Effect of honey mesquite on the water balance of Texas Rolling Plains rangeland

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Abstract

Understanding hydrologic processes on rangelands is essential to determine if water yield will increase through shrub management. Nine nonweighable lysimeters were monitored for 3 years to determine the water balance as influenced by vegetation. Cover types studied were honey mesquite *(Prosopis glandulosa)* plus herbaceous vegetation (M+H), mesquite removed leaving only herbaceous vegetation (H), and mesquite and herbaceous vegetation removed (BG). Throughout the study, BG lysimeters had greater soil water content than the vegetated sites but, regardless of cover type, only 0.5–1.4% of precipitation drained below 3 m. Runoff and interrill erosion were closely associated with rainfall amount, peak short-term storm intensity, and amount of bare ground. Evapotranspiration accounted for over 95% of water leaving the vegetated sites. Herbaceous vegetation on the H lysimeters increased following mesquite removal. This increase offset any water yield benefit that may have accrued through shrub management. Results indicate that there is essentially no net change in deep drainage, evapotranspiration, or runoff on sites where the herbaceous component increases in response to shrub removal.

Key Words: water balance, lysimeter, shrub management, water yield, interrill erosion

Rangeland watersheds are the source of most surface flow and aquifer recharge in the Southwestern U.S. (Hibbert 1979). Rangeland management practices which affect vegetation cover and composition can affect both on-site and off-site water availability. Water yield augmentation through vegetation manipulation is theoretically feasible by replacement of deep-rooted species with shallow-rooted species that consume less water (Davis and Pase 1977). The current policy debate in the Southwest about shrub management for water yield enhancement has not advanced beyond the initial question of how much additional water could be made available as a result of widespread shrub control. There is a need for additional studies of the relationship between vegetation cover type and hydrology before supply forecasts and economic analyses of shrub management can be assessed (Griffin and McCarl 1989).

Hydrologic responses vary greatly depending on vegetation, soils, and climate (Ponce and Meiman 1983). The great diversity of these factors on rangelands complicates predicting the water balance and leads to diverse opinion regarding the potential for increased water yield as a result of vegetation manipulation. Hibbert (1983) estimated about 6 mm of additional water yield could be expected in Arizona for each 25 mm of annual precipitation in excess of 384 mm following elimination of woody species. This would occur principally from increased subsurface flow and ground water recharge.

Approximately 40 million ha of Texas rangeland is dominated by woody shrubs and trees, prompting speculation that shrub removal in Texas could also result in an increased supply of water for off-site use (Griffin and McCarl 1989). Preliminary research in Texas (Richardson et al. 1979, Weltz 1987, Franklin 1987) suggests that expected water yields would generally fall below those predicted by Hibbert's (1983) hypothesis. Additional research is required to understand the hydrologic processes determining the water balance on rangelands. The objective of this study was to determine the influence of type of vegetation cover on water balance and interrill erosion in the Texas Rolling Plains.

Study Area

The study area was located on the eastern edge of the Rolling Plains resource region within a 16-ha livestock exclosure approximately 22 km north of Throckmorton, Texas (33° 20'N, 99° 14'W). Climate is semiarid continental. Annual precipitation (1950–1988 median = 646 mm) was bimodal, with peaks occurring in May and September (Fig. 1). Average maximum/minimum daily temperatures ranged from 13.1/–2.6° C in January to 36.1/21.2° C in July. The average frost-free growing period was 220 days. Elevation of

