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Soil Water Availability in the Patagonian Arid Steppe: Gravel Content Effect

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Abstract *A model for estimating volumetric water content as a function of soil water potential and gravel content was developed. In the system studied gravel can withhold up to 67% of the amount held by the fine material. Water content at field capacity decreases 50% when gravel content (>11 mm) increases from 0% to 40% of total soil weight. For those values of gravel content, penetration depth of a rainfall of 20 mm increases from 38 cm to 59 cm when the initial water content is 60% of the field capacity.*

Keywords gravel, Patagonia, water availability, water retention.

Introduction

Water is the limiting factor for arid ecosystems. Precipitation in arid regions is scarce and unpredictable (Noy Meir 1973). Water availability for plants is determined by the interaction of the precipitation pattern with several characteristics of the soil. Many arid environments have soils with gravel and stones that decrease the soil water availability for plants. Hanson and Blevins (1979) and Coile (1953) found that soil gravel can hold different amounts of water according to its size and type. They pointed out the important role of gravel content in determining the amount of water available for plants growing in these soils.

The Patagonian arid steppe, southwest of Chubut, Argentina (45° to 47° S, 70° to 71°30′ W), has some of the characteristics listed above. Mean annual rainfall is 150 mm. Most of the precipitation occurs from March to August, the coldest period for the Southern hemisphere. Mean monthly temperatures range from 2°C in July, reaching 14°C in January. Soils are mainly derived from glacial and volcanic materials. Texture is commonly coarse and different sizes of gravel and stones ("Patagonian pebbles") are found throughout the soil (Soriano *et al.* 1983, Soriano and Sala 1983).

The objective of this paper was to evaluate the effect of variations on the content of gravel and stones on the soil water availability in the Patagonian arid steppe.

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Materials and Methods

Soil samples of about 1800 cm^3 were taken from a Calciorthids (Etchevehere 1971) in a stand corresponding to the community of *Stipa speciosa* Trin. et Rupr., *Stipa humilis* Cav., *Adesmia campestris* (Rendle) Skottsb., *Berberis heterophylla* Juss., and *Poa lanuginosa* Poir (Golluscio *et al.* 1982) which is the most conspicuous on this steppe. Ten samples were taken from the upper layer of the soil and six from the lower calcareous layer (Table 1). Dry samples were sieved to separate 4 particle-size classes (<2 mm, 2–5 mm, 5–11 mm, and >11 mm) and weighed.

Water retention curves (Richards and Fireman 1943) were constructed for the <2-mm particle-size from the two layers at 0, 0.005, 0.01, 0.02, 0.03, 0.05, 0.09, 0.1, 0.3, 0.8, and 1.5 −MPa water potential values. To obtain the water retention curves for gravel fractions 2–5 mm and 5–11 mm, gravels were placed in rubber rings between two fine soil layers (<2-mm particle-size), ensuring the continuity of capillarity between gravel and the ceramic plate (0.01, 0.03, 0.05, and 0.075 −MPa) or the cellulosic membrane (0.1, 0.5, and 1.5 −MPa) (Hanson and Blevins 1979). Gravels were soaked for 15 days before determination. The water content of gravels was calculated as:

$$\mathrm{WCg} = \frac{\mathrm{WCt} - (\mathrm{fs\ WCs})}{\mathrm{fg}} \tag{1}$$

where WCt is the total gravimetric water content (%), WCs is the gravimetric water content for the fraction <2 mm (%), WCg is the gravimetric water content for gravel (%), fs is the proportion of soil in the ring (gg^{-1}), and fg the proportion of gravel in the ring (gg^{-1}). All percentages were fractions of total weight. The values of pressure were considered as estimates of water potential.

The use of disturbed soil samples was the only way to measure the water retention curves in this soil due to the high gravel content. Salter and Williams (1965) compared moisture characteristic curves of disturbed and undisturbed soil samples with different textures and found that in the coarsest samples the differences were not significant. As the texture of the soils under study was coarser than that of their soils, we considered that the error due to the use of disturbed samples would be almost negligible.

