Evapotranspiration from a Greasewood–Cheatgrass Community

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Abstract. Groundwater elevation, soil moisture, and precipitation were monitored to evaluate the components of water loss from two greasewood–cheatgrass (*Sarcobatus vermiculatus-Bromus tectorum*) communities in south central Washington. Annual evapotranspiration was 21–25 cm, 18–31% of which was the transpiration of groundwater. The greatest loss from the system was the evapotranspiration of stored soil moisture, but this moisture was unavailable to greasewood. This study confirms that water use rates are a function of depth to water up to 2.3 meters, but indicates a more complicated mechanism at depths of up to 13 meters. Shrub height, canopy coverage, and total leaf surface area are inversely related to depth to water, and the rate of water use is in turn directly related to these plant-associated features.

Semiarid lands of the Pacific Northwest are characterized by low annual precipitation that occurs principally between October and March when evapotranspiration demands are the least. This timing results in the improved efficiency of precipitation in terms of water availability to plants. Most wild plants of the region exhibit life cycles in phase with the relatively moist and cool period of the year. A major exception involves phreatophyte communities and the continuous availability of water to them.

This report describes the water use of a plant community dominated by the greasewood shrub (*Sarcobatus vermiculatus*). During the dry season water is available to greasewood from a groundwater supply perched near the soil surface. The community studied is similar to those that cover thousands of square kilometers of saline areas in the Great Basin [*Robinson,* 1958]. The soil differs somewhat in that salinity is not the result of impeded drainage but rather is a result of the geologic past. The groundwater is not saline although the surface soil is rich in sodium and other cations, especially immediately beneath greasewood shrubs where localized recycling occurs [*Rickard,* 1964; *Rickard and Keough,* 1968].

The relationship between groundwater drawdown and phreatophyte transpiration was recognized as early as 1916 [*White,* 1932]. This relationship has been used in numerous water balance investigations such as the studies of riparian vegetation by *Qashu and Evans* [1967] and the salt cedar (*Tamarix* sp.) tank experiments of *van Hylckama* [1970]. It has also been applied to greasewood in several tank studies [*White,* 1932; *Robinson,* 1970], but our study estimates the water use by naturally occurring undisturbed greasewood plants.

STUDY AREA

The study area is located near Rattlesnake Spring on the Hanford Reservation belonging to the Atomic Energy Commission in south central Washington. Floodplain silts were deposited by backwaters of a Pleistocene lake at the eastern terminus of an anticlinal ridge. Tectonic deformation of these silts formed a broad shallow impervious saucer that has perched water some 30 meters above the regional water table [*Brown,* 1970]. Subsurface water from higher elevation snowmelt and numerous large springs in the drainage basin recharges this perched groundwater. Soils above the impermeable silts are comprised of fine sand and silt occasionally veneered with eolian material and range in depth from 4 meters to more than 13 meters. The exact perimeter of the perched water table is unknown, but the area appearing to influence plant growth roughly coincides with the extent of the greasewood com-

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munity. The area is nearly level and covers approximately 115 ha. Greasewood occurs locally in pure stands but is generally mixed with other shrubs such as spiny hopsage (*Grayia spinosa*) and occasionally big sagebrush (*Artemisia tridentata*). Perennial salt grass (*Distichlis stricta*) and annual cheatgrass brome (*Bromus tectorum*) are the major understory herbs. The area was heavily grazed prior to 1943, grazed intermittently from 1943 to 1960, and ungrazed since 1960.

METHODS

A 250 m^2 circular plot was established in each of two pure stands of greasewood to evaluate water usage associated with obvious physiographic and physiognomic differences. Study plots were 800 meters apart and differed by 15 meters in elevation.

The shrub canopy coverage and leaf area were characterized at each plot. Detailed maps were constructed and canopy coverages were determined by planimetering areas of shrub crowns. The number of branches per shrub crown was determined for 10 shrubs in each plot. One branch was harvested from each of the 10 shrubs and all leaves were removed and dried. Leaf surface areas were calculated for 10-leaf subsamples prior to drying to obtain a ratio of surface area to weight. Leaf weight data were converted to surface areas per plot.

During the 1970 water year (October 1969 through September 1970), groundwater elevations were determined at weekly intervals by lowering a steel tape into observation wells. The study area was instrumented with 29 wells, two of which were used in this comparative study. The wells consisted of 3.8 cm steel conduit placed in holes hand-augered into the groundwater and served also as access tubes for a neutron soil moisture probe. Neutron probe measurements were made at 20 cm increments at least once a month.

