WATER YIELD IMPROVEMENT FROM RANGELAND WATERSHEDS

Final Report

to

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R.W. Knight, Associate Professor, Project Leader
T.L. Thurow, Assistant Professor
R.K. Heitschmidt, Professor
K.W. Owens, Assistant Professor
M.A. Hussey, Assistant Professor
D.D. Briske, Associate Professor
R.C. Maggio, Assistant Professor
R.J. Ansley, Postdoctoral Research Associate
D.L. Price, Visiting Assistant Professor
D.H. Carlson, Research Associate
S.L. Dowhower, Research Associate
C.L. Clark, Research Assistant
A.A. Desai, Graduate Research Assistant
R.A. Hicks, Graduate Research Assistant
P.A. Julien, Graduate Research Assistant
G.L. Holmstead, Graduate Research Assistant
T.A. Wright, Graduate Research Assistant

Data presented in this report have not been completely analyzed and are subject to change, results are preliminary and should be interpreted as such. Cathryn Loschiavo's assistance with the typing and organization of this report is greatly appreciated.

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PROJECT SUMMARY

This project was funded in 1986. The Throckmorton and La Copita study sites were installed and instrumented at the time funding was received. The installation of the Uvalde sites started late in 1986. The overall project had several funding sources which are listed in the acknowledgements.

Research at the La Copita site looked at differences in water yield between a brush dominated site and one covered with grasses. The research utilized large non-weighable lysimeters with open bottoms at about 3 meters deep. The study ran for about 18 months before financial and personnel requirements required it to shut down. The water yield difference for this period was about 25 mm more from the grass lysimeter when compared to the brush lysimeter.

The Throckmorton site at the Wagon Creek Spade Ranch was installed in 1985 and early 1986. Research at this site also addressed the effects of grass type on water yield. Interception and leaf area estimate techniques were also developed. Water use of mesquite areas converted to grass initially showed greater water yields of about 10 mm, but over a four year period the increased grass production that resulted from the mesquite removal negated any water yield differences. There were no differences in annual water yields from three grasses: sideoats grama, common curlymesquite and Texas wintergrass. There were seasonal differences in water yield between the cool- and warm-season species.

Rooting studies at the Wagon Creek Spade site showed very little differences in root biomass or distribution on the three study species. About 60% of the grass roots occurred in the upper 130 mm of the soil profile. Mesquite roots were concentrated in the upper 300

mm of the soil profile but had extensive lateral and deep tap roots. Lateral roots extended to over 30 mm from the main stem, and roots extended down below 3 m.

Photographic and video techniques were developed to estimate mesquite leaf and canopy areas. These estimates were needed to be able to extend estimates of rainfall interception and transpiration losses from individual trees to larger areas. Both ground based and aerial photographs proved useful when analyzed with image analysis software.

The Lyles Ranch study site was instrumented similar to the Wagon Creek Spade site, but with the addition of small watersheds to obtain a larger scale estimate of water use. Grass species studied at the Lyles Ranch site included buffelgrass, kleingrass and sideoats grama. Water use by the kleingrass and buffelgrass was greater than the sideoats grama because of greater leaf area. The sideoats grama was able to respond to rainfall faster, giving it a slight competitive advantage over the other two species. Water yield from the large lysimeters was the same from both sideoats grama and mesquite lysimeters that received supplemental water. For the lysimeters receiving only natural rainfall, the sideoats grama dominated sites had a greater water yield than the mesquite dominated sites.

Water yield from treated mixed brush dominated watersheds at the Lyles Ranch was variable and no differences due to treatments could be detected. This was due to possible lack of herbicidal action on the brush because of dry conditions.

Water yield from treated watersheds on the Annandale Ranch in the Edwards Aquifer recharge area tended to be higher than from the untreated watersheds. There were not enough runoff events to make statistical comparisons. A study on water use by live oak and blueberry juniper showed the live oaks used more water than the junipers during wet periods. The exact opposite was true for dry periods with juniper using more water.

Plans are to continue the water yield research at the Throckmorton and Uvalde sites. As funding becomes available, detailed studies on the factors influencing water yield, water use by plants and water quality of runoff will be conducted. Water yield measurements over 3 to 5 years are needed to accurately estimate water yield increases and to parameterize models that can be used to make state-wide estimates.

ACKNOWLEDGEMENTS

This study was possible only through the efforts of a large number of people. Many people contributed time, hard work, facilities and land resources. Numerous graduate students and student workers, in addition to the authors, were responsible for design, installation and data collection on the studies.

Project funding came from several sources in addition to the Texas Water Development Board. In addition to Expanded Research monies from the Texas Agricultural Experiment Station, funds were provided by the USDA Soil Conservation Service, USDA Special Grants Program, Edwards Underground Water District and E. Paul and Helen Buck Waggoner Foundation.

The Throckmorton study site on the Wagon Creek Spade Ranch was provided by Dr. Dub Waltrip. Installation assistance was also provided by Swenson Land and Cattle Company personnel. The initial project was installed under the guidance of Mr. Joe Franklin.

Valuable assistance in project design and initial grant acquisition was provided by Dr. Will Blackburn. Dr. Bill Holloway provided study site locations and installation assistance through the Texas A&M Research Center at Uvalde. Mr. Bill Cofer provided the study site location on the Annandale Ranch.

Appreciation goes to Mr. Comer Tuck and the Texas Water Development Board for their support and guidance. Without funding from the Texas Water Development Board, this study could not have been conducted.

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INTRODUCTION

Approximately 66% of Texas lands are classified as rangelands. These rangelands are often dominated by a mixture of shrub species which have been estimated to transpire and evaporate approximately 38% of the state's available water. It is hypothesized that water yields from these rangelands will increase following removal of shrubs. It is also hypothesized that water yields can be dramatically altered as a function of type of herbaceous plant community. Previous research has shown that both runoff and sediment production are greater in short grass dominated communities than in midgrass dominated communities. Research has also shown that various grazing management strategies can alter the species composition of plant communities relative to the abundance of short- and midgrasses. This research project is designed to evaluate the influence of vegetation manipulation on the hydrologic processes of Texas rangelands, with emphasis on off- and on-site water yields.

The research objectives are: 1) to determine the water balance of shrub/grass dominated sites as influenced by vegetation manipulation; 2) to determine the water use efficiency of brush and grass species on managed/mixed grass sites; and 3) to quantify aboveground herbaceous growth dynamics and belowground biomass of shrub/grass dominated sites.

The following research report represents the progress made during FYs 1988-89. Results are reported from three study locations: 1) Wagon Creek Spade Study Area located 5 km north of the Texas Experimental Ranch in Throckmorton; 2) Lyles Ranch located 30 km southwest of Uvalde; and 3) Annandale Ranch located 32 km northeast of Uvalde near Concan.

This project is presently active in the data collection phase at all three study locations. Great care should be taken with the actual interpretation of results presented in this report and by no means should they be considered final.

WAGON CREEK SPADE STUDY AREA

The research area is part of the Rolling Plains resource area which consists of 6.3 million hectares of rolling to nearly level uplands and broad valleys. The research site is located on a Nuvalde silty clay loam (1-3% slopes) soil series; normal precipitation for the area is 679 mm. The dominant midgrasses are sideoats grama (*Bouteloua curtipendula*), a warm-season midgrass, and Texas wintergrass (*Stipa leucotricha*), a cool-season midgrass. The shortgrass interspaces are dominated by common curlymesquite (*Hilaria berlangeri*) and buffalograss (*Buchloe dactyloides*). A dense stand of single stemmed honey mesquite (*Prosopis glandulosa*) trees encompass most of the research area as well as the Rolling Plains.

ROOTING PATTERNS OF THREE PERENNIAL GRASSES IN A SOUTHERN MIXED GRASS PRAIRIE

D.L. Price, R.K. Heitschmidt, and S.L. Dowhower

SUMMARY

The biomass and pattern of distribution of roots of 3 major graminoides were examined in a southern USA mixed grass prairie. Species studied were: *Stipa leucotricha,* a cool season midgrass; *Bouteloua curtipendula,* a warm season midgrass; and *Hilaria berlangeri,* a warm season shortgrass. Results show that from the surface to a depth of 103 cm, there were no differences between species in total belowground biomass, and patterns of distribution were similarly variable. Averaged across species, total belowground biomass was 540 g m^{-2}. There was a difference in belowground biomass in the top 3 cm of the soil profile averaging 273 g m^{-2} for *Bouteloua curtipendula,* 174 g m^{-2} for *Stipa leucotricha* and 154 g m^{-2} for *Hilaria berlangeri*. Distribution patterns followed the allometric function of $y = 335x^{-7.60}$ where y equals percentage of total belowground biomass in 10 cm increments to a depth of 103 cm, and x equals the mid-point depth of each increment. Approximately 59% of the total biomass was in the top 13 cm of the soil profile. There were no differences among monoliths relative to soil texture, organic matter content or bulk density.

INTRODUCTION

The spatial arrangement of plant species is affected by many abiotic and biotic factors. However, at the individual plant, population or community level of organization, the major factors are related to the intrinsic properties of the soil as they affect a plant's ability to exploit its growth medium (St. John et al. 1984, Eissenstat and Caldwell 1988). Aboveground patterns of distribution are a partial function, therefore, of variation among individual plants and populations of plants in their functional ability to exploit a heterogeneous soil environment over time and space relative to seed germination, seedling establishment, survival and propagation (e.g., see Fowler 1988).

In the mixed grass prairies of north central Texas, plant communities are dominated by an overstory of honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) trees with an understory of mid- and shortgrasses. Three of the dominant perennial grasses are sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], a warm season (C_4), rhizomitous, sod-forming midgrass; Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), a cool season (C_3), bunch midgrass; and common curlymesquite [*Hilaria berlangeri* (Steud.) Nash], a warm season (C_4), stoloniferous, sod-forming shortgrass. These 3 species often grow together in a mosaic, along with other grasses and forbs; however, nearly pure stands of each of the 3 species are commonly found within the mosaic. We hypothesized that stand dominance was associated with differences among the 3 species in their relative ability to exploit varying soil media. The objective of this study was to test this hypothesis by quantifying differences among stands in root distribution and biomass and to relate these to several macro-scale soil parameters.

METHODS

The study site was located on the eastern edge of the Rolling Plains of Texas in Throckmorton County. Climate is semi-arid continental with warm, wet springs and falls, hot summers and mild winters. Average (1960-1987) annual precipitation at the site is 680 mm (SD=102) ranging from highs of 92 (SD=61) and 106 mm (SD=79) in May and September, respectively, to a low of 21 mm (SD=32) in January (Heitschmidt et al. 1985 and unpublished). Average maximum daily temperatures range from 35.8°C (SD=2.1) in July to 11.4°C (SD=3.0) in January. Average minimum daily temperatures range from 22.0 (SD=1.2) to -2.4°C (SD=2.1) in July and January, respectively.

The 0.5 ha study area was located within a 15 ha exclosure established in 1985. Soils within the nearly level study area were classified as either Nuvalde clay loam (fine-silty, mixed, thermic Calciustolls) or Rowena clay loam (fine, mixed thermic Calciustolls). Both soils are similarly deep (A horizon = 0-30 cm; B horizon = 31-90 cm) and well drained. Because of a gradual transition across the area from Nuvalde to Rowena soils, the area was blocked prior to locating study stands with block 1 dominated by Nuvalde soils, and block 3 dominated by Rowena soils. Block 2 was the transitional area.

During the summer of 1986, nine 2 m long, 1 m wide and 1.5 m trenches were dug with a backhoe through each of 3 strands in each of the 3 blocks. All stands were approximately 10 m^2 in size. A 1.0 x 1.03 m area on 1 wall of each trench was then leveled and smoothed for excavation of one hundred 1000 cm^3 blocks. Prior to excavation, aboveground standing crop (shoots and stolons) was harvested at ground level within the 1.0 x 0.1 m area located directly above the 1.0 x 1.03 x 0.1 m soil monolith. Next, the top 3 cm of the soil monolith were removed in 10 x 10 x 3 cm blocks for estimation of crown, rhizome and root standing crops. Finally, the 10 rows of the 1000 cm^3 blocks were removed for estimation of root standing crop in 10 cm increments.

All belowground samples were stored in plastic bags and frozen prior to washing. Samples were subsequently thawed in tepid water and washed following the procedures outlined by Lauenroth and Whitman (1971). All identifiable woody and suberized tap roots of shrubs and forbs were removed following washing. Samples were dried at 60°C, weighed and ashed at 105°C for expression on an organic matter basis. The aboveground herbage samples were dried at 60°C and weighed for expression on a dry-weight basis.

Following excavation, soil samples were collected from each pit at 10 cm vertical increments for bulk density (Black 1965), organic matter content (Walkley and Black 1934) and textural (Bouyoucos 1962) analyses.

Standing crops were examined statistically using standard analysis of variance (AOV) procedures for a randomized complete block design. Root biomass and soil parameters within the 10 cm incremental depths were evaluated using a randomized split-plot AOV model. Arc-sin transformations were used in the analyses of all percentage data. When appropriate, means were separated using Duncan's multiple range test. Unless otherwise noted, significant differences are at $P<0.10$.

RESULTS

The belowground biomass data are presented in Figure 1. Statistical analyses of these data showed the only significant difference among stands was standing crop of crowns, rhizomes and roots in the top 3 cm of the soil profile (Table 1). Presumably, the greater amount of crowns and rhizomes found in the *Bouteloua curtipendula* dominated stands was the result of the presence of rhizomes. Of the three species, only *Bouteloua curtipendula* is rhizomitous. Significant differences did occur among depths in the various parameters examined (Table 2); however, the absence of any significant species by depth interactions showed root distributions were similar regardless of species. Distribution followed the allometric function of $y = ax^b$ ($R^2 = 0.63$, $n = 90$, $P<0.01$) as described by Sims and Singh (1978) for a wide array of grasslands. There were no differences between species in least square coefficients ($a = 355$, $b = -7.60$).

There were no differences between soil monoliths relative to average bulk density, organic matter content and texture (Table 1). There were differences, however, between strata

(Table 2), but the absence of any significant species by depth interactions showed these differences did not vary among stands. This is not surprising since there were only minor descriptive differences in the profiles of the Nuvalde and Rowena soils, according to USDA Soil Conservation Service scientists (personal communication), and stands of all 3 species occurred on both soils.

DISCUSSION

The results of this study show that: 1) aboveground standing crop and biomass and distribution of roots was similar among species, but crown and rhizome standing crops varied among species; and 2) there were no major differences in the soil parameters measured that would adequately explain aboveground differences in species composition of stands. Thus, based on these results we cannot accept our original hypothesis that stand dominance on this study site is associated with varying differences between the 3 species in their inherent ability to exploit varying soil mediums. Caution should be exercised, however, in any attempt to extend this conclusion to a macro-scale level of resolution because: 1) the data are only applicable to these 3 species at this location at a single point in time, and previous research has shown that spatial arrangements of plants is a temporally dynamic process (Fowler 1984) and varies in these (Heitschmidt et al. 1985, 1989) and other grasslands (e.g., see Sims and Singh 1978) as a function of many factors, of which soil type and livestock grazing intensity are major; 2) it is well known that rooting patterns of graminoides do vary as a function of species (e.g., see Weaver 1954) and 3) only 3 soil attributes were examined in this study, and it may very well be that factors other than texture, organic matter content and bulk density are important factors regulating the rooting patterns of these 3 species.

The results of this study are also in partial conflict with previous findings from a study conducted on an area located on a similar site about 3 km from this study site (Heitschmidt et al. 1982). In that study, aboveground standing crop was quite similar to the 280 g m^{-2} reported in this study; however, crown and rhizome standing crop was much less (99 g m^{-2}), whereas, root standing crop to a depth of 80 cm was much greater (950 g m^{-2}). We believe these discrepancies are in part the result of differences between studies in methodology in that: 1) in the earlier study, crowns and rhizomes were removed from the 0-10 cm sample core after washing; whereas, in the current study, the 0-3 cm sample included crowns, rhizomes and roots; 2) no attempt was made in the earlier study to remove forb roots from samples; and 3) root cores were not frozen in the earlier study prior to washing. Price and Heitschmidt (1989) showed that estimated biomass of roots was significantly reduced (26%) in the top 10 cm of the soil profile when sample cores were frozen prior to washing. After correcting for this discrepancy, estimated standing crop of graminoid crowns, rhizomes and roots in the top 13 cm of the soil profile was 392 g m^{-2} in the current study as compared to an estimate of 563 g m^{-2} for both grasses and forbs in the top 10 cm of the soil profile in the earlier study. These estimates are well within the range reported for other North American grasslands (Sims and Singh 1978).

The results from this study also provide cursory evidence that conflicts with the belowground grazing lawn hypothesis (McNaughton 1984) as forwarded recently by Milchunas and Lauenroth (1989). In their study, they examined the long-term effects of livestock grazing on the horizontal distribution of aboveground and belowground biomass in the shortgrass prairie of Colorado. Although species composition was similar in both their ungrazed and grazed treatments, they found "the horizontal distribution of aboveground parts, crowns and roots was smoother on grazed than ungrazed sites." Their conclusion was based on differences between the grazed and ungrazed sites in coefficients of variation. Our data does not lend support to their hypothesis if the functional aspects of the hypothesis are extended to include grasslands in which grazing causes a shift in species composition from a midgrass to a shortgrass dominant to occur as in the case in this grassland. For example, Heitschmidt et al. (1985, 1989) have shown that as grazing intensity is increased in this region, species composition shifts from a *Bouteloua curtipendula* - *Stipa leucotricha* complex to a *Stipa leucotricha* - *Hilaria berlangeri* complex. Thus, support for their hypothesis from this study would arise if the horizontal variation in belowground biomass was less for *Hilaria berlangeri* than *Bouteloua curtipendula*, which is definitely not the case (Figure 1).

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Table 1. Average standing crops of shoots and stolons (aboveground), crowns, rhizomes and roots (0-3 cm) and roots (3-103 cm) and average bulk density, organic matter content and soil texture for monoliths in stands of *Bouteloua curtipendula* (Bocu), *Stipa leucotricha* (Stle) and *Hilaria berlangeri* (Hibe).

	Species			
Parameter	Bocu	Stle	Hibe	Average
Standing Crop (g m^{-2})				
Shoots and stolons (aboveground)	284	291	264	280
Crowns, rhizomes and roots (0-3 m)	273a[1]	174ab	154b	200
Roots (3-103 cm)	313	312	394	340
Total	870	778	812	820
Soil monolith (4-103 cm)				
Bulk density (g cm^{-3})	1.3	1.3	1.3	1.3
Organic matter (%)	2.2	2.2	2.2	2.2
Sand (%)	10.3	13.6	13.5	12.5
Silt (%)	37.4	36.8	37.5	37.2
Clay (%)	52.3	49.6	49.0	50.3

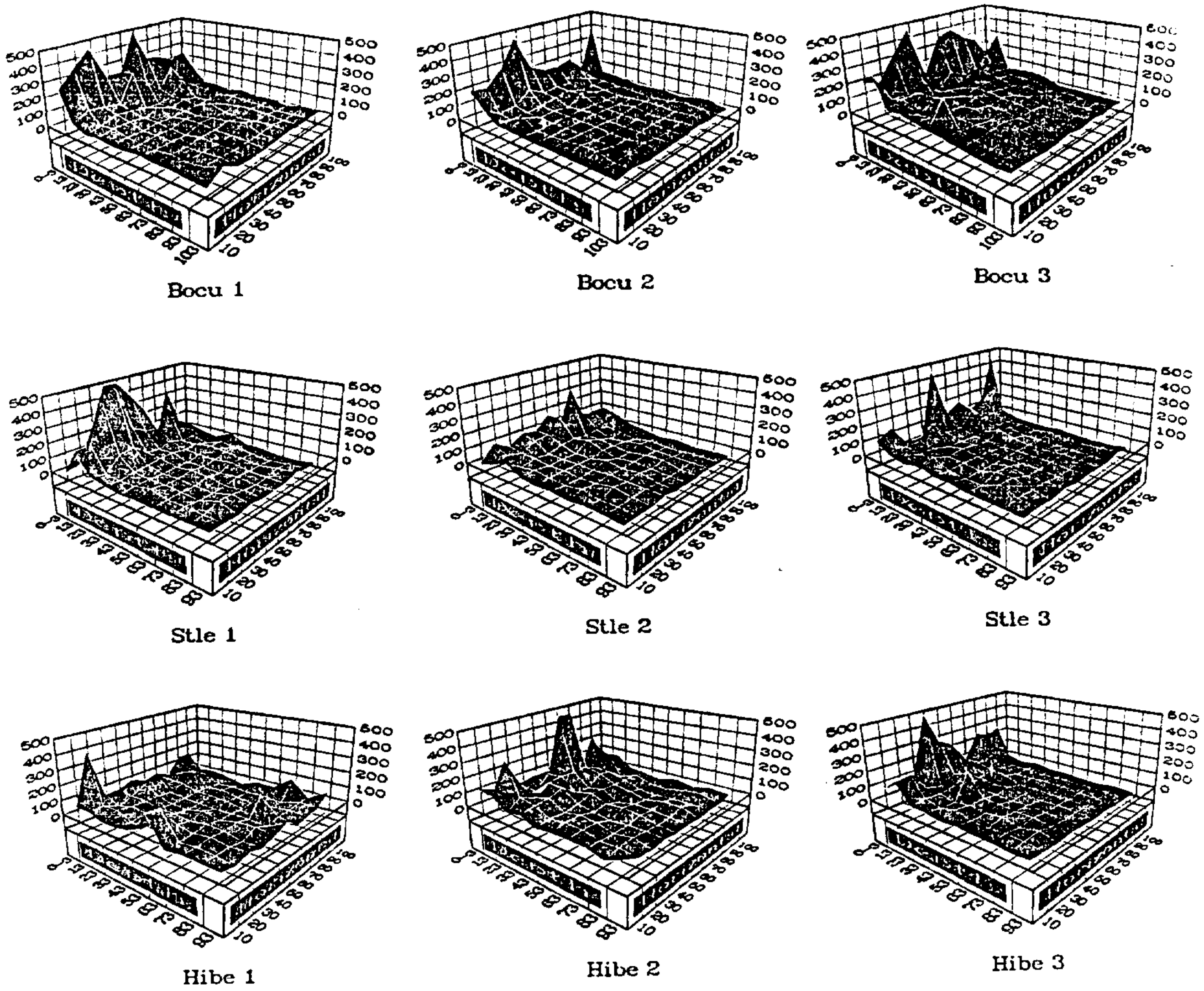
[1] Species means in a row followed by same letter are not significantly different at $P<0.05$.

Table 2. Average standing crop of roots, percentage of total roots and average bulk density, organic matter content and soil texture at 10 cm increments for monoliths in stands of *Bouteloua curtipendula*, *Stipa leucotricha* and *Hilaria berlangeri*.

			Soil Parameters				
					Texture		
Sample increment (cm)	Root standing crop ($g\ m^{-2}$)	(%)	Bulk density ($g\ cm^{-3}$)	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)
0-3[1]	200a[2]	37a	1.2a	4.8a	14a	46a	40a
3-13	121a	22b	1.2ab	3.8b	13ab	40b	47b
13-23	50cb	9c	1.2ab	2.9bc	12ab	38bc	50c
23-33	38cd	7cd	1.2ab	2.4cd	12ab	36c	52c
33-43	25cd	5cd	1.3bc	1.7de	12ab	36c	52c
43-53	27cd	5cd	1.4cd	1.7de	12ab	35c	53c
53-63	19d	4d	1.4d	1.8de	13ab	36c	51c
63-73	20d	4d	1.4d	1.2ef	14ab	35c	51c
73-83	15d	3d	1.5d	1.3ef	12ab	35c	53c
83-93	12d	2d	1.5d	1.4def	13ab	36c	51c
93-103	13d	2d	1.5d	0.8f	11b	36c	53c

[1] Crowns, rhizomes and roots.

[2] Means in a column followed by same letter are not significantly different at $P \leq 0.05$.



Bocu 1

Bocu 2

Bocu 3

Stle 1

Stle 2

Stle 3

Hibe 1

Hibe 2

Hibe 3

Figure 1. Vertical and horizontal distribution (cm) of belowground biomass (g m^{-2}) in all 9 (3 blocks x 3 species) excavated monoliths.

USE OF REMOTE SENSING TECHNIQUES TO QUANTIFY A SHRUB COVER

Anjana Desai, R.W. Knight and R.C. Maggio

SUMMARY

Canopy cover measurements are frequently used in the study of range and watershed management. The actual amount of surface cover provided by the plant canopy is required to obtained the raindrop impacting area. The rain drop impacting area is required to obtain the erosion reduction potential of a plant and the amount of water available at the base of the stem in the form of stemflow. Stemflow is usually expressed as inches or mm of water per unit ground projected area of the plant canopy. Various methods have been developed to quantify the cover of a particular plant. Leaf area measurements have been and continue to be the primary data source used to estimate the cover of a plant (Marshal, 1968; Mutchler and Young, 1975). Other techniques used are line transect, mean of projected crown diameter, shape of the crown, ocular estimates, dot counting, light interception (Burstall and Harris 1983),and recently overhead slides and photographs (Thomas et. al. 1988). However these techniques do not give an accurate picture of the cover potential of a particular shrub canopy. For example, shrubs like mesquite often have crooked and dropped branches with small leaflets and many gaps. The projected canopy area includes these gaps and thus tends to over estimate the cover and subsequently underestimate stemflow. One of the best methods available to estimate canopy cover is through remote sensing. By obtaining photographs, slides or video images, the canopy cover impacted by the vertical rainfall can be measured. Remote sensing has been successfully used for the measurement of plant

parameters in the last two decades (Carneggie and De Gloria 1974, Carneggie et. al. 1983, Manzer and Copper 1982, Edwards 1982, Escobar et. al. 1983, Everitt and Nixon 1985a, b).

The objective of this research was to develop a non-destructive technique to quantify cover using remotely sensed data and image processing techniques. The procedure should process data quickly and should be easy to use, require little human judgement and thus reduce error.

METHOD

Color video images and 35mm color slides were taken 13 m. above the ground, of mesquite trees in both the growing and nongrowing season. Thirteen mesquite trees were randomly selected for cover estimation by field and video techniques. Field measurements of the shrubs were taken during the growing season. This was done by measuring at every 0.5 m interval the width of the canopy along the longest axis (Figure 1). The canopy measured was recorded on graph paper and planimeter to determine the area. The aerial pictures were taken with the help of a boom truck and the ground underneath was covered with white bed sheets to negate the effect of ground reflectance. A 50 by 50 cm scaling target board was imaged along with the tree and was used to estimate unit area per pixel on the resulting image. A Howtek scanmaster scanner was used to scan the slides and output in a Targa 32 format. The videotape was framegrabbed through the Targa card and output in Targa 16 format. TIPS software was used to mask out the unwanted background area. The files were transferred from compaq deskpro to sperry IT 286 pc. The targa format were converted to spot image satellite format. The targa card performs analog to digital conversion of video images. The resultant 3 channel RGB image had a resolution of 512 pixels in x-direction and 400 pixels in y-direction, with frequency distribution of grey values from 0-255. This image was analyzed for obtaining canopy area with digital image processing software-Microimage version 3.0 developed by the Terramar corporation.

CLASSIFICATION SYSTEMS

Three different classification systems are offered by the software: 1) Parallelapiped Criterion, 2) Maximum Likelihood Criterion (MLC), 3) Unsupervised Euclidean Distance. The Unsupervised Euclidean distance type of classification presented a problem when shadows were present or when canopy density varied, and thus was not considered. The MLC was promising and gave results similar to parallelapiped Criterion, but it was time consuming and the details obtained were not useful for the present study. The Parallelepiped classification had two different options available, 1) Classification which required training sets to be given: The training sets had to represent all the spectral ranges in an image, or else it would underestimate the canopy area. On the other hand if the training sets are large , they would over estimate the canopy area. Moreover the procedure was time consuming and hence was not used. 2) Classification which needed information about color band and range of spectral values, from 0-255 for that color band. This range of spectral values was obtained from another process - The Lookup table modification, which is used for analyzing individual pixels. This process is totally interactive and dynamic, and also fast and easy. This procedure was used for the estimation of mesquite canopy area (video-actual). The vegetation (branches and leaves) was best delineated from background (shadows) by blue plane, with spectral values ranging from a minimum of 17 to maximum of 190. But during nongrowing season no particular color plane or spectral range was consistent. To check the validity of the results obtained by the computer process, the total area of the shrub cover including the gaps was found. This was done by a different menu in the software - Polygon Manipulation. Vectors were drawn all along the edge of the canopy and the area enclosed within was obtained (video-total). The canopy cover calculated in both the above cases is the projected cover. The actual canopy cover is calculated by using similarity of triangle theorem as the average height of the canopy is known. The statistical analysis included a paired comparisons, using t-test, for the data set. The field technique and video technique were compared. An analysis of variance test was also used to evaluate significant differences in the canopy cover estimates among procedures. Tests for correlation were used to further evaluate the two techniques. In all the statistical analysis, the 0.05 and 0.01 levels were used as a basis for determining "significant" and "highly significant" results, respectively.

RESULTS AND DISCUSSIONS

Using a paired comparison t-test, the canopy cover estimated by the video technique was not significantly different from the field technique, but the size of the data set, n=13, may not have been large enough to detect a significant difference. From these statistics, the video technique appeared to estimate percent cover accurately. Analysis of variance test also found no significant difference in canopy cover estimates among techniques. Based on the above results, the actual area (excluding within canopy gaps) obtained by analyzing the video image during the growing and nongrowing season are accurate. The data is presented in Figure 2.

ADVANTAGES AND DISADVANTAGES OF REMOTE SENSING

ADVANTAGES:

1) It is a nondestructive technique and change over time can be noted. 2) Since the technique is computer based it requires little human judgement and can handle large amount of data. 3) The technique is comparatively fast and easy to use.

DISADVANTAGES:

1) Cost of image processing system is pretty high. But the equipment can be used for projects other than canopy cover estimation. 2) Background interference is a problem that needs to be addressed. The threshold between soil and canopy intensities has to be overcome for studies involving large areas and frequent sampling. We overcame this problem by placing white sheets underneath the tree.

ADVANTAGES AND DISADVANTAGES OF VIDEO VS SLIDES

The foremost advantage of video is it is cheaper compared to the slides, as there is just one time cost of cassette and involves no processing cost. It provides instantaneous, and informative imagery. Availability of a live image during acquisition makes video more error proof than photography. Electronic format of the image signal permit not only instantaneous image as mentioned earlier but ready conservation into a digital form for computer processing. The main advantage of slides is, they have better resolution than video images.

APPLICATIONS

This technique can be used in studies involving biomass production, canopy photosynthesis, stand evaporation and transpiration, processes of forest growth, interception and water balance, and cover estimation.

