excavation was made to expose the soil profile. One soil psychrometer was placed laterally in the undisturbed soil profile there at three depths: 10, 25 and 60 cm. The excavations were filled up with the extracted soil. The experimental plot had in total 9 sensors ( $n = 27$  total sensors in the three experimental plots). Readings were taken with intervals between 15 and 30 days during the period September–May 2001–2004 using a microvoltmeter (Wescor HR 33, USA). At each sampling date (56 in total), 27 psychrometers were read sequentially between 11:00 and 14:00 hs. During the June 2002–June 2003 period, soil temperature at 5 cm depth was recorded hourly using a single TC1047 sensor in each experimental plot ( $n = 3$ ), (Microchip, EEUU) and data loggers.

Spatial distribution of soil water content in different patches was explored in January 2007. A total of 363 patches 10 cm or wider were identified in Canfield lines in experimental plots and adjacent areas. They were classified into: tussock grasses ( $n = 108$ ), short grasses ( $n = 109$ ), dwarf shrubs ( $n = 61$ ) and bare soil ( $n = 85$ ). Soil water content was estimated once at the center of each patch using a 15-cm deep TDR probe (model FM-3 Trime, Eijkelkamp, Giesbeek, The Netherlands).

### 2.4. Root systems

In order to study root structure and root biomass distribution, nine 60-cm deep excavations were performed adjacent to medium-sized individuals of: *P. spiciformis* ( $n = 3$ , crown diameter  $9 \pm 0.7$  cm), *F. gracillima* ( $n = 3$ , crown diameter  $28 \pm 5.4$  cm) and *N. bryoides* ( $n = 3$ , crown diameter  $78 \pm 25.8$  cm). Low root density was observed deeper than 40 cm in the soil profile in all cases. In order to analyze vertical and horizontal root distribution, samples were taken from the 0–40 cm layer, where most of the roots were observed. A pit was dug directly beneath each plant in order to expose the soil block containing the root biomass. The nail board method (Böhm, 1979) was used to assess root biomass. A board with 5-cm long nails placed systematically in a  $5 \times 5$  cm pattern was introduced in the visible face of the soil profile of the pits. A second pit was excavated on the opposite side in order to obtain a 5-cm thick monolith of soil. These blocks were  $40 \times 40 \times 5$  cm size for *F. gracillima* and *N. bryoides*. Smaller plants of *P. spiciformis* were sampled in  $25 \times 40 \times 5$  cm monoliths. Nail boards were washed in horizontal position in the laboratory to remove soil particles. Exposed roots in each  $5 \times 5$  cm quadrat were cut, oven-dried and weighed. In the case of the shrub, the pit was combined with a

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