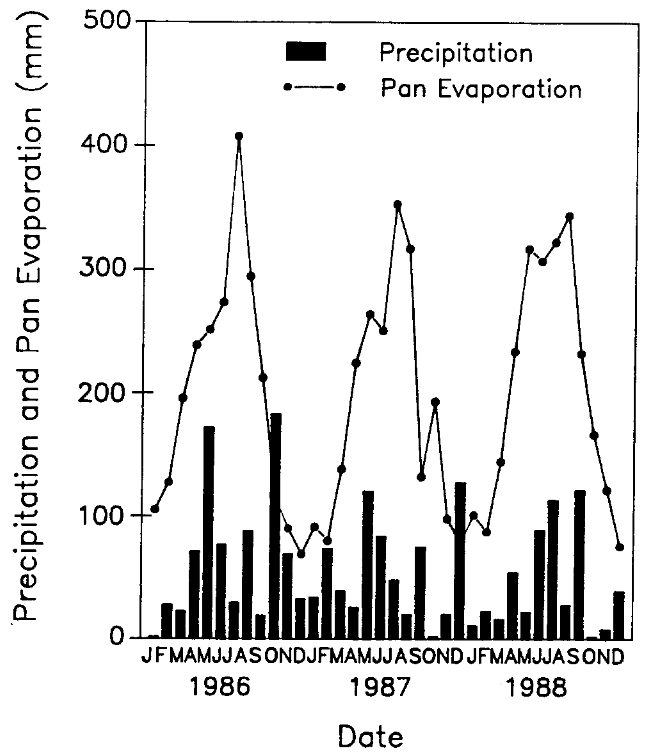

Fig. 1. Monthly precipitation and pan evaporation (mm) throughout the study period.

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the study site is 450 m.

Soils are fine, silty, mixed, thermic Typic Calciustolls (Nuvalde silty clay loam) that are deep, well-drained, and slowly permeable. This soil type is located on upland slopes (1–3%) formed from limey alluvium or outwash (SCS 1984). The silty clay loam surface is approximately 280 mm thick, and the silty clay loam subsoil is about 560 mm thick. The underlying parent material is calcitic silty clay. Range site classification is clay loam. The potential climax community is estimated to consist of 90% grasses, 10% forbs, and a trace of woody plants (SCS 1984). The dominant midgrasses found on the site are sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), a warm-season perennial, and Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.), a cool-season perennial (Heitschmidt et al. 1985). Subdominant graminoides are: meadow dropseed (*Sporobolus asper* (Michx.) Kunth.) and red threeawn (*Aristida longesita* Steud.), warm-season perennial midgrasses; buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) and common curlymesquite (*Hilaria belangeri* (Steud.) Nash), warm-season perennial shortgrasses; and Japanese brome (*Bromus japanicus* Thumb.), a cool-season annual. Dominant forbs are heath aster (*Aster ericoides* L.) and Texas broomweed (*Xanthocephalum texanum* (DC.) Shinners). A virgin stand of honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa)* is the dominant woody species on the site, providing about 30% canopy cover.

Methods

Site Preparation

In July 1985, 9 mature honey mesquite trees of similar size (trunk basal diameter about 0.18 m, canopy area about 12 m^2) were selected as sites for placement of nonweighable lysimeters. Trenches about 1 m beyond the canopy drip-line were cut around each tree to a depth of 2.5 m. The inner trench wall was lined and sealed with 2 layers of 6 mil plastic to prevent lateral movement of water and root extension. The trenches were back-filled, and fiberglass partitions extending 0.2 m above the soil surface were placed around the perimeter and sealed to the plastic sheets to prevent overland flow from entering or exiting the lysimeters. Area of lysimeters ranged from 15.0 to 26.7 m^2.

Three treatments were established for study. The honey mesquite trees in 6 lysimeters were killed by cutting and removing the trees, and treating the stumps with 1 liter of diesel oil. Of these 6 lysimeters, 3 were left with the herbaceous component intact (H treatment) and 3 were completely denuded (no litter) and treated with tebuthiuron (BG treatment). The herbaceous and woody cover in the 3 remaining lysimeters was not disturbed (M+H treatment).

Field and Laboratory Techniques

Detailed soil profile descriptions were made for each lysimeter before the trench was back-filled. Soil samples were collected from each horizon and analyzed for soil texture by the particle size distribution technique (Gee and Bauder 1986), bulk density by the core method (Blake and Hartge 1986), desorption using a pressure plate apparatus (Klute 1986), hydraulic conductivity by the constant head method (Klute and Dirksen 1986), soil organic matter content using the Walkley-Black technique (Nelson and Sommers 1986), and soil aggregate stability by the wet-sieve method (Kemper and Rosenau 1986).

