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Water interception by two arid land shrubs

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Water is a critical commodity in short supply in arid environments. Therefore, its judicious use and disposition is critical for improving the environment both economically and esthetically. Two desert shrubs, creosotebush and tarbush, have invaded former productive grasslands and intercept rainfall that would normally enter the soil and be available for the growth of useful plants. A creosotebush community with 30 per cent crown cover would intercept 12 per cent of the summer rainfall. Native communities of tarbush with approximately 15 per cent crown cover would intercept 6 per cent of the average summer rainfall.

The objective of this study was to examine the interception of artificially applied rainfall by creosotebush and tarbush plants for improved understanding of this phenomenon in hydrologic processes. A range of shrub-size classes of both species was treated with simulated rainfall applied at the rate of 6 cm/h for 30 min. Canopy cover was determined from 10 line intercept transects 30·5 m long in both a creosotebush and tarbush dominated community. Least squares analysis was used to determine which of 10 measured canopy attributes result in the best relationship to the interception of rainfall. Tarbush shrub green weight accounted for 75% of the variability of the intercepted rainfall. Creosotebush leaf area was highly correlated ($R^2 = 0{\cdot}52$) with intercepted rainfall. Crown cover was used in developing a generalized equation to describe rainfall interception by both shrub species. Native stands of creosotebush had 30% crown cover and rainfall loss by interception would equal approximately 12%. Tarbush, with 15% crown cover, intercepted 6% of the average rainfall from May through October. Because a high percentage of precipitation from small storms is intercepted by the shrub canopy and subsequently evaporated back into the atmosphere, interception by desert shrubs is of significant importance.

Introduction

The hydrologic cycle is an extremely important process in arid land ecosystems and its components have been the subject of a large number of experiments. This cycle is probably the best known of the abiotic cycles. Interception, a process affecting the disposition of water in the hydrologic cycle, may be considered as the trapping, storage, and disposition of materials on the vegetative surfaces of plants (Zinke, 1966) or as the process of aerial redistribution of precipitation by vegetation (Collins, 1970).

A falling raindrop strikes either a living or dead plant surface, or drops through the canopy directly to the soil surface. When a raindrop strikes a plant surface, it may break up and splash back into the air, or it may temporarily adhere. If it adheres to the plant, it may

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evaporate, drip off, drain down the stem to the soil, or pass directly into leaves through the stomates or cuticle (Cooper, 1970).

Although some information is available concerning rainfall interception by trees (Zinke, 1966; Helvey, 1967; Helvey & Patric, 1965) there is a paucity of information concerning water interception by arid and semi-arid rangeland shrubs. Arid rangelands are characterized by low amounts of rainfall and have not been studied as thoroughly as forested lands. Reasons for this lack of information may be the small, inconspicuous stature of shrubs compared to trees, and the limited vegetational cover of shrubs. This is often less than 50%, and presents the appearance of individual plants rather than a solid block such as is presented by a dense stand of trees.

Rainfall interception by large saltbush (*Atriplex argentea* Nutt.) plants, in dense stands, intercepted 50% of a 150 mm rain artificially applied in 30 min. Burning bush (*Kochia scoparia* [L.] Roth), similarly treated, intercepted 44% (Collins, 1970). Rainfall interception by dense stands of big sagebrush (*Artemisia tridentata* Nutt.) was determined to be approximately 30% of the rainfall between 1 April and 30 October (Hull, 1972; Hull and Klomp, 1974). By spraying 10 individual plants with water they determined the potential interception per rainfall event to be 1·1 mm. Rowe (1948) and Hamilton and Rowe (1949) concluded that interception amounted to about 8% of the annual rainfall for the chaparral type in central and southern California. Most of the published literature or rainfall interception by shrubs is for California chaparral (Zinke, 1966).

Water interception by individual plants of big sagebrush and shadscale (*Atriplex confertifolia* [Torr. & Frém.] Wats.) was determined by West and Gifford (1976). Water interception was 1·5 mm for both species, averaged over three sampling dates and two intensities. Utilizing this information and the average rainfall from 1 April to 30 November for northern Utah, and ignoring storm events less than 1·5 mm, an average of 5·9 mm of rainfall was calculated to be intercepted by big sagebrush and shadscale communities. This amounted to about 4% of the total precipitation that fell as rain.

Different approaches describing the problem of water accumulation on tree foliage have been advanced. A dynamic model to predict the amount of rainfall intercepted by trees was developed by Rutter *et al.*, (1972) and Rutter *et al.*, (1975). Jackson (1975) and Merriam (1973) used a more empirical approach for rain and fog, respectively, by developing logarithmic or exponential regression equations to fit observed data.

The objective of this study was to describe the interception of artificially applied rainfall by creosotebush (*Larrea tridentata* [DC.] Cov.) and tarbush (*Flourensia cernua* [DC.]) for improving the understanding of this phenomenon in hydrologic processes on arid rangelands in the Southwest.

