Rainfall Interception by Midgrass, Shortgrass, and Live Oak Mottes

T.L. THUROW, W.H. BLACKBURN, S.D. WARREN, AND C.A. TAYLOR, JR.

Abstract

Interception, as a function of simulated rainfall intensity and duration, was determined for a midgrass [sideoats grama (Bouteloua curtipendula (Michx.) Torr.)] and a shortgrass [curleymesquite (Hilaria belangeri (Steud.) Nash)]. In addition, the redistribution of natural precipitation via plant interception was determined for live oak (Quercus virginiana Mill.) mottes. Interception storage capacity for sideoats grama and curleymesquite was 81 and 114% of dry weight, respectively. This difference was attributed to physical characteristics of the species and their respective growth forms. However, because sites dominated by sideoats grama had more standing biomass (3,640 kg ha⁻¹) than sites dominated by curleymesquite (1,490 kg ha⁻¹), it was estimated that a sideoats grama dominated site had an interception storage capacity of 1.8 mm compared to curleymesquite dominated site with an interception storage capacity of 1.0 mm. Based upon precipitation event size and distribution for the study site at the Texas Agricultural Experiment Station near Sonora, Texas, the estimated interception loss for curleymesquite dominated sites was 10.8% of annual precipitation, compared to 18.1% interception loss for sideoats grama dominated sites. Only 54% of the annual precipitation reached mineral soil beneath the oak mottes as throughfall or stemflow. The remainder of the precipitation was intercepted by the motte canopy or litter layer and evaporated. Due to the water concentrating effect of stemflow, soil near the base of trees received about 222% of annual precipitation. Soil at a distance greater than approximately 100 mm from a tree trunk received only 50.6% of annual rainfall. Individual tree canopy width, height and depth measurements were insignificant predictors of stemflow and throughfall. Interception, throughfall and stemflow, expressed as percent of storm precipitation, were well-defined curvilinear functions.

Key Words: standing crop, rainfall intensity, rainfall duration, throughfall, stemflow

Availability of water is one of the predominant factors influencing rangeland productivity. It has been demonstrated that plant interception can substantially influence the water budget of an area (Clark 1940, Kittredge 1948, Helvey and Patric 1965, Delfs 1967, Corbett and Crouse 1968, Douglass 1983, Hibbert 1983, and Seastedt 1985).

To date, grass interception research has been characterized by a diversity of techniques that includes simulating rainfall on grass clippings arranged in a wire basket (Beard 1956), sealing the soil surface and measuring the amount of runoff (Corbett and Crouse 1968), measuring the amount of water that reached a collection area below grasses that had been cut at the soil surface and placed on a screen over a funnel (Clark 1940), or the use of interceptometer pans (Clark 1940). Clark (1940) reported that interception losses by big bluestem (Andropogon gerardi Vitman.), a tall grass 560 to 910 mm in height, ranged from 57 to 84% of simulated rainfall applied by liters of 8 mm for a duration of 30 minutes. He likewise determined the interception losses by buffalo grass (Buchloe dactyloides (Nutt. Engelm.), a shortgrass, to be 17 to 74% of simulated rainfall applied at intensities on 3 to 13 mm for a duration of 30 minutes. Haynes (1940) estimated interception loss by Kentucky bluegrass (Poa pratensis L.) to be 56% of annual precipitation. Beard (1956) estimated interception loss from a South African grassland composed primarily of Themeda spp. and Cymbopogon spp. to be about 13% of annual rainfall. Kittredge (1948) estimated net interception of a California grassland composed primarily of Avena spp., Stipa spp., Lolium spp. and Bromus spp. to be about 26% of annual precipitation. Few attempts have been made to express interception as a function of biomass or cover, even though these factors have been identified as major sources of potential variation (Clark 1940, Haynes 1940).

It has been documented that some tree species intercept a greater percent of annual precipitation than others (Kittredge 1948, Helvey and Patric 1965, Helvey 1971). Generally, coniferous and hardwood (with leaves) species interception loss averages about 30 and 13%, while stemflow is approximately 3 and 5%, respectively of the annual precipitation. Canopy interception by shrubs has been documented by relatively few studies (Tromble 1983) with interception losses ranging from 4 to 50% depending upon canopy density and species. Shrub interception studies have been mostly restricted to California chaparral species (Hamilton and Rowe 1949) or juniper (Skau 1964, Young et al. 1984) whose interception losses averaged about 13 and 18%, respectively, of annual precipitation. Litter interception is largely determined by the amount of litter accumulated and its drying rate (Helvey and Patric 1965). Maximum water holding capacity of eastern forest litter, expressed as a percent by weight, has been reported to range from 215% (Helvey 1964) to 263% (Bernard 1963).