Herbaceous standing crop was monitored at approximately 1-month intervals from March through November of 1986–1988 using the nondestructive 10-point frame technique (Levy and Madden 1933). Hits per pin were recorded by species or species group as live lamina, dead lamina, or stem along permanent transect lines. Similar areas outside lysimeters were sampled to establish the relationship between frequency of hits and standing crop biomass and cover. Leaf area index (LAI) by species group and litter cover were also determined. Herbaceous vegetation above 50 mm height was mowed in February of each year to prevent excessive layers of litter and standing dead from accumulating. For a more detailed description of herbaceous vegetation methodology, refer to Heitschmidt and Dowhower (1991).

A micrologger weather station was used to monitor ambient atmospheric conditions at the site. Maximum, minimum, and average daily air temperature and total precipitation, storm duration and intensity (5-minute intervals) were measured. Runoff measurements were taken from lysimeters by funneling surface runoff through a trough attached to the downslope side of each lysimeter. In-line filters trapped sediment prior to the runoff being automatically pumped through a water meter. Volume of runoff was divided by the area of the lysimeter to obtain runoff in millimeters. Sediment trapped by the filters was oven-dried and weighed. In addition, a 1-liter subsample of runoff passing through the water meter was collected. This subsample was filtered through a tared Whatman #1 filter, oven-dried, weighed, and converted to sediment production based on total runoff. Total sediment collected from each lysimeter was expressed as kg ha^{-1} based on area of the lysimeter.

Volumetric soil water content was monitored in five 3.1-m access tubes per lysimeter using a calibrated neutron moisture gauge. Weekly measurements were taken at 0.18, 0.38, 0.60, 0.88, 1.15, 1.45, 1.70, 2.15, 2.60, and 3.05 m below the soil surface. Total soil water (mm) in each lysimeter was determined by weighting each volumetric reading by the thickness of the corresponding soil layer. Net inputs of water into each soil layer were calculated on a monthly basis. Deep drainage was defined as those inputs reaching the 3.05-m layer.

Evapotranspiration was calculated on an annual basis from the water balance equation: $ET = P - R - D \pm S$; where ET = evapotranspiration including interception losses, P = total precipitation, R = runoff, D = deep drainage, and S = soil water content. Data were analyzed using analysis of variance procedures (SAS Institute 1988). Where appropriate, means were separated using the Duncan's New Multiple Range Test. Significant levels were determined at $P < 0.05$. Treatment differences discussed are significant unless stated otherwise. Stepwise multiple regression analysis determined the relationship between runoff and interrill erosion and selected variables that characterized soil (surface antecedent soil moisture, bulk density, texture, hydraulic conductivity, organic matter, and aggregate stability), vegetation (mid-grass, shortgrass, forb and total standing crop and LAI, litter, and bareground), and storm event (total precipitation, short-term intensity, and storm duration). Variables entered into regression models were significant at $P<0.05$.

Results and Discussion

Soil Water Content

Soil water content (SWC) was closely linked to precipitation patterns. The 3-year mean SWC of the entire soil profile was greater in the BG treatment (736 mm) than in the H (629 mm) treatment, and the SWC of the H treatment was greater than that of the M+H (593 mm) treatment. The SWC in the BG treatment was greater than in H and M+H treatments at all depths except 2.60 and 3.05 m (Fig. 2). At these 2 depths H lysimeters had greater SWC. The H lysimeters had greater SWC than M+H lysimeters at 0.18 m and at all depths below 0.88 m. The M+H treatment had greater SWC at depths between 0.18 and 0.88 m. Unconsolidated caliche layers at approximately 1.30 m (hydraulic conductivity = 20 mm hr^{-1}) and 2.38 m (hydraulic conductivity = 0.01 mm hr^{-1}) accounted for the sharp breaks in SWC curves associated with all treatments. The H and M+H treatments had similar SWC in the top 1.3 m of soil (i.e., above the first caliche layer) in winter and