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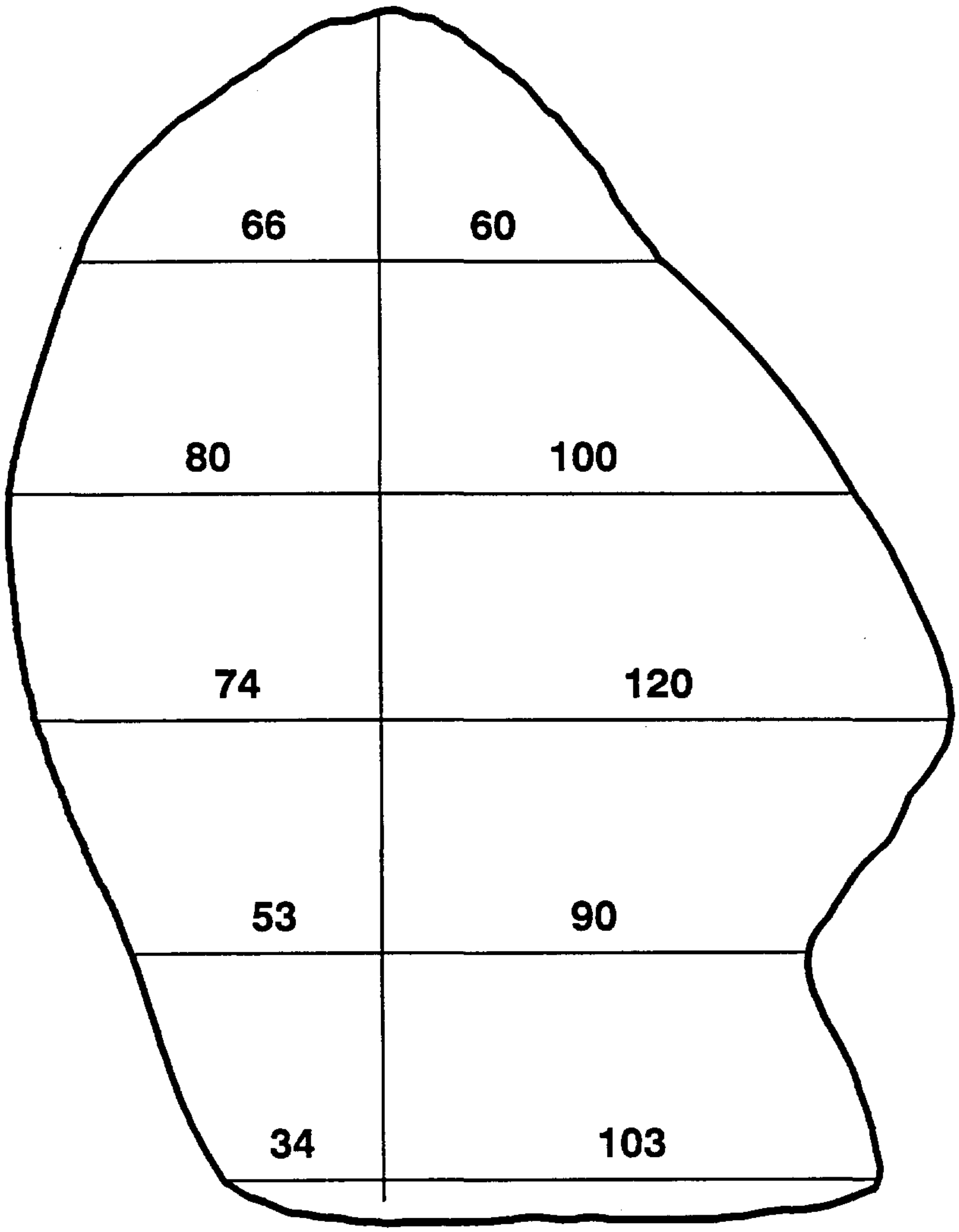

Figure 1. Outline of mesquite tree canopy showing manual measurement technique.

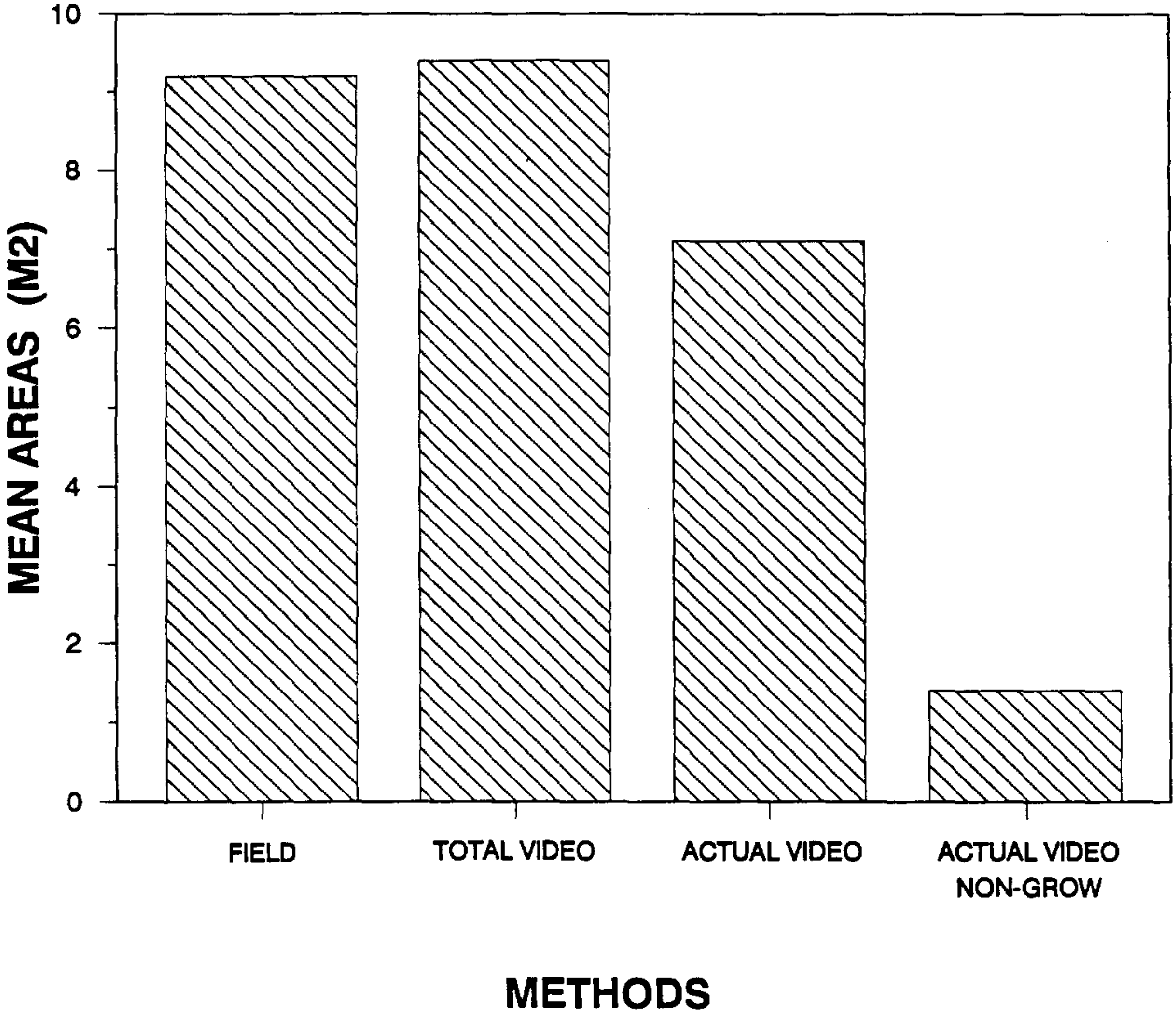

Figure 2. Comparison of methods for measuring canopy areas.

CO-EXISTENCE OF A PERENNIAL C_3 BUNCHGRASS IN A C_4 DOMINATED GRASSLAND: AN EVALUATION OF GAS EXCHANGE CHARACTERISTICS

R.A. Hicks, D.D. Briske, C.A. Call and R.J. Ansley

SUMMARY

Stipa leucotricha, a native C_3 perennial bunchgrass, represents an anomaly to the anticipated distributional patterns of C_3 species because it is restricted to grasslands below 35° N latitude. The objective of this investigation was to evaluate the seasonal patterns of gas exchange which potentially confer *S. leucotricha* with the ability to successfully compete with a co-dominant C_4 bunchgrass, *Bouteloua curtipendula*, in an environment presumably most suitable for C_4 species. Gas exchange estimates and tiller water potentials (δ) were taken *in situ* for one diurnal period each month during the 1987 growing season. *S. leucotricha* displayed a maximum seasonal photosynthetic rate (A) in March when sufficient leaf area had not yet developed for sampling in the C_4 species. Maximum daily A in *S. leucotricha* occurred at leaf temperatures comparable to those of the C_4 species, 30 to 40C, but water-use efficiencies conformed to those anticipated for C_3 species. Both species maintained low A at δ of -3.0 to -4.0 MPa, but *S. leucotricha* attained a greater percentage of its maximum seasonal A at more negative δ than did *B. curtipendula*. An estimate of seasonal carbon assimilation, derived by summing the mean monthly A, indicated that both species assimilated approximately 1.5 mol CO_2 m^{-2} of leaf area during the season. A prolonged period of carbon assimilation, over an uncharacteristically wide temperature range, confers this C_3 grass with the capability to co-exist with C_4 competitors in grasslands at relatively low latitudes.

INTRODUCTION

Species within the Poaceae assimilate carbon via the Calvin-Benson (C_3) or Hatch-Slack (C_4) photosynthetic pathways. Each pathway possesses unique biochemical and anatomical features that confer adaptive value in specific environments. A single pathway is not optimally adapted to all environments because each encounters physiological limitations over a range of abiotic variables (i.e., cost of the CO_2 pump in C_4 species or photorespiration in C_3 species; Ehleringer 1978, Ehleringer and Pearcy 1983). C_3 species are assumed to possess a physiological advantage in cool, moist, environments with relatively low irradiance, while C_4 species are assumed to function nearer their physiological optimum in warm, dry, environments with high irradiance. An increase in the percentage of C_3 species with increasing latitude or elevation substantiates this generalization (Teeri and Stowe 1976, Stowe and Teeri 1978, Boutton et al. 1980), but several exceptions have also been noted (see Pearcy and Ehleringer 1984).

Several C_4 species can conduct photosynthesis at temperatures substantially lower than anticipated for this pathway. *Atriplex confertifolia*, a C_4 shrub, exhibited maximum rates of photosynthesis in the cool spring months and an annual rate of carbon assimilation comparable to *Certoides lanata*, a co-existing C_3 shrub, in an environment presumably best suited to C_3 species in N. W. Utah (Caldwell et al. 1977). Similarly, *Spartina anglica*, a C_4 grass which grows in the coastal salt marshes of N. W. Europe, photosynthesizes at rates comparable to C_3 species at temperatures of 5 to 10C (Dunn et al. 1987, Long and Woolhouse 1978). Temperature is also the predominate abiotic variable influencing growth initiation and minimizing competition between *Agropyron smithii* (C_3) and *Bouteloua gracilis* (C_4), which co-exist in the shortgrass prairie of eastern Colorado (Kemp and Williams 1980, Christie and

Detling 1982, Monson et al. 1983). However, early season air temperatures above ambient in the microtopographic positions occupied by *B. gracilis* and frequent, drought-imposed restrictions on the length of growing season minimize the temporal separation of growth between these two species (Monson et al. 1986).

Stipa leucotricha Trin. & Rupr. represents somewhat of an anomaly to the anticipated distributional patterns of C_3 species because its range is confined within 25° and 35°N latitude in the south-central U.S. and northern Mexico (Fig. 1; Gould 1975, Waller and Lewis 1979). Strong correlations between the distribution of C_4 grasses and minimum daily temperatures during the warmest month of the growing season indicate that approximately 60% of the grassland flora of North America possesses the C_4 pathway at 33°N latitude (Teeri and Stowe 1976). Yet, *S. leucotricha* functions as a co-dominant with *Bouteloua curtipendula* (Michx.) Torr. (C_4) in the Rolling Plains of north-central Texas (Heitschmidt et al. 1982). The objective of this investigation was to evaluate the seasonal patterns of gas exchange and water potential which potentially confer *S. leucotricha* with the ability to successfully compete with a C_4 co-dominant in an environment presumably most suitable for C_4 species. Both species possess comparable growth-forms and rooting habits prompting us to evaluate physiological processes as the most probable means of adaptation.

MATERIALS AND METHODS

The study site was located on the Wagon Creek Spade Ranch near Throckmorton, Texas (99° 14'W, 33° 20'N), in the Rolling Plains Resource region which comprises approximately six million ha of rolling to rough topography in north-central Texas (Fig. 1). Species associated with the two co-dominants include *Buchloe dactyloides* (C_4), *Aristida* spp. (C_4) and *Sporobolus cryptandrus* (C_4) (Waller and Lewis 1979, Heitschmidt et al. 1982). A sparse over story of *Prosopis glandulosa* var. *glandulosa* is common throughout much of the region.

Experimental plants were located in both weighing lysimeters and adjacent paired-plots. Lysimeters were established by drilling a section of steel pipe (76 cm dia.) into the ground to a depth of 120 cm to enclose established monocultures of each species from native grassland. Six lysimeters, three per species, were established in a completely randomized design. Three paired-plots of each species (1 m^2), located within 15 m of the lysimeters on similar soils, were used to compare physiological and morphological responses of plants within the lysimeters to those on undisturbed sites. Hydrological data collected within the lysimeters will be reported separately.

Although physiological responses of both species displayed similar seasonal trends within lysimeters and paired-plots, lysimeters significantly affected leaf temperature (T), apparent net photosynthetic rate (A) and produced a significant species x lysimeter interaction for stomatal conductance (g) ($p<0.05$). Consequently, data could not be pooled between lysimeters and paired-plots. It is recognized, however, that lysimeter effects reflected changes in microclimate or resource availability induced by lysimeter installation, i.e., heat loading or plant density, rather than inherent physiological differences between plant populations.

Instantaneous measurements of transpiration (E), A and g were taken on leaf blades of one to four tillers *in situ* with a portable gas exchange system (Li-Cor Model LI-6000, Li-Cor 1983). Gas exchange measurements were recorded for one diurnal period each month from mid-March to mid-October 1987. Diurnal gas-exchange measurements were initiated 1 h post-sunrise or as soon as dew accumulation had dried and repeated at 3 h intervals on the same leaf material until 1 h prior to sunset on each sampling date.

A minimum of 6 cm^2 of leaf area is required within the cuvette for accurate estimation of A. Typically, three to four tillers of *S. leucotricha* (each with two blades) and one to two tillers of *B. curtipendula* (each with three to five blades) were included in each sample to exceed the minimum area. Two separate groups of tillers were randomly selected for measurement within each lysimeter and paired-plot ($n=6$ per species per date). A standardized leaf orientation within the cuvette, parallel to the soil surface, was employed during each measurement to standardize radiation microenvironments.

Initial CO_2 concentrations and relative humidity within the cuvette were maintained as near to ambient as possible at each sampling period during the season. Cuvette relative humidity, cuvette air temperature, T and photosynthetic photon flux density (PPFD) outside the cuvette (perpendicular to the soil surface) were monitored during each sample period. Leaf area was harvested after the cuvette was removed on the final diurnal reading for each sampling date and estimated with a leaf area meter to compute gas exchange rates on an area basis. A pressure chamber was used to estimate xylem water potentials of individual tillers (δ). Three to five tillers were evaluated for each species, both in the lysimeters and in the paired-plots, at each sampling period. δ values were obtained predawn and 0.5 h preceding the second, third and fourth gas exchange measurements. δ during the first gas exchange measurement was assumed to be similar to the predawn measurement.

A, E, A/E, g and δ were subjected to analysis of variance procedures to test for date, species and lysimeter effects. A split-plot analysis was used to evaluate diurnal response when repeated measurements were taken on the same experimental unit. Seasonal responses were evaluated with procedures appropriate for a completely randomized design. Least squares means were used for mean separation when significant differences were indicated by analysis of variance.

RESULTS

ABIOTIC VARIABLES

Total annual precipitation for 1987, 560 mm, approached the 30 yr average of 624 mm, but the distribution was highly irregular (Fig. 2, A & B). Precipitation was 21% above average during the first six months of 1987 but decreased to 56% of the 30 yr average during the last six months. PPFD ranged between 1170 to 1690 umol m^{-2} s^{-1} at the time of the second gas exchange measurement within a diurnal period (time of optimal PPFD and δ; approximately 4 to 5 h post-sunrise; Table 1). Mean ambient air temperatures for each sample date increased from a low in March, 6.5C, to a season high of 31.6C in June and then declined for the remainder of the season. The 1987 growing season for *S. leucotricha* began in early March and extended through October, while that of *B. curtipendula* extended from mid-April through October.

MEAN SEASONAL RESPONSES

B. curtipendula exhibited A equal to or greater than that of *S. leucotricha* throughout most of the season, but a significant species x date interaction was observed ($p<0.01$; Fig. 3, A & E). A of *B. curtipendula* exceeded that of *S. leucotricha* by 2-fold inside the lysimeters and 2.5-fold within the paired-plots early in the growing season ($p<0.01$). In July, *S. leucotricha* exhibited a significantly higher A than did *B. curtipendula* ($p<0.05$). From August through October, the two species demonstrated similar A. A inside the lysimeters was higher than within the paired-plots throughout the season ($p<0.05$).

E of *S. leucotricha* was equal to or greater than that of *B. curtipendula* throughout most of the season, but a significant species x date interaction was observed ($p<0.01$; Fig. 3

B & F). E of *B. curtipendula* was significantly higher than that of *S. leucotricha* during April ($p<0.05$), but significantly lower during June through September ($p<0.01$). The magnitude of these differences decreased as the season progressed.

A/E of *B. curtipendula* was equal to or greater than that of *S. leucotricha* throughout the season, but a significant species x date interaction was observed ($p<0.05$; Fig. 3, C & G). A/E of *B. curtipendula* was significantly greater than that of *S. leucotricha* in June, July, September and October within the lysimeters and in September and October within the paired-plots ($p<0.05$). A/E of *S. leucotricha* within the lysimeters was 2-fold greater than within the paired-plots ($p<0.05$). A significant species x lysimeter interaction was not observed, indicating that both species were responding in a similar manner even though absolute differences occurred between the lysimeters and paired-plots.

S. leucotricha generally displayed greater g than did *B. curtipendula* throughout the season, but a significant species x date interaction was observed ($p<0.01$; Fig. 3, D & H). Early in the season, g was similar for both species. However, g of *S. leucotricha* increased to two to four times that of *B. curtipendula* in June and remained at this level through September ($p<0.01$). No significant lysimeter or lysimeter x date effect occurred for g. A significant species x lysimeter interaction was observed indicating that g of *S. leucotricha* within the paired-plots was higher than within the lysimeters, while g of *B. curtipendula* within the paired-plots was lower than within the lysimeters ($p<0.05$).

T of the two species remained within 1.5C of each other throughout the season, but T of *B. curtipendula* was significantly greater than that of *S. leucotricha* in April, June, July and September ($p<0.05$) (not shown). T was significantly warmer within the paired-plots than within the lysimeters ($p<0.05$), but a significant species x lysimeter effect was not observed. Mid-day δ of *S. leucotricha* was approximately 1.0 MPa lower than that of *B. curtipendula* on all dates except April, June and October when δ of the two species were equal ($p<0.05$). Predawn δ did not vary significantly between species. δ decreased significantly as the season progressed ($p<0.05$). No significant lysimeter, lysimeter x date or species x date interactions were observed for δ. T and δ values associated with the occurrence of maximum A for each of the diurnal periods are presented in figures 4 A-D and 5 A-D.

MAXIMUM PHOTOSYNTHESIS AND ASSOCIATED VARIABLES

Maximum daily A of *B. curtipendula*, 20 umol m^{-2} s^{-1}, occurred in April, decreased dramatically in May and stabilized at approximately 5 umol m^{-2} s^{-1} during July through October (Fig. 4, A & B). T at the time of maximum daily A ranged from 23 to 43C (Fig. 4, C & D). Associated daily maximum E and g values paralleled A as anticipated. Associated δ ranged between -0.9 and -3.0 MPa within the lysimeters and -0.4 and -2.3 MPa within the paired-plots. An increase in δ to -0.4 MPa in August (paired-plots), following a 20 mm precipitation event, did not appreciably increase A. Conversely, A of approximately 4 umol m^{-2} s^{-1} was observed when δ ranged between -3.0 and -4.0 MPa. Seasonal maximum A of *B. curtipendula* was attained at a T of 38C and δ of -2.0 MPa (Fig. 4, A-D).

Maximum daily A of *S. leucotricha* occurred in July within the lysimeters (11 umol m^{-2} s^{-1}) and in March within the paired-plots (13 umol m^{-2} s^{-1}) at a T of 35 and 31C, respectively (Fig. 5, A & B). The three subsequent seasonal maxima (July and September) occurred at a T of 32, 36 and 33C (Fig. 5, C & D). Associated daily maximum E and g values were erratic and less closely coupled to A than those of *B. curtipendula*. Three to four-fold increases in E were associated with only modest increases in A as the season progressed. δ at the time daily maximum A was attained ranged between -0.9 and -4.3 MPa (Fig. 5, C & D). Low A values, 5 umol m^{-2} s^{-1}, were observed at δ between -3.0 and -4.0 MPa. Seasonal maximum A of *S. leucotricha* was attained at a T of 30C and δ of -1.9 MPa (Fig. 5, A-D).

Both species attained maximum daily A at similar times during the diurnal period within the lysimeters and the paired-plots (not shown). In instances where the times of absolute maxima differed, they did not significantly differ from secondary or tertiary diurnal seasonal maxima with only one exception; *B. curtipendula* attained maximum daily A 3 h later than did *S. leucotricha* within the paired-plots in April. δ of *S. leucotricha* was lower than that of *B. curtipendula* at the time of maximum daily A within both the lysimeters and paired-plots on all dates except June and October (Fig. 4, A-D & 5, A-D).

DISCUSSION

Seasonal mean and maximum diurnal A values indicate that *B. curtipendula* conforms to the published norm for a C_4 species with regard to temperature optima and A/E. *S. leucotricha* displayed daily maximum A comparable to that of *B. curtipendula* at T of 30 to 40C and A/E values 2 to 4-fold less than *B. curtipendula* (Fig. 3, C & G; Fig. 5, A-D). These temperatures are above the established temperature optimum for photosynthetic activity in the C_3 pathway, while the relative ranking of A/E between the two species conform to the published norm (Pearcy et al. 1981, Pearcy and Ehleringer 1984). Photosynthetic activity at T in excess of 30C suggests that RuBP-carboxylase is active over an uncharacteristically wide temperature range in this species. A values of *S. leucotricha* were comparable to those of the C_4 species throughout much of the season in spite of the inherent inefficiencies associated with C_3 photosynthesis at high temperatures (a reduction in the CO_2:O_2 ratio which increases photorespiration and decreases quantum yield; Ehleringer and Pearcy 1983). This response is analogous to the adjustment in temperature optima displayed by two C_4 species, *Spartina* *anglica* and *Atriplex confertifolia*, which were associated with C_3 species in cool temperate environments (Caldwell et al. 1977, Long and Woolhouse 1978).

Although, maximum seasonal A displayed the anticipated order between species, the rates were quite low in comparison with those of other native grasses, even in the early portion of the year when precipitation exceeded the long-term mean (Fig. 2 A & B; Monson et al. 1986). δ in excess of -1.0 MPa on all but two sampling dates for both species undoubtedly reduced maximum A (Fig. 4, A-D; Fig. 5 A-D; Brown and Trlica 1977, Kemp and Williams 1980). A of *S. leucotricha* appeared more responsive to intermittent increases in δ associated with small rainfall events than that of *B. curtipendula* (e.g. Sala and Lauenroth 1982). Since both species experienced similar levels of water deficit and no new leaf production was observed, this response is assumed to have been physiological in origin. Both species were capable of maintaining low A at δ values between -3.0 to -4.0 MPa, but *S. leucotricha* attained a greater percentage of its seasonal maximum A at more negative δ than did *B. curtipendula* (Fig. 4, A-D; Fig. 5, A-D). This suggests that *S. leucotricha* may be capable of partially compensating for low A/E with greater drought tolerance. Brown and Trlica (1977) suggested that A of *Agropyron smithii* (C_3) was more tolerant of water stress than that of *Bouteloua gracilis* (C_4) (but see Kemp and Williams 1980). This difference is presumably secondary to temperature and soil water availability in regulating the growth dynamics of *S. leucotricha* and *B. curtipendula*.

Although maximum A of *S. leucotricha* was lower than that of *B. curtipendula*, photosynthesis can potentially be maintained for a greater portion of the year. For example, *S. leucotricha* exhibited seasonal maximum A in March when *B. curtipendula* still had not developed sufficient leaf area for sampling. Abnormally cool temperatures and high precipitation in May and early June undoubtedly allowed *S. leucotricha* to maintain a large amount of live leaf area and continue photosynthesis for a greater portion of the summer than usual (Table 1, Fig. 2 A & B). This species usually senesces and becomes quiescent in early summer. In addition, if precipitation had been available in the autumn, *S. leucotricha* could have potentially continued to assimilate carbon through November and December as temperatures and vapor pressure deficits decreased. Alternatively, *B. curtipendula* employed a strategy of rapid carbon assimilation over a relatively short portion of the year when temperature and soil water availability were most favorable. Temporal separation of growth between species with contrasting photosynthetic pathways appears to be of greater significance to resource partitioning in this grassland than in the shortgrass prairie (Monson et al. 1986) or cold-desert shrub communities (Caldwell et al. 1977) referenced previously. The potential growing season in the two latter communities is constrained to a greater extent by the availability of soil water during the portion of the year when temperature is favorable for growth than in the Rolling Plains Resource region.

An estimate of seasonal carbon assimilation, derived by summing mean monthly A and assuming a standardized photoperiod of 10 h, indicates that both species assimilated approximately 1.5 mol CO_2 m^{-2} of leaf area within the undisturbed paired-plots. Comparable rates of seasonal carbon assimilation would establish the basis for codominance between these two species. However, the stochastic nature of the abiotic environment makes it difficult to assess competitive superiority on a seasonal or annual basis. Seasonal variation in precipitation, in conjunction with temperature, may periodically confer competitive superiority to one species over the other by influencing the extent of photosynthetic surfaces and the rate of photosynthesis realized. Over the long-term, the prolonged period of carbon assimilation displayed by *S. leucotricha*, albeit at a low rate with a relatively inefficient use of water, appears to confer this C_3 species with the capacity to co-exist with C_4 competitors in grasslands at relatively low latitudes.

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Table 1. Mean photosynthetic photon flux densities (PPFD; umol m^{-2} s^{-1}) at the time of the second diurnal gas exchange measurement, maximum, minimum and mean air temperatures (C) and mean relative humidity (RH; %) on each of eight dates that gas exchange measurements were taken for *S. leucotricha* and *B. curtipendula*.

Month	PPFD	Temperature			RH
		Max	Min	Mean	
March	1692 ± 89	14.0	2.1	6.5	48.3
April	1842 ± 52	30.5	16.2	24.3	21.3
May	1596 ± 88	22.4	16.2	19.7	59.6
June	1492 ± 98	37.1	20.3	31.6	20.1
July	1330 ± 98	34.4	19.5	25.9	19.0
August	1534 ± 110	-----	-----	-----	-----
September	1171 ± 83	30.6	14.0	21.7	18.2
October	1490 ± 79	25.9	11.0	15.2	20.3

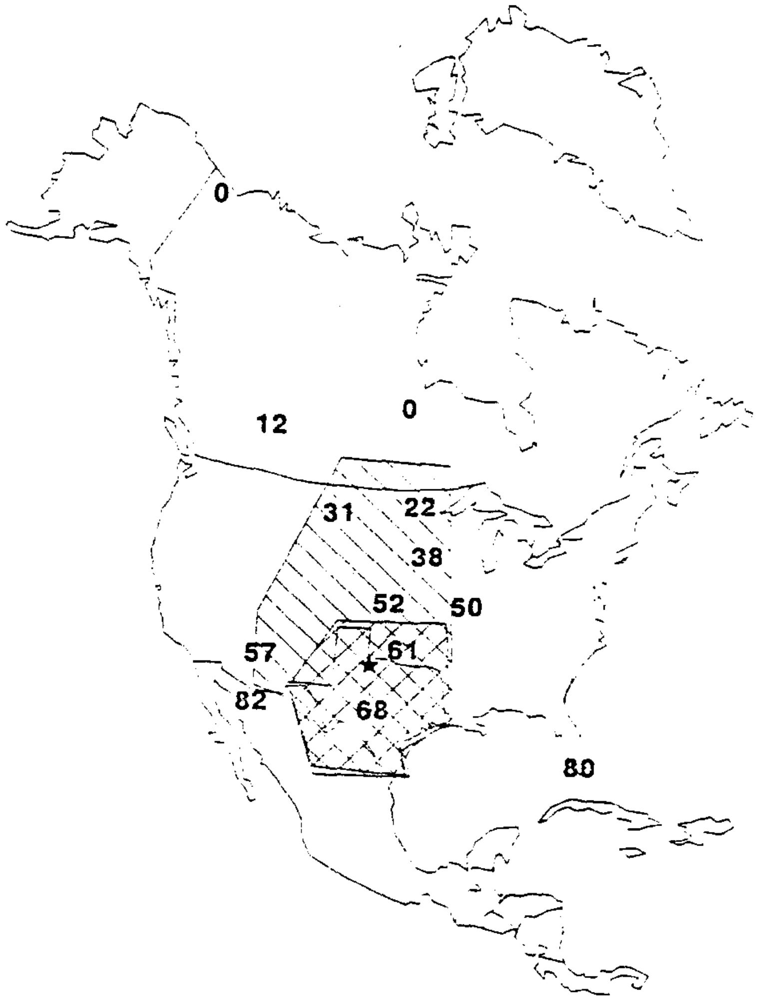

Figure 1. Illustration of the percentage of C_4 grasses at various locations in North America, the distributional range of *S. leucotricha* (cross-hatched lines) and *B. curtipendula* (diagonal lines), and location of the study site (star). [Illustration modified from Teeri and Stowe (1976)].