Methods

The rainfall interception studies were conducted near Las Cruces in southern New Mexico (Tromble, 1983*a*; 1983*b*). Forty-four creosotebush and 12 tarbush shrubs were subjected to simulated rainfall from a sprinkling type rainfall simulator. Rainfall intensity was 6 cm/h for 30 minutes. This high intensity was selected to ensure that water loss by evaporation would be minimized because the primary objective was to quantify rainfall intercepted and stored by the shrub canopy. Individuals of each species were selected to include the range in size variation within the population of plants at field sites.

Parameters determined for each shrub included: crown cover; shrub height; weight of green leaves; green weight of all stems; oven-dry weight of leaves; oven-dry weight of all stems; number of stems; leaf area; shrub volume; and shrub green weight. After the number of stems were counted and measurements for determining shrub volume were made, the shrub was severed at the soil surface, weighed, and subjected to simulated rainfall for 30 minutes. The shrub was weighed at the end of this period and the difference between these two weights was intercepted rainfall. Leaf area was determined using a leaf area meter. Dry weight of green leaves and stems was determined after being dried at 60°C for 24 and 48 hours, respectively. The shrub crowns were elliptical, thus, both maximum and minimum diameters were measured for determining crown cover using the equation for an ellipse. Shrub volume was calculated by multiplying crown area by shrub height.

The average crown cover of each of the two communities was determined from 10 line intercept transects 30·5 m long. Rainfall interception was calculated for each community on an areal basis utilizing the interception storage data determined from individual shrubs and data from the line transects.

Results and discussion

The results of the present experiments should be considered in the context of the process of water interception. During a rainfall event, there is an initial period when the vegetation canopy is wetted and the interception storage capacity is satisfied. After the storage capacity is satisfied, the excess water above evaporative losses will drip through the canopy onto the soil as throughfall of flow down the stem as stemflow.

Interception by the plant canopy is that fraction of precipitation intercepted by and evaporated from the external surface of the plant (Lee, 1980). The air within the canopy has high humidity during the evaporation process and the energy consumed during evaporation is not available for transpiration. Thus, during the evaporation period, there would be a reduced demand on soil water by plants. This reduction is not, however equivalent to the rate of evaporation because intercepted water evaporates more rapidly than transpiration can occur under the same atmospheric conditions (Lee, 1980).

Canopy storage capacity is the quantity of water that can be held on the aerial portions of the plant and is expressed in the same units as precipitation (i.e., mm). Thus, it is generally expressed as an average depth for a plant community in terms of liquid water equivalents. Interception storage capacity is a function of the amount and configuration of the intercepting surfaces. In a field situation during natural rainfall the amount of intercepted water would be influenced by wind and needs to be assessed. The impact of raindrops may influence water flow across leaf surfaces and also influence the leaf angle. These factors, plus gravitational forces and others that influence leaf surface tension forces will also affect canopy water storage capacity.

Ludwig *et al.*, (1975) used the equation for an inverted cone for calculating canopy volume on a sample of 12 creosotebushes. It was found for this study that determining the canopy volume using the equation for an elliptic cylinder for the 44 creosotebush shrubs to be equally precise. The coefficient of determination being 0·19 for both cases.

The means, standard deviations, and regression equations for 10 canopy components for tarbush and creosotebush plants are given in Tables 1 and 2, respectively. Stepwise regression analysis for maximum R^2 improvements (Helwig & Council, 1979) was used to analyze the data. This method determines the best one variable model, the best two variable model, . . . the best *n* variable model for describing the influences of the measured variables on the water intercepted. The best one variable linear model ($R^2 = 0{\cdot}75$) for tarbush was shrub green weight (leaves plus stems), accounting for 75% of the variability of the intercepted rainfall. A three variable model ($R^2 = 0{\cdot}89$) for tarbush which accounted for 89% of the variability included shrub green weight (leaves plus stems), crown area, and stem dry weight. Leaf area was the best one variable model ($R^2 = 0{\cdot}46$) for creosotebush. The best four variable model for creosotebush included crown cover, shrub height, leaf dry weight, and shrub volume with a coefficient of determination of 0·61. Crown cover is easily measured in the field and was highly significant in the interception process. Therefore, crown cover was used in the development of a generalized equation to describe rainfall interception by the two desert shrubs.