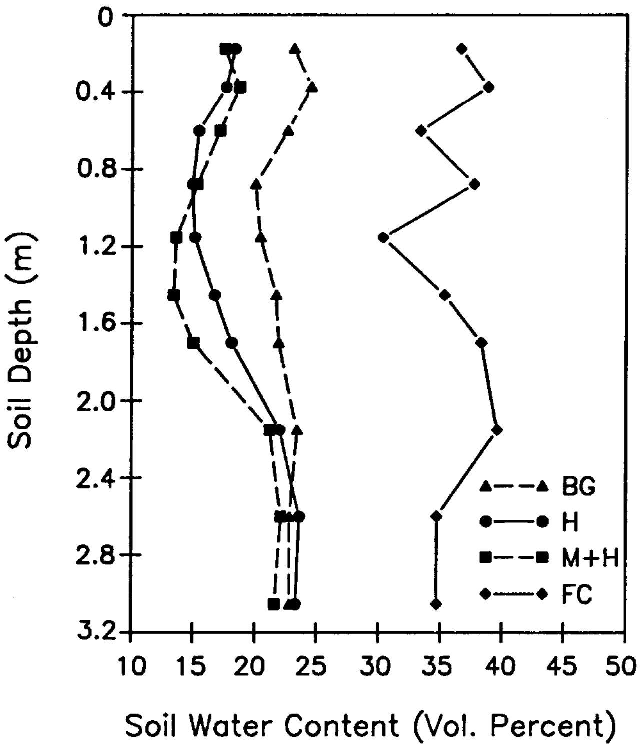

Fig. 2. Weekly mean soil water content (volumetric percent) at various depths (m) in the bareground (BG), herbaceous (H), and herbaceous plus mesquite (M=H) treatments averaged across all dates (N=2250). Field capacity (FC) is also shown.

Table 1. Seasonal 3-year average soil water content (mm) in bareground (BG), herbaceous (H), and herbaceous plus mesquite (M+H) treatments at 3 depths in the soil profile.

		Treatment		
Soil depth	Season	BG	H	M+H
0–130 cm				
	Winter	288b	238a	233a
	Spring	299b	223a	219a
	Summer	288c	182a	192b
	Fall	275c	189a	197b
130-238 cm				
	Winter	240c	205b	183a
	Spring	247c	218b	188a
	Summer	244c	207b	184a
	Fall	235c	196b	180a
238-327 cm				
	Winter	203b	209c	195a
	Spring	208b	213c	199a
	Summer	207b	212c	198a
	Fall	204b	210c	195a

[1]Means in a row followed by the same letter are not significantly different ($P<0.05$).

spring (Table 1). In summer and fall, however, H lysimeters had less SWC than did M+H lysimeters in this zone.

The consistently greater SWC of the BG treatment compared to the vegetated treatments supports the findings of Weltz (1987), who studied similar vegetation types in south Texas. The 2 caliche zones that restricted percolation greatly influenced the pattern of SWC by depth. As a result, seasonal variation in SWC was primarily confined to the soil above the 1.30-m restrictive layer (Table 1). Water use in the top 0.88 m was generally greatest on sites dominated by herbaceous vegetation. This corresponds with root data from the site indicating that 98% of herbaceous root biomass occurs above 0.88 m (Price and Heitschmidt unpubl. data). Mesquite-dominated sites had lowest SWC at 0.18 m and below 0.88 m, which may correspond to both the extensive shallow lateral rooting and the deeper rooting activity of this species at the site (Heitschmidt et al. 1988).

Runoff and Interrill Erosion

Most runoff occurred during intense spring and fall thunderstorms. The percent of precipitation lost to runoff was greatest for the BG treatment (Table 2). On vegetated sites only a small percentage (generally <8%) of precipitation was lost as runoff (Fig. 3). This is consistent with estimates for South African savanna (Whitmore 1971). Runoff was lowest from the H treatment, although it significantly differed from the M+H treatment only in 1986. Similar trends in interrill erosion occurred as a result of collinearity between runoff and interrill erosion ($r = 0.89$).