The water year was considered to consist of two parts: a recharge period from October through March, and a depletion period from April through September. Transpired groundwater was obtained from the curves of the annual fluctuation of groundwater elevation by a method similar to that used by *White* [1932] and *Troxell* [1936], who calculated transpiration from diurnal changes in groundwater elevation. At the end of each measurement period, the change in groundwater elevation is the algebraic sum of recharge and transpiration during that period, i.e., $\Delta E = R - T$ where ΔE is the change in elevation, R is recharge, and T is transpiration. Rates of recharge R were obtained from the slope of the elevation curve between October 1 and March 1 when greasewood shrubs were leafless and the slope of the groundwater elevation curve thus equaled the rate of recharge. The inverse relationship between the recharge rate and the groundwater elevation [*Troxell*, 1936] was used to estimate the recharge rates for the depletion period. At early spring and late summer transpiration and recharge were equal, and groundwater was at its highest and lowest levels, respectively. Weekly values of T were obtained by multiplying the sum of recharge and drawdown for each measurement period by the specific yield of the aquifer. Textural properties of the soil samples taken from the zone of fluctuating groundwater were determined by the hydrometer method [*Day*, 1965] and related to the aquifer texture and specific yield relationships discussed by *Todd* [1959].

RESULTS AND DISCUSSION

Table 1 compares the structural features between the study areas. Gross differences include depth to the water table and shrub characteristics. The soil-related features of the aquifer region are very similar.

Functional relationships are expressed in Figure 1. The groundwater elevations were highest

TABLE 1. Comparison of Plot Characteristics for Two Greasewood Stands

	Plot A	Plot B
Depth to water table, meters	7.1	12.7
Soil textural class	loam	loam
Sand, %	44	44
Silt, %	48	49
Clay, %	8	7
Aquifer specific yield, %	15	15
Number of shrubs per 250 m^2	29	29
Average shrub height, meters	1.7	0.8
Canopy coverage, %	42	21
Total leaf surface area, m^2	71.5	11.0

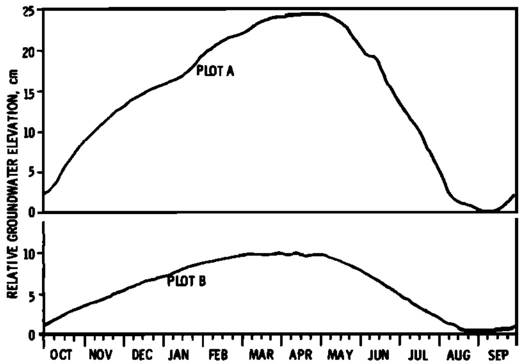

Fig. 1. Annual fluctuation of groundwater elevation beneath two greasewood stands. Elevation of plot B was 15 meters higher than that of plot A.

and lowest nearly at the same time at each site. When the elevation data were converted to express greasewood transpiration, curves indicating the periods of actual water use resulted. Weekly values of T are plotted in Figure 2 and show that annual transpiration at each plot began in mid-March, coincident with the emergence of greasewood leaves, and continued at low rates throughout April and early May while the leaves were expanding. Maximum rates occurred in June followed by decreasing rates through July and August. Transpiration apparently ceased in late September although green leaves persisted until about November 1.

The effect of a cool cloudy period between June 8 and 16 is evident in Figure 2. The elevation measurement on June 18 at plot A revealed no change in water level, and indicated reduced transpiration. Although this effect was not similarly noted at plot B, it was detected at several wells of similar depth in greasewood stands in the vicinity of plot B.

The rate of groundwater use by phreatophytes such as greasewood is a function of depth to water and vegetation density when the water table is within 2.3 meters of the ground surface [*Robinson,* 1958]. Our results indicate that the relationship can be more complicated when a greater depth to water is considered. Data given in Tables 1 and 2 indicate that the greasewood community at plot A used more than twice the amount of groundwater as that used at plot B, where the water table was nearly twice as deep. Shrub height, canopy coverage, and total leaf surface area are inversely related to depth to water. A greater crown density and a closer spacing of shrubs in plot A not only caused the shading of interior leaves, but also probably reduced the transport of water vapor and advective energy. Shrubs in plot B, however, had thin crowns and were more widely spaced. The shading was considerably less, and the transport of water vapor and advective energy was enhanced within individual crowns. These differences between plots could account for only a two-fold difference in water use associated with over a six-fold difference in leaf area. The commonly noted reduction in the number of roots with increasing depth and other features such as internal resistance to water movement may also be important rate-determining factors. Thus community structure appears to be a