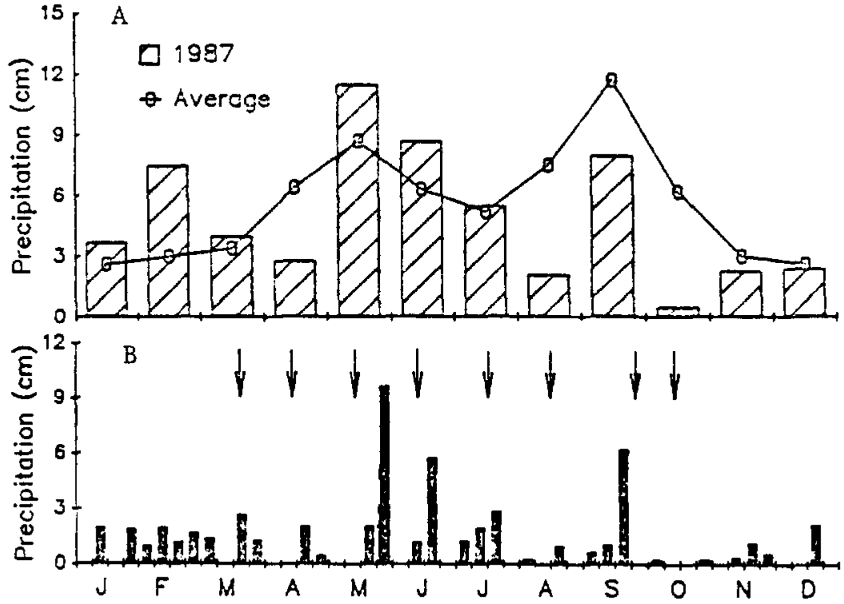

Figure 2. (A) Cumulative monthly precipitation for 1987 and 30 year mean monthly precipitation and (B) cumulative weekly precipitation recorded at the study site during 1987. Arrows represent the times gas exchange measurements were taken.

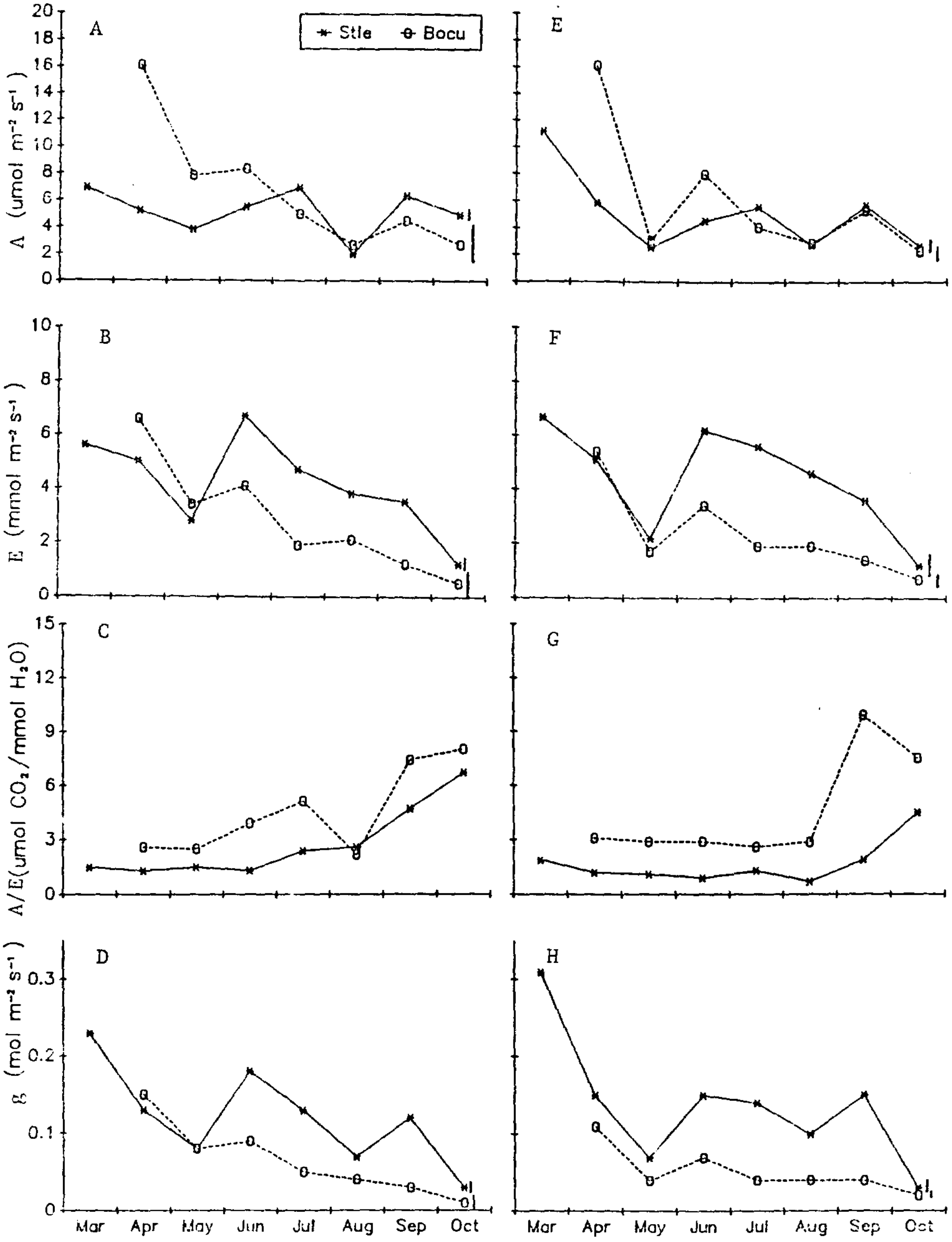

Figure 3. Mean diurnal estimates of net apparent photosynthesis (A), transpiration (E), A/E, and stomatal conductance (g) for *S. leucotricha* and *B. curtipendula* within (A-D) lysimeters and (E-H) adjacent paired-plots for eight dates during 1987.

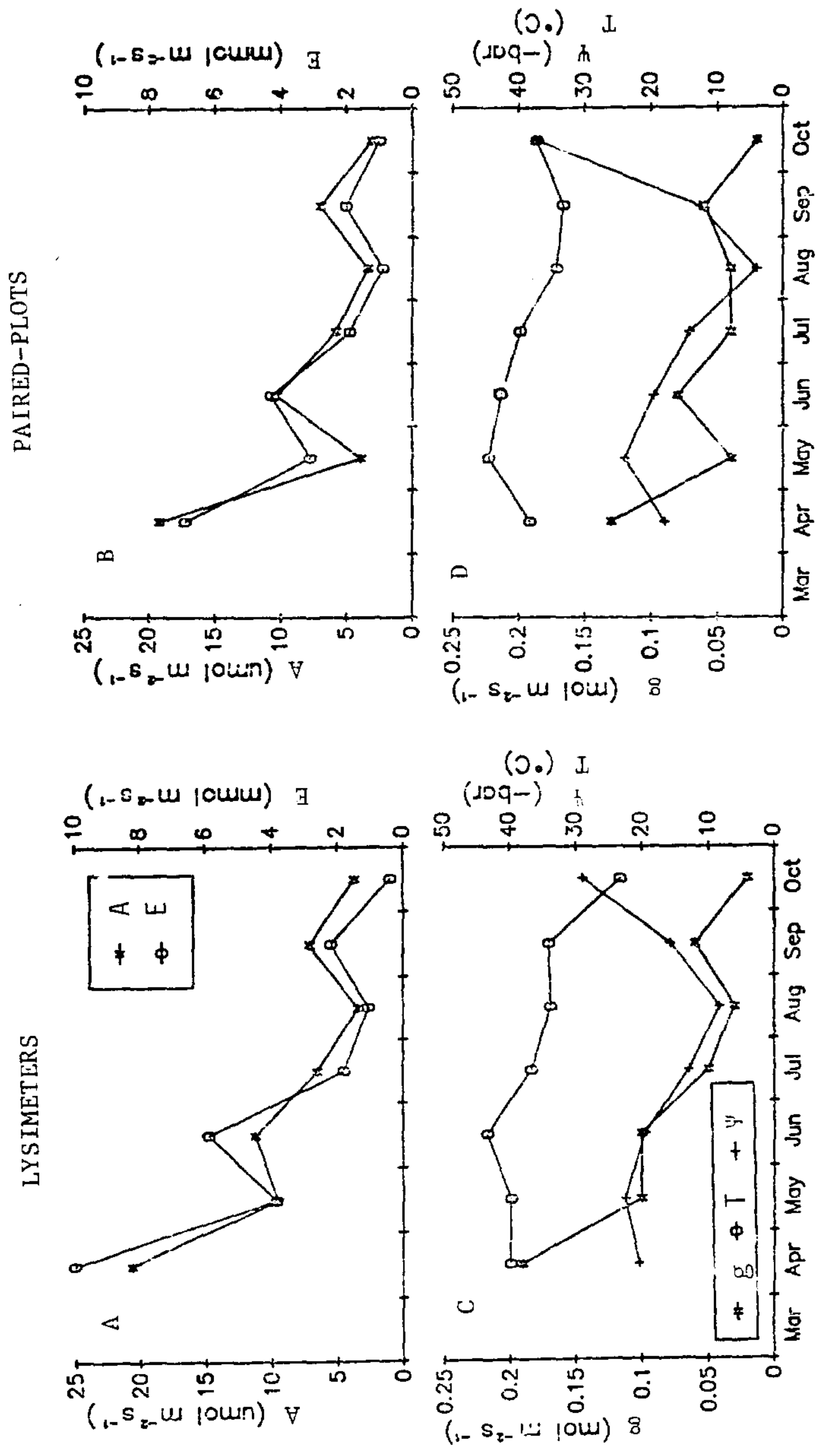

Figure 4. (A & B) Maximum net apparent photosynthesis (A) recorded within eight diurnal periods and associated values for transpiration (E), and (C & D) stomatal conductance (g), leaf temperature (T) and tiller water potential (ψ) for *B. curtipendula* within lysimeters and adjacent paired-plots during 1987.

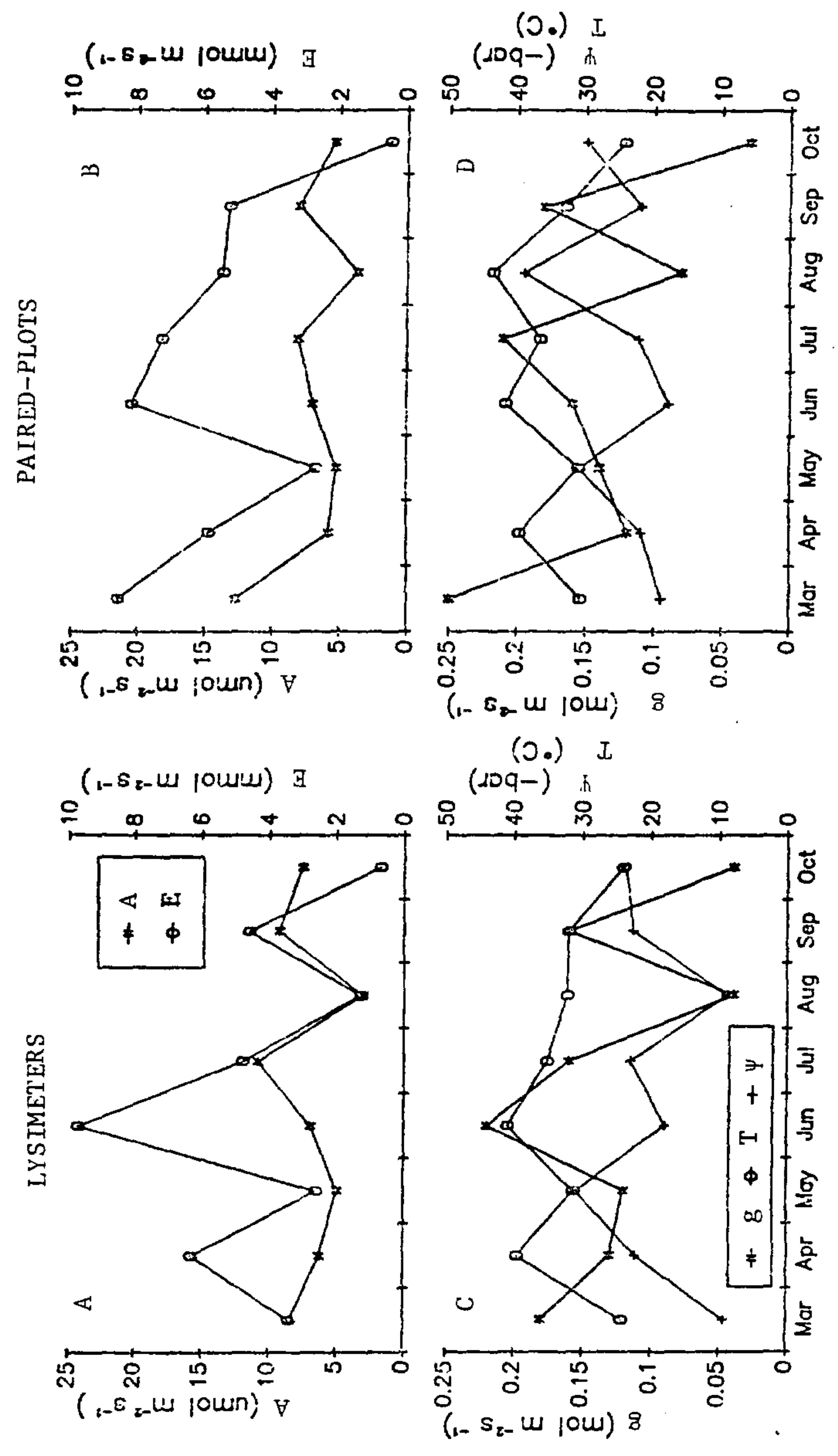

Figure 5. (A & B) Maximum net apparent photosynthesis (A) recorded within eight diurnal periods and associated values for transpiration (E), and (C & D) stomatal conductance (g), leaf temperature (T) and tiller water potential (ψ) for *S. leucotricha* within lysimeters and adjacent paired-plots during 1987.

WATER YIELD OF NORTH TEXAS NATIVE GRASSLANDS

Thomas A. Wright, R.W. Knight and R.K. Heitschmidt

SUMMARY

Research conducted from January 1986 to December 1987 at the Wagon Creek Spade Ranch evaluated water budgets from North Texas native grasses to determine the influence of native grasses on water yield. The three native grasses evaluated were: sideoats grama, a warm-season midgrass; common curly mesquite, a warm-season shortgrass; and Texas wintergrass, a cool-season midgrass. Soil water content was obtained weekly from January 1986 to December 1987 with a Troxler neutron probe.

Water balance data were summarized by season and year. Runoff, deep drainage, evapotranspiration, and soil water content were subjected to repeated measures least squares analysis of variance. Main effects were treatment, and either season and year, or year.

Evapotranspiration in the spring was 35 and 45% greater than ET during the summer and fall. Above average precipitation during the fall of 1986 and winter of 1987 recharged soil water for spring growth. Early occurrence of precipitation during fall of 1986 produced an increase in ET and allowed for continued soil water use.

Deep drainage showed significant year by season interaction although the total average was less than 1 mm. Deep drainage occurred when winter and spring drought created cracks in the soil. This in conjunction with high intensity spring rains funneled into the deep profiles down these cracks. Water balance indicated that 98.22% of water in the system was lost through ET with 1.38 and 0.40% lost through water yield and change in soil water.

INTRODUCTION

Water is the most limiting factor affecting production of rangeland ecosystems. Thus, an understanding of how various processes affect the utilization and availability of water in rangeland ecosystems is critical for sound resource management.

Greater infiltration has been shown on midgrass plots than shortgrass plots (Rauzi and Kuhlmann 1961, Dee et al. 1966, Brock et al. 1982, Pluhar et al. 1987). Most literature on infiltration rates or runoff reports a negative correlation between infiltration and grazing (Alderfer and Robinson 1947, Duley and Domingo 1949, Marston 1952, Liethhead 1957, Rauzi 1963, Tromble et al. 1974, and Pluhar et al. 1987). As grazing pressure increases, biomass decreases and bare soil increases thus, infiltration rates decrease. However, a positive correlation exists between standing crop and infiltration. Increase in grazing pressure will alter the composition of the community by shifting composition dominance from midgrass to shortgrass. This shift in grass composition from a more desirable to a less desirable reduces infiltration rates. The successional stage of a community also affects the infiltration rates. Research indicates that those lands in a higher successional stage have a higher infiltration rate than those in a lower stage (Liethhead 1959).

Past studies dealing with water yield have either used high intensity rainfall simulators on small plots at simulated rates of 55 to 112 mm/hr or large watersheds that determined water yield without determining the effects of grass phenotype or species. This study will attempt to evaluate how cool-season midgrass, warm-season midgrass, and warm season shortgrass affect water yield in north central Texas by using soil monoliths in lysimeters. Specific hypotheses to be tested were: 1) Water yield will be greater from warm-season shortgrass than warm-season midgrass dominated sites, and 2) Water yield will be greater from the warm-season than the cool-season midgrass dominated sites.

METHODS

Lysimeters were installed in the summer of 1985 by drilling a 1.22 m long, 76 cm diameter, 6 mm thick walled steel pipe into native stands of the selected vegetation. A total of 12 monoliths were encased: four from each of sideoats grama, a warm-season midgrass (Bocu); common curleymesquite, a warm-season shortgrass (Hibe); and Texas wintergrass, a cool-season midgrass (Stle). Vegetation in 3 of the lysimeters, 1 of each species, was treated with herbicide to create bare ground (BG) plots.

Following excavation, the lysimeters were inverted and 4 ceramic porous cups were installed in 10 cm of sand. These cups were connected to a plastic pipe system that extended inside one wall of the lysimeter to the soil surface. Before turning the lysimeters upright, a steel plate was welded to the bottom of each lysimeter and sealed with silicon. The porous cup system was used to quantify deep drainage.

An aluminum neutron probe access tube 48 mm in diameter and 1.1 m in length was installed in the center of each lysimeter for monitoring weekly soil moisture measurement at depths of 17.5, 37.5, 57.5, 77.5, and 95 cm. Runoff was collected by cutting a 3 cm wide hole in the side of each lysimeter and installing a plastic pipe system which directed runoff into a 5 liter bucket. The lysimeters were then placed inside 0.9 m diameter metal culverts that were concreted 0.5 m apart and buried 1.4 m in the ground.

Standing crop was measured periodically through both years of the study using a non-destructive sampling scheme. Frequency hits (Levy and Madden 1933) from a vertical 10-point frame at permanent sample points within each lysimeter were recorded by live leaf, dead leaf and stem. During each sampling period, a similar sample scheme was used in areas outside the lysimeters to establish a relationship between frequency hits and above ground biomass by species and tissue category.

Evapotranspiration (ET) was estimated from the water balance equation:

$$ET = PPT-WY-S$$

where PPT = precipitation, WY = runoff (RO) + deep drainage (DD), and S = change in soil water.

DATA SUMMARIZATION AND ANALYSIS

Water balance data were summarized by season and year prior to statistical analyses. Seasons were winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Aug), and fall (Sep-Dec). Parameters subjected to analyses were RO, DD, ET, and WY.

RESULTS

WATER BALANCE

Bare Ground Treatment. Inclusion of bare ground (BG) in the analysis of variance repeatedly showed significant treatment effects (BG vs. other) relative to amounts of runoff (RO) and evapotranspiration (ET) on a monthly and seasonal basis. The treatment by year interaction was not significant, however. Analysis of soil water content (SW) was similar to those for RO and ET except treatment was not significant. Deep drainage (DD) displayed a significant 3-way interaction effect of treatment by year by month, and treatment by year by season. Amount of annual RO, ET, and SW varied between years while RO and ET varied among treatments on an annual basis.

Because of the over-riding effects of BG on the various parameters evaluated, subsequent analyses were conducted excluding data from the BG treatment.

Vegetated Lysimeters Treatments. Season, year, and the year by season interaction were significant for RO (Table 1). The year by season interaction was the result primarily of differences in amounts of RO during spring. Runoff during the spring of 1986 was considerable because of several high intensity rainfall events, low herbage standing crop and high antecedent SW. Four high intensity storms, each greater than 26.0 mm, occurred during May of 1986. Although the first storms did not produce substantial RO, they did increase soil water content whereby RO from later storms was substantial.

The significant season effect resulted from greater amounts of RO during spring than winter, fall, and summer. Year was significant effect because RO in 1986 was 84% greater than 1987, primarily as a result of greater RO during the spring of 1986. Year and season effects were dominated by the 4.9 mm of RO from the spring of 1986 compared to no RO during the spring of 1987. Small amounts of RO were consistently produced during the winter while summer showed no measurable RO. It is probable that if the plots had not been clipped during winter, RO during the spring of 1986 would have been less.

Analyses of ET estimated significant year and year by season interactions but no treatment effects. The year by season interaction (Table 2) resulted from a 48% difference in ET between the fall of 1986 and the fall of 1987. Precipitation totals were similar for the fall of 1986 and 1987, but the fall of 1986 received its majority during October when warm temperatures were available for ET compared to 1987 when its majority occurred during December after the plants have senescesed. Late precipitation of 1987 did not have high evaporation rates or favorable temperatures for growth. Precipitation in combination with increased standing crop, and high evaporation potential during 1986 provided for greater ET in 1986 than 1987.

Significant season effects resulted from 35 and 45% greater ET in the spring than summer and fall, respectively. Winter had 60, 36, and 26% less ET than spring, summer, and fall, respectively. Spring was significantly greater than other seasons because of high antecedent SW, lower standing crop, and warmer temperatures. Reduced antecedent soil water limited ET during the summer while cooler temperatures and reduced standing crop reduced ET in the fall. The evapotranspiration for winter, spring, and summer seasons of 1987 were consistently greater than those of 1986. No other significant main effects or interactions occurred.

Deep drainage was affected only by the year by season interaction. The year by season interaction (Table 3) was the result of differences between years during spring and winter. Deep drainage tended to only occur after several months of substantial rainfall such as following the winter of 1986 and the fall of 1987. There were no other significant main effects or interactions recorded for DD.

Total water yield is the sum of RO and DD. When summed, significant year season and year by season interaction effects were revealed (Table 4). Again, the spring of 1986 was the major influence on the analysis with all three species reporting DD. Deep drainage was only 4.56% of the total water yield. Of the total water yield from HIBE, only 8.8% was due to DD. STLE and BOCU had less than 1% of their total WY due to DD.

MANAGEMENT IMPLICATIONS

Water yield could be increased significantly by reducing standing crop during the spring and early fall, peak precipitation periods. This would be most efficiently done through a grazing management program involving rotational grazing. High stocking rates during the winter and spring would decrease standing crop allowing for greater RO to occur. Light continuous grazing during the same period would allow for increased infiltration rates, thus less RO.

A deferred rotation grazing system would be the best alternative in providing high quality RO and maintaining range condition. The rotational grazing system provides less of an impact on the pasture by providing "rest" and quality cover unlike continuous grazing.

A decision making process involving water yield should be incorporated into grazing management schemes. To increase water yield, rangeland should be grazed during the late winter, early spring and in early fall in order to reduce the amount of standing crop available for evapotranspiration and interception of precipitation. However, with greater RO, there will be less water available to infiltrate into the soil.

Table 1. Mean annual and seasonal amounts of runoff (mm) from weighing lysimeters averaged across species.[1]

Year	Season				
	Winter	Spring	Summer	Fall	Average
1986	0.21 b(x)	4.91 a(w)	0.00 b(w)	0.13 b(w)	1.32 (w)
1987	0.85 a(w)	0.00 a(x)	0.00 a(w)	0.00 a(w)	0.21 (x)
Average	0.53 b	2.46 a	0.00 b	0.06 b	

[1] Seasonal means in a row (no parentheses) or column (parentheses) followed by same letter are not significantly different at $P<0.05$.

Table 2. Mean annual and seasonal amounts of evapotranspiration (mm) from weighing lysimeters averaged across species.[1]

Year	Season				
	Winter	Spring	Summer	Fall	Average
1986	24.59 c(w)	84.20 a(w)	41.99 bc(w)	59.88 b(w)	58.61 (w)
1987	42.90 c(w)	94.59 a(w)	65.82 b(w)	41.14 c(x)	52.67 (w)
Average	33.74 c	83.40 a	53.91 b	50.51 b	

[1] Seasonal means in a row (no parentheses) or column (parentheses) followed by same letter are not significantly different at $P<0.05$.

Table 3. Mean annual and seasonal amounts of deep drainage (mm) from weighing lysimeters averaged across species.[1]

Year	Season				
	Winter	Spring	Summer	Fall	Average
1986	0.00 b(x)	0.10 a(w)	0.00 b(w)	0.00 b(w)	0.05 (w)
1987	0.16 a(w)	0.00 b(x)	0.00 b(w)	0.00 b(w)	0.00 (w)
Average	0.08 a	0.05 a	0.00 a	0.00 a	

[1] Seasonal means in a row (no parentheses) or column (parentheses) followed by same letter are not significantly different at $P<0.05$.

Table 4. Mean annual and seasonal amounts of water yield (mm) from weighing lysimeters averaged across species.[1]

Year	Season				
	Winter	Spring	Summer	Fall	Average
1986	0.10 b(x)	1.50 a(w)	0.01 b(w)	0.30 b(w)	0.47 (w)
1987	0.17 a(w)	0.02 b(x)	0.00 b(w)	0.00 b(w)	0.10 (w)
Average	0.14 b	0.76 a	0.15 b	0.15 b	

[1] Seasonal means in a row (no parentheses) or column (parentheses) followed by same letter are not significantly different at $P<0.05$.

EFFECT OF HONEY MESQUITE ON THE WATER BALANCE OF TEXAS ROLLING PLAINS RANGELAND

D.H. Carlson, T.L. Thurow, R.W. Knight, and R.K. Heitschmidt

SUMMARY

Understanding the hydrologic processes determining the water balance on rangelands is necessary to aid management decisions regarding assessment of shrub management as a means to increase off-site water yield. Nine non-weighable lysimeters were monitored for three years to determine the water balance as influenced by vegetation. Cover types studied were honey mesquite (*Prosopis glandulosa*) plus herbaceous vegetation (H+M), mesquite removed leaving only herbaceous vegetation (H), and mesquite and herbaceous vegetation removed (BG). Throughout the study, BG lysimeters had significantly 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, intensity and amount of bare ground. Evapotranspiration accounted for over 95% of water leaving the vegetated sites. The increase in herbaceous vegetation on the H lysimeters offset any water yield benefit that may have accrued through mesquite removal.

INTRODUCTION

Rangeland watersheds are an important source of most surface flow and aquifer recharge in the Southwestern U.S. (Hibbert 1979). It is hypothesized that rangeland management practices which affect vegetation cover and composition will 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 water balance/water yield 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 inherent in these factors complicates predictions of rangeland water use and thereby confounds speculation on 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 percolation.

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/water yields 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 semi-arid continental. Annual precipitation (1950-1988 median=646 mm) was bimodal, with peaks occuring in May and September (Fig. 1). Average maximum/minimum daily temperatures range from 13.1/-2.6° C in January to 36.1/21.2° C in July. The average frost-free growing period is 220 days. Elevation of the study site is 450 m.

Soils were fine, silty, mixed, thermic Typic Calciustolls (Nuvalde silty clay loam) that were deep, well-drained and slowly permeable. This soil type is located on upland slopes (1-3%) formed from limey alluvium or outwash (USSCS 1988). The silty clay loam surface was approximately 280 mm thick, and the silty clay loam subsoil was about 560 mm thick. The underlying parent material was calcitic silty clay. Range site classification was clay loam. The potential climax community is 90% grasses, 10% forbs, and a trace of woody plants (USSCS 1988). The dominant midgrasses found on the site were 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 were: 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 were heath aster (*Aster ericoides* L.) and Texas broomweed (*Xanthocephalum texanum* (DC.) Shinners). A virgin stand of honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) was the dominant woody species on the site, providing about 30% canopy cover.

METHODS

SITE PREPARATION

In July 1985, nine mature honey mesquite trees of similar size (trunk basal diameter about 180 mm, canopy area about $12 m^2$) were selected as sites for placement of non-weighable 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 growth. After trenches were back-filled, fiberglass partitions extending 200 mm above the soil surface were placed around the perimeter and sealed to the plastic sheets to prevent overland flow from entering or exiting lysimeters. Area of lysimeters ranged from 15.0 to 26.7 m^2.

Three treatments were established for study. The honey mesquite trees in six lysimeters were killed by cutting and removing the trees and treating the stumps with 1 liter of diesel oil. Of these six lysimeters, three were left with the herbaceous component intact (H treatment). The three remaining mesquite-free lysimeters were completely denuded and treated with tebuthiuron (BG treatment). The herbaceous and woody cover in three lysimeters was not disturbed (H+M 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 amd 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 to November of 1986-1988 using the non-destructive 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. Herbaceous vegetation above 50 mm height was mowed in February of each year.

A micrologger weather station (Campbell CR21) was used to monitor ambient atmospheric conditions at the site. Maximum, minimum, and average air temperature and total precipitation, storm duration and intensity were measured. A standard rain gauge was installed to provide a check for the recording tipping bucket gauge.

Runoff measurements were taken from lysimeters following each precipitation event. Surface runoff funneled 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 mm. 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 neutron moisture gauge access tubes per lysimeter using a calibrated moisture depth gauge (Troxler 3320 series). Weekly measurements were taken at 0.18, 0.38, 0.60, 0.88, 1.15, 1.45, 1.70, 2.15, 2.60, and

3.50 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. Deep drainage was estimated by calculating the net inputs of water into each soil layer on a monthly basis. Deep drainage was defined as those inputs reaching the 3.50 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. Data were analyzed using the Statistical Analysis System analysis of variance procedures (SAS Institute 1988). Stepwise multiple regression analysis was used to determine the relationship between runoff and sediment and selected soil, vegetation, and storm variables. Variables entered into regression models were significant at $P < 0.05$, and to stay in the model variables had to improve the r^2 value by at least 0.02. Where appropriate, means were separated using the Duncan's New Multiple Range Test. Significant levels were determined at $P < 0.05$.

RESULTS AND DISCUSSION

SOIL WATER CONTENT

Soil water content (SWC) was closely linked to precipitation patterns (Fig. 1). Mean SWC of the entire soil profile was significantly greater in the BG treatment (736 mm) than either the H (629 mm) or H+M (593 mm) treatments. The mean SWC of H lysimeters was significantly greater than in H+M lysimeters. SWC in the BG treatment was significantly greater at all depths except 2.60 and 3.05 m where H lysimeters had significantly greater SWC (Fig. 2). H lysimeters had significantly greater SWC than the H+M lysimeters at 0.18 m and at all depths below 0.88 m. The H+M treatment had greater SWC at depths between 0.18 and 0.88 m than the H treatment. 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. H and H+M treatments had similar SWC in the top 1.3 m of soil (ie. above the first caliche layer) in winter and spring (Table 1). In summer and fall, however, H lysimeters had less SWC than did H+M lysimeters in this zone.