It was not possible to determine water retention experimentally for particle sizes greater than 11 mm. The water retention was calculated using a regression model based

Table 1

Physical and chemical characteristics of the two soil layers in the community of *Stipa speciosa, Stipa humilis, Adesmia campestris, Berberis heterophylla,* and *Poa lanuginosa* (Values are averages and standard deviations in parentheses)

Soil parameter	Upper layer	Calcareous layer
Depth (cm)	0–45	45–60
Texture	sandy	sandy-loam
Dry bulk density ($g \cdot cm^{-3}$)	1.77 (0.083)	2.08 (0.22)
$CaCO_3$ (%)	0.68 (0.072)	34.78 (0.715)
Organic matter (%)	0.40 (0.012)	—
pH	6.1	7.3
Electrical conductivity ($dS\ m^{-1}$)	0.41	0.31

on 5 particle-size classes (1.65–2.35, 2.35–2.85, 2.85–4.55, 4.55–8, and 8–11 mm) and their water retention at a pressure of −0.05 MPa. This value was chosen because the water retention of the 2–5- and 5–11-mm fractions did not change between −0.03 and −1.5 MPa.

Dry bulk density was determined in both sample areas with an iron hollow punch, 15-cm diameter and buried at 10-cm depth, and the soil inside was weighed after drying. The volume of the hole was measured with dry sand (Howward and Singer 1981).

The available water was calculated as the difference between the water content at −0.01 MPa (field capacity) (Campbell and Harris 1981) and −5.9 MPa ("wilting point"), multiplied by the depth of the profile. The "wilting point" was estimated by measuring the soil water potential of the wettest layer of the profile in the dryest period of the year (Noy Meir 1973, Campbell and Harris 1981). All differences were tested by analysis of variance (Steel and Torrie 1980).

Results

The data for particle-size class less than 2 mm for the two layers were fitted to the following equations:

$$WC = 4.61 - 1.10 \ln(\psi) \qquad (R^2 = 0.87\ p < 0.001) \text{ (for upper layer)} \tag{2}$$

$$WC = 16.55 - 1.86 \ln(\psi) \qquad (R^2 = 0.95\ p < 0.001) \text{ (for lower layer)} \tag{3}$$

where ψ is the water potential (Mpa) and WC the gravimetric water content (%).

The soils in the studied area had high gravel contents in the two layers analyzed. The gravel fraction greater than 11 mm was the most important and had the highest variability in both layers (Figure 1). Total gravel content and the percentage of gravel greater than 11 mm were higher in the calcareous layer (Figure 1).

Water content of the 2–5-mm particle-size class was higher than in the 5–11-mm size class at each water potential but differences were significant only for −0.01 MPa ($P < 0.01$) (Table 2). The water content of the 2–5-mm fraction reached its maximum value at −0.01 MPa and was significantly higher than water contents at all water potentials below −0.01 MPa. The water content of the 5–11-mm fraction was the same at every water potential measured.

Data for water content at −0.05 MPa for the five particle-size classes were fitted by a negative power function (Landsberg 1976):

$$WC = 2.057\ ASC^{-0.32} \qquad (R^2 = 0.96,\ P < 0.005) \tag{4}$$

where WC is the water content (%) and ASC the average size class (mm).

Considering that the mean diameter of stones greater than 11 mm was 24 mm, the water content for this fraction extrapolated from Equation 4 was 0.90%. We considered that this value was not changing in the range from −0.01 to −1.5 MPa, analogous to the behavior of the 5–11-mm fraction.

Table 1 shows the mean dry bulk density for both layers. Dry bulk density was significantly ($P < 0.001$) correlated with gravel content for both layers. The following equations were fitted:

$$BD = 1.348 + 1.006\ SC \quad (R^2 = 0.68) \quad \text{(for upper layer)} \tag{5}$$

$$BD = 0.424 + 2.149\ SC \quad (R^2 = 0.85) \quad \text{(for lower layer)} \tag{6}$$

where BD is the dry bulk density ($g.cm^{-3}$) and SC the proportion of stones and gravels.

