Root Profiles and the Ecological Effect of Light Rainshowers in Arid and Semiarid Regions

ABSTRACT: A previous study reported results from an evaluation of root biomass under nine vegetation types in Montana and concluded that since root biomass in the top 1-cm soil layer was low, this should be taken as evidence that light rainshowers are of little value to plants. The objective of this note is to present an analysis which will test the generality of this conclusion.

Our calculations for a range of sites showed that even under very dry conditions, a 5-mm rainshower should wet the root zone and become a potential soil water resource for plants. Furthermore, basing our assertion on root morphology and the distribution of roots in the soil, we suggest that the value of light rainshowers to plants may vary with their life form.

Weaver (1982) presented results from an evaluation of root biomass under nine vegetation types in Montana. He made two main points: (1) Root biomass in the top 1-cm soil layer was low for all nine sites sampled; (2) since few roots were found in the top 1-cm layer, this should be taken as evidence that light rainshowers are of little value to plants. Our objective is to present an analysis which will test the generality of point number two.

Weaver's conclusion that light rainshowers are of limited usefulness to plants is not a clearly logical consequence of his data. He reached this conclusion by combining the idea of a nearly root-free surface layer with the assumption that 1 cm of dry soil might hold 1-6 mm of water.

As a starting point for our analysis, let us assume that a 5-mm rainfall represents a light rainshower (Sala and Lauenroth, 1982). If we accept Weaver's assumption about the water-holding capacity of dry soil, then a soil that holds 6 mm/cm will hold the entire 5 mm in the surface layer. On the other hand, if the water-holding capacity is 1 mm/cm, the remaining 4 mm will infiltrate into the root zone. It is clear that Weaver's conclusion is logical only for soils with a water-holding capacity of ≥5 mm/cm.

We now will investigate the validity of the assumption that 1-6 mm/cm is a reasonable range for the water-holding capacity of surface soils. We will change the problem slightly by asking how deep into the soil will a 5-mm rainshower penetrate. Hanks and Ashcroft (1980) presented an equation for calculating the depth of penetration of a rainfall event as a function of water content at field capacity, the initial water content and the amount of water added.

$$D = \frac{W}{\Theta_{vfc} - \Theta_{vi}}, \quad (1)$$

where D (cm) is the depth a rainfall penetrates in the soil, W (cm) is the amount of water added, Θ_{vfc} is the water content (v/v) at field capacity, and Θ_{vi} is the initial water content (v/v).

Our calculations for a range of arid and semiarid sites indicated that when initial soil water content was 30% of the water content at field capacity, a 5-mm rainfall event completely wets, in all cases, the 0- to 3-cm layer (Table 1). Moreover, in coarse soils, water penetrates more than 5 cm. Water content of 30% of field capacity is what van Keulen (1975) considered the average value for water content at wilting point. If the surface soil was as dry as 10% of field capacity, a 5-mm rainfall would still penetrate a minimum of 2.4 cm (Table 1). The lowest water content measured after a 56-day drying cycle in the shortgrass steppe was 16% of field capacity in the upper layer and 50% in lower layers (Sala *et al.*, 1981). Soil water potential, which corresponded to 16% of field capacity, was −6 MPa.

The average volumetric water content for 30% of field capacity for the soils presented in Table 1 was 5.6%. Bloemen (1980) reported for 22 soils an average residual saturation (minimum volumetric water content) of 6%, which is quite similar to the lowest water contents used in Table 1. Most frequently found conditions are similar to the 50% or 30% of field capacity. These calculations demonstrated that 5-mm rainfall events wet a soil layer where roots are abundant.

This information agrees with the results of experiments designed to test the hypothesis that small rainshowers could be used by plants in the shortgrass steppe and therefore that they were ecologically significant (Sala and Lauenroth, 1982). We found that experimental 5-mm rainshowers increased soil water potential at 5 cm of depth. A clearer test of the hypothesis was

TABLE 1.—Depth (cm) to which a 5-mm rainfall penetrates in the soil, for seven arid and semiarid sites under three initial conditions of water content. Data for sites 1-6 from SCS (1975) and for site 7 from van Keulen (1975). Θ_{vfc} = the water content at field capacity (v/v), and Θ_{vi} = the initial water content (v/v)