Watersheds where vegetation cover has been converted from shrub to grasses have yielded significantly greater amounts of water in areas receiving more than 457 mm of annual precipitation (Burg and Pomroy 1958, Corbett and Crouse 1968, Hibbert 1983). Increased runoff associated with conversion of shrub cover to grass cover has generally been attributed to lower water use by grasses when compared to shrubs. However, investigators have documented that interception can be an important loss in addition to transpiration losses (Thorud 1967, Rutter 1967, Nicolson et al. 1968, Waggoner et al. 1969 and Murphy and Knoerr 1975).

Sideoats grama [Bouteloua curtipendula (Michx.) Torr.] and curleymesquite [Hilaria belangeri (Steud.) Nash] are the dominant bunchgrass and shortgrass over much of the Edwards Plateau region of Texas. Live oak (Quercus virginiana Mill.) is a sclerophyllous, evergreen, low-growing tree that covers 20 to 50% of the rangeland on the Edwards Plateau. The objectives of this study were: (1) to determine the relationship of interception storage to storm intensity and duration for bunch-type midgrass (sideoats grama) and sod-type shortgrass (curleymesquite) growth forms; and (2) to characterize interception by live oak motte canopy and litter, and the degree to which throughfall and stemflow redistribute the water reaching the soil. This project was part of a larger project supported by USDA, Soil Conservation Service RCA Special Study No. 7442-4-2800 and USDA, Science/Education Grant No. 83-CR-51-2266. The authors gratefully acknowledge the assistance of personnel of the Texas Agricultural Experiment Station at Sonora, Tex. Special thanks to S.L. Hennefer for typing the manuscript.

Manuscript accepted 24 April 1987.
effort to determine the influence of vegetation manipulation on the water budget.

**Study Area**

Research was conducted at the Texas Agricultural Experiment Station, located 56 km south of Sonora at 632 m elevation, in Edwards and Sutton Counties, Texas (30° N; 100° W). The rolling stoney hilltopography that characterizes the station is typical of the Edwards Plateau. Annual median precipitation, 1918–1984, was 438 mm and ranged from 156 mm to 1,054 mm. The annual mean precipitation for the same period was 609 mm. Such a wide disparity between the mean and median annual precipitation is indicative of the annual variability caused by frequent droughts and occasional very wet years. Cool-season precipitation is generally the result of frontal storms, whereas warm-season precipitation occurs from brief, intense convective storms. The mean frost-free period is 240 days.

Currently, the region’s vegetation is a mixture of grasses, forbs, and woody species. Woody plant distribution is often clustered, with dominant species being live oak, ash juniper (Juniperus ashei Buchh.), and honey mesquite (Prosopis glandulosa Torr. var. glandulosa). The dominant midgrass is sideoats grama and the dominant shortgrass is curlymesquite. Oak mottles at the study site were characterized by a dense monospecific canopy with sparse understory and heavy litter accumulation.

**Methods**

**Midgrass and Shortgrass**

During July, 1984, monospecific 300 by 300-mm squares of sideoats grama and curlymesquite sod were excavated and placed into a square wire mesh container of the same size. The plants were actively growing, and the standing crop was typical of natural variation of the study site. The container held the soil and root portion of the grasses together and thus maintained the original configuration of the grasses. These grass sample units were taken to the laboratory where simulated rain was applied within minutes of collection. Moisture content of excavated grass sample units was determined by clipping adjacent representative samples of grass, weighing the samples, drying them at 60°C for 48 hours and reweighing them.

Water was applied to the grass sample using a drip-type rainfall simulator (Blackburn et al. 1974). Ten sample plots of each grass species for each rainfall intensity/duration combination were used. The following combinations of rainfall intensity and duration were used: intensity of 25 mm h⁻¹ for a duration of 1, 2.5, 5, 7.5, 10, 15, and 20 minutes; intensity of 114 mm h⁻¹ for a duration of 0.3, 0.6, 1, 2.5, 5, 7.5, and 10 minutes; and 5 minutes duration with an intensity of 25, 50, 90, 114, 150, and 175 mm h⁻¹. The rainfall intensity/duration combinations were selected to establish interception response curves and to determine the interception storage capacity of the grasses. At the conclusion of the simulated rainfall, the samples were carefully placed in a freezer (−46°C) that was adjacent to the rainfall simulator. Water intercepted by the grasses was frozen within 5 minutes. The frozen grasses were clipped at the soil surface while in the freezer, and then weighed. The grass sample was composed of live and dead standing crop. Detached litter lying on the soil surface was not included in the sample. The grass was then dried at 60°C and weighed again. The difference between frozen grass weight and dried grass weight represented the sum of the plant water content and intercepted water. Water intercepted by the grass standing crop (expressed as percent of grass dry weight) was calculated by subtracting the percent moisture content of the representative grass sample (estimated from the moisture content data collected from grass of the same species growing adjacent to the excavated grasses) from the percent plant water content and intercepted water retained by the grasses after simulated rainfall. An analysis of variance was conducted to determine species’ differences in interception of simulated rainfall.
vided data needed to construct a curve of litter interception as percent of storm intensity.