The consistently greater SWC of the BG treatment compared to the vegetated treatments collaborates the findings of Weltz (1987) who studied similar vegetation types in south Texas. The two 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 corresponds 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 (RO) occurred during intense spring and fall thunderstorms. The percent of precipitation lost to RO was significantly greater for the BG treatment as compared to H and H+M treatments (Table 2). On vegetated sites only a small percentage (< 5%) of precipitation was lost as RO (Fig. 3). This is consistent with estimates for South African savanna (Whitmore 1971). RO was least in the H treatment although it was significantly less than in the H+M treatment in only 1986. Similar trends in interrill erosion (IE) occurred as a result of collinearity between RO and IE (r=.89).

Stepwise regression models indicated that total amount of precipitation during any given rainfall event was the major factor affecting amount of RO (r=.71) and IE (r=.71) regardless of treatment. Other important factors were percent bare ground and storm intensity for both RO and IE (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 reduces breakdown of soil aggregates and detachment of soil particles. Storm intensity also is a measure of the raindrops kinetic energy.

Analyses by treatment also showed precipitation was the major factor affecting RO (r=.65 to .87) and IE (r=.65 to .84). Precipitation was the only variable selected by stepwise regression to predict RO on the BG treatment. On vegetated plots (H and H+M) storm intensity variables were also important for predicting RO and IE.

Many studies have shown that RO from bareground is greater than from vegetated sites but, in contrast to this research, these studies have shown that RO from shrub-dominated sites (shrub canopy zone) is less than from herbaceous (interspace) plots (Blackburn 1975, Brock et al. 1982, Thurow et al. 1986, Weltz 1987). The greater RO and IE from the H+M lysimeters in this study was apparently the result of lower herbage standing crop and leaf area index (LAI) on the H+M than H plots (Heitschmidt and Dowhower unpubl. data) and less cover on the H+M plots. This relationship was reflected by stepwise multiple regression analyses (Table 3) and is in agreement with results from simulated rainfall studies conducted near the study site (Wood and Blackburn 1981, Pluhar et al. 1987). The fact that the stepwise multiple regression analyses generally chose the same variables for the predictive equations of RO and IE is due to the close relationship between runoff and interrill erosion on rangeland (Thurow et al. 1988).

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 great potential evapotranspiration loss and the presence of the two caliche layers which slowed percolation. These data are comparable to the results 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

In general, ET losses from the H and H+M lysimeters were about 14% greater than the evaporation loss from the BG lysimeters (Table 2, Fig. 3). During the low precipitation year of 1988 however, evaporation losses from BG lysimeters exceeded ET losses from the vegetated lysimeters. The plant and litter cover on vegetated sites in 1988 may have reduced evaporation from the soil enough to offset the transpirational water loss from the slow growing and senescent vegetation. BG lysimeters also began the growing season with relatively greater SWC, hence more water was available for evaporation loss. South Texas (Weltz 1987) and South African (Opperman et al. 1977) bare ground lysimeters averaged 70% and 74% annual evaporation, respectively compared to mean 84.4% evaporative loss from bare soil documented by this study. This difference may be attributed to soil cracking at this site which allowed evaporation to occur from deeper in the soil profile.

ET losses from H and H+M treatments were similar. Differences in phenology, water use efficiency, rooting pattern, and interception loss between mesquite and herbaceous vegetation are some factors which would be expected to influence the ET pattern on the H and H+M 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; greater standing crop on H compared to H+M treatments occurred throughout the study (Heitschmidt and Dowhower unpubl. data). The herbaceous component was dominated by Texas wintergrass (Heitschmidt and Dowhower unpubl. data), which continued to grow throughout the winter. This species has been shown to be inefficient in its water use compared to associated warm-season grasses (Hicks 1988). In contrast, mesquite is very efficient in its water use and can greatly reduce transpiration losses during dry periods (Ansley et al. unpubl. data).

CONCLUSIONS

The results of this study indicate that mesquite removal coupled with maintenance of the herbaceous cover had no benefit in terms of off-site water yield. Slow percolation through the clay soil, coupled with two 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 RO or ET. The ungrazed herbaceous vegetation provided a more complete soil cover than was present under the mesquite. Bare ground was an important determinant of RO and IE. Therefore RO and IE were less on the herbaceous interspaces 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.

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

		Season			
Soil Depth	Treatment	Winter	Spring	Summer	Fall
0-130 cm					
	BG	288b[1]	299a	288b	275c
	H	238a	223b	182d	189c
	H+M	233a	219b	192d	197c
130-238 cm					
	BG	240b	247a	244a	235c
	H	205b	218a	207b	196c
	H+M	183bc	188a	184b	180c
238-327 cm					
	BG	203b	208a	207a	204b
	H	209b	213a	212a	210ab
	H+M	195c	199a	198b	195c

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

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

Year	Treatment		
	BG	H	H+M
1986			
Rainfall (mm)	769	769	769
ET (mm)	511a[1]	644b	658b
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)	646a	804b	756b
Drainage (mm)	14a	6a	2a
Storage (mm)	-82a	-137b	-99ab
Runoff (mm)	95a	3b	17b
Sediment (kg ha^{-1})	32684a	48b	431b
1988			
Rainfall (mm)	529	529	529
ET (mm)	566a	555ab	512b
Drainage (mm)	4a	4a	3a
Storage (mm)	-87a	-32b	+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 ($P<0.05$).

Table 3. Stepwise multiple regression equations for runoff and interrill erosion for bareground (BG), herbaceous (H), and herbaceous plus mesquite (H+M) 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	.75
H	$y = -.076 + .009PPT + .049MAX5$	178	.56
H+M	$y = -.090 + .014PPT + .055MAX10 + .070MAX20$	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
H+M	$y = -.264 + .045PPT + .119MAX5$	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

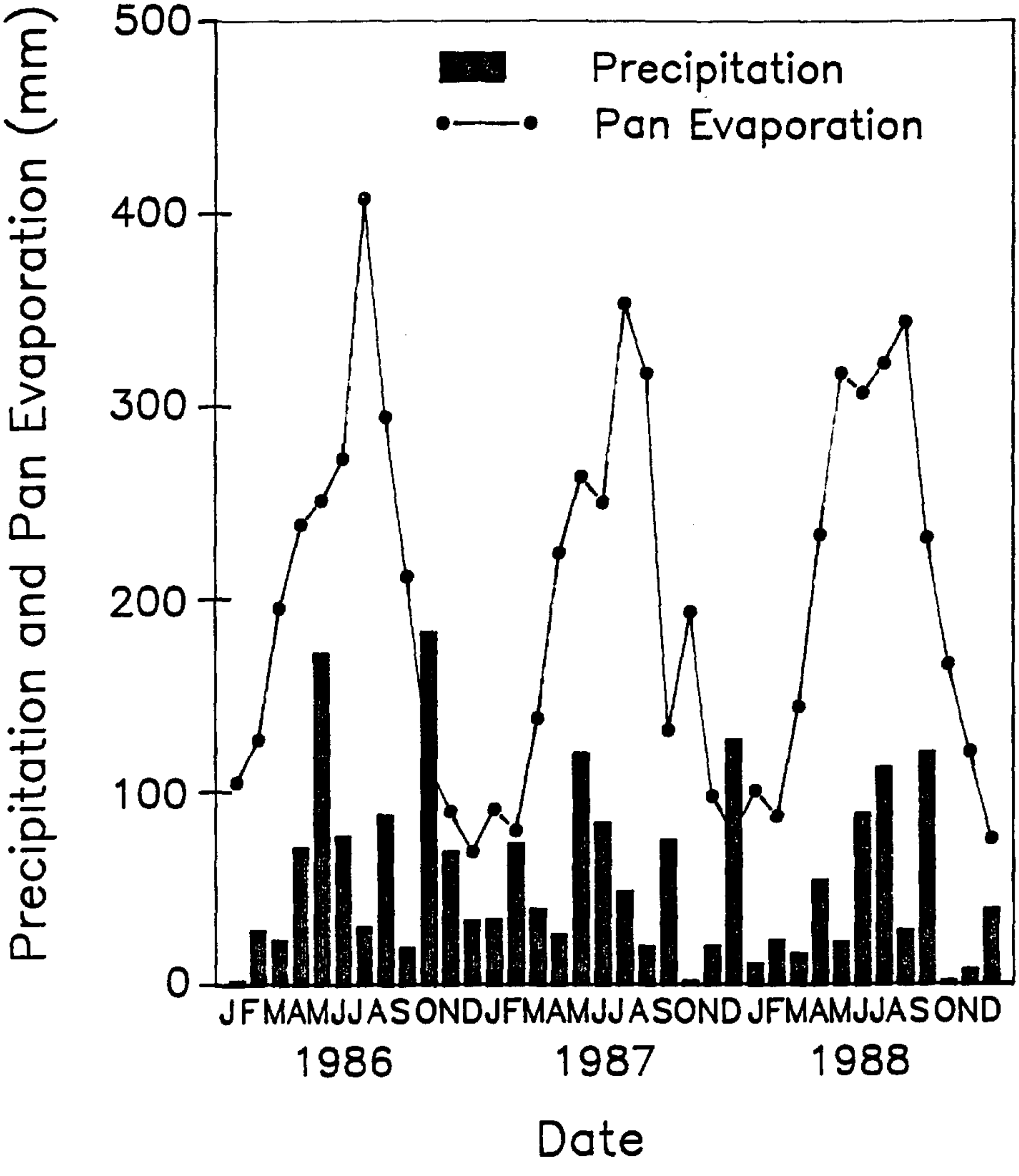

Figure 1. Monthly precipitation and pan evaporation (mm) throughout the study period.

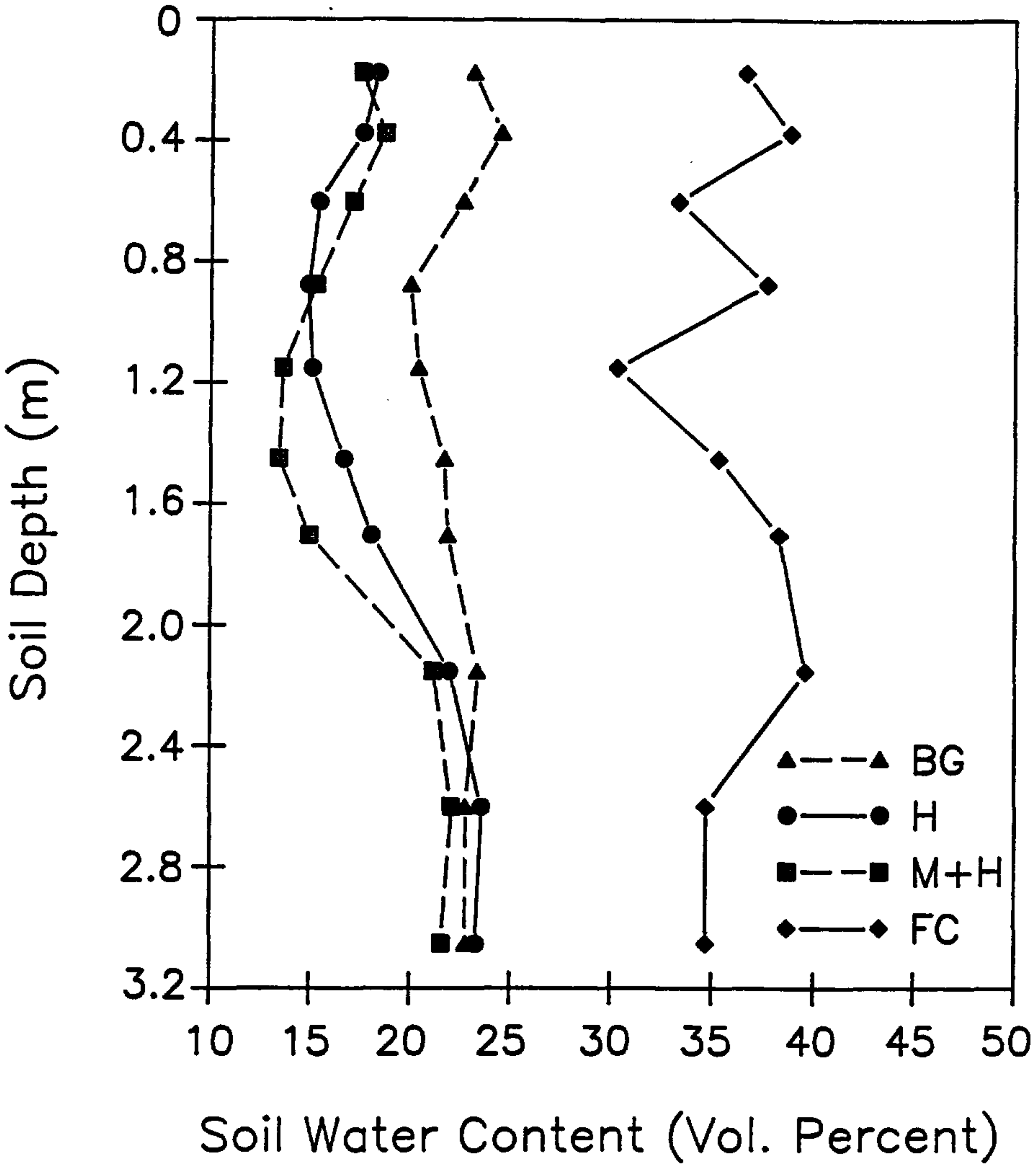

Figure 2. Mean soil water content (mm) at various depths (cm) in the bareground (BG), herbaceous (H), and herbaceous plus mesquite (H+M) treatments averaged across dates. Soil water content with the same letter for the same depth are not significantly different (P<0.05).

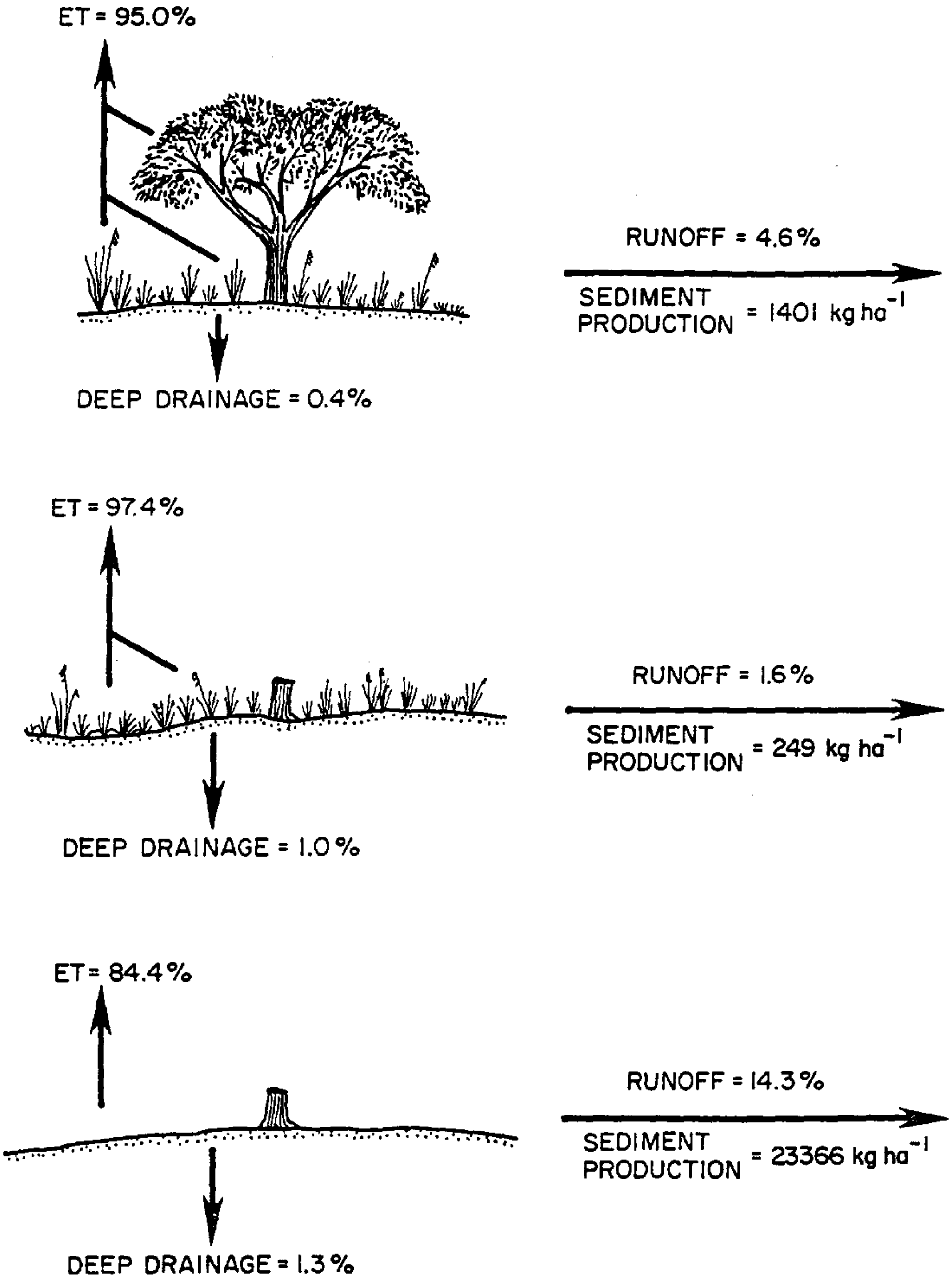

Figure 3. Annual water balance for the bareground (BG), herbaceous (H), and herbaceous plus mesquite (H+M) treatments during the 3-year study.

LYLES RANCH STUDY SITE

The Lyles Ranch is located adjacent to the Nueces River about 30 km southwest of Uvalde, in Uvalde and Zavala Counties (Fig. 1). The gentle slopes of the study site are typical of the Rio Grande Plains land resource area. Normal precipitation of the area is 547 mm of which 60% usually falls in April through September. The heaviest 1-day rainfall on record for the area was 173 mm at Crystal City on 4 October 1959. Thunderstorms occur on about 45 days each year, mostly during spring. Soils are in the Duval-Webb-Brystal map unit. Honey mesquite and blackbrush are the dominate shrubs with a sparse understory of grasses and forbs.

The lysimeter site consisted of 12 non-weighable lysimeters and 12 weighable lysimeters (Fig. 2). The lysimeters are described in detail in the individual reports.

LYLES RANCH STUDY SITE

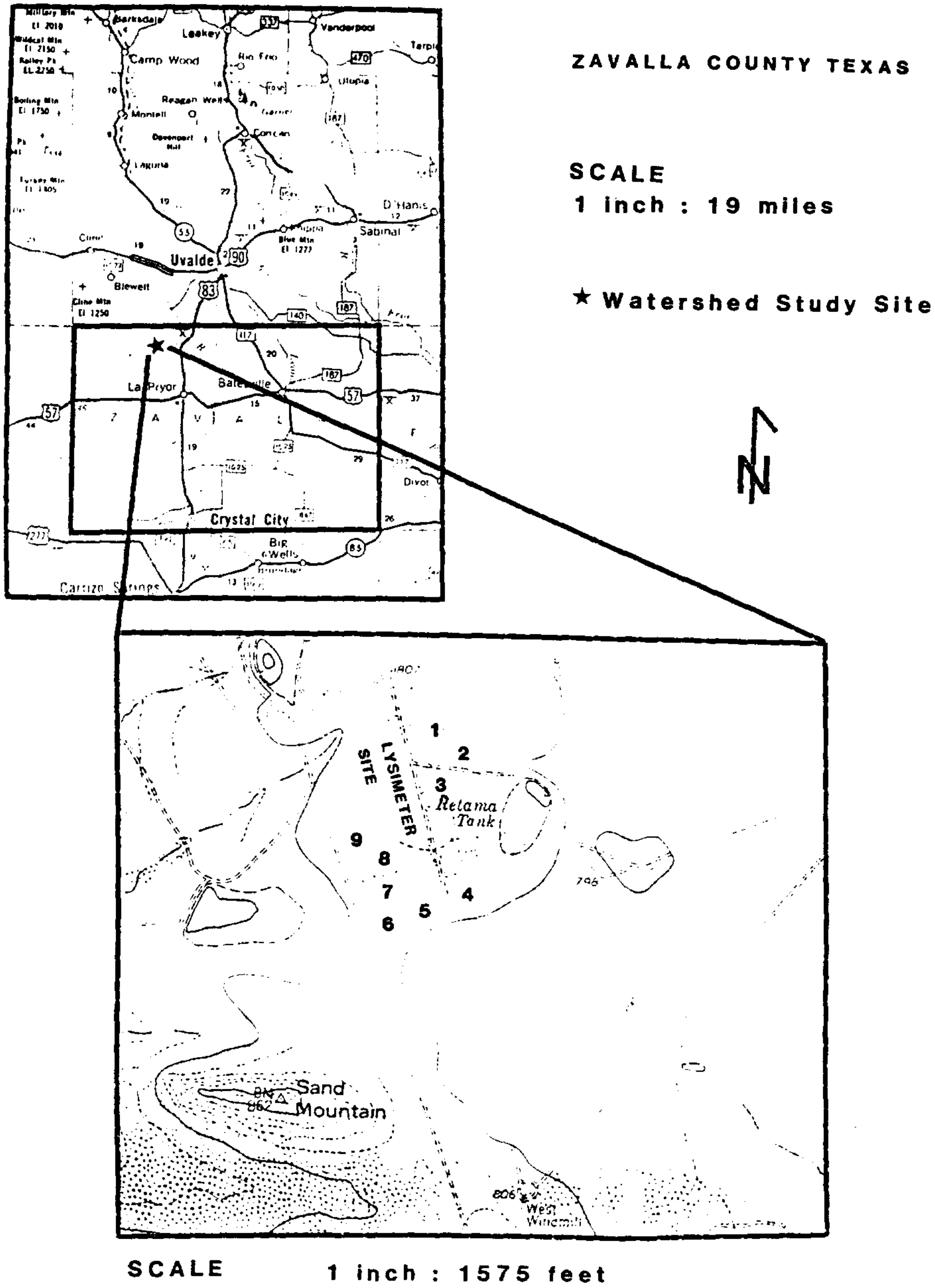

Figure 1. Location of Lyles Ranch watershed study site.

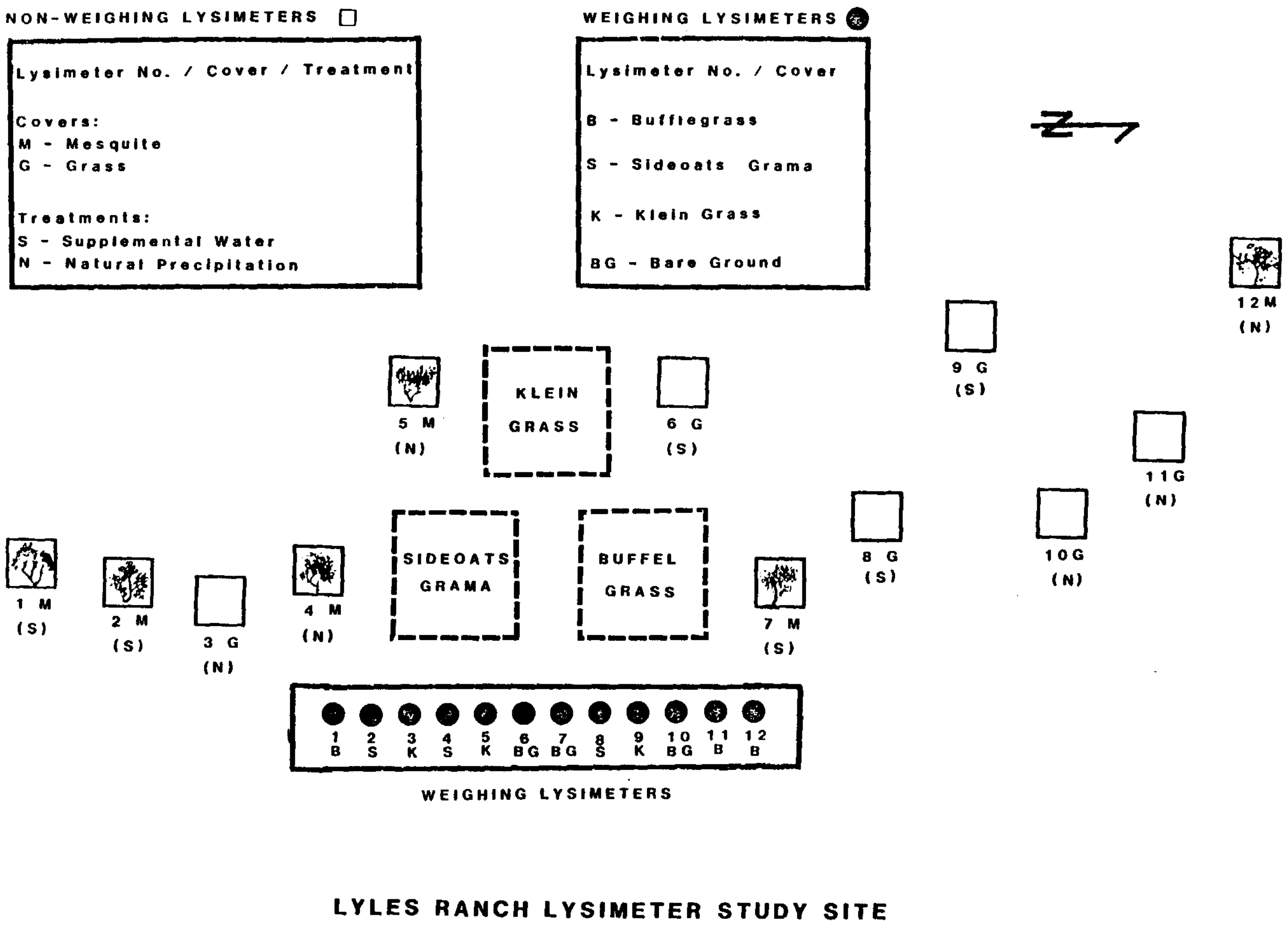

Figure 2. Lysimeter study layout on the Lyles Ranch.

WATER-USE AND WATER YIELD OF THREE C_4 BUNCHGRASSES IN THE SOUTH TEXAS PLAINS

Gary L. Holmstead, R.W. Knight, and M.A. Hussey

SUMMARY

Plant water relations for three C_4 bunchgrasses, kleingrass (*Panicum coloratum* L., 'Selection 75'), buffelgrass (*Cenchrus ciliaris* L., 'Common'), and sideoats grama (*Bouteloua curtipendula* Michx., 'Haskell') were investigated over 2 growing seasons on a rangeland watershed using non-weighing lysimeters (695 l). Buffelgrass was predicted to have the greatest total water-use (transpirational-use and soil moisture depletion) throughout the study, sideoats grama the lowest. Although not significant ($P>0.05$) sideoats yielded the most runoff (45.87 mm) and drainage (0.035 mm), buffelgrass the least (24.60 and 0.012 mm, respectively). Buffelgrass was able to maintain more favorable and less fluctuating plant water potential (WP) across both growing seasons. Minimum WP exhibited in buffelgrass was -3.15 MPa as compared to -4.53 and -4.23 MPa for kleingrass and sideoats grama, respectively. Soil moisture was rapidly utilized and most depleted at depths >100 cm in buffelgrass and kleingrass during the first growing season, whereas sideoats utilized comparatively greater soil moisture at 15 cm in the lysimeters. Sideoats exhibited rapid increases in plant WP following light rainfall events whereas buffelgrass appeared to be most dependent on deeper soil moisture. All three species had exploited the entire soil volume of the lysimeters by the end of the second growing season.

INTRODUCTION

To meet water demands, Texas is currently mining about 11 percent more ground water than is being recharged annually. By the years 2000 and 2030, Texas is projected to experience water shortages of 0.75 million ha-m and 1.20 million ha-m respectively (Grubb 1981). Two-thirds or 42 million ha of Texas is classified as rangeland and about 82% of the rangeland in Texas is occupied by shrub species that intercept and transpire large amounts of water (Rechenthin and Smith 1967). It is hypothesized that water yield can be increased in these areas by removing the shrub species and replacing them with grasses that utilize less water. Controlling critical area of shrub concentration could increase water yield (Weltz 1987 unpublished data, McCarl et al. 1987).

This study was conducted to investigate variability in water-use by dominant grass species in the South Texas Plains. Three grasses commonly used for revegetation in this region, kleingrass (*Panicum coloratum* L., 'Selection 75'), buffelgrass (*Cenchrus ciliaris* L., 'Common'), and sideoats grama (*Bouteloua curtipendula* Michx., 'Haskell'), were investigated under field conditions during a 2 year establishment period.

MATERIALS AND METHODS

STUDY SITE

This research was conducted during 1987 and 1988 at the George W. Lyles ranch (99°52' W, 29°07' N; elevation=247 m) near Uvalde, Texas. The ranch is located in the Nueces river watershed and is part of the South Texas Plains vegetation region which comprises about 8 million ha of level to rolling topography. Soils of the study site are of the Brystal series (fine-loamy, mixed family of hyperthermic aridic Paleustalfs). Average annual precipitation of the area is 612 mm with rainfall most often being associated with thunderstorm activity. Heavy downpours may occur at any time, but they are most common in spring and early fall. The average frost free period is 285 days, usually from late February to early December. Mean annual temperature is 20.5°C and pan evaporation is 1747 mm. Major herbaceous species include pink pappusgrass (*Papophorum bicolor*), tanglehead (*Heteropogon contortus*), hooded windmill grass (*Chloris cucullata*), western ragweed (*Ambrosia psilostachya*), and annual broomweed (*Xanthocephalum dracunculoides*). Dominant woody plants include honey mesquite (*Prosopis glandulosa*), and an associated complex of *Acacia* species such as huisache (*A. farnesiana*), guajillo (*A. berlandieri*), and blackbrush (*A. rigidula*).

LYSIMETERS

Twelve lysimeters were built by drilling steel pipe, 150 cm in length and 76 cm in diameter (695 l), into the ground to attain relatively undisturbed soil cores. Four ceramic cups were placed in the bottom of each lysimeter with an access tube running to the surface to allow for the extraction of drainage water. The lysimeters were sealed at the bottom and placed in a common trench inside an 80 cm diameter pipe of the same height. The outer pipe was previously cemented into a 15 cm concrete pad at the bottom of the trench. Three of the lysimeters and area immediately surrounding each lysimeter were seeded to kleingrass, 3 to sideoats grama, and 3 to buffelgrass in April of 1987. The remaining 3 lysimeters were maintained at bare ground by hand weeding. A completely randomized design was utilized for lysimeter placement. A surface runoff line was attached to each lysimeter to collect runoff in nearby catchment facilities. Soil moisture was monitored through neutron probe access tubes (1.5 m) which were installed in the center of each lysimeter. Measurements were taken at 15, 45, 75, 105, and 135 cm depths with a Troxler 3320 Series moisture depth gauge. Soil moisture data was collected at weekly intervals from July 1987 to December 1988.