					Depth (cm)		
Site	Soil	Location	Vegetation	Θ_{vfc}(%)	$\Theta_{vi} = 0.5\Theta_{vfc}$	$\Theta_{vi} = 0.3\Theta_{vfc}$	$\Theta_{vi} = 0.1\Theta_{vfc}$
1	Typic durixeralf	Placer County, Calif., USA	*Bromus rigidus*, *Trifolium hirtum*, *Bromus mollis*, *Medicago* sp., *Festuca megalura*	22.7	4.4	3.1	2.5
2	Typic paleargid	Cochise County, Ariz., USA	*Bouteloua gracilis*, *B. eriopoda*, *B. rothrockii*	17.6	5.7	4.1	3.2
3	Typic durargid	Cochise County, Ariz., USA	*Bouteloua gracilis*, *Swaeda moquini*	14.0	7.1	5.1	4.0
4	Borollic natrargid	Blaine County, Mont., USA	*Agropyron smithii*, *Bouteloua gracilis*, *Artemisia frigida*, *Opuntia* sp.	22.3	4.5	3.2	2.5
5	Typic natrargid	Cochise County, Ariz., USA	*Sporobolus airoides*, *Hilaria mutica*	18.1	5.5	3.9	3.1
6	Typic xerochrept	San Diego County, Calif., USA	Annual weeds and grasses	13.5	7.4	5.3	4.1
7	Lössial sierozem	Migda, Northern Negev, Israel	*Phalaris minor*, *Hordeum murinum*, *Stipa capensis*, *Erucaria boveana*, *Reboudia pinnata*, *Antemis melaleuca*	23.0	4.4	3.1	2.4

provided by the response of *Bouteloua gracilis,* the dominant perennial grass species of the semiarid steppe of the central and southern Great Plains of North America. Leaf water potential and leaf conductance to water vapor, two variables closely related to key plant processes, rapidly increased after the rainfall.

Weaver (1982) supported his conclusion with published data from experiments in which a palm and a shrub failed to absorb ^{32}P from upper soil layers. Rather than the conclusion that light rainshowers are of limited importance, these data suggest that different plant life forms may have different abilities to use different soil water resources. Light rainshowers may be important for arid and semiarid systems and may be ecologically significant, even though they are not used by all the life forms. Moreover, we suggested that the ability of *Bouteloua gracilis* to utilize small rainshowers may influence its persistence as a dominant species in the steppe region (Sala and Lauenroth, 1982). The differences in root system characteristics among life forms are important in understanding soil water partitioning in arid and semiarid regions. We hypothesize that life forms such as shrubs, which possess root systems composed mainly of coarse roots (Hellmers *et al.,* 1955; Tabler, 1964; Walter, 1979; Rutherford, 1983), will not be able to use the increments in soil water resulting from small rainshowers.

Acknowledgments.—We would like to thank S. B. Perelman and R. S. Lavado for their assistance and suggestions. This work was supported by NSF grants INT 8414037 and BSR 8114822.

LITERATURE CITED

BLOEMEN, G. W. 1980. Calculation of hydraulic conductivities of soils from texture and organic matter content. *Z. Pflanzenernaehr. Bodenkd.,* **143**:581-605.

HANKS, R. J. AND G. L. ASHCROFT. 1980. Applied soil physics. Soil water and temperature applications. Springer-Verlag, Berlin, Heidelberg, New York. 159 p.

HELLMERS, H., J. S. HORTON, G. JUHREN AND J. O'KEEFE. 1955. Root systems of some chaparral plants in southern California. *Ecology,* **36**:667-678.

KEULEN, H. VAN. 1975. Simulation of water use and herbage growth in arid regions. Simulation monographs. Pudoc, Wagenningen. 176 p.

RUTHERFORD, M. C. 1983. Growth rates, biomass and distribution of selected woody plant roots in *Burkea africana-Ochna pulchra* savanna. *Vegetatio,* **52**:45-63.

SALA, O. E. AND W. K. LAUENROTH. 1982. Small rainfall events: An ecological role in semiarid regions. *Oecologia (Berl.),* **53**:301-304.

———, ———, W. J. PARTON AND M. J. TRLICA. 1981. Water status of soil and vegetation in a shortgrass steppe. *Ibid.,* **48**:327-331.

TABLER, R. D. 1964. The root system of *Artemisia tridentata* at 9500 feet in Wyoming. *Ecology,* **45**:633-636.

U.S. SOIL CONSERVATION SERVICE. 1975. Soil taxonomy. *U.S. Dep. Agric. Handb. No. 436.* Washington, D.C. 754 p.

WALTER, H. 1979. Vegetation of the earth. Springer-Verlag, New York. 274 p.

WEAVER, T. 1982. Distribution of root biomass in well-drained surface soils. *Am. Midl. Nat.,* **107**:393-395.

O. E. SALA, Departmento de Ecología and PROSAG, Facultad de Agronomía, Universidad de Buenos Aires, Av San Martin 4453, 1417 Buenos Aires, Argentina, AND W. K. LAUENROTH, Range Science Department, Colorado State University, Fort Collins, CO 80523. *Submitted 6 August 1984; accepted 16 November 1984.*