All statistics were calculated using SAS Institute Inc. (1985) procedures. Regression analysis was used to determine the degree of association between variables. Analysis of variance techniques were conducted to determine if differences between oak mottes existed for throughfall, stemflow, or litter accumulation (Steel and Torrie 1980). Significance levels were determined at $p \leq 0.05$.

Results and Discussion

Midgrass and Shortgrass

Curlymesquite and sideoats grama represent 2 different grass growth forms. Curlymesquite is a stoloniferous species with flat blades (50–200 mm long and 1–2 mm wide) that are pilose (1–2 mm long). The slender stolons grow horizontally along the soil surface and are characterized by wiry internodes and pubescent nodes. In contrast, the sideoats grama at the study site is characterized by a bunch growth form that has flat to subinvolute blades (20–300 mm long and 2–4 mm wide) with scattered hairs only along the blade edges. During the 7-year period (1978–1984), curlymesquite dominated sites had a mean foliar cover of 56% and a mean standing crop of 1,490 kg ha$^{-1}$. Sites dominated by sideoats grama had a mean foliar cover of 62% and a mean standing crop of 3,640 kg ha$^{-1}$.

It is hypothesized that the pilose blades and the horizontal growth form of curlymesquite aided water retention, compared to the relatively vertical smooth blades of sideoats grama. The length of time needed to reach the storage capacity of the grasses varied with rainfall intensity. Interception storage capacity per unit dry weight was exceeded after 8 minutes for the 25 mm h$^{-1}$ rainfall event (Fig. 1) and after 5 minutes for the 114 mm h$^{-1}$ event (Fig. 2). Likewise, storage capacity was exceeded by storm intensity of 40 mm h$^{-1}$ for 5 minutes (Fig. 3).

The greater potential for curlymesquite foliage to intercept water is offset by a lower standing crop production potential when compared with that of sideoats grama. Consequently, the interception storage capacity was significantly greater for sideoats grama-dominated sites (1.8 mm) than for curlymesquite-dominated sites (1.0 mm). These values are comparable with the estimated storage capacity of 1.1 mm for a mixture of fescue (Festuca spp.) and soft chess (Bromus mollis L.) (Burgy and Pomeroy 1958). Based on the 10-year mean storm size distribution of the study site, interception loss from curlymesquite-dominated sites would be 10.8% of annual precipitation compared to 18.1% loss from sideoats grama-dominated sites. Interception loss corresponds to the amount of grass standing crop and would thus be greatest during the growing season and lowest during the dormant season.

Live Oak Mottes

Most rainfall at the study site occurred as convective or frontal storms which were characteristically intense, short duration events. Analysis of data showed no significant differences for stemflow or throughfall attributable to duration or intensity of storm. Seasonal variability was not evident due to the evergreen nature of the live oak foliage. Thus, storm size was the principal determinant of stemflow and throughfall. In addition, there were no differences in stemflow, throughfall, or litter accumulation among the 4 mottes monitored in this study; therefore, data from the 4 mottes were pooled.

The mean foliar cover above the throughfall receptacles was 42% and ranged from 3 to 85% with a standard deviation of 25.3. Mean absolute cover was 124% and ranged from 5 to 400% with a standard deviation of 107.6. For small rainfall events, percent throughfall was approximately the inverse of percent foliar cover (Fig. 4), implying that most of the water striking foliage was held within the canopy. As storm size increased, percent throughfall increased due to drip loss from the canopy, and eventually became fairly

Fig. 1. Interception as percent of dry standing crop across time for a rainfall intensity of 25 mm h$^{-1}$. Vertical bars indicate confidence limits ($p \leq 0.05$). Interception response curves denote predicted dependent variables from an intuitive model based on the exponential saturation growth function.

Fig. 2. Interception as percent of dry standing crop across time for a rainfall intensity of 114 mm h$^{-1}$. Vertical bars indicate confidence limits ($p \leq 0.05$). Interception response curves denote predicted dependent variables from an intuitive model based on the exponential saturation growth function.

Fig. 3. Interception as percent of dry standing crop after a rainfall duration of 5 minutes. Vertical bars indicate confidence limits ($p < 0.05$). Interception response curves denote predicted dependent variables from an intuitive model based on the exponential saturation growth function.
Table 1. Distribution of annual rainfall within oak mottes based on the 10-year average storm size distribution at the study site, Edwards Plateau, Texas.