GAS EXCHANGE AND PLANT WATER POTENTIAL

Transpiration rate (E) was measured on recently expanded leaves of each species with a LI-6000 portable photosynthesis system (Li-Cor, Inc., Lincoln, NE) equipped with a 0.25 l leaf chamber. Leaves were monitored at 3-hour intervals over a diurnal period. Measurements were repeated at ca. 24 d intervals throughout the growing season. At least 6 leaf lamina were sampled for each species on each sampling date. A standardized leaf orientation, parallel to the soil surface, was maintained during each measurement. After obtaining gas exchange measurements, leaves were cut, placed between wet toweling, and stored in plastic bags. Upon return to the laboratory, leaf area was measured with a LI-3000 area meter (Li-Cor, Inc., Lincoln, NE). These values were used to calculate E on a leaf area basis. Measurements were taken on 5 dates from July to November of 1987, and on 4 dates from July to November of 1988. Drought conditions during the first half of 1988 (Fig. 1, Period 2) resulted in insufficient plant material for gas exchange measurements during this period.

Concurrent with gas exchange measurements, plant water potential (WP) was measured with a pressure chamber (3000 Series, Soil moisture Equip. Corp., Santa Barbara, CA). A tiller was excised at ground level, inserted into the pressure chamber, and the pressure (MPa) at which liquid appeared on the cut surface noted (Turner 1988). A rapid initial pressurization rate was used (0.2 MPa s^{-1}), which was slowed down to about 0.05 MPa s^{-1} within 1.0 MPa of the expected endpoint. This was done as a compromise between the need for slow pressurization (Turner 1981, Blum et al. 1973), and the need for many measurements in a short time. A minimum of 3 plant tillers per species were sampled at one hour predawn and one half hour preceding the second, third, and forth gas exchange measurements. Only 2 dates were sampled in period 2 because of insufficient plant material due to increasing water stress.

Increasing drought conditions from January to June of 1988 necessitated supplemental watering in order to investigate comparative water-use between species. Additional water was supplied by sprinkler irrigation from July to December of 1988 to simulate a wet years monthly rainfall. Monthly rainfall was averaged from 5 years of above normal rainfall and the amount of water not received in natural rainfall events was applied at the end of each month to total the 'wet' month average.

Data were analyzed using the Statistical Analysis System (SAS) analysis of variance procedures. Years were analyzed separately, and because treatments and time generally interact, we analyzed the data by sampling dates within each year. This study focuses on three 6-month periods during 1987 and 1988 which are characterized by different rainfall regimes.

RESULTS

Long term precipitation for the South Texas Plains vegetative region follows a bimodel pattern with peak rainfall usually occurring in May and October. Both 1987 and 1988 were unusual rainfall years. The first half of 1987 was the wettest period on record. Precipitation for January through June of 1987 was 200% higher (584 mm) than the 30-year average of 292 mm for this period. The last half of 1987 was one of the driest periods on record, receiving just 47% (152 mm) of the 321 mm normally received from July through December. This drought continued into 1988. January to June of 1988 received just 35% of normal rainfall. It became evident that in order to investigate comparative water-use of these grasses, water had to be available for use. Insufficient plant material was available for gas exhcange measurements during the first half of 1988 because of drought conditions. Supplemental watering began in July of 1988 and therefore July through December of 1988 received 184% (591 mm) of the average rainfall for the period.

The amount of rainfall received created 3 distinct periods in which data were analyzed (Fig. 1). Plants were seeded at the first of 1987 and were considered fully established by the end of the first growing season. Period 1 represents comparative plant performance during the first year in production. Although precipitation was low during period 1, soil moisture was high from unusually high rainfall events earlier in the year. The second period represents species response to increasing water stress. Rainfall and supplemental watering events during the third period created more favorable growing conditions and stimulated plant growth.

WATER-USE

Although not always significant ($P>0.05$), maximum leaf transpiration (E) rates were generally achieved by buffelgrass on each sampling date in both 1987 and 1988 (Fig. 2). Peak E values were observed in July-August of each year following rainfall/irrigation events. Mean diurnal E reached 5.1 umol m^{-2} s^{-1} in buffelgrass during 1987, and 4.33 umol m^{-2} s^{-1} in sideoats and kleingrass. Mean diurnal E reached just 2.62, 2.04, and 1.40 umol m^{-2} s^{-1} in buffelgrass, sideoats, and kleingrass, respectively, in 1988. Leaf E declined in all species as leaves became senescent at the end of each growing season in November.

Leaf transpiration analyzed across 1987 showed no significant difference ($P=0.20$) amoung species although buffelgrass had the highest E followed by sideoats and kleingrass at 2.59, 2.24, and 1.99, respectively. Analysis of leaf transpiration for the 1988 growing season showed significant differences ($P\leq0.001$) between species where buffelgrass had the highest average E followed by sideoats and kleingrass at 1.79, 1.18, and 1.04 umol m^{-2} s^{-1}, respectively.

It is believed that the introduced species had significantly higher standing crop and leaf area index in the lysimeters than sideoats grama. These assumptions are based on field observations and results of non-destructive sampling techniques (not presented) using measurements from adjacent paired plots of each species. Leaf area index and standing crop was measured from 16x16 m plots of each species established adjacent to the lysimeters (Holmstead 1989 unpublished data). Both leaf area index and standing crop were found to be significantly higher ($P \leq 0.05$) in kleingrass and buffelgrass across a growing season. Standing crop at the end of the 1988 growing season was 2654 and 2313 kg ha^{-1} for kleingrass and buffelgrass, respectively, compared to just 1152 kg ha^{-1} in sideoats. Both kleingrass and buffelgrass have been shown to exhibit high production rates (Norris 1976, Woodward 1980a, 1980b).

Although kleingrass exhibited relatively low E rates, high leaf area of kleingrass is believed to result in relatively high plant transpirational water-use. High leaf area in buffelgrass combined with high E rates are believed to result in the greatest transpirational water-use in this species. These assumptions are supported by soil moisture and deep drainage measurements in the lysimeters.

Soil moisture data collected during the first growing season (Period 1) indicates significant differences ($P \leq 0.05$) between species at depths greater than 100 cm (Fig. 3C). Buffelgrass and kleingrass lysimeters had significantly less soil moisture at 105 cm (not shown) and 135 cm than sideoats from September-December of 1987. By the end of the second growing season differences in soil moisture became non-significant at 135 cm between species. Analyzed across the entire study, soil moisture at 135 cm was significantly lower ($P \leq 0.05$) in buffelgrass and kleingrass (17.44 and 17.66%, respectively) compared to sideoats (20.34%). It appears that the introduced species had the capacity to exploit deep soil moisture quickly after establishment in the lysimeters. Buffelgrass and kleingrass have been shown to exhibit deep root systems (Taerum 1970, Hussey and Simecek 1987) with buffelgrass roots reaching depths of 260-280 cm in field studies in East Africa (Taerum 1970). Taerum (1970) reported maximum root yield in buffelgrass was achieved about 10 months from planting. A deep root system would be important in allowing buffelgrass to access more soil moisture and maintain higher E.

Soil moisture at 15 cm depth was generally lower in sideoats lysimeters on all sampling dates in 1987 and 1988 (Fig. 3A). When all data were analyzed across the study, sideoats was found to exhibit significantly ($P \leq 0.05$) less soil moisture (9.78%) at 15 cm depth compared to kleingrass and buffelgrass (11.29 and 10.92%, respectively).

It is believed that sideoats has a more extensive, fibrous root system in the upper soil levels, whereas buffelgrass and kleingrass develop deeper root systems. Measurements of plant water potential indicate sideoats to be the most responsive to light rainfall events, exhibiting rapid increase in plant WP. The sampling date in September of 1987 (Fig. 4) was one day after a 12.7 mm rainfall event. Minimum plant WP reached during diurnal sampling increased >1.5 MPa in sideoats from August to September 1987, whereas WP increased <0.2 MPa in buffelgrass and kleingrass over this time. A 7.6 mm rainfall event occurred during diurnal WP measurements in September 1988, just following the third measurement (7 hours post sunrise). Plants of each species had reached minimum WP values of -2.10, -2.16, and -1.86 MPa in sideoats, kleingrass, and buffelgrass, respectively. Three hours later plant WP values were -0.33, -0.67, and -0.87 MPa for sideoats, buffelgrass, and kleingrass, respectively. This represented significant increases ($P \leq 0.01$) in WP in all species of 1.77, 1.49, and 0.99 MPa for sideoats, kleingrass, and buffelgrass, respectively. Sala and Lauenroth (1982) reported extremely rapid response in leaf conductance and water potential of *Bouteloua gracilis* to a 5 mm rainfall event. They concluded that this characteristic allowed *Bouteloua gracilis* to utilize sporatic rainfall which accounts for 70% of the rainfall events in the shortgrass steppe environment. Buffelgrass may be more dependent on deep roots for water uptake.

Less fluctuation was found in WP measurements for buffelgrass across each season (Fig. 4). Buffelgrass had a range of 1.7 MPa during 1987 sampling dates compared to ranges of 2.9 and 1.8 MPa for sideoats and kleingrass, respectively. Water potential ranged 1.4 MPa in buffelgrass between 1988 sampling dates compared to ranges of 2.8 and 3.1 MPa for sideoats and kleingrass, respectively. A deeper (possibly more extensive) root system would allow buffelgrass to access more soil moisture and maintain more favorable and less fluctuating WP during dry periods. In the tallgrass prairie of Central Oklahoma, Hake et al. (1984) found *Andropogon gerardi* to maintain higher and less fluctuating WP across the growing season as compared to 3 other C_4 grasses. This was attributed to a deeper root system in *Andropogon gerardi*.

WATER YIELD

A single deep drainage event was recorded from the grass lysimeters during the 2 year study period. This occurred on the first sampling date, 31 July 1987. This date was preceded by unusually high rainfall in May and June. Deep drainage was consistently generated from bare ground lysimeters in both 1987 and 1988. On 31 July 1987 drainage was significantly different ($P \leq 0.08$) between grass lysimeter treatments where 0.035, 0.012, and 0 mm was recorded for sideoats, kleingrass, and buffelgrass, respectively. Differences in drainage between grass species were not significant ($P>0.05$) when analyzed across the entire season (Table 1A).

Several surface runoff events were observed during both years. Problems with hose connections between the lysimeters and runoff lines made interpretation of runoff data during 1987 impossible. Runoff data for 1988 indicated few significant differences ($P \leq 0.05$) between grass lysimeter treatments (Table 2). Analyzed across 1988, there was no significant difference ($P=0.31$) between grass species, yet sideoats yielded 45.87 mm of water compared to 24.91 and 24.60 mm for kleingrass and buffelgrass, respectively (Table 1B).

The higher standing crop and leaf area of the introduced species are thought to contribute to greater interception and evaporation of water from foliage, thus reducing surface runoff in kleingrass and buffelgrass lysimeters. Work in the Edwards Plateau region of Texas has shown that hydrologic parameters can be altered by different grasses (Blackburn 1983, Knight et al. 1984, McCalla et al. 1984). Generally species with high vegetative cover (standing crop and mulch accumulation) exhibit high infiltration and lower surface runoff (Gifford 1974). High standing crop is also thought to slow the flow of surface runoff.

DISCUSSION

In this study, differences in water-use were predicted between stands of kleingrass, buffelgrass, and sideoats grama, with buffelgrass having the greatest water-use. This was attributed to higher leaf transpiration rates, leaf area index, and a deeper root system. Sideoats grama was predicted to have the lowest water-use. This was attributed to less leaf area, and a shallower root system in sideoats. By the end of the second growing season, all species had exploited the entire soil volume in the lysimeters, such that few differences were found in soil moisture between species at all depths.

The apparent increase in rooting depth of sideoats from July 1987 through July of 1988 (Fig. 3C) may be in response to increased water stress. Molyneux and Davies (1983) have shown rooting response to soil drying to be species specific. Roots of perennial ryegrass (*Lolium perenne*) which, in wet soil are deep rooting were restricted in their rooting, while roots of water-stressed orchard grass (*Dactylis glomerata*) seedlings grew deeper into the soil profile than did roots of well-watered plants when subjected to soil drying. When water was withheld from plants, deeper rooting apparently resulted in a more favorable shoot water balance which had a beneficial effect on shoot growth.

Minimum plant WP exhibited in buffelgrass was -3.15 MPa as compared to -4.53 and -4.23 MPa for kleingrass and sideoats, respectively, during the study. A deep root system would contribute to maintenance of favorable plant WP and high leaf E in buffelgrass during periods of low rainfall.

Maintenance of high WP by buffelgrass may also be explained by a high capacity for osmotic adjustment in this species. Ford and Wilson (1981) found that the accumulation of inorganic ions contributed -8.72 bar of osmotic adjustment of water stressed leaves of buffelgrass compared to -5.53 bar in green panic (*Panicum maximum*). Comparing buffelgrass, spear grass (*Heteropogon contortus*), and green panic, Wilson et al. (1980) reported minimum WP attained in water stressed leaves were -3.3, -3.8, and -4.4 MPa for the three species, respectively. They also reported high osmotic adjustment to water stress in buffelgrass compared to the other grasses.

The comparative slow increase in plant WP of buffelgrass following light rainfall events suggests it was more dependent on deep soil moisture. Sideoats exhibited rapid increases in WP and was found to utilize greater soil moisture at shallow soil depths in comparison to kleingrass and buffelgrass.

Water yield was not significantly different (P>0.05) between species. Although not significant across growing seasons, sideoats yielded both the most surface runoff and drainage, buffelgrass the least.

The plants used in this study were grown in monocultures. This may not be the situation in most range conditions. Introduced species or varieties are usually seeded in pure stands, while native species are generally seeded in mixtures (Haferkamp and Mutz 1982). Buffelgrass and kleingrass are often the dominant species in improved pastures in South Texas. Sideoats grama is rarely found as a monoculture. The responses of individual plants grown in monocultures are often very different from those of plants grown in mixed cultures (Van den Bergh 1969, Austin and Austin 1980). Further studies are needed to quantify competitive interactions, rooting demography, and stand persistence, production, and differences in water-use and water yield between species with increasing stand age.

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Table 1. Cumulative water yield as: drainage A) and runoff B) in 1987 (beginning 31 July) and 1988 for lysimeter treatments[1].

TREATMENT	A) DRAINAGE (mm x 100) 1987	A) DRAINAGE (mm x 100) 1988
Bare Ground	29.9 a	10.7 a
Sideoats grama	3.5 b	0.0 b
Buffelgrass	0.0 b	0.0 b
Kleingrass	1.2 b	0.0 b

TREATMENT	B) RUNOFF (mm) 1987	B) RUNOFF (mm) 1988
Bare Ground	NA[2]	277.77 a
Sideoats grama	NA	45.87 b
Buffelgrass	NA	24.60 b
Kleingrass	NA	24.91 b

[1] Means followed by the same letter in a column are not significantly different at P≤0.05.

[2] Not applicable. Could not be determined as a result of rodent damage to runoff line connections.

Table 2. Runoff events (mm) from lysimeter treatments in 1988[1].

YEAR	DATE	Bare Ground	Sideoats	Buffelgrass	Kleingrass
1988	13 APR	16.24 a	11.98 a	2.24 b	1.14 b
	5 MAY	0.27 a	0.00 a	0.00 a	0.00 a
	20 JUN	0.44 a	0.00 a	0.00 a	0.00 a
	8 JUL	55.48 a	0.03 b	0.00 b	0.00 b
	12 JUL	12.27 a	0.15 b	0.03 b	0.07 b
	23 AUG	49.97 a	3.31 b	0.00 b	2.94 b
	12 SEP	16.90 a	0.02 b	0.02 b	0.00 b
	1 OCT	2.46 a	0.00 b	0.00 b	0.00 b
	8 OCT	7.94 a	0.00 b	0.00 b	0.00 b
	31 OCT	43.06 a	9.41 b	4.69 b	6.47 b
	9 NOV	45.56 a	4.42 b	3.67 b	4.41 b
	16 NOV	22.04 a	15.80 a	13.22 a	9.86 a
	20 DEC	5.14 a	0.75 b	0.73 b	0.02 b

[1] Means followed by the same letter in a row are not significantly different at P≤0.05.

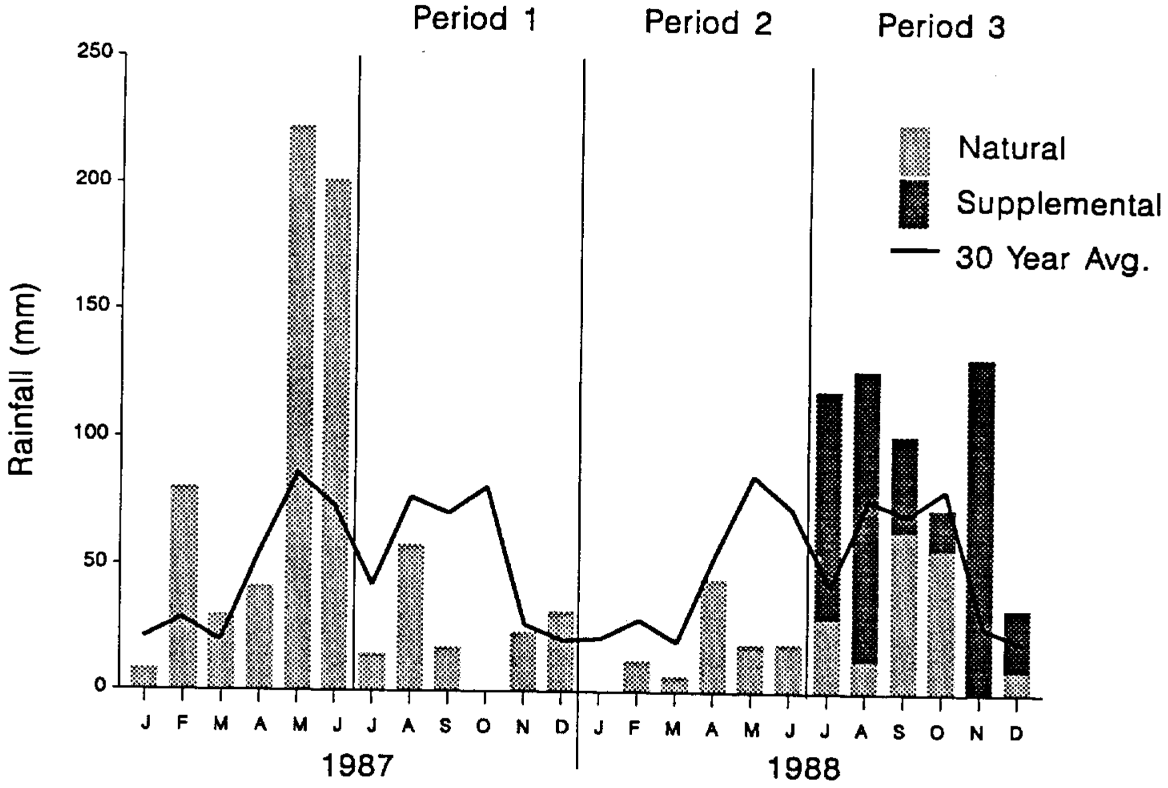


Figure 1. Thirty-year mean monthly rainfall from Uvalde and cumulative rainfall/irrigation recorded for 1987 and 1988 at the Lyles Ranch study site.

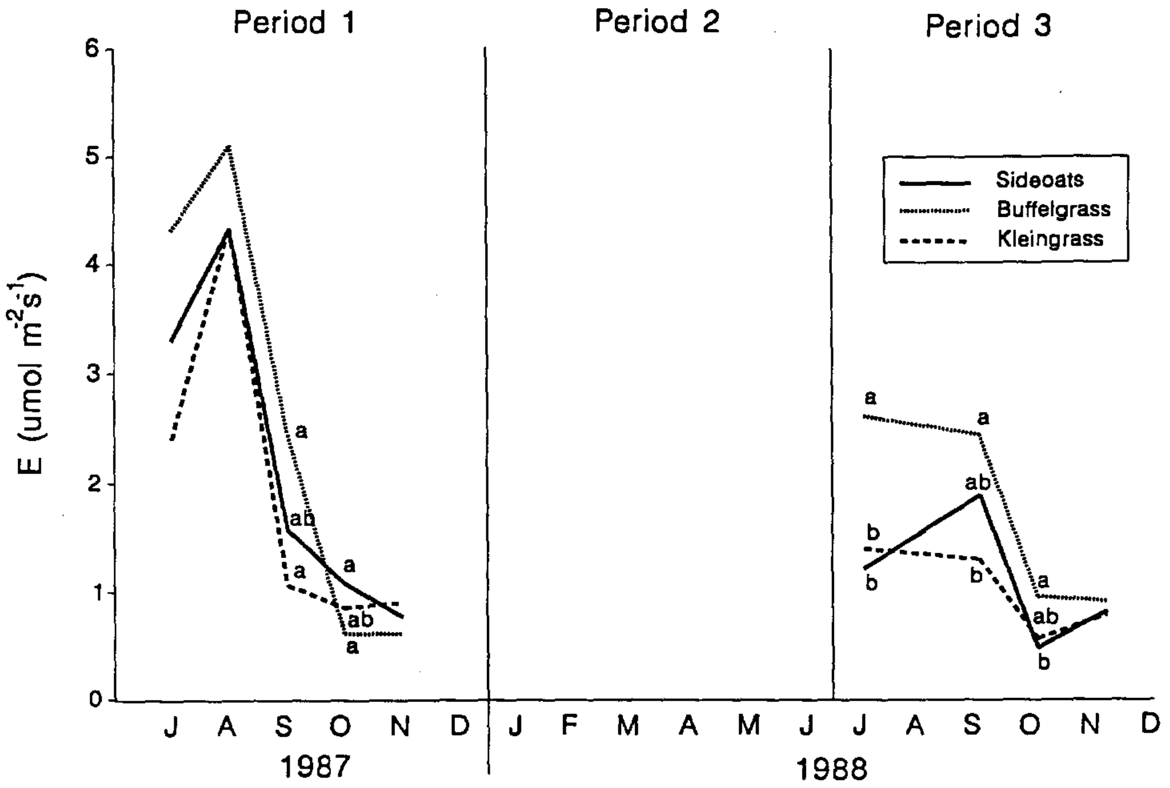


Figure 2. Mean diurnal leaf transpiration (E) for each sampling date in 1987 and 1988. Species with the same letter across a date are not significantly different at P≤0.05. If no letters are present, then values are not significantly different for that date.

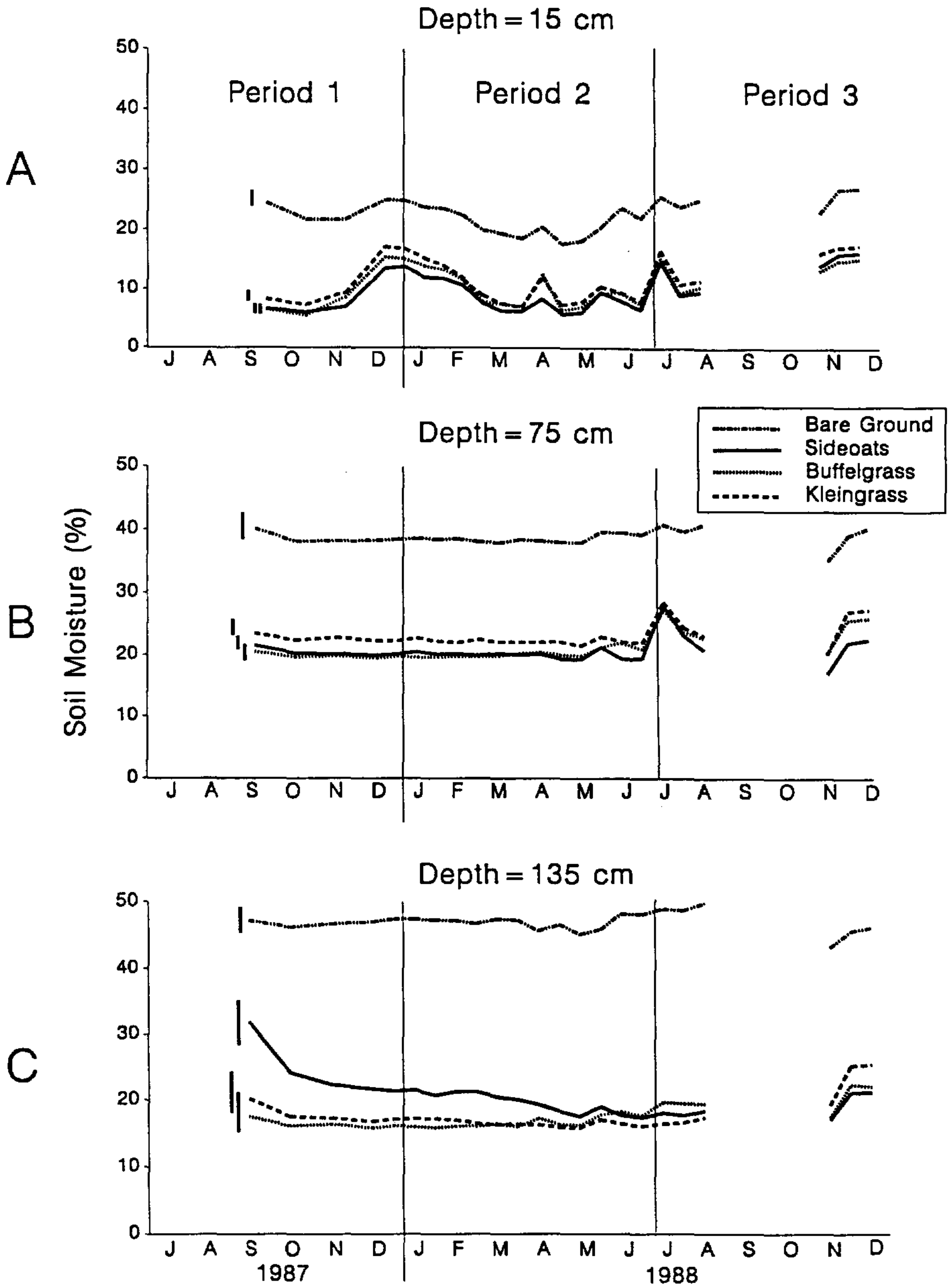


Figure 3. Soil moisture readings at 15 cm A), 75 cm B), and 135 cm C), depths in lysimeter treatments for 1987 and 1988. Vertical lines represent the maximum SE of the mean within a treatment. Missing data in period 3 due to damaged (and repaired) moisture depth gauge.

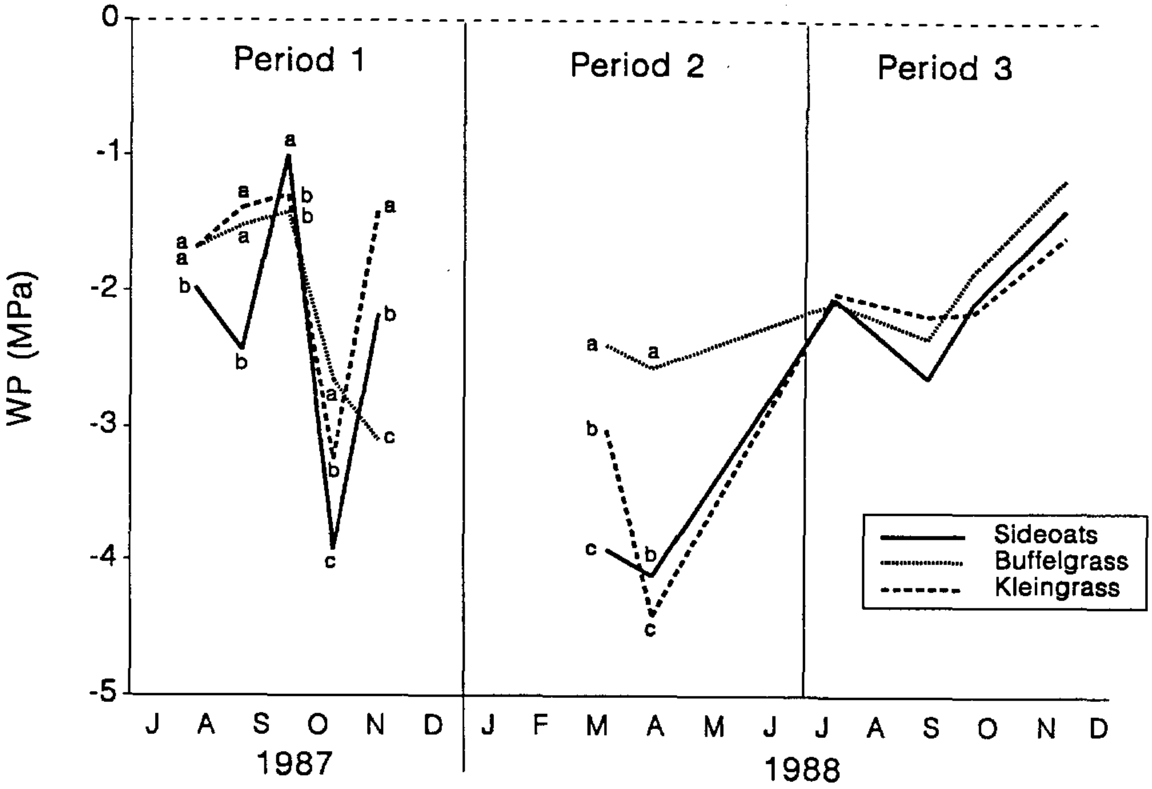


Figure 4. Minimum plant water potential reached during diurnal measurements on each sampling date in 1987 and 1988. Species with the same letter across a date are not significantly different at $P \leq 0.05$. If no letters are present, then values are not significantly different for that date.