Table 2. Annual water balance and interrill erosion (sediment) for bareground (BG), herbaceous (H), and herbaceous plus mesquite (M+H) treatments from 1986 to 1988.

		Treatment		
Year		BG	H	M+H
1986				
	Rainfall (mm)	769	769	769
	ET (mm)	512a[1]	644b	658b
	Deep Drainage (mm)	10a	11a	5a
	Storage (mm)	+97a	+86a	+44a
	Runoff (mm)	150a	28c	62b
	Sediment (kg ha^{-1})	17096a	614b	2702b
1987				
	Rainfall (mm)	677	677	677
	ET (mm)	649a	804b	756b
	Deep Drainage (mm)	14a	6a	2a
	Storage (mm)	–81a	–136b	–98ab
	Runoff (mm)	95a	3b	17b
	Sediment (kg ha^{-1})	32684a	48b	431b
1988				
	Rainfall (mm)	529	529	529
	ET (mm)	566a	555ab	511b
	Deep Drainage (mm)	4a	4a	3a
	Storage (mm)	–87a	–31b	+2b
	Runoff (mm)	46a	3b	13b
	Sediment (kg ha^{-1})	20319a	87b	1070b

[1]Means within a row followed by the same letters are not significantly different ($P<0.05$).

Stepwise regression models indicated that total amount of precipitation during any given rainfall event was the major factor affecting the amount of runoff ($r = 0.71$) and interrill erosion ($r = 0.71$) regardless of treatment. Other important factors were percent bare ground and storm intensity (Table 3). Percent bare ground indicates how much soil surface is exposed to direct raindrop impact. Cover dissipates the kinetic energy associated with raindrops and thus protects soil aggregates and reduces detachment of soil particles. Storm intensity is also an indication of the raindrops' kinetic energy. The peak short-term intensity was more important than overall storm intensity for influencing runoff and interrill erosion.

Analyses by treatment also showed precipitation was the major factor affecting runoff ($r = 0.65$ to 0.87) and interrill erosion ($r = 0.65$ to 0.84). Total precipitation was the only variable selected by stepwise regression to predict runoff on the BG treatment. On vegetated plots (H and M+H), storm intensity variables were also