<table>
<thead>
<tr>
<th>Water (mm)</th>
<th>Percent of Annual Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual precipitation</td>
<td>523</td>
</tr>
<tr>
<td>Throughfall</td>
<td>373</td>
</tr>
<tr>
<td>Canopy interception</td>
<td>133</td>
</tr>
<tr>
<td>Litter interception</td>
<td>108</td>
</tr>
<tr>
<td>Water reaching mineral soil</td>
<td>282</td>
</tr>
</tbody>
</table>

throughfall estimates developed on eastern deciduous hardwoods may not be representative of tree growth forms in semiarid regions.

Stemflow did not begin on most trees until gross precipitation exceeded 7 mm, but increased thereafter in a pattern similar to throughfall (Fig. 4). The mean dbh of the 46 collared trees was 90 mm (range 23–229 mm; SD = 48 mm). The mean canopy diameter was 1.6 m (range 0.6–4.2 m; SD = 0.9 m). The mean tree height was 3.8 m (range 1.7–7.0 m; SD = 1.2 m). These values were poorly correlated with stemflow ($R^2 < 0.2$). The canopy volume and indices composed of various combinations of the measured variables also yielded low coefficients of determination ($R^2 < 0.28$). The greatest coefficient of determination was obtained by correlating stemflow with an index composed of canopy depth divided by canopy width ($R^2 = 0.28$). This index provides a general quantification of canopy shape (i.e., gradient ranging from tall and narrow to short and broad). This index to stemflow is intuitively sound since tall, narrow canopies have the potential to funnel more water down the trunk compared to broad, shallow canopies that have a horizontal branching structure with many potential drip points. Unmeasured variables such as branch angles, drip points along branches, bark roughness, lichen growth on bark, etc., are apparently important factors for predicting individual tree stemflow. Nevertheless, mean stemflow of the sample population was very predictable and the quadratic curve which fit the data accounted for a significant portion of the sample variation. The stemflow at the study site was 3.3% of annual rainfall (Table 1). This value is comparable to estimates summarized by Kittredge (1948) and Helvey and Patric (1965).

I litter biomass under oak mottes averaged 41,300 kg ha$^{-1}$. This degree of accumulation is relatively high when compared to litter accumulation in most other regions of the country (Helvey and Patric 1965). The high accumulation of litter under live oaks in the study region may be attributable to the sclerophyllous oak leaves which are resistant to decomposition, the semiarid climate and low moisture availability which deter microbial decomposition, and the absence of fire. The 210% maximum interception by litter was similar to previously reported values of 225% (Blow 1955) and 215% (Helvey 1964). The minimum water content of litter was 17% which is similar to reported values of 20% (Blow 1955), 22% (Semago and Nash 1962) and lower than 40% reported by Helvey (1964).

The percent of precipitation intercepted by litter and oak canopy from storms of various sizes is illustrated in Figures 5 and 6. The percent precipitation reaching mineral soil based on a series of storm sizes is shown in Figure 7. On the average, 53.9% of the annual rainfall actually reaches the soil, 25.4% is lost by canopy interception and 20.7% by litter interception (Table 1). Distribution of water reaching the soil under the oak motte is variable. Stemflow concentrates water at the base of the trunks. Mean water
Infiltration rate into oak motte soil was 199 mm hr⁻¹ (Thurow et al. 1986). Based on a mean stemflow of 955 ml per storm event, a radius of about 100 mm around the trunk would be needed to fully accommodate infiltration of the stemflow. This means that a 100 mm radius of soil around the tree would receive approximately 222% of annual precipitation, whereas the soil under the canopy farther than 100 mm away from the trunk would receive only 53.9% of annual precipitation. This concentration of water at the base of the trees represents an effective water harvesting factor that could be an important mechanism of water and nutrient supply. Areas away from the tree trunks receive less rainfall, making it a drier environment for plant establishment and growth.

Interception data collected on live oak mottes (the dominant shrub species on the study site) confirm the intuitive expectation that shrub cover intercepts more than grasses. Live oak motte interception loss by the canopy was 25.4% of the annual precipitation. This implies that canopy interception losses from the shrub component may be 2.4 times greater than losses by the grass-dominated interspaces. Infiltration rate under oak mottes (199 mm hr⁻¹) is greater than for midgrass sites (162 mm hr⁻¹) or shortgrass sites (109 mm hr⁻¹) (Thurow et al. 1986). Shifts in the kind and amount of vegetation on the Edwards Plateau have the potential for greatly influencing the hydrologic water balance and, to a large extent, determining the amount of rainfall retained, lost, or yielded from a watershed.

**Literature Cited**