An additive model (Equation 7) for the volumetric soil water content was constructed. It considered the proportion of total weight and water content for each particle-size class and for each value of soil water potential:

$$WCt(\psi) = [fs\ WCs(\psi) + \sum_{i=1}^{n} fi\ WCi(\psi)]\ BD \tag{7}$$

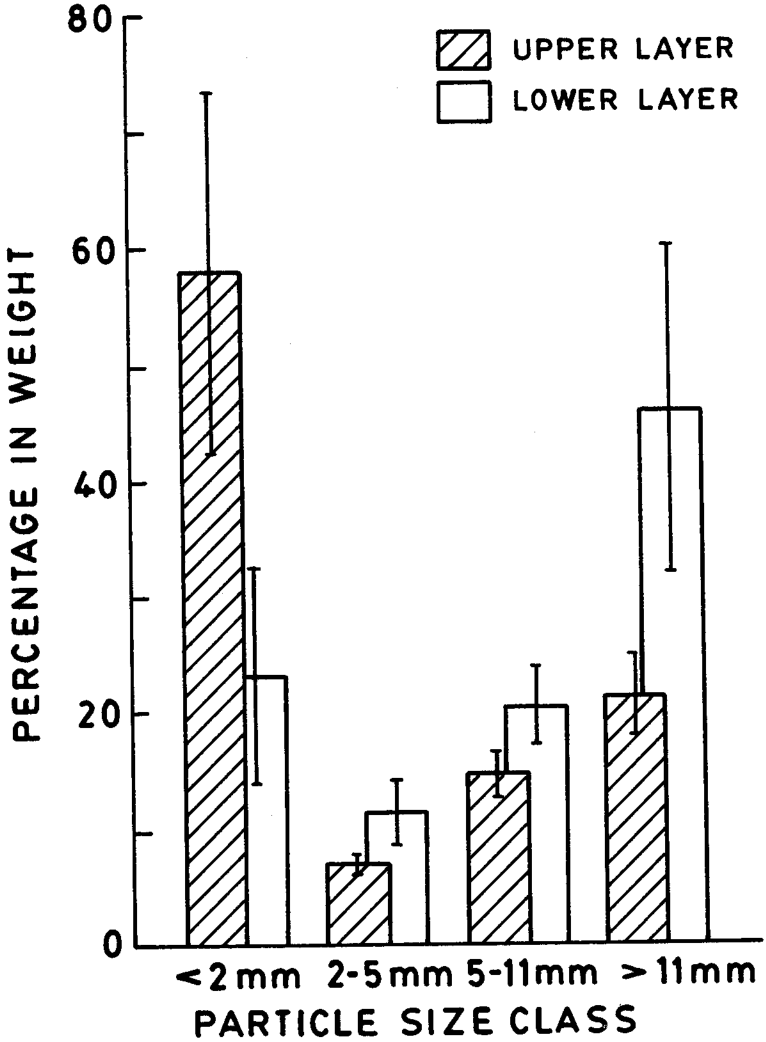

Figure 1. Weight percentage of the four particle-size classes of the two soil layers. Vertical bars are standard errors.

Table 2

Gravimetric water content (%) for the two different size-classes of gravel at seven water potentials (MPa) (Values are means and standard deviations, in parentheses)

	Gravel-size class (mm)	
Water potential (MPa)	2–5	5–11
−0.01	5.41 (1.17) a*	1.20 (0.28) a
−0.03	1.48 (0.31) b	1.47 (0.19) a
−0.05	1.73 (0.30) b	1.08 (0.21) a
−0.075	1.55 (0.26) b	1.36 (0.27) a
−0.10	1.64 (0.13) b	1.51 (0.23) a
−0.50	1.41 (0.04) b	1.17 (0.16) a
−1.50	1.53 (0.36) b	1.27 (0.43) a

* The different letters indicate significant differences ($p < 0.05$) between values for each fraction.

where fi is the proportion of gravel of size i (gg^{-1}), WCi is the gravimetric water content for size i (%), n is the number of defined particle-size classes, and BD is the dry bulk density.

The values of WCs(ψ) were taken from Equations 2 and 3. The water contents of the gravels were calculated from Table 2. We used the average water content as Wci(ψ), for the 5–11- and >11-mm fraction class since there were no differences among water potentials. For the 2–5-mm particle size class the water content for potential higher than −0.03 MPa was obtained by interpolation between −0.01 MPa and −0.03 MPa. For water potential lower than −0.03 MPa, the average water content was used, as for the 5–11-mm fraction. The WC(ψ) for the >11-mm particle size was calculated from Equation 4, considering a mean size of 24 mm. Figure 2 presents the volumetric water retention curves, obtained by using the mean gravel content for each layer. The dry bulk density was calculated using Equations 5 and 6.