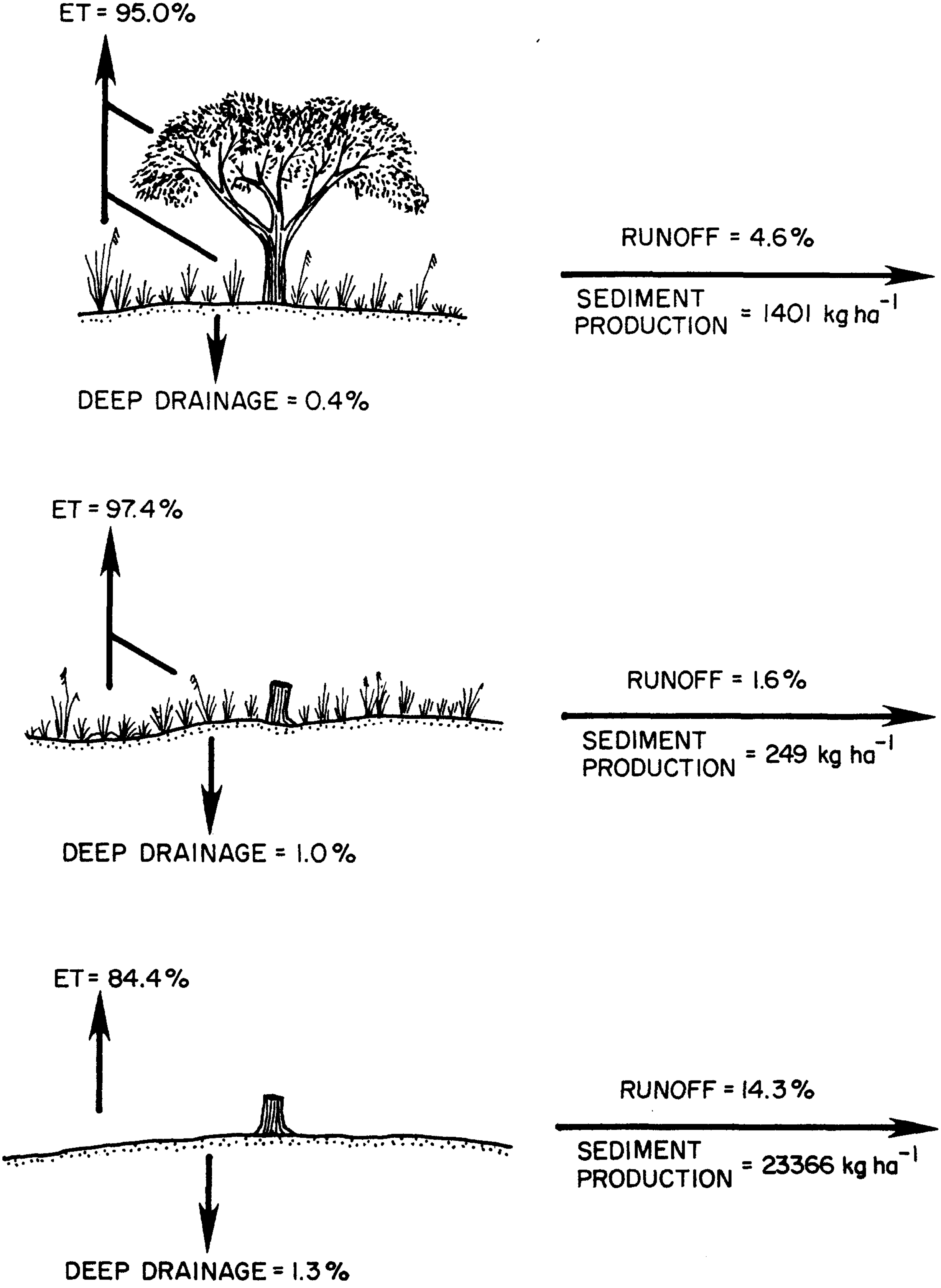

Fig. 3. Annual water balance expressed as a percent of precipitation for the bareground (BG), herbaceous (H), and herbaceous plus mesquite (M+H) treatments during the 3-year study.

Table 3. Stepwise multiple regression equations for runoff and interrill erosion for bareground (BG), herbaceous (H), and herbaceous plus mesquite (M+H) treatments separately and in combination (ALL). All regressions were significant at $P<0.001$.

	Regression Equation	N	R^2
RUNOFF			
BG	y=-.069 + .031PPT	185[1]	.75
H	y=-.076 + .009PPT + .049MAX5	178	.56
M+H	y= -.090 + .014PPT + .055MAX10 + .070MAX20	180	.71
ALL	y= -.110 + .018PPT + .134BG%	543	.57
INTERRILL EROSION			
BG	y= -.255 + .070PPT + .084MAX60	185	.75
H	y= -.041 + .028PPT - .657SLA	178	.46
M+H	y= -.264 + .045PPT + .119MAX5	180	.70
ALL	y= -.481 + .053PPT + .511BG% + .111MAX5	543	.59

VARIABLE DEFINITIONS

Variable	Definition
PPT	Total amount precipitation for the storm (mm)
MAX5	Maximum rainfall in any 5 minute period (mm)
MAX10	Maximum rainfall in any 10 minute period (mm)
MAX20	Maximum rainfall in any 20 minute period (mm)
MAX25	Maximum rainfall in any 25 minute period (mm)
MAX60	Maximum rainfall in any 60 minute period (mm)
BG%	Percent bareground
SLA	Leaf area index of shortgrasses

[1]Differences in N were due to missing data caused by pump failures, etc.

important for predicting runoff and interrill erosion.