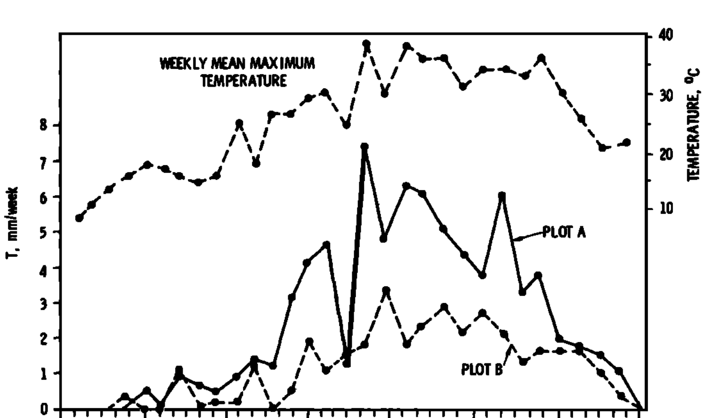

Fig. 2. Weekly transpiration of groundwater by two greasewood stands. The top curve is air temperature measured at 1.3 meters aboveground.

TABLE 2. Sources of Gain or Loss of Water at Each Greasewood Study Plot

	Plot A	Plot B
Recharge period (Oct.–March)		
Precipitation	14.9	14.9
Soil moisture	12.7	13.2
Evapotranspiration loss	2.2	1.7
Depletion period (April–Sept.)		
Precipitation	2.2	2.2
Soil moisture use	12.7	13.2
Groundwater use by greasewood	7.7	3.7
Evaporation loss	2.2	2.2
Annual evapotranspiration	24.8	20.8

All values are given in centimeters.

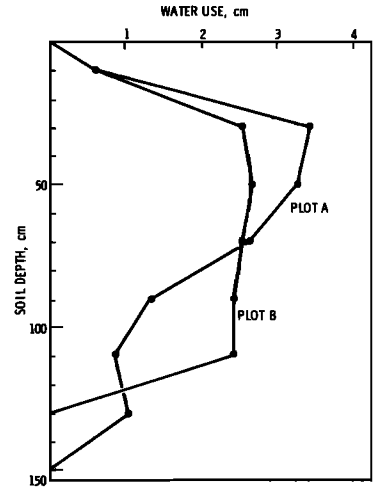

Fig. 3. Profiles of soil moisture use by two greasewood–cheatgrass communities. Values are based on differences in soil moisture for March and October and show the percolation depth for each plot.

function of depth to water, and in turn the rate of water use is related to community structure.

During the recharge period most of the precipitation that occurred in the area was stored as soil moisture. Soil moisture use from the upper 1.5 meters of soil profile during the 1970 water year is shown in Figure 3. The values given are the differences between the amounts of soil moisture present in March and in October. Although vertical distribution of soil moisture use differed slightly between plots, total uses were quite similar. Plot A used 12.7 cm whereas plot B used 13.2 cm. These amounts correspond to 85–89% of the precipitation measured at the study area during the recharge period. The other 11–15% was lost by evaporation and transpiration from cheatgrass prior to the greasewood growing season. Spring and summer precipitation amounted to 2.2 cm and was lost mainly by evaporation. The water balance of each plot is summarized in Table 2.

The calculations of groundwater use may be significantly underestimated because of the availability of specific retention water remaining in the capillary fringe as the water table drops. Specific retention is analogous to soil moisture at field capacity and we estimate the former at 20% for both plots. If we assume that the lowest water content of the soil layer between the precipitation zone and the capillary fringe (5% by volume) approximates the lower limit of water availability, 1.5 cm of water per 10-cm depth increment would be available for uptake. The water table dropped about 25 cm at plot A and about 10 cm at plot B for the year. If half the available water were used, about 1.9 and 0.8 cm additional water at plots A and B, respectively, could have been used during the year. Hence groundwater use, as noted in Table 2, could be underestimated by 20% at plot A and 18% at plot B.

Greasewood typically grows where the habitat provides water at low tensions, and it is probable that this is an essential requirement. Where groundwater is present the maximum rooting depth is governed by the depth to a saturated zone, and the shrub is normally deep-rooted but has some shallow roots at least near the soil surface. Studies in the same locality of soil moisture from precipitation recharge [*Rickard*, 1967] indicate the difference between cheatgrass and greasewood phenologies results in a reduction of stored soil moisture available to greasewood. That is, cheatgrass matures early in the spring and uses most of the soil moisture stored for that season. By the time greasewood is in full growth it must use deeper sources of water. Thus data presented on the water table drawdown and calculations of the rate of water use closely represent actual water transpired by the shrubs. The influence of evaporation on groundwater fluctuation is nonexistent at the depths to water studied here.

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