Water retention curves calculated with Equation 7 for different gravel contents showed the importance of gravel content on soil water dynamics (Figure 3). The dry bulk density was calculated for each situation as for Figure 2. The available water calculated for the first 45 cm of the profile in a soil without stones was 46.62 mm, while that for a soil with 40% of stones was 23.35 mm.

Discussion

Our moisture characteristic curves and water contents at field capacity were similar to others presented for soils with similar textures (Hillel 1971, Salter and Williams 1965, 1969). Differences in moisture characteristic curves between the two layers would be due to differences in texture and/or calcium carbonate content. Water contents of gravel were lower than other reported values (Coile 1953, Hanson and Blevins 1979). This disagreement could be explained by the lesser porosity of the "Patagonian pebbles." Hanson and Blevins (1979) reported bulk density values of 2.07 to 2.35 gcm^{-3} for micaceous sandstones, while that for the "Patagonian pebbles" was 2.59 gcm^{-3}.

The results point out the importance of considering water held by gravel in the estimation of water content in soils with coarse fragments. Gravels of 2–5 mm can hold up to 67% (at −1.5 MPa) of the volumetric water content of fine material. Coarser gravels (5–11 mm) can hold up to 56% of the volumetric water content of fine material. The

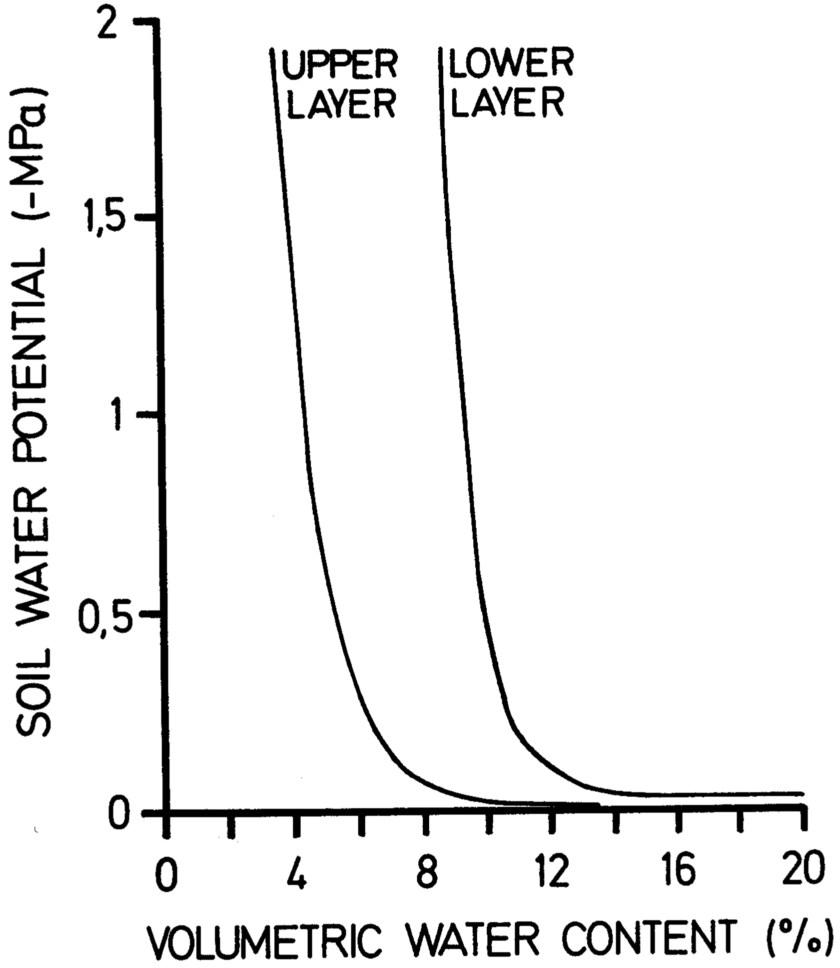

Figure 2. Volumetric water retention curves for the two layers. They were obtained by using the additive model (Equation 7) with average values of gravel content and dry bulk density for each layer.

difference between the estimation of volumetric soil water content with or without water held by gravel is 34% at -0.01 MPa. The water availability is more than 50% higher without stones than in a soil with 40% of gravels >11 mm.