WATER YIELDS FROM MESQUITE AND GRASS LYSIMETERS ON THE CARRIZO-WILCOX SANDS AQUIFER IN SOUTHWEST TEXAS

P. A. Julien, R. W. Knight and C. L. Fischer

SUMMARY

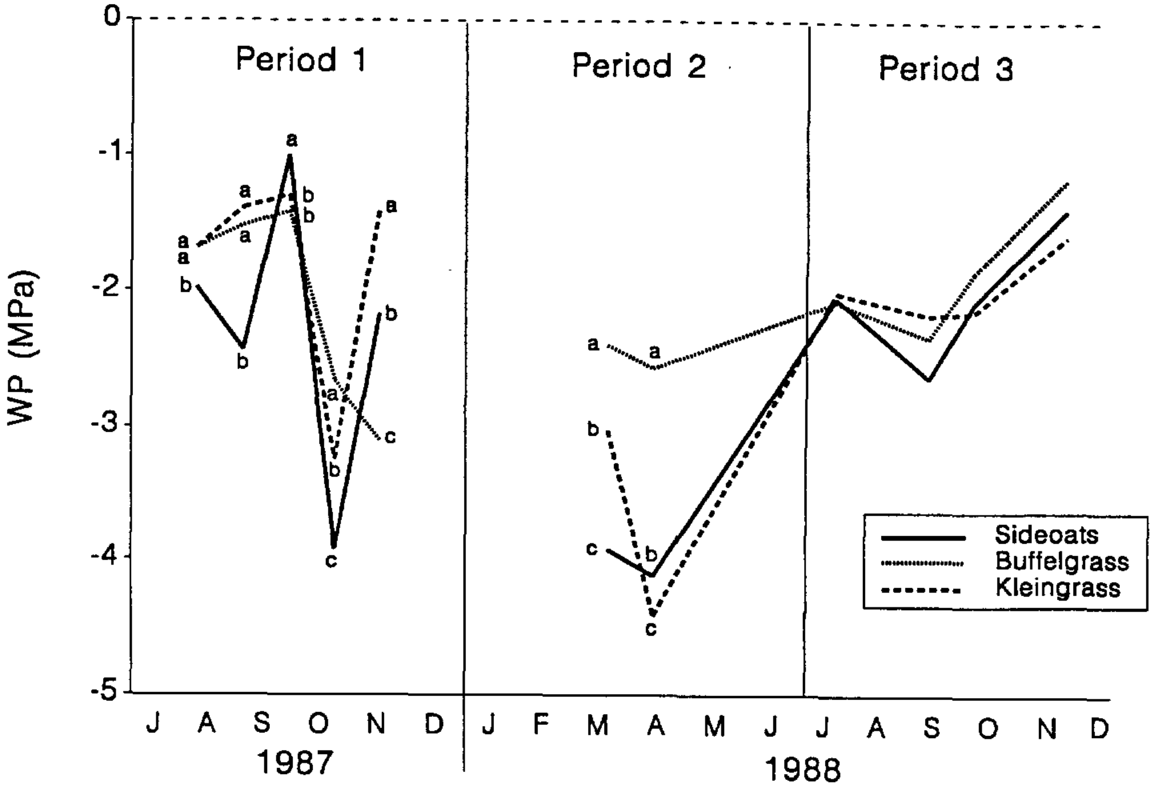
Lysimeter water budget studies under shrub and grass cover were conducted from December 1987 through October 1989 on a 0.6 ha site located on the recharge zone of the Carrizo-Wilcox Sands aquifer on the Lyles Ranch in Zavala County, Texas (Fig. 1). The purpose of the study was to determine if differences in water yields (surface runoff and deep drainage) from the two cover types were significant enough to warrant brush management as a method of increasing water yields. Smaller scale grass lysimeter studies showed that of the three grasses studied: (1) sideoats grama, Haskell var. (*Bouteloua curtipendula*), (2) kleingrass, selection 75 (*Panicum coloratum*), and (3) common buffelgrass (*Cenchrus ciliarius*), water yields were greatest from sideoats grama (5.8% of 804 mm of precipitation in 1988, and 3.0% of 818 mm of precipitation in 1989). Sideoats grama had the most bare ground of the three grass species. Water yields represent surface runoff values, as no deep drainage below the root zone was recorded in 1988 and 1989.

Water yields were also measured concurrently on twelve adjacent larger lysimeters, six of which were seeded to sideoats grama and six which each contained a honey mesquite shrub,(*Prosopis glandulosa* var. Torr.), 3.0 - 4.5 m tall, and its associated understory. Half the lysimeters received natural rainfall treatments and half received additional monthly supplementary sprinkler irrigation to match the average precipitation of the wettest years on record at La Pryor, 15 miles to the south of the study site.

Water yields from the supplementary watered mesquite matched those of sideoats grama in 1988, i.e. 12.0 and 12.7 mm respectively (representing 1.2% and 1.3% of water received). In 1989, water yields were higher from mesquite (19.9 mm) than sideoats grama (10.2 mm), representing 2.24% and 1.17%, respectively, of water received. Natural precipitation water yields were slightly higher from the sideoats grama in 1988 and 1989. In 1988 water yields were 6.1 mm from the sideoats grama and 0.6 mm from the mesquite (2.1% and 0.2% of precipitation). In 1989 yields were 8.6 mm from sideoats grama and 5.1 mm from mesquite (1.6% and 0.9% of precipitation).

The bare ground smaller scale lysimeters produced 16 mm of deep drainage in 1988 and 16.2 mm in 1989. Deep drainage was recorded beneath the larger mesquite and sideoats grama lysimeters in 1987, but not in 1988 and 1989. Rainfall in May and June 1987, 222 mm and 201 mm respectively, was higher than the May/June average of the wettest years on record. Drainage for these two months averaged 6.4 mm for sideoats grama and 15.5 mm from mesquite.

Rainfall events are widely spaced (more than two weeks apart) in Southwest Texas, and evaporation rates are high (Fig. 2), so soil moisture in the upper 30 cm under mesquite and sideoats grama dries to similar levels prior to rainfall. The closeness in the surface runoff values from the two cover types on the non-weighing lysimeters was due primarily to their similar antecedent moisture conditions. Because of the site's sandy loam soil and low antecedent moisture, infiltration rates were high and surface runoff was low (Fig. 3). Differences in surface runoff between the two cover types were attributed to percentage bare ground as soil texture was consistent across the site. The effect of vegetation density and percentage bare ground cover on differences in surface runoff was more noticeable on the smaller weighable lysimeters where depression storage was lower than on the larger non-



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Wet years (above 900 mm annual rainfall) have occured on average once every 6.5 years in Zavala County since 1950. Although the supplementary irrigation treatments did not accurately simulate wet year conditions, (because of higher evaporation rates resulting from the extremely dry state of the surrounding countryside), the results of this study show that water yields would not be significantly increased by brush management. In the wet year treatments, mesquite surface runoff was equal to or higher than that of sideoats grama, because of the lower vegetative density of its understory and greater percentage of bare ground compared to that of sideoats grama. Surface runoff from sideoats grama would be higher in drier years when vegetation density declines and percentage bare ground is above that of mesquite. In drier years small differences in surface runoff between the different cover types from a hydrologic point of view would be insignificant as at the watershed scale much, if not all surface runoff would be lost to depression storage or evaporation before it reached a stream.

STUDY SITE

The Carrizo Sands aquifer is a very permeable, massive, cross-bedded, medium-grained sand 45-365 m thick. It is the principle source of irrigation water for the Winter Garden District, encompassing Dimmit, Zavala and Maverick Counties. The study site was located on an outcrop of the Carrizo-Wilcox aquifer on the Lyles Ranch in Zavala County. The climate of Zavala County is warm and subhumid. The average frost free period is 285 days, from late February to early December. Yearly mean temperature is 22° and yearly mean precipitation is 612 mm. Pan evaporation averages 1747 mm. Annual precipitation ranges from 250 to 1000 mm and its distribution is bimodal, with peaks occurring in spring and fall. Storm intensities are highest in summer and fall when localized thunderstorms occur.

The research site is a nearly level upland rangeland with slopes ranging from 1-1.5%. The soils are closely related to the Brystal series, and consist of well-drained fine sandy loams (mixed, hyperthermic aridic Paleustalfs). The parent material is composed of coarsely fractured interbedded sandstone, siltstone and shale. Vegetative cover is predominantly mature single-stemmed honey mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.) 3.5 - 4.0 m in height. Excavation of a mesquite tree showed a dense root system spreading laterally above an ironstone nodule, clay-matrix cemented layer (40-60 cm below the surface), and a tap root system which branched around the ironstone nodules and extended to the parent material 3 m below. As few roots were present at 3 m and less than 0.5 cm in diameter, it is unlikely that they were utilizing the water table 60 m below the surface.

METHODS

Measurements of precipitation, surface runoff, deep drainage and soil moisture were made from bare ground, mesquite and grass lysimeters on the Carrizo-Wilcox Sands aquifer located on the Lyles Ranch in Zavala County, Texas from spring 1987 through fall 1989. The objectives were: (1) to identify which grass cover produced the highest water yields, and (2) to quantify the range of water yields that could be expected from the dominant shrub and grass cover under wetter and drier conditions.

Twelve weighable lysimeters, 75 cm in diameter and 150 cm deep, and twelve non-weighable lysimeters, 7 m in diameter and 3 m deep, were instrumented to collect surface runoff and deep drainage. The weighable lysimeters were built by drilling steel pipe, 150 cm in length and 76 cm in diameter, into the ground to obtain relatively undisturbed soil cores.

They were then sealed at the bottom and placed in a common trench inside an 80 cm diameter pipe of the same height.

The non-weighing lysimeters were each built by trenching around a soil monolith, 7 m in diameter and 3 m deep, and wrapping the monolith walls with plastic to prevent lateral inflow or outflow of water. Deep drainage from each weighable lysimeter was periodically pumped from an access tube running from four porous ceramic cups at the bottom of each lysimeter to the soil surface. To collect deep drainage from the non-weighable lysimeters, two tension plates per lysimeter, 30.5 cm square, were installed in the monolith wall at the bottom of each lysimeter between the soil overburden and the parent sandstone (Fig. 4). Surface runoff was collected from each weighable lysimeter via a flexible hose connected to nearby catchment containers. Surface runoff catchment troughs on the non-weighable lysimeters were sited at the lowest topographic point next to the lysimeters. One neutron probe access tube (1.5 m) per weighable lysimeter, and four (2.85 m) per non-weighing lysimeter were installed to monitor soil moisture changes. Soil moisture was measured with a Troxler 3320 Series neutron probe moisture gauge every two to four weeks, beginning at 15 cm below the soil surface and continuing at 30 cm increments of soil depth to the bottom of the lysimeters. An on-site Campbell weather station recorded precipitation, wind run, temperature, solar radiation, relative humidity and soil temperature at 0.1 and 0.5 m depths. A standard rain gauge was also used to record precipitation.

The weighable lysimeters were seeded to sideoats grama, kleingrass and buffelgrass, with three replicates of each cover type. The remaining three lysimeters were maintained as bare ground. Six of the non-weighing lysimeters were cleared and seeded to sideoats grama and the remaining six each contained a single-stemmed mesquite shrub, 3.5 - 4.0 m high, with its associated understory. Three of the mesquite and three of the sideoats grama non-weighing lysimeters received supplementary sprinkler irrigation on a monthly basis so that total water received matched that of the average of the five wettest years on record (Fig. 5). The rate of sprinkler irrigation, 5 cm hr^{-1}, is typical of storm rates in Southwest Texas (Weltz 1987). A 16x16 m control plot of each grass species was established adjacent to the the weighable lysimeters and two neutron access tubes, 3 m deep, were installed in each plot. These plots received the supplementary watering treatment from June 1988 and provided plant material for live leaf area index and standing crop measurements to correlate with data collected on the lysimeters. The site layout and lysimeter treatments are illustrated in Fig. 6.

To determine standing crop and live leaf area for the grasses studied, live leaf hits per 0.25 m^2 quadrat were recorded for six to ten randomly selected quadrats per grass species on each sample date. Vegetation within each quadrat was then clipped to ground level and placed in paper bags. All biomass was dried at 50°C for 48 h, weighed, and specific leaf weights (g cm^{-2}) calculated. Sideoats grama, kleingrass and buffelgrass standing crop on the lysimeters were determined by regressing the number of live leaf hits on each control plot quadrat against its corresponding standing crop (Fig. 7).

Mesquite standing leaf crop was estimated by regressing leaf area against leaf mass (Fig. 8). Leaf area changes on each lysimeter's mesquite tree were measured through time by monitoring leaf area on sample branches (4 per tree). Leaf area was estimated using the technique developed by Wendt et al. (1967) to derive a regression equation relating rachise length to leaf area (Fig. 9). Rachise lengths were measured periodically on the sample branches, and the regression equation used to calculate leaf area. The total leaf area of each mesquite was estimated by multiplying leaf area per unit sample branch volume by the total branch volume for each sampling date. These data points were used to derive third order polynomial regression equations describing leaf area changes through time for each mesquite

(Fig. 10). Standing leaf crop could be estimated for any point in time by using the regression equation to calculate total leaf area and find the corresponding standing leaf crop using the leaf area/leaf mass equation. Mesquite leaf and grass standing crop changes through time on each lysimeter are listed in Table 3.

RESULTS AND DISCUSSION

Annual precipitation and water yields for 1988 and 1989 are listed in Table 1 for the weighable lysimeters, and Table 2 for the non-weighing lysimeters. The largest amounts of surface runoff recorded in 1988 followed rainfall in late October and early November. Standing crop on the weighable lysimeters (Table 3(a)), was greatest on sideoats grama 10/1/88 and surface runoff was also greatest from sideoats grama in October and November. Antecedent soil moisture conditions were similar for sideoats grama, buffelgrass and kleingrass (averaging 5.2, 6.4 and 5.6 mm respectively for the upper 30 cm of soil on 11/14/88). Although sideoats grama standing crop estimates at this time are higher than those of buffelgrass or kleingrass, surface litter was observed to be greater on buffelgrass and kleingrass than it was on sideoats grama, which consistently had more bare ground than the other two grasses throughout the study. Storms on 8/12/89 and 10/26/89 produced more average surface runoff from the sideoats grama lysimeters. Sideoats grama standing crop was lower than kleingrass or buffelgrass on 8/15/89, and lower than buffelgrass on 10/25/89, but percentage bare ground was lowest on sideoats grama. Surface runoff was also high from lysimeter 5, kleingrass, which had a lower standing crop and more bare ground than the other kleingrass and buffelgrass lysimeters. Surface runoff was greatest in both years from the bare ground lysimeters, which had higher antecedent moisture levels and lacked litter cover.

Surface runoff from the sideoats non-weighing lysimeters was half that of the weighable lysimeters, due to the effects of depression storage, which was greater on the larger non-weighing lysimeters. On the natural precipitation lysimeters, surface runoff was higher in both years from the sideoats grama lysimeters than the mesquite lysimeters. Seedling establishment was low on the natural precipitation sideoats grama lysimeters, and ground cover standing crop was below that of the natural precipitation mesquite lysimeters. As antecedent soil moisture conditions were similar on the two cover types, the greater percentage of bare ground and possibly the lack of overstory canopy to reduce rainfall impact velocities resulted in greater surface runoff from the natural precipitation sideoats grama lysimeters.

Surface runoff from the non-weighing lysimeters receiving supplementary sprinkler irrigation was similar for sideoats grama and mesquite in 1988, and greater for mesquite in 1989. Standing crop at the surface was higher on the sideoats grama lysimeters than the mesquite under better soil moisture conditions, and percentage bare ground was higher on the mesquite lysimeters. Antecedent soil moisture values were similar during the growing season on both cover types.

CONCLUSIONS

Because of the long periods between rainfall events, and high evaporation rates, antecedent moisture prior to rainfall was low and surface soil moisture values were similar under both cover types within each treatment. Dry soil conditions and a highly permeable sandy loam soil resulted in low surface runoff from both the sideoats grama and the mesquite. Surface runoff differences were attributed to the percentage bare ground on the lysimeters, which was greater on the natural precipitation lysimeters than the supplementary irrigated lysimeters. Water yields were greater from the sideoats grama non-weighable lysimeters than from the mesquite lysimeters (under natural conditions) Data from the weighable lysimeters indicate this may be the same if they were planted to buffelgrass or kleingrass.

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Table 1. Annual precipitation (natural plus supplementary irrigation) and water yields (mm): weighable lysimeters.

(a) 1988

Lysimeter	Surface Runoff	Deep Drainage	Water Yield	Precipitation
B 1	35.9	0.0	35.9	1006.4
B 11	14.0	0.0	14.0	831.6
B 12	11.0	0.0	11.0	813.3
K 3	6.6	0.0	6.6	788.9
K 5	76.9	0.0	76.9	814.3
K 9	0.0	0.0	0.0	830.1
SOG 2	45.8	0.0	45.8	801.6
SOG 4	80.0	0.0	80.0	814.3
SOG 8	16.4	0.0	16.4	795.0
BG 6	347.9	19.4	367.3	789.4
BG 7	244.9	16.3	261.2	794.0
BG 10	250.1	12.3	262.4	869.0

(b) 1989

Lysimeter	Surface Runoff	Deep Drainage	Water Yield	Precipitation
B 1	11.0	0.0	11.0	813.8
B 11	0.0	0.0	0.0	827.8
B 12	0.0	0.0	0.0	819.4
K 3	16.0	0.0	16.0	832.4
K 5	28.1	0.0	28.1	832.4
K 9	0.0	0.0	0.0	833.4
SOG 2	22.2	0.0	22.2	812.3
SOG 4	50.4	0.0	50.4	812.3
SOG 8	0.0	0.0	0.0	827.8
BG 6	387.9	7.1	395.0	854.5
BG 7	418.8	5.5	424.3	848.9
BG 10	444.8	4.1	448.9	837.4

*** B - Buffelgrass: K - Kleingrass: SOG - Sideoats grama: BG - Bare ground

NB: Surface runoff values affected by variability in sprinkler irrigation amounts and percentage bare ground per lysimeter.

Table 2. Annual precipitation (natural plus supplementary irrigation) and water yields (mm): non-weighing lysimeters.

(a) 1988

Lysimeter	Surface Runoff	Deep Drainage	Water Yield	Precipitation
M(N) 4	1.3	0.0	1.3	285.2
M(N) 5	0.3	0.0	0.3	285.2
M(N)12	0.2	0.0	0.2	285.2
SOG(N) 3	8.8	0.0	8.8	285.2
SOG(N)10	7.4	0.0	7.4	285.2
SOG(N)11	1.9	0.0	1.9	285.2
M(S) 1	8.1	0.0	8.1	1020.6
M(S) 2	9.4	0.0	9.4	949.7
M(S) 7	18.5	0.0	18.5	997.7
SOG(S) 6	10.2	0.0	10.2	960.9
SOG(S) 8	9.8	0.0	9.8	994.7
SOG(S) 9	18.1	0.0	18.1	1007.6

(b) 1989

Lysimeter	Surface Runoff	Deep Drainage	Water Yield	Precipitation
M(N) 4	6.2	0.0	6.2	550.7
M(N) 5	4.4	0.0	4.4	550.7
M(N)12	4.6	0.0	4.6	550.7
SOG(N) 3	10.1	0.0	10.1	550.7
SOG(N)10	10.2	0.0	10.2	550.7
SOG(N)11	5.4	0.0	5.4	550.7
M(S) 1	16.2	0.0	16.2	930.4
M(S) 2	19.3	0.0	19.3	844.6
M(S) 7	24.3	0.0	24.3	886.2
SOG(S) 6	6.0	0.0	6.0	834.1
SOG(S) 8	8.1	0.0	8.1	831.1
SOG(S) 9	16.4	0.0	16.4	941.8

*** M - Mesquite; SOG - Sideoats grama; (N) - Natural precipitation; (S) - Supplementary sprinkler irrigation

Table 3. Standing crop (kg/ha): non-weighing lysimeters.

(a) weighable lysimeters:

	1988					1989		
Lysimeter	6/7	6/30	7/19	8/22	10/1	7/12	8/15	10/25
B 1	719	1177	4147	325	3668	1190	6760	1190
B11	474	1518	2423	1114	4147	2370	3951	2577
B12	1106	3115	3554	1666	5347	2073	2073	957
K 3	1032	2679	2767	1732	3227	2316	2979	553
K 5	715	816	1207	868	1662	2750	2602	398
K 9	1951	2424	2261	1459	2947	1915	2750	907
SOG 2	661	1935	3922	1331	7142	3370	2153	794
SOG 4	1244	2289	2820	927	6638	1819	1409	643
SOG 8	643	1423	2820	1825	5061	2512	2096	957

(b) non-weighing lysimeters:

	1988					1989			
Lysimeter	6/8	6/30	7/19	8/23	10/1	5/26	7/12	8/16	10/25
M(N) 4	272	336	482	214	398	625	368	394	203
M(N) 5	739	423	428	350	316	586	540	569	401
M(N)12	854	688	685	572	468	1121	944	897	696
SOG(N) 3	497	174	137	184	300	988	246	221	546
SOG(N)10	356	342	390	93	174	618	303	250	297
SOG(N)11	572	322	493	167	498	790	467	535	503
M(S) 1	689	642	897	452	601	1513	1086	1410	668
M(S) 2	1071	1127	1790	720	1368	1606	1347	1759	668
M(S) 7	595	487	481	379	687	871	997	827	374
SOG(S) 6	331	1693	3494	4318	4177	1412	2123	3356	559
SOG(S) 8	1575	2346	7467	5447	4365	1916	1500	2181	465
SOG(S) 9	1355	2174	4328	6949	5430	1366	2794	2884	622

*** B - Buffelgrass; K - Kleingrass; SOG - Sideoats grama; M - Mesquite; N - Natural precipitation; S - Supplementary sprinkler irrigation

NB: Mesquite standing crop includes mesquite leaves and understory grass cover. Mesquite stems and branches are excluded.

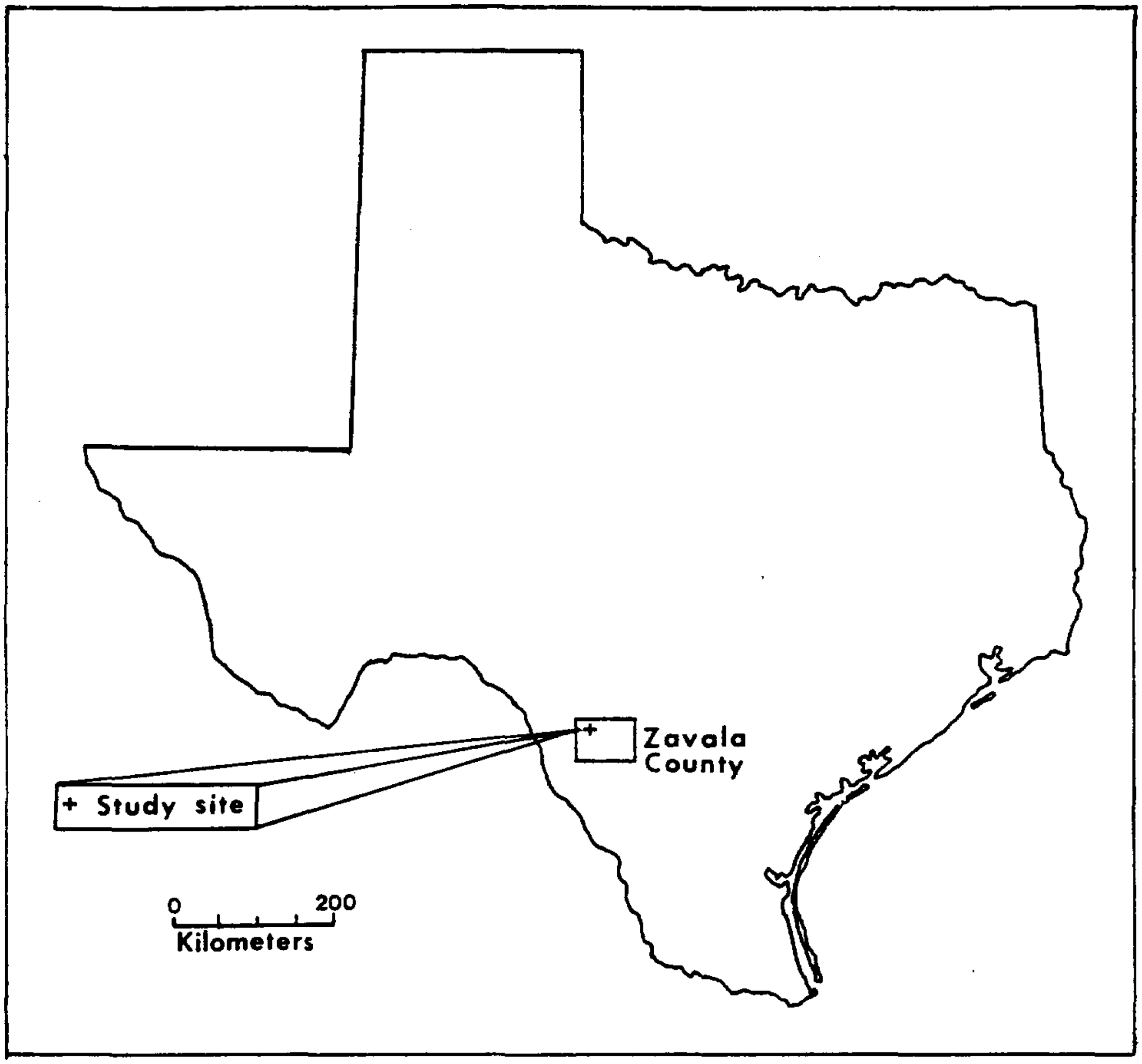


Figure 1. Location of the study site in Zavala County, Texas.

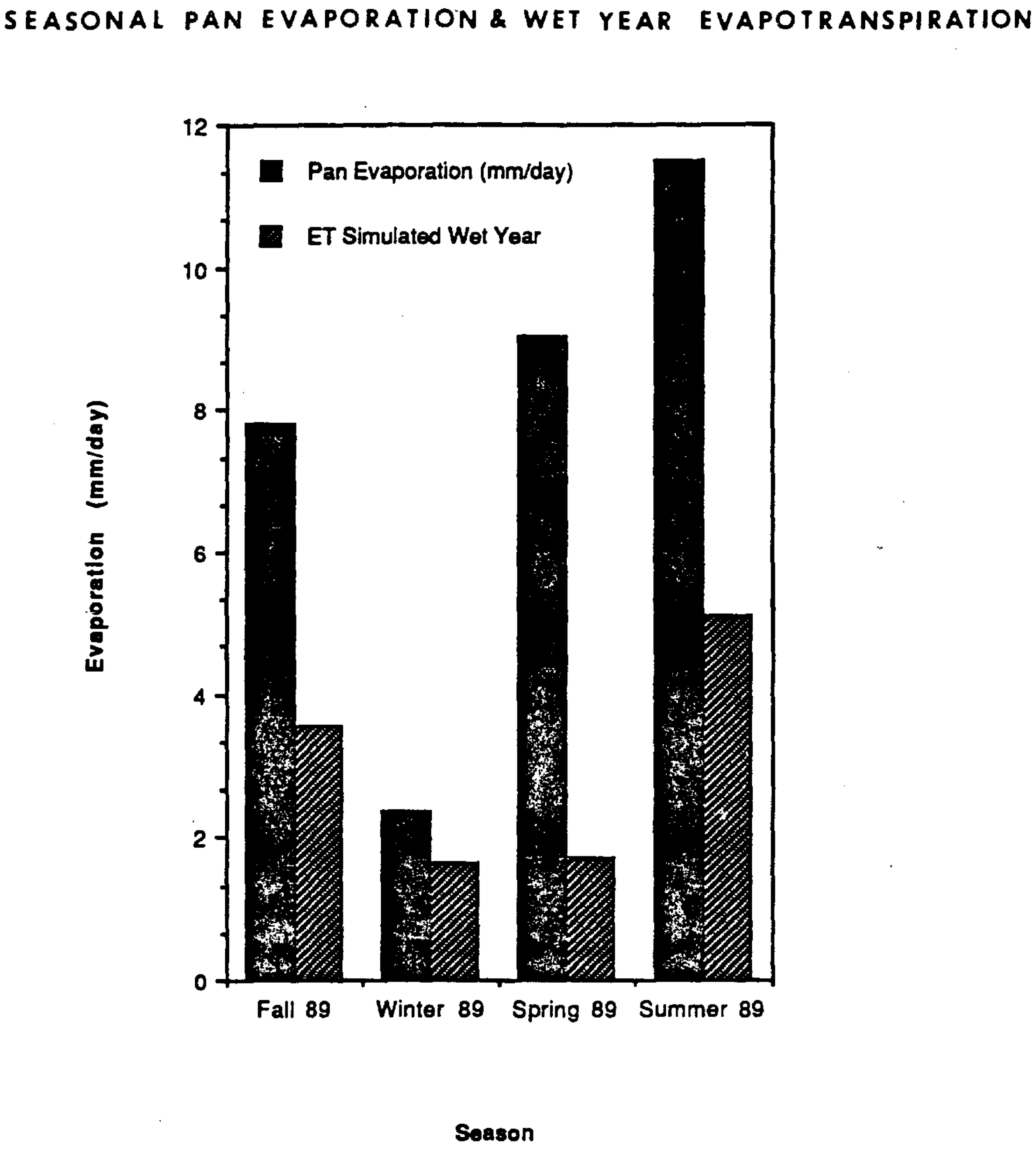


Figure 2. Seasonal pan evaporation and evapotranspiration from the non-weighing lysimeters receiving supplementary irrigation.

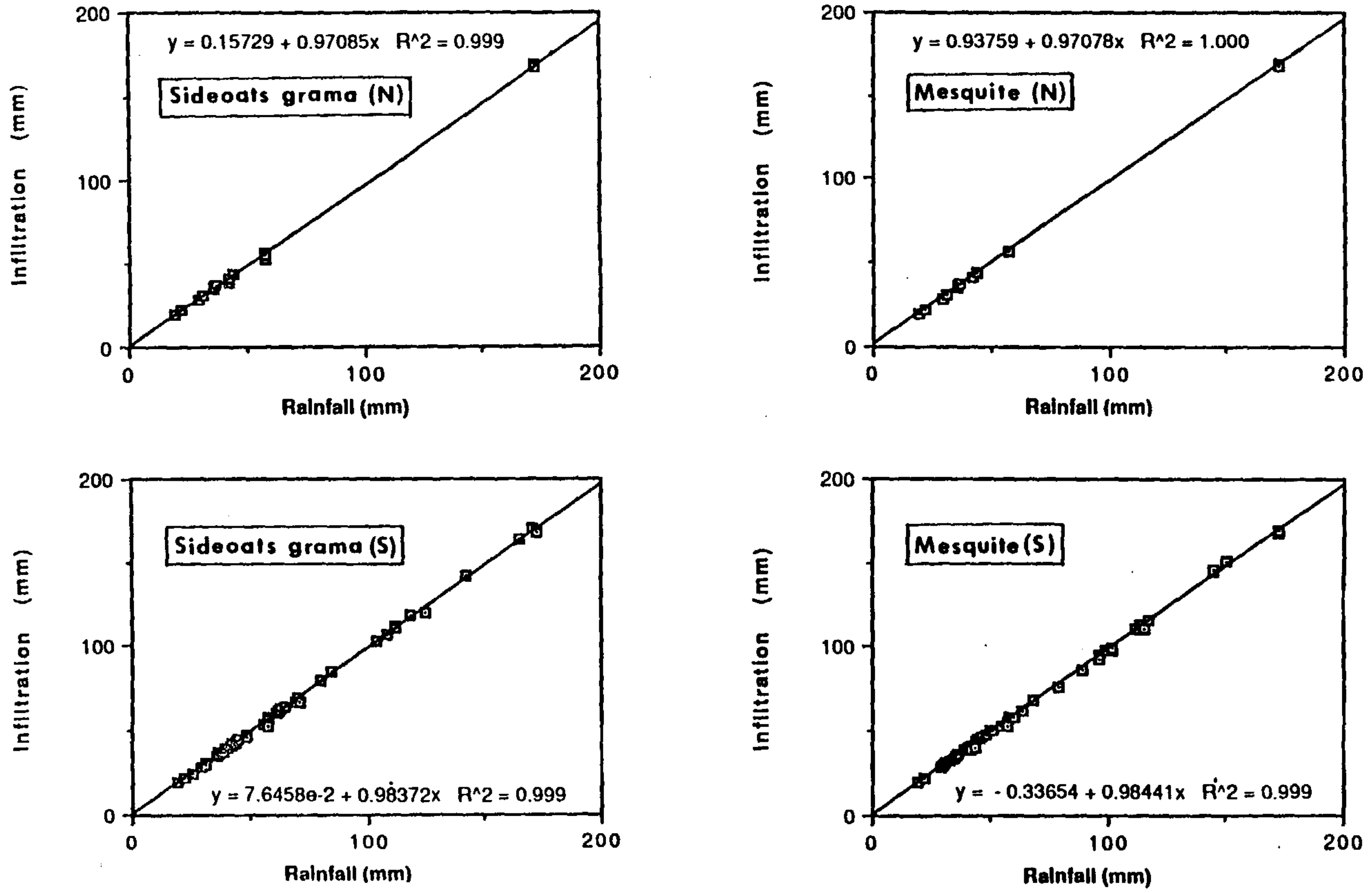


Figure 3(a). Infiltration curves for (N) natural precipitation, and (S) supplementary irrigation treatments on the non-weighing lysimeters.