Many studies have reported greater runoff from bareground than from vegetated sites but, in contrast to this research, these studies have shown that runoff from shrub-dominated sites (shrub canopy zone) is less than from herbaceous (interspace) sites (Blackburn 1975, Brock et al. 1982, Thurow et al. 1986, Weltz 1987). The slightly greater runoff and interrill erosion from the M+H lysimeters in this study was apparently the result of lower herbaceous standing crop and LAI on the M+H than H plots (Heitschmidt and Dowhower 1991) and less total cover on the M+H plots. This relationship was reflected by stepwise multiple regression analyses (Table 3) and agrees with results from simulated rainfall studies conducted near the study site (Wood and Blackburn 1981, Pluhar et al. 1987).

Deep Drainage

Deep drainage was consistently small regardless of treatment or annual precipitation (Table 2, Fig. 3). This was most likely the result of the combined effect of high evapotranspiration loss and the presence of the 2 caliche layers which slowed percolation. These data are comparable to the estimates for a *Burkea* savanna in South Africa where deep drainage accounted for only 3% of total precipitation (Whitmore 1971). One year of data collected in south Texas on a sandy clay loam soil showed deep drainage beyond 2 m was about 10% on bare ground plots, 2% on herbaceous, and zero on mesquite lysimeters (Weltz 1987).

Evapotranspiration

Annual ET losses from the H and M+H lysimeters were about 12% greater than the evaporation loss from the BG lysimeters (Table 2, Fig. 3). However, during the low precipitation year of 1988, ET losses from BG lysimeters exceeded ET losses from the vegetated lysimeters. BG lysimeters began the growing season with relatively greater SWC, hence more water was available for evaporation loss. Also, the plant and litter cover on vegetated sites in 1988 limited cracking of the soil surface. This reduced the depth to which soil evaporation occurred when vegetation was senescent. In contrast, deep cracking was observed on BG lysimeters during the summer of 1988; this allowed evaporation to occur from deeper in the soil profile. South Texas (Weltz 1987) and South African (Opperman et al. 1977) bare ground lysimeters averaged 70% and 74% annual evaporation, respectively, compared to the mean 84.4% evaporative loss from bare soil documented by this study.

Differences in phenology, water use efficiency, rooting pattern, and interception loss between mesquite and herbaceous vegetation are factors which would be expected to influence the ET pattern on the H and M+H treatments. However, their interaction resulted in similar ET losses from H and M+H treatments. About 15% of precipitation at the site occurs in storms smaller than 12 mm, so that the interception component of ET may be as high as 20% or more (Thurow et al. 1987). There was an increase in herbaceous standing crop on H plots after removal of mesquite resulting in greater standing crop on H compared to M+H treatments throughout the study (Heitschmidt and Dowhower 1991). The herbaceous component was dominated by Texas wintergrass (Heitschmidt and Dowhower 1991), which continued to grow throughout the winter. This species is a relatively inefficient water user compared to associated warm-season grasses (Hicks et al. 1990). In contrast, mesquite is very efficient in its water use and can greatly reduce transpiration losses during dry periods (Ansley et al. 1990).

Conclusions

The results of this study indicate that mesquite removal, coupled with a subsequent increase in the herbaceous cover, had no benefit in terms of off-site water yield. Slow percolation through the clay soil, coupled with 2 water restrictive caliche layers, resulted in the soil water being lost via ET before it could percolate below the root zone. Consequently, deep drainage loss was slight and the only major outflow routes were runoff or ET. Bare ground was an important determinant of runoff and interrill erosion. Therefore runoff and interrill erosion were slightly less on the herbaceous lysimeters than on mesquite dominated stands. ET accounted for almost all of the water outflow from the vegetated sites. There was no difference between the net ET loss of the mesquite and herbaceous sites. Removal of mesquite did not result in decreased ET due to the increase in herbaceous vegetation on H lysimeters. These results imply that essentially no net change in deep drainage, ET or runoff is likely to occur on rangelands where the herbaceous component increases in response to shrub removal.

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