Through its effect on water-holding capacity, the gravel content modifies the depth of water penetration from a rainfall event. The depth of water penetration is a function of the water content at field capacity (Hanks and Ashcroft 1980). A 20-mm rainfall may reach a depth of 59 cm if the >11-mm particle-size class content is 40% and the initial water content is 60% of field capacity. If the >11-mm size gravel is excluded, water would penetrate only 38 cm.

Noy Meir (1973) remarked that the wetting depth will be proportionally higher in sandy or stony soils than in fine-textured ones. Taking into account the ecological importance of light rainshowers (less than 5-mm precipitation) (Sala and Lauenroth 1982, 1985) in arid and semiarid regions, gravel content becomes more important for these

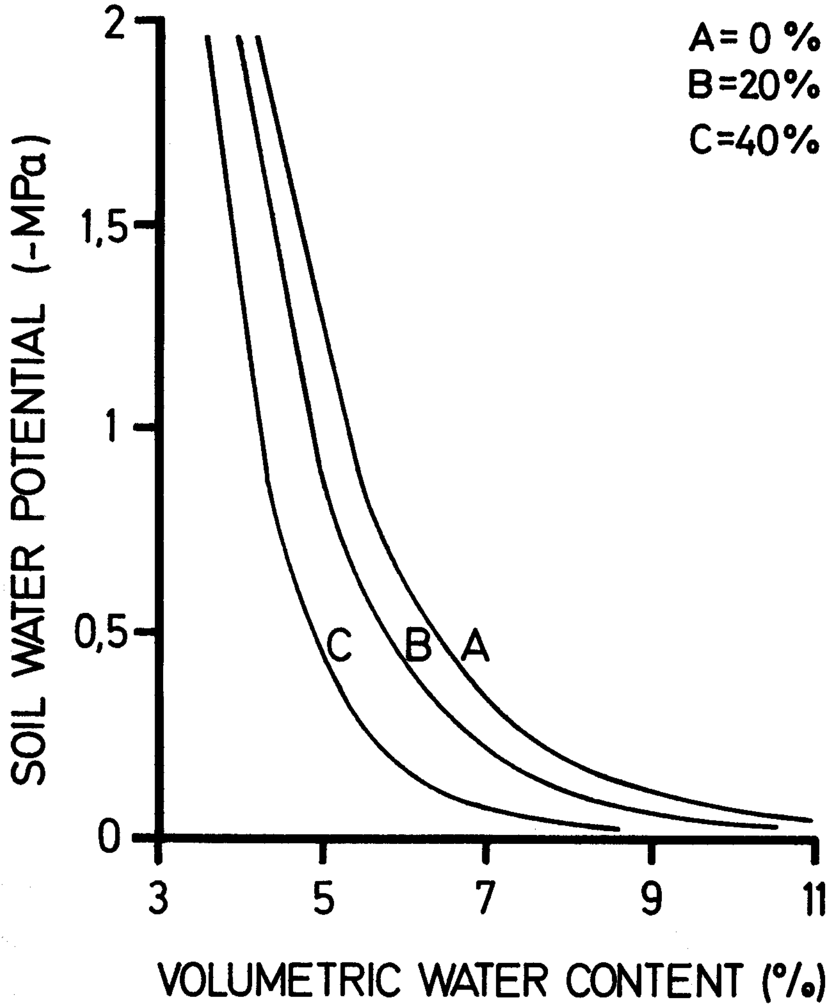

Figure 3. Volumetric water retention curves for the upper layer simulated (equation 7) for different stone fractions. The letters A, B, and C represent pebble (>11 mm) content in soils, per cent.

systems. If water penetrates deeper it may be less susceptible to evaporative losses (Alizai and Hulbert 1969, Hillel and Tadmor 1962).

Noy Meir (1973) proposed that in arid climates sandy or gravelly soils support a denser perennial vegetation than finer soils. So, under the same precipitation regime, variations in soil gravel content determine different hydrological situations. The variations in water availability for plants and its distribution in the soil profile may determine the presence of different plant associations with different structural and floristic characteristics.

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