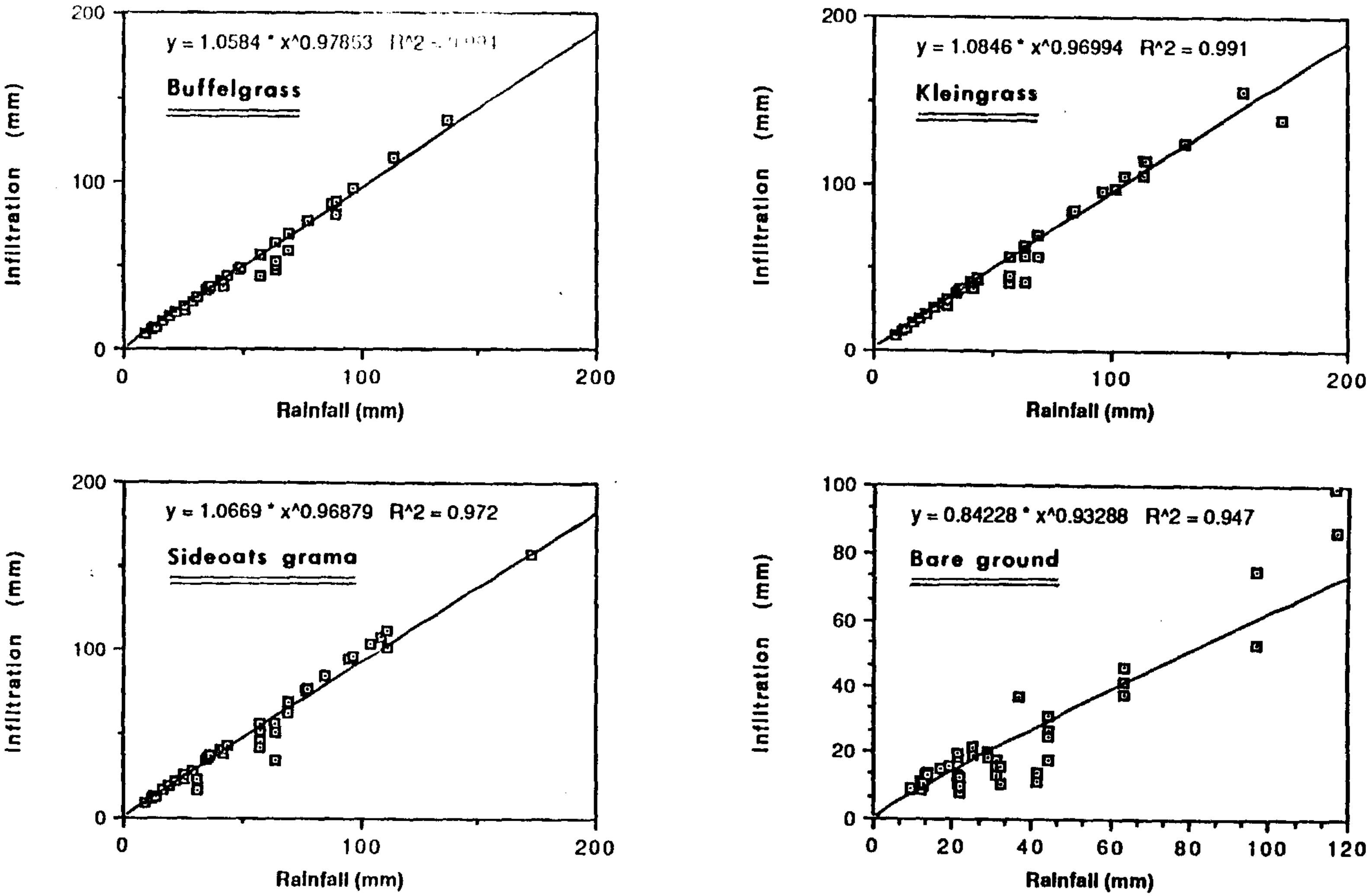


Figure 3(c). Infiltration curves for each treatment on the weighable lysimeters.

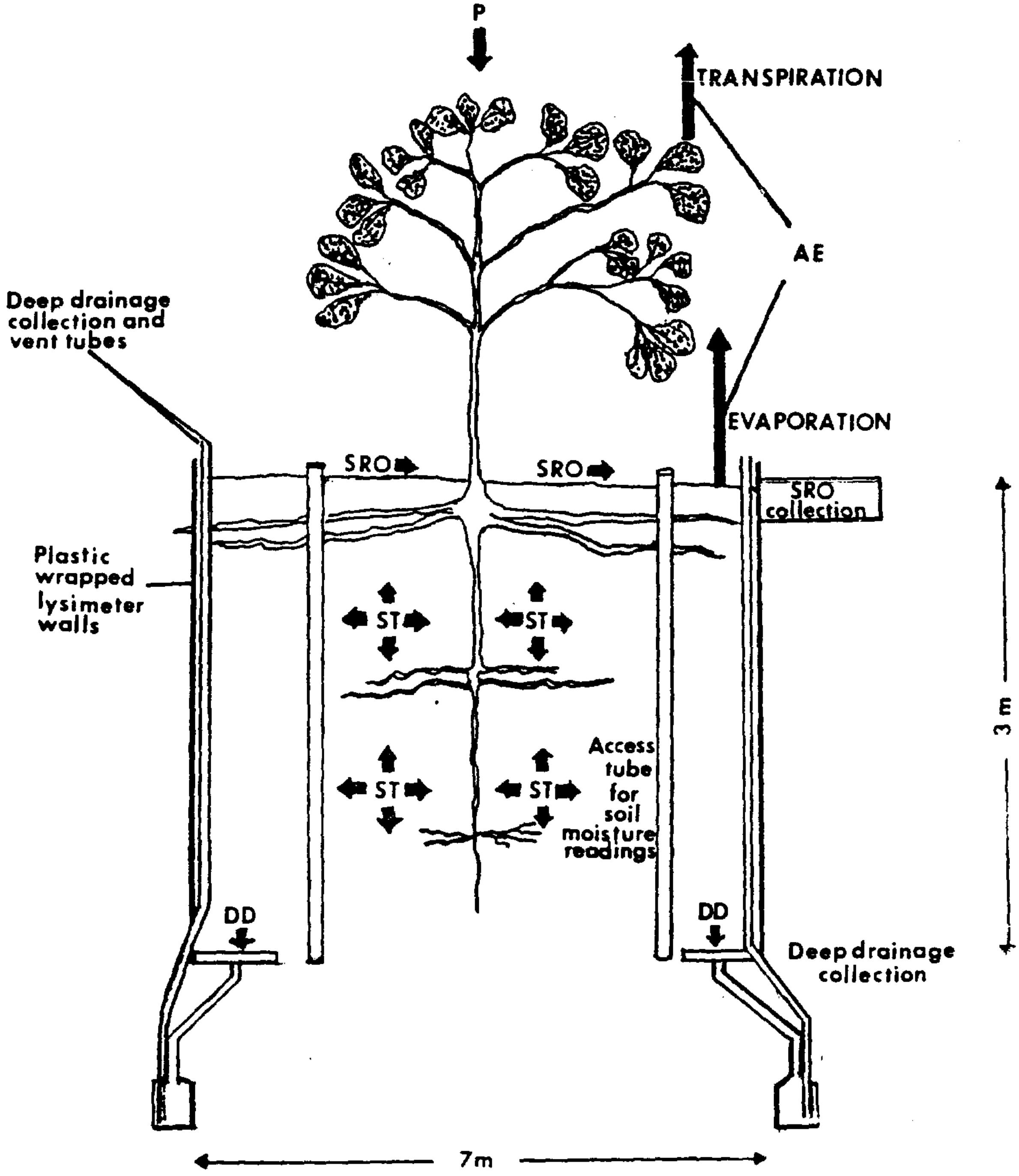
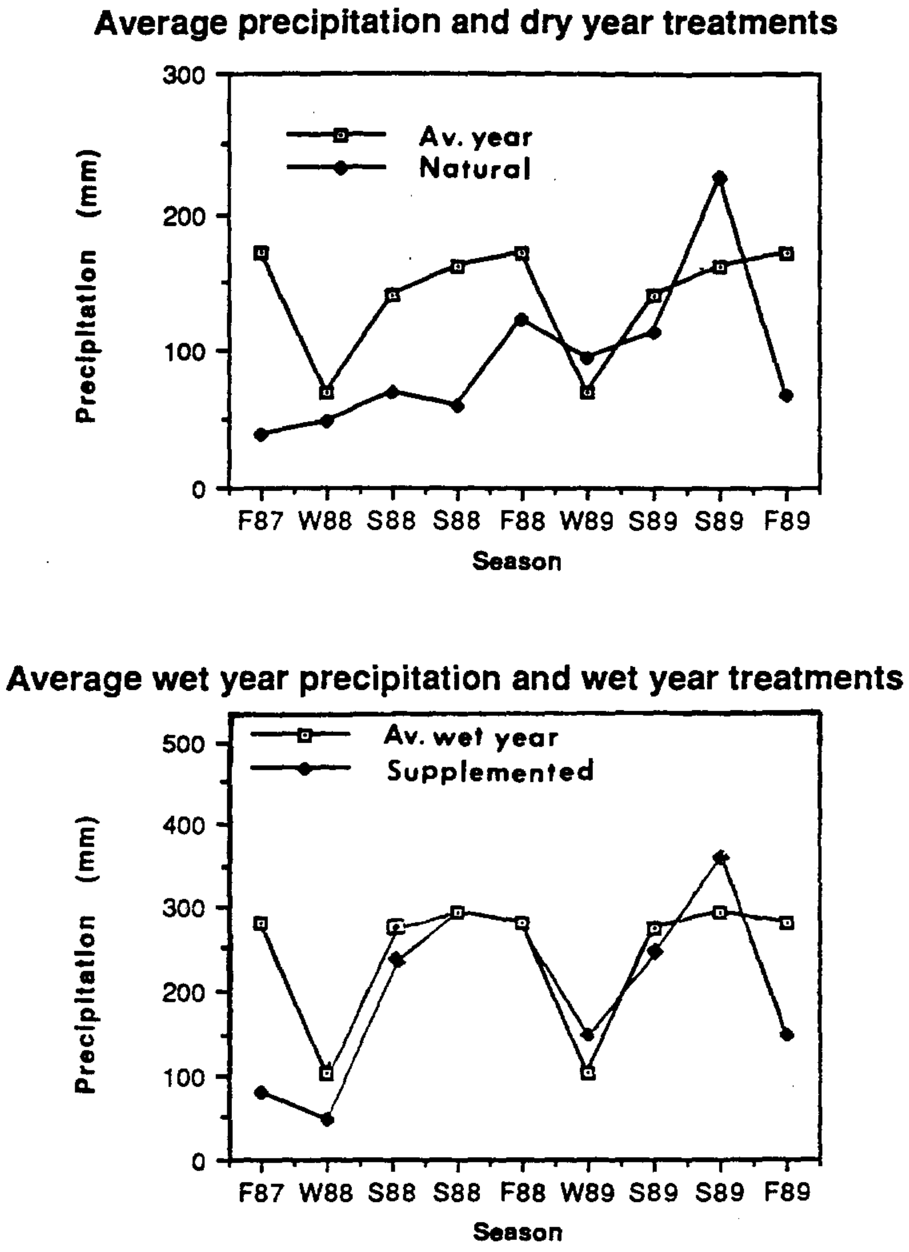


Figure 4. Cross section of a mesquite non-weighing lysimeter showing instrumentation.



Average precipitation and dry year treatments

Average wet year precipitation and wet year treatments

Figure 5. Average seasonal wet and dry year watering treatments compared with average annual and wet year precipitation.

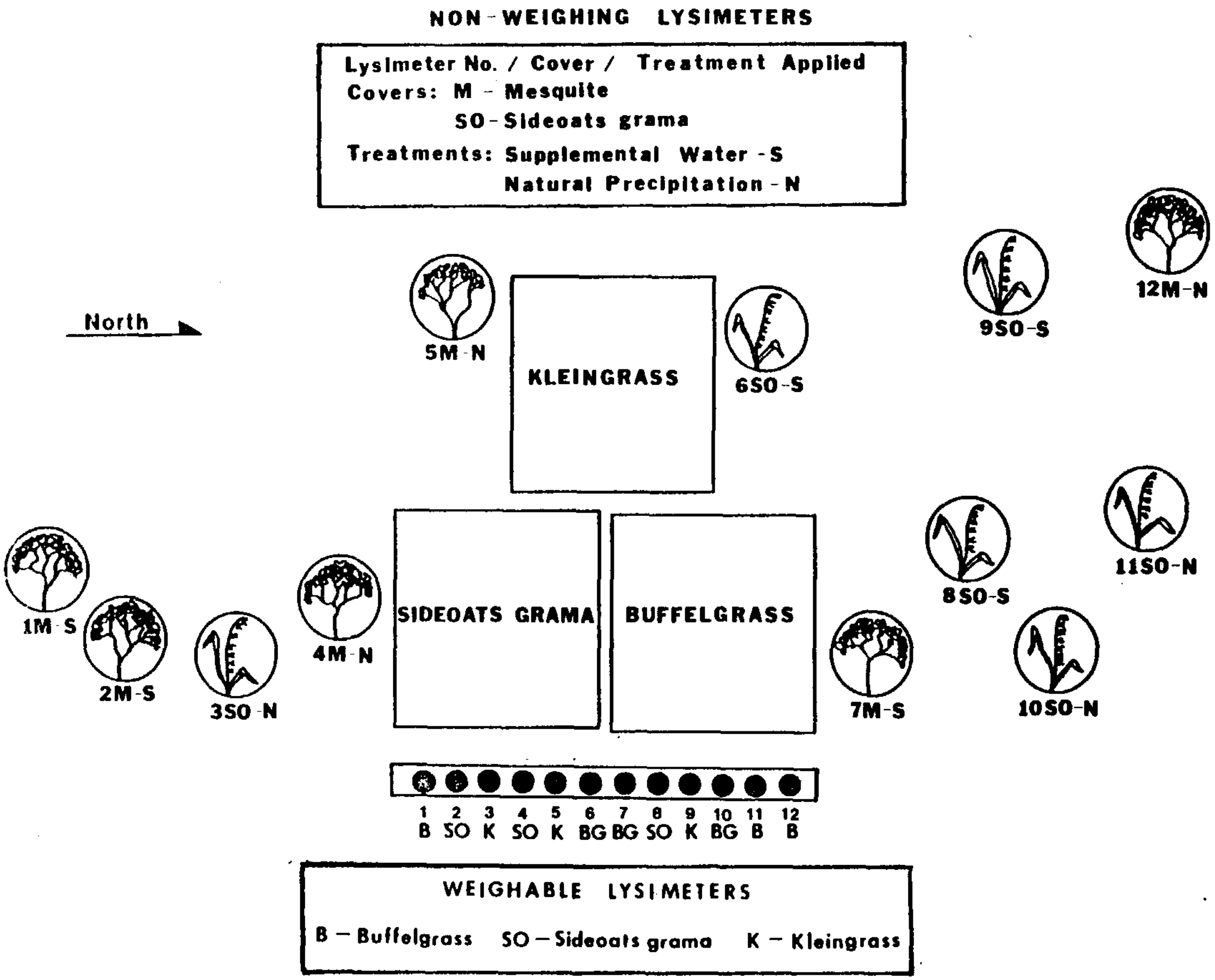


Figure 6. Site layout and lysimeter treatments.

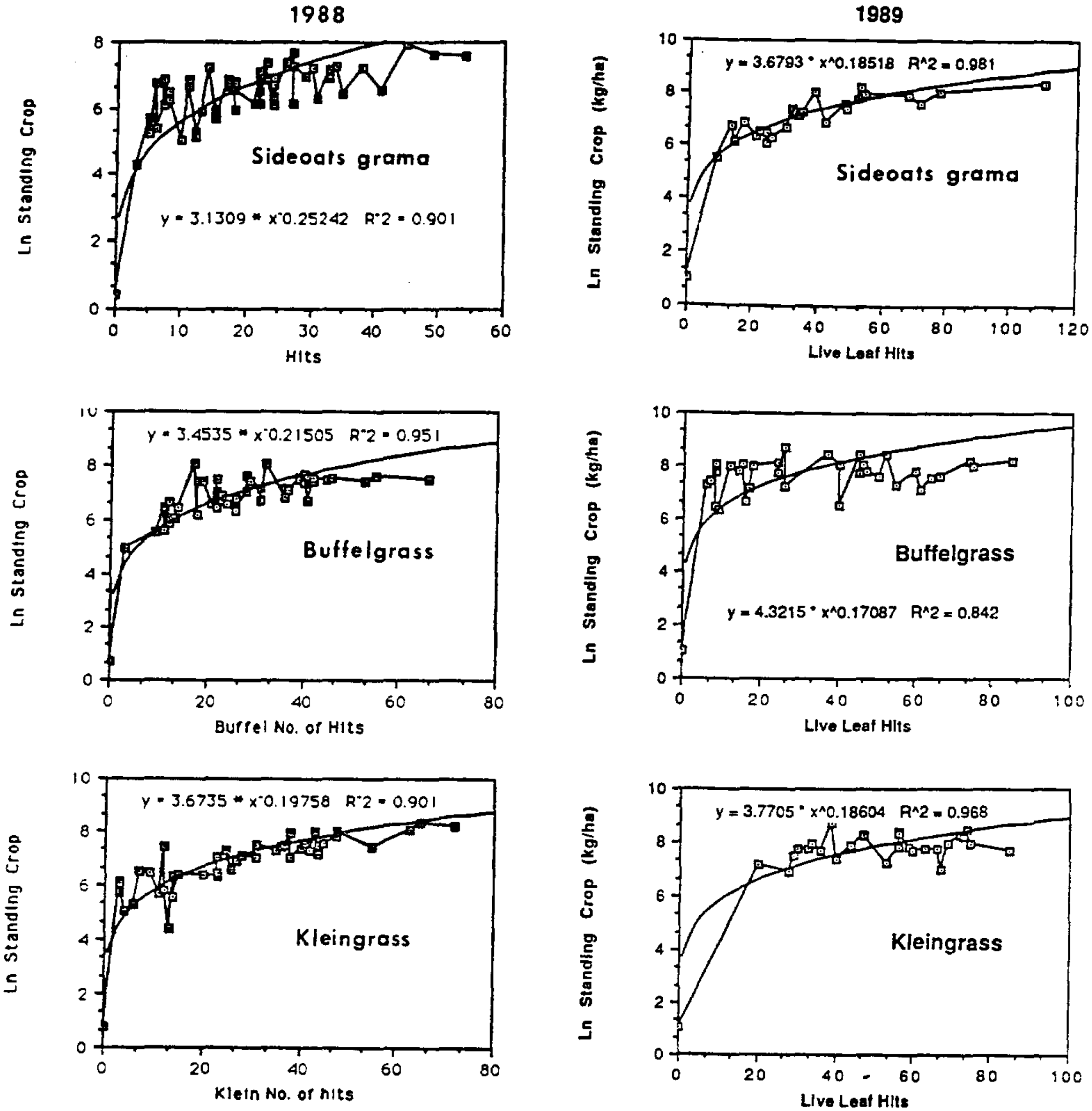


Figure 7. Live leaf hits and standing crop regressions for sideoats grama, kleingrass, and buffelgrass.

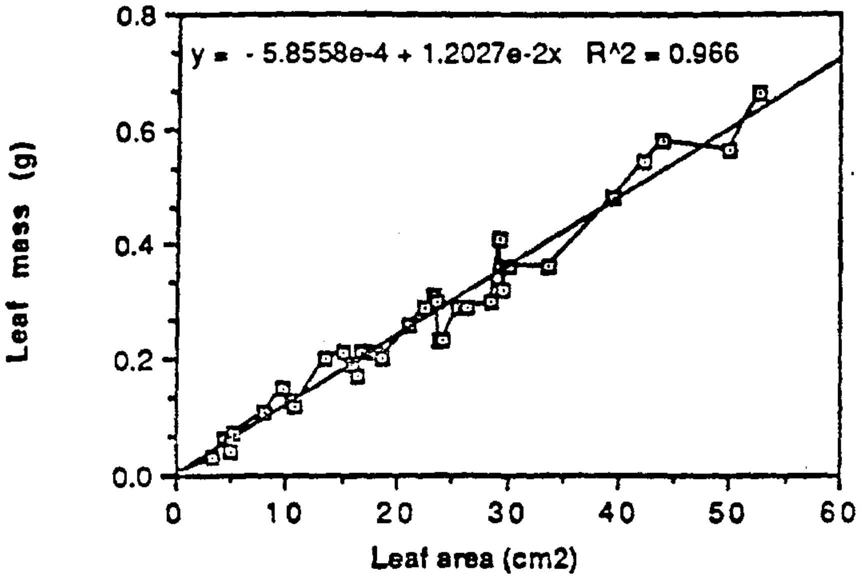


Figure 8. Mesquite leaf area and leaf mass regression.

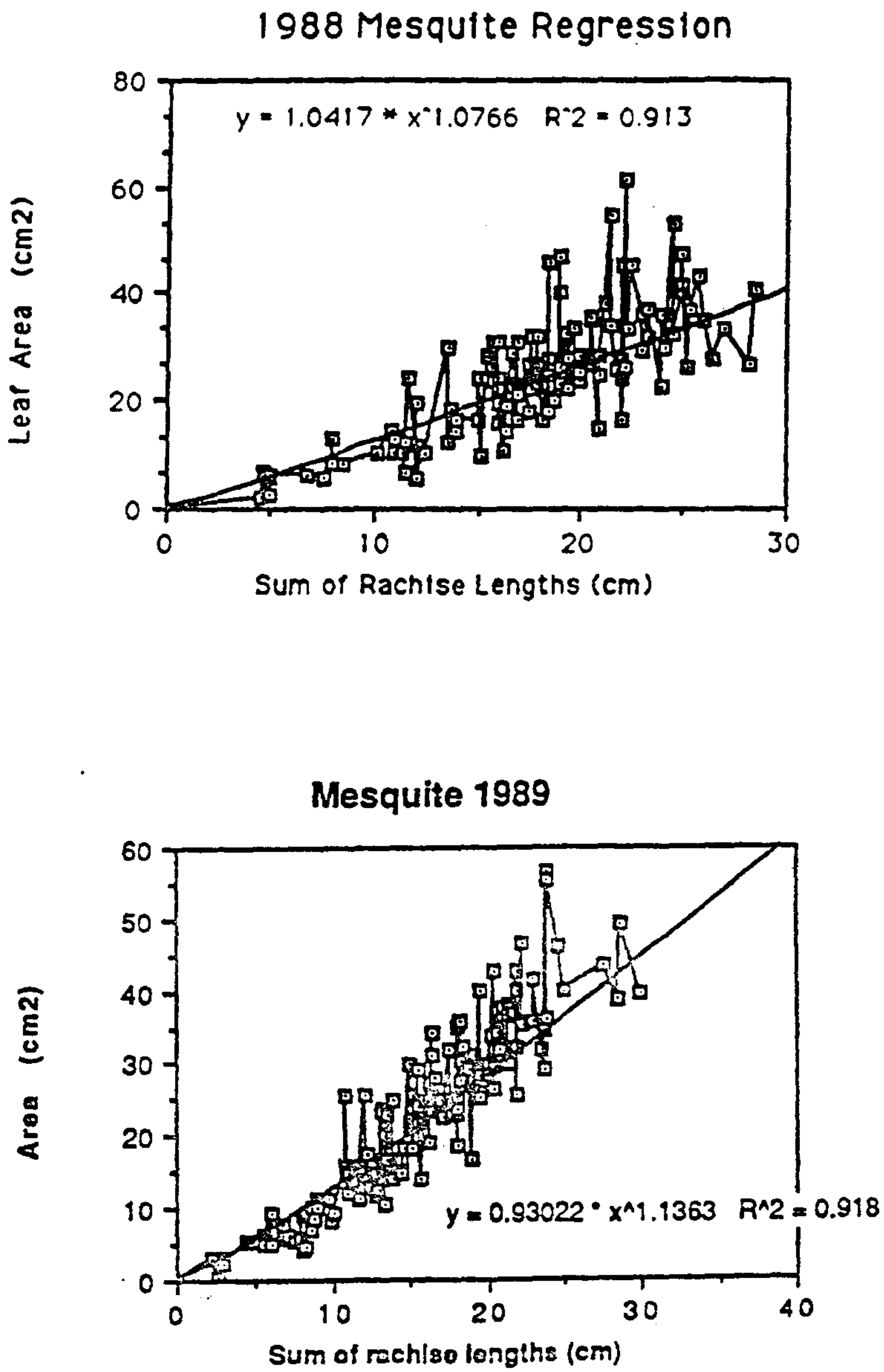


Figure 9. Mesquite rachise length and leaf area regression.

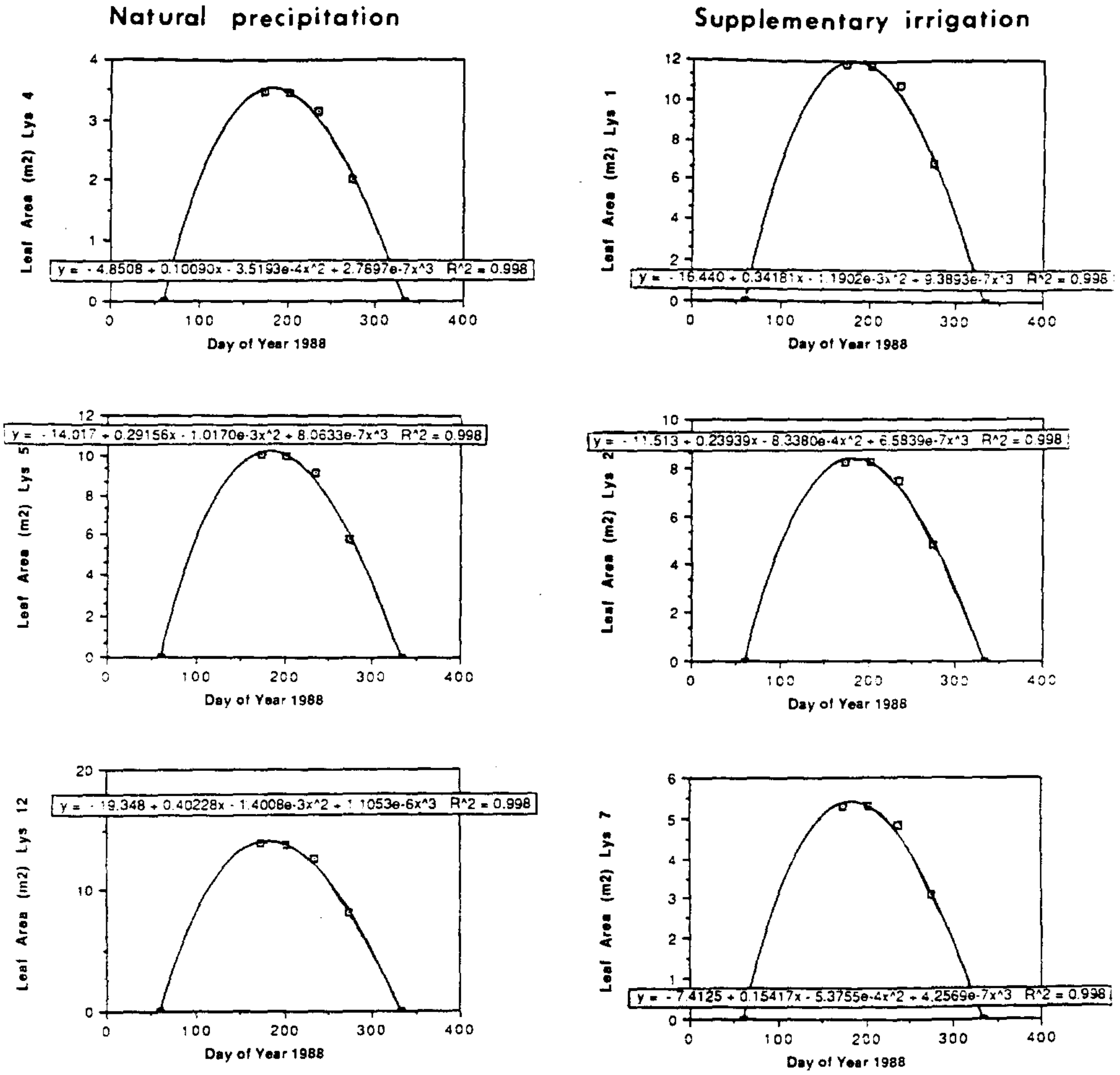


Figure 10(a). Mesquite leaf-area changes by lysimeter for 1988.