Table 1. *Means (+ S.D.) and regression equations for each of the measured variables for 12 tarbush plants*

Variable	Mean ± S.D.	Regression equation	R^2
crown cover (cm^2)	3800 ± 634	y = 410·9 + 0·19 (x)	0·21
shrub height (cm)	63 ± 8	y = 1374·1 − 3·71 (x)	—
stem green weight (gm)	511 ± 153	y = 762·8 + 0·74 (x)	0·28
stem dry weight (gm)	410 ± 125	y = 764·8 + 0·92 (x)	0·29
leaf green weight (gm)	85 ± 27	y = 789·6 + 4·13 (x)	—
leaf dry weight (gm)	66 ± 19	y = 769·0 + 6·15 (x)	0·43
number of stems	9 ± 5	y = 1004·3 + 14·74 (x)	—
leaf area (cm^2)	194 ± 55	y = 1067·2 − 0·09 (x)	—
shrub volume (cm^3)	239234 ± 55915	y = 849·3 + 0·001 (x)	0·20
shrub weight (gm)	3285 ± 766	y = 483·4 + 0·20 (x)	0·75

Table 2. *Means (± S.D.) and regression equations for each of the measured variables for 44 creosotebush plants*

Variable	Mean ± S.D.	Regression equation	R^2
crown cover (cm^2)	4798 ± 1379	y = 88·5 + 1·25 (x)	0·24
shrub height (cm)	77 ± 12	y = 5755·1 + 4·38 (x)	—
stem green weight (gm)	478 ± 174	y = 1796·0 + 8·99 (x)	0·20
stem dry weight (gm)	349 ± 159	y = 1421·4 + 13·38 (x)	0·36
leaf green weight (gm)	146 ± 65	y = 331·5 + 39·41 (x)	0·52
leaf dry weight (gm)	101 ± 44	y = 257·9 + 58·01 (x)	0·51
number of stems	14 ± 6	y = 2242·6 + 293·30 (x)	0·25
leaf area (cm^2)	5197 ± 2305	y = 333·7 + 1·11 (x)	0·52
shrub volume (cm^3)	372087 ± 130346	y = 1691·7 + 0·01 (x)	0·19
shrub weight (gm)	12000 ± 4636	y = 110·4 + 0·50 (x)	0·43

A test for determining differences between the regression coefficients on the measured variables for the two shrubs was performed using an analysis of covariance. It was concluded that the regression coefficients for stem green weight, crown cover, stem dry weight, and shrub volume for creosotebush and tarbush were significantly different. No significant differences were detected among the regression coefficients for the other variables.

Measurements from 10 line transects in each community were used to calculate crown cover from the creosotebush community and the tarbush community from which the shrubs were selected for this study. Crown cover values for the creosotebush and tarbush communities were 30 and 15% respectively. Calculated interception of artificially applied rainfall was extrapolated to the native creosotebush and tarbush communities. Considering rainfall events of sufficient size to completely wet these shrub communities, the creosotebush communities would intercept 3·6 mm and the tarbush communities would intercept 3·0 mm of rainfall. Therefore, ignoring events of less than 3·6 mm for creosotebush and 3·0 mm for tarbush, a 12% and a 6% loss of summer precipitation would be due to interception by the two shrubs communities, respectively.

The equation describing canopy interception can be written as:

$$L = [a(P) + b]C$$

where: a = empirically determined constant; b = empirically determined constant; C = crown cover expressed as a decimal; L = total water intercepted per event in mm; P = mm of water per rainfall event.

Constants a and b are derived for the site being studied and interception calculated using equation 1. Interception for this study was determined utilizing crown covers of 30 and 15% for the creosotebush and tarbush communities, respectively, and equation 1 for each rainfall event. Using equation 1 and a rainfall event of 25·4 mm, for example, a dense creosotebush community would intercept 0·95 mm and a tarbush community would intercept 0·40 mm. Rainfall events of less than 3·6 mm for the creosotebush community and 3·0 mm for the tarbush community can be disregarded because these rainfall events would result predominantly in the water being intercepted. A summation of intercepted rainfall over time, results in the total seasonal or annual interception losses.

The data from the water interception study may be related to field conditions by using the following analogy. The intercepted precipitation would be expected to be held above the soil surface in proportion to the amount of crown cover and would be subjected to evaporation losses at a rate exceeding that from the soil surface. There was an average of 14 events greater than 3·6 mm and 17 events greater than 3·0 mm that occurred each year from May to 31 October as determined from long-term precipitation records. The average annual precipitation for the experimental site is 230 mm. Approximately 55%, or 126 mm, of the annula precipitation is received during summer.

Total water intercepted and lost to evaporation is a significant quantity of water (Helvey & Patric, 1965). In more arid regions rainfall losses are proportionally smaller than those of higher rainfall areas. Nevertheless, losses may be more important in arid regions because less water is available. In addition, the amount of rainfall received from individual rainfall events is typically small in arid regions. Thus, interception would substract a valuable proportion of the total amount of summer rainfall.

Interception of precipitation by the plant canopies is important hydrologically because it redirects the water balance. Thus, results of plant canopy water interception studies can be used in watershed analyses, water budget analyses, and in modeling efforts directed toward understanding water movement from precipitation within plant communities.

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