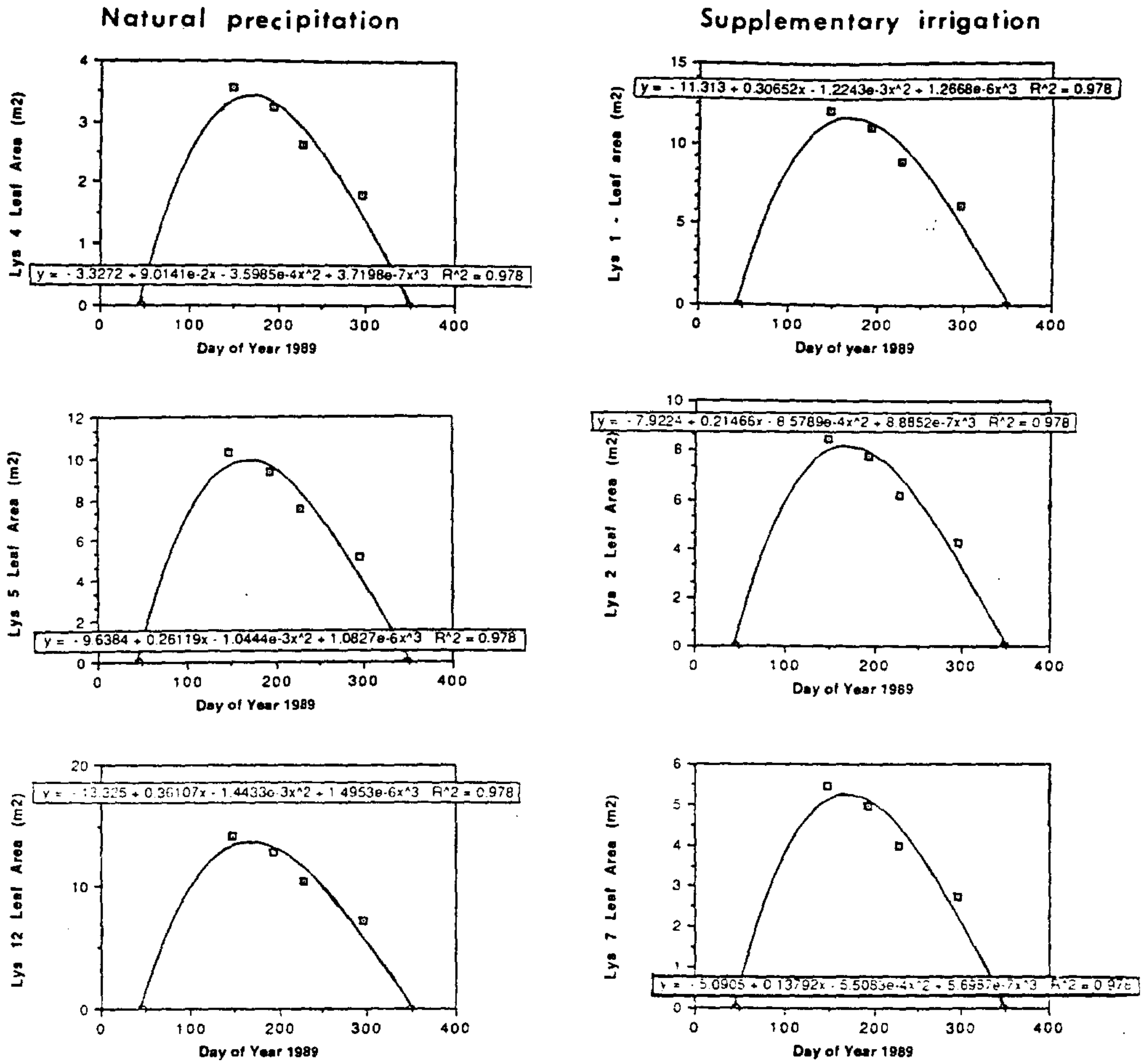


Figure 10(b). Mesquite leaf-area changes by lysimeter for 1989.

SEASONAL TRANSPIRATION DIFFERENCES BETWEEN SHRUB AND GRASS COVER ON THE CARRIZO-WILCOX AQUIFER RECHARGE ZONE OF SOUTHWEST TEXAS.

P. A. Julien, G. L. Holmstead and R. W. Knight

SUMMARY

Diurnal transpiration rates and plant water potentials of sideoats grama (*Bouteloua curtipendula* var. *Haskell*) a warm-season perennial C_3 bunchgrass, and honey mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.), a C_4 shrub dominant on the study site, were measured periodically on non-weighing lysimeters within the Carrizo-Wilcox aquifer recharge zone on the Lyles ranch in Southwest Texas between July 1988 and October 1989. Concurrent data on live leaf area and soil moisture were also gathered. The objective was to assess the seasonal differences in transpiration depth per lysimeter between the two species under the two extremes of soil moisture conditions typical of the region's wet and dry year precipitation range of 300 to 1,000 mm. Similar data for sideoats grama was also gathered from a 16x16 m control plot adjacent to the lysimeters which was used for biomass and live leaf area sampling.

The results showed that although transpiration rates (mmol m^{-2} s^{-1}) on a leaf area basis were higher from mesquite than sideoats grama in 1988, on a transpiration depth per lysimeter basis i.e. (Live Leaf Area/Lysimeter Area x Transpiration Rate x Day Length (mm day^{-1})), transpiration was higher from the sideoats grama lysimeters. On the mesquite and sideoats grama lysimeters receiving supplementary irrigation to wet year levels (>800 mm), live leaf area and standing crop was greater on the sideoats grama lysimeters. The reverse was true for the natural precipitation lysimeters which received between 320 - 440 mm annual rainfall in 1988 and 1989. Transpiration depths per lysimeter were greatest from the supplementary

irrigated sideoats grama lysimeters and lowest from the natural precipitation sideoats grama lysimeters. Live leaf area index i.e. (Live Leaf Area/Lysimeter Area) was a major variable affecting transpiration loss from the lysimeters, and should be considered in any comparative water use studies between species.

METHODS

Twelve non-weighing lysimeters (3 m deep and 7 m in diameter) were prepared for water budget studies over 0.6 ha of the recharge zone of the Carrizo-Wilcox aquifer on the Lyles Ranch in Zavala County, Texas during 1987. Six of the lysimeters were seeded to sideoats grama and six each contained a single-stemmed mesquite shrub, ranging from 3.0-4.5 m in height, together with its associated understory. The area in between the lysimeters was seeded to kleingrass (*Panicum coloratum*) which grew and maintained a dense cover through 1988 and 1989. Mesquite shrubland surrounds the site.

Transpiration rates and other gas exchange parameters for sideoats grama and mesquite were measured with a LI-6000 portable photosynthesis system equipped with a 0.25 l leaf chamber. Leaves, oriented parallel to the soil surface, were monitored at approximately 1, 4, 7, and 10 hours post sunrise (HPS) on each sample date. Concurrent with transpiration measurements, plant water potential (PWP) was measured with a pressure chamber (3000 Series, Soil-moisture Equip. Corp., Santa Barbara, CA) using compressed nitrogen as the pressurizing gas.

Half the mesquite and sideoats grama lysimeters and the control plot received supplementary watering at the end of each month if natural rainfall fell below the monthly average of the five wettest years on record at La Pryor weather station, fifteen miles to the south. Watering of the control plot was begun on July 29, 1988, nine days after the first day of transpiration measurements.

On each sampling date gas exchange measurements of six recently expanded sideoats grama leaves were taken diurnally both on the weighing lysimeter and outside on the control plot. Ten measurements per leaf per sample period were taken. Four leaf petioles, each containing three to four leaves, were monitored at mid to lower canopy level on each mesquite tree. Two sample petioles were from the east side of the tree and two were from the west. One sample from each side was shaded and the other had full sun exposure. Sample leaves were cut at the end of each sampling date and leaf area determined with a LI-3000 area meter. These values were used to calculate transpiration on an area basis.

Mesquite leaf areas were estimated using the technique developed by Wendt et al (1967) whereby a regression equation describing the relationship between rachise length and leaf area is developed for each growing season (Table 1). The total leaf area per shrub on each sampling date was estimated by measuring each rachise length on each of the sample branches and calculating total leaf area using the regression equation, then finding leaf density (i.e. sample branch leaf area/sample branch volume), and multiplying the average leaf density of the sample branches by the shrub's total branch volume. Average sample branch volume was 0.15 m^3. Initially four branches per shrub were sampled but this number was reduced to two or three per shrub, depending upon shrub size, when it was found that shrub leaf density varied little between sample branches.

Regression analysis was performed on each shrub's calculated leaf area changes through time. These third order polynomial regression equations had r^2 values ranging from 0.978 to 0.998, and were similar for both years (Table 2). Maximum leaf area was reached around 21 July, the time of the summer solstice, and ranged from 4 m^2 to 11 m^2. Mesquite live leaf area index was expressed as leaf area, (derived using the day of the year in the regression equation), divided by lysimeter area.

To determine sideoats grama live leaf area, point frame sampling of live leaf hits was carried out on ten $0.25m^2$ quadrats on the control plot adjacent to the lysimeters. Sampling dates coincided with or were generally within one or two days of those dates on which gas exchange measurements were made. Vegetation on each quadrat was collected and two to three subsamples per quadrat were taken. Live leaves in each subsample were sorted out and their area measured in a LI-3000 leaf area meter before drying. The oven dried leaves were weighed and specific leaf weights (g cm^{-2}) calculated. Oven-dry weights were measured for the remaining portion of each subsample to find the percent live leaves (by weight) of the entire sample. Live leaf area index (LLAI) was calculated from total leaf mass of each 0.25 m^2 quadrat and specific leaf weight. Live leaf hits were regressed against corresponding LLAI to derive a regression equation for each sampling date to estimate LLAI from live leaf hits on the sideoats grama lysimeters (Fig. 1). Four quadrats per lysimeter were sampled, the average number live leaf hits per quadrat determined, and used in the regression equation for each sample date to estimate the LLAI for each lysimeter. Live leaf area on the lysimeter was calculated by multiplying LLAI by lysimeter area. Live leaf area was multiplied by average daily transpiration rate and day length to estimate plant water use.

Gas exchange, water potential and leaf area measurements were conducted on all six mesquite within the lysimeters on seven sample days between July 1988 and October 1989. Within two days of the mesquite measurements, and under similar environmental conditions, sideoats grama was monitored on the irrigated lysimeters and the adjacent control plot. Because of drought conditions and invasion by more competitive species such as hooded windmill grass (*Chloris cucullata*) and Arizona cottontop (*Digitaria californica*) on the natural rainfall lysimeters, sideoats grama live leaf area was often considered too low to be hydrologically significant and fewer gas exchange measurements were taken.

RESULTS

Average daily transpiration rate ranges were 1.277 to 3.229 mmol m^{-2} s^{-1} for sideoats grama and 2.281 to 4.456 mmol m^{-2} s^{-1} for mesquite on the irrigated lysimeters; and 0.553 to 4.051 mmol m^{-2} s^{-1} for sideoats grama and 0.943 to 2.459 mmol m^{-2} s^{-1} for mesquite on the natural rainfall lysimeters (Table 3). Sideoats grama transpiration rates on the control plot were initially lower than on the irrigated lysimeters. Supplementary watering of the control plot was not begun until July 1988 and rooting density would have been lower, and more representative of conditions on the sideoats grama natural rainfall lysimeters than on the irrigated lysimeters. By late September 1988, sideoats grama transpiration rates on the control plot were similar to those on the irrigated lysimeters. Mesquite transpiration rates on the irrigated lysimeters were higher in 1988 than 1989. There was little difference in soil moisture, vapor pressure deficits, photosynthetically active radiation and plant water potentials between similar dates in 1988 and 1989. Summer rainfall (340 mm in 1988 and 464 mm in 1989) and ground cover standing crop (288 kg ha^{-1} in August 1988 and 1115 kg ha^{-1} in August 1989) were higher in 1989. Mesquite transpiration rates may have been reduced in 1989 as a result of low soil moisture below 60 cm and increased competition with its below-canopy cover for soil water in the upper 60 cm of soil (where grass and mesquite rooting density was greater).

Live leaf area indexes are given in Table 4. Sideoats grama live leaf area fluctuated with rainfall. Mesquite leaf area peaked in late July each year and declined to zero early in December. Sideoats grama live leaf area was greater than mesquite leaf area after rainfall on the irrigated lysimeters, but lower than mesquite on the natural rainfall lysimeters.

Transpiration rates were multiplied by the live leaf area index (LLAI) and day length to obtain mesquite and sideoats grama average transpiration depth per day (mm day^{-1}) for each treatment (Table 5). Transpiration depths per day ranged from 0.188 to 1.646 mm on the irrigated sideoats grama lysimeters, and from 0.230 to 0.889 mm on the irrigated mesquite lysimeters. On the natural rainfall lysimeters, transpiration depths ranged from 0.026 to 0.302 mm on sideoats grama and 0.182 to 0.242 mm on mesquite. Transpiration depths per day were highest from the irrigated sideoats grama and lowest from the natural rainfall sideoats grama because live leaf area was much greater on the irrigated sideoats grama lysimeters. Mesquite transpiration depths were below those of the irrigated and above those of the natural rainfall sideoats grama. In 1988, mesquite transpiration depths were greater on the irrigated than on the natural rainfall lysimeters because of the higher transpiration rates, but these rates declined in 1988, and there was less difference in the transpiration depths in 1988. Mesquite transpiration depths on the natural rainfall lysimeters were slightly higher in May and August 1988 because average LLAI was higher on the natural rainfall lysimeters.

Plant water potentials of the irrigated mesquite were similar to those of the natural precipitation lysimeters, and the range of water potentials was greater for sideoats grama than for mesquite (Table 6). Under drier soil moisture conditions, sideoats grama was under more moisture stress, i.e. higher negative water potentials, than mesquite. Sideoats grama has an extensive fibrous root system (Weaver 1968) whereas honey mesquite has a major tap root (Phillips 1963) and limited fibrous roots. The zone of the soil where mesquite roots are most actively absorbing water is within the upper 60 cm (Easter and Sosebee 1975). During times of moisture stress in the upper soil layers, the tap root of mesquite allows it to survive drought by exploiting soil moisture below 60 cm (Thomas (1976). Sideoats grama presumably has limited acces to soil moisture below 30 cm depth because 78% of its root biomass is in the upper 30 cm of the soil profile (Price and Heitschmidt 1987). The greater range of plant water potentials measured on sideoats grama compared to those of mesquite may reflect the effect of these rooting pattern differences as there is more variability in soil moisture in the upper 30 cm of the soil profile through time than in the entire profile.

In this study soil moisture changes below 60 cm in 1988 and 1989 were similar for both mesquite and sideoats grama suggesting that water use was similar for both species from 60-300 cm soil depth (Fig. 2). Van Auken and Bush (1989) found that roots of sideoats grama and mesquite were present in the bottom of 2 m pots one year after planting so both species could compete for water below 60 cm when it was available. On the study site, because of the low soil moisture and reduction in rooting density below 60 cm, most plant water use came from between 0-60 cm of soil depth.

Live leaf area was greater on the irrigated sideoats grama lysimeters than on the irrigated mesquite lysimeters. Less water per unit live leaf area on sideoats grama would be available for transpiration compared to mesquite and this may explain the higher negative water potentials on sideoats grama.

Results are also displayed graphically in Figs. 3 and 4. The upper portion of the figures shows diurnal changes in transpiration and rainfall for the two weeks prior to the gas exchange measurements for each treatment and sample date. There was little difference among soil moisture values in the upper 60 cm of the soil on the sample dates. Prior rainfall was a better indicator of changes in transpiration rates than soil moisture. The density of fine roots may increase after rainfall, which would increase plant transpiration. The lower portion of the figures shows average lysimeter transpiration in mm day^{-1} and corresponding live leaf area index for each treatment and sample day.

In Fig. 3(a), diurnal transpiration rates in 1988 on the irrigated lysimeters were higher from mesquite than from sideoats grama until November, when they were similar. Prior rainfall and irrigation were higher on sideoats grama than they were on mesquite in November. Transpiration rates were lower in September, when prior rainfall was lower. Sideoats grama transpiration in mm day^{-1} was higher than mesquite on all sample days except September 8 and 10. Although sideoats grama live leaf area was greater on all dates, because of lower prior rainfall, sideoats grama leaf transpiration rates were much lower than those of mesquite on September 10.

In Fig. 3(b), diurnal transpiration depths in 1989 on the irrigated lysimeters were lower from mesquite than sideoats grama. Live leaf area and transpiration in mm day^{-1} were higher on all sampling dates except for July. July rainfall was very low and this reduced sideoats grama live leaf area.

On the natural rainfall lysimeters during 1988 and 1989, Figs. 4(a) and 4(b), mesquite leaf area was greater than that of sideoats grama except for September 29, 1988. Where comparisons were available, they showed sideoats grama transpiration rates were much lower than those of mesquite when prior rainfall was low (e.g. July 20 and 22, 1988), and higher when prior rainfall was high. Even where sideoats grama transpiration rates were high following rainfall, e.g. August 16 and 18, 1989, transpiration depth was slightly below that of mesquite because of the lower live leaf area of the sideoats grama.

CONCLUSIONS

Mesquite water use is probably higher than that of sideoats grama in drier years because mesquite canopy is maintained throughout the growing season whereas sideoats grama live leaf area is reduced as soil moisture declines. In wetter years sideoats grama maintains a live leaf area that declines as soil moisture dries but which is usually well above that of mesquite. Sideoats grama probably transpires more than mesquite in wetter years because of its greater live leaf area.

Data gathered in 1988 and 1989 will be used to develop a model for mesquite transpiration based on the dynamic simulation model WATBAL designed to model water use by sorghum (Van Bavel et al. 1984). WATBAL is an application of an evaporation and transpiration theory, an infiltration and redistribution of soil moisture theory, and a root water uptake theory. Actual transpiration will be determined from standard daily weather data, leaf area index and estimated root density as inputs, and from canopy resistance, which is a function of the effective water potential of the leaf canopy. Water uptake from each soil layer will be determined from its relative root density and the difference in water potential between the canopy and that layer.

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Table 1. Mesquite rachise length /leaf area equations.

1988	
$Y = 1.0417(X^{1.0766})$[1]	$R^2 = 0.913$
1989	
$Y = 0.93022(X^{1.1363})$	$R^2 = 0.918$

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[1] Y = Mesquite leaf area (cm^2)
X = Sum of the two rachise lengths of each mesquite leaf (cm)

Table 2. Mesquite leaf area equations for 1988 and 1989.

Lysimeter	Leaf area equations 1988
1(S)	$Y = -16.440 + 0.34181X - 1.1902\text{x}10^{-3}(X^2) + 9.3893\text{x}10^{-7}(X^3)$[1]
2(S)	$Y = -11.513 + 0.23939X - 8.3380\text{x}10^{-4}(X^2) + 6.5839\text{x}10^{-7}(X^3)$
7(S)	$Y = -7.412 + 0.15417X - 5.3755\text{x}10^{-4}(X^2) + 4.2569\text{x}10^{-7}(X^3)$
4(N)	$Y = -4.851 + 0.10090X - 3.5193\text{x}10^{-4}(X^2) + 2.7897\text{x}10^{-7}(X^3)$
5(N)	$Y = -14.017 + 0.29156X - 1.0170\text{x}10^{-3}(X^2) + 8.0633\text{x}10^{-7}(X^3)$
12(N)	$Y = -19.348 + 0.40228X - 1.4008\text{x}10^{-3}(X^2) + 1.1053\text{x}10^{-6}(X^3)$
	$R^2 = 0.998$ for all 1988 equations
Lysimeter	Leaf area equations 1989
1(S)	$Y = -11.313 + 0.30652X - 1.2243\text{x}10^{-3}(X^2) + 1.2668\text{x}10^{-6}(X^3)$
2(S)	$Y = -7.922 + 0.21466X - 8.5789\text{x}10^{-4}(X^2) + 8.8852\text{x}10^{-7}(X^3)$
7(S)	$Y = -5.091 + 0.13792X - 5.5083\text{x}10^{-4}(X^2) + 5.6987\text{x}10^{-7}(X^3)$
4(N)	$Y = -3.327 + 0.09014X - 3.5985\text{x}10^{-4}(X^2) + 3.7198\text{x}10^{-7}(X^3)$
5(N)	$Y = -9.638 + 0.26119X - 1.0444\text{x}10^{-3}(X^2) + 1.0827\text{x}10^{-6}(X^3)$
12(N)	$Y = -13.325 + 0.36107X - 1.4433\text{x}10^{-3}(X^2) + 1.4953\text{x}10^{-6}(X^3)$
	$R^2 = 0.978$ for all 1989 equations

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[1] Y = Leaf area in m^2
X = Day of year.
(S) = Supplementary irrigation treatments;
(N) = Natural precipitation treatments.

Table 3. Average daily transpiration rates on a leaf area basis (mmol m^{-2} s^{-1}) by treatment.

Date	SOG Control[1]	SOG(S)	M(S)	SOG(N)	M(N)
7/03/88	0.610	3.229	-------	-------	-------
7/22/88	-------	-------	4.456	-------	2.459
9/10/88	-------	-------	3.047	-------	1.570
9/29/88	1.120	1.471	-------	-------	-------
10/01/88	-------	-------	3.777	-------	2.236
5/23/89	2.354	3.246	-------	-------	-------
5/25/89	-------	-------	1.299	-------	1.889
7/10/89	1.100	1.751	-------	-------	-------
7/15/89	-------	-------	1.343	-------	0.943
8/14/89	3.083	4.354	-------	4.051	-------
8/16/89	-------	-------	2.281	-------	2.316
10/25/89	1.477	1.277	-------	0.553	-------

[1] SOG - Sideoats grama; M - Mesquite; (S) - Supplementary precipitation treatment; (N) - Natural precipitation treatment.

Table 4. Live leaf area indexes by treatment.

Date	SOG Control[1]	SOG(S)	M(S)	SOG(N)	M(N)
7/21/88	0.415	0.496	0.217	0.214	0.241
9/10/88	0.279	0.297	0.167	0.038	0.179
10/30/88	0.464	0.680	0.130	0.163	0.140
5/25/89	0.949	0.566	0.205	0.146	0.224
7/15/89	0.112	0.108	0.208	0.028	0.225
8/17/89	0.313	0.322	0.183	0.087	0.198
10/25/89	0.102	0.188	0.031	0.026	0.034

[1] SOG - Sideoats grama; M - Mesquite; (S) - Supplementary precipitation treatment; (N) - Natural precipitation treatment.

Table 5. Average daily transpiration rates on a lysimeter basis (mm day^{-1}) by treatment.

Date	SOG Control[1]	SOG(S)	M(S)	SOG(N)	M(N)
7/03/88	0.176	1.455	-------	-------	-------
7/22/88	-------	-------	0.889	-------	0.424
9/10/88	-------	-------	0.400	-------	0.216
9/29/88	0.426	0.774	-------	-------	-------
10/01/88	-------	-------	0.341	-------	0.229
5/23/89	1.772	1.646	-------	-------	-------
5/25/89	-------	-------	0.242	-------	0.361
7/10/89	0.072	0.172	-------	-------	-------
7/15/89	-------	-------	0.230	-------	0.183
8/14/89	0.705	1.207	-------	0.302	-------
8/16/89	-------	-------	0.270	-------	0.318
10/25/89	0.082	0.188	-------	0.026	-------

[1] SOG - Sideoats grama; M - Mesquite; (S) - Supplementary precipitation treatment; (N) - Natural precipitation treatment.

Table 6. Average daily water potentials for mesquite and sideoats grama (MPa).

Sample Date	M(S)	M(N)	SOG Control	SOG(S)	SOG(N)
Jly 88	1.99[1]	2.26	3.45	-----	-----
Sep 88	2.41	2.67	2.67	-----	-----
Oct 88	2.61	2.79	0.86	-----	-----
Nov 88	1.86	1.57	1.12	-----	-----
May 89	2.02	2.07	3.15	2.45	-----
Jly 89	2.55	2.71	5.14	3.45	-----
Aug 89	1.80	1.72	1.46	1.38	1.49
Oct 89	2.63	2.57	2.79	3.17	2.18

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[1] Smaller values indicate higher plant water stress.

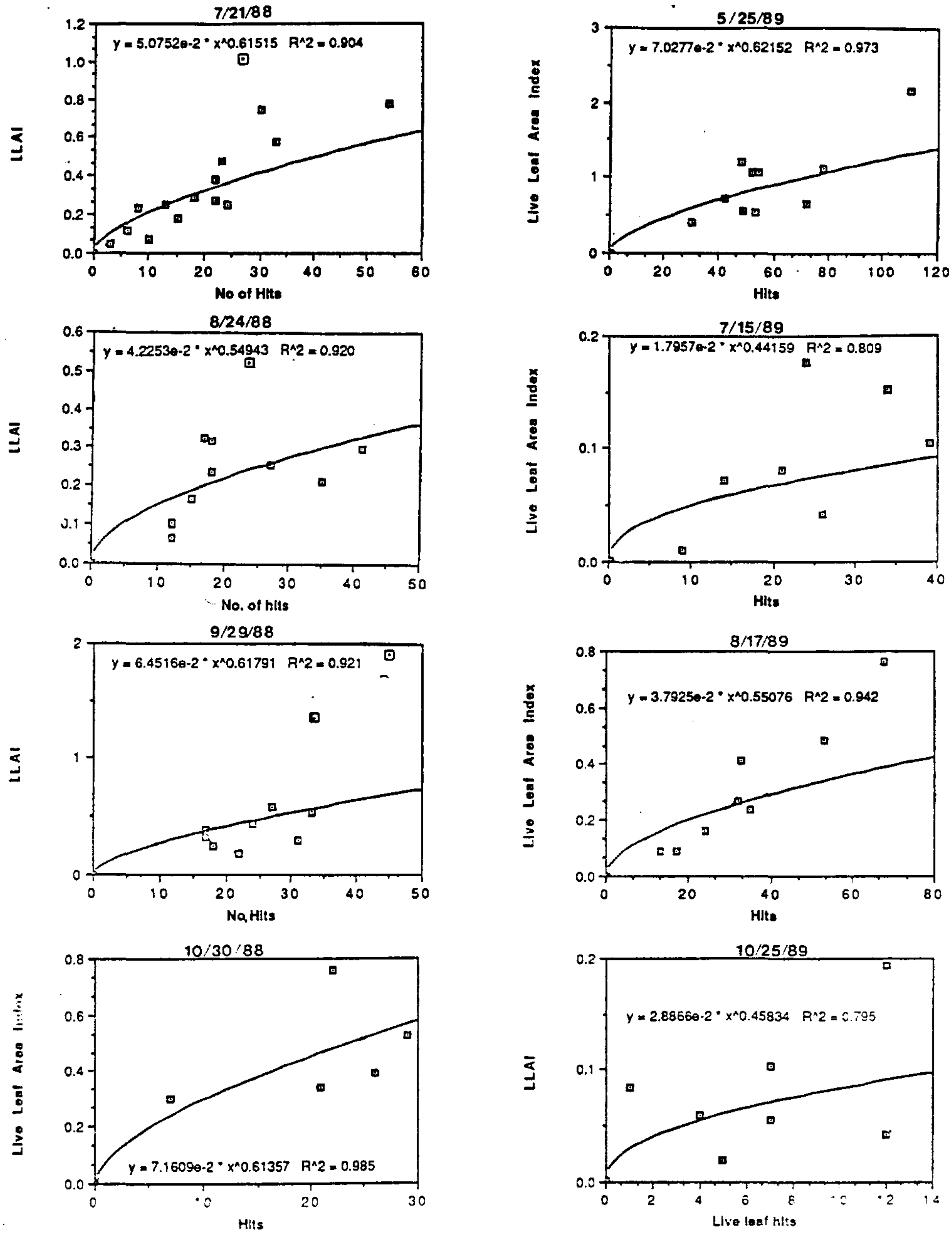


Figure 1. Live leaf hits and live leaf area index regressions for sideoats grama on each sampling date.

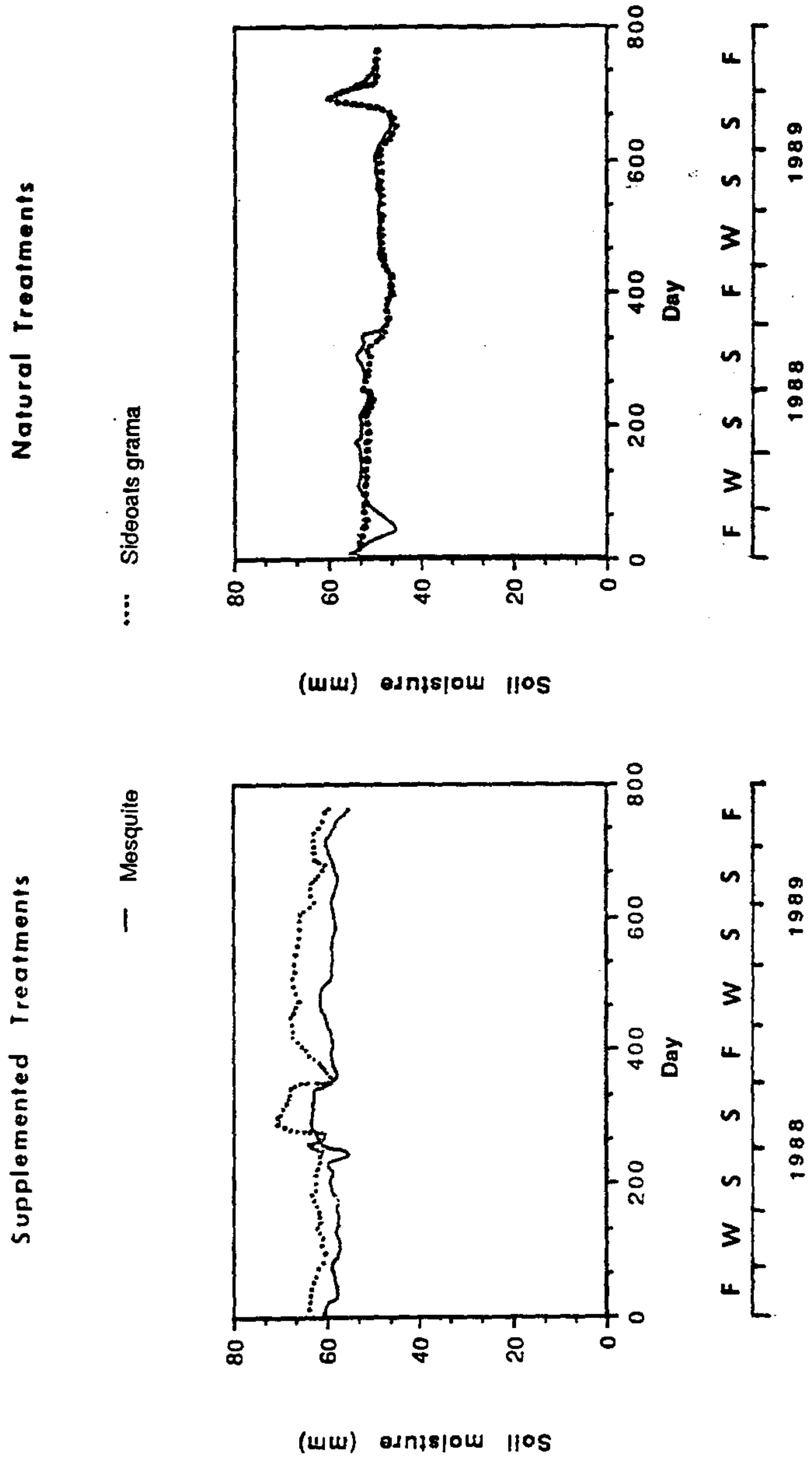


Figure 2. Soil moisture below 60 cm on the non-weighing lysimeters by treatment for 1988 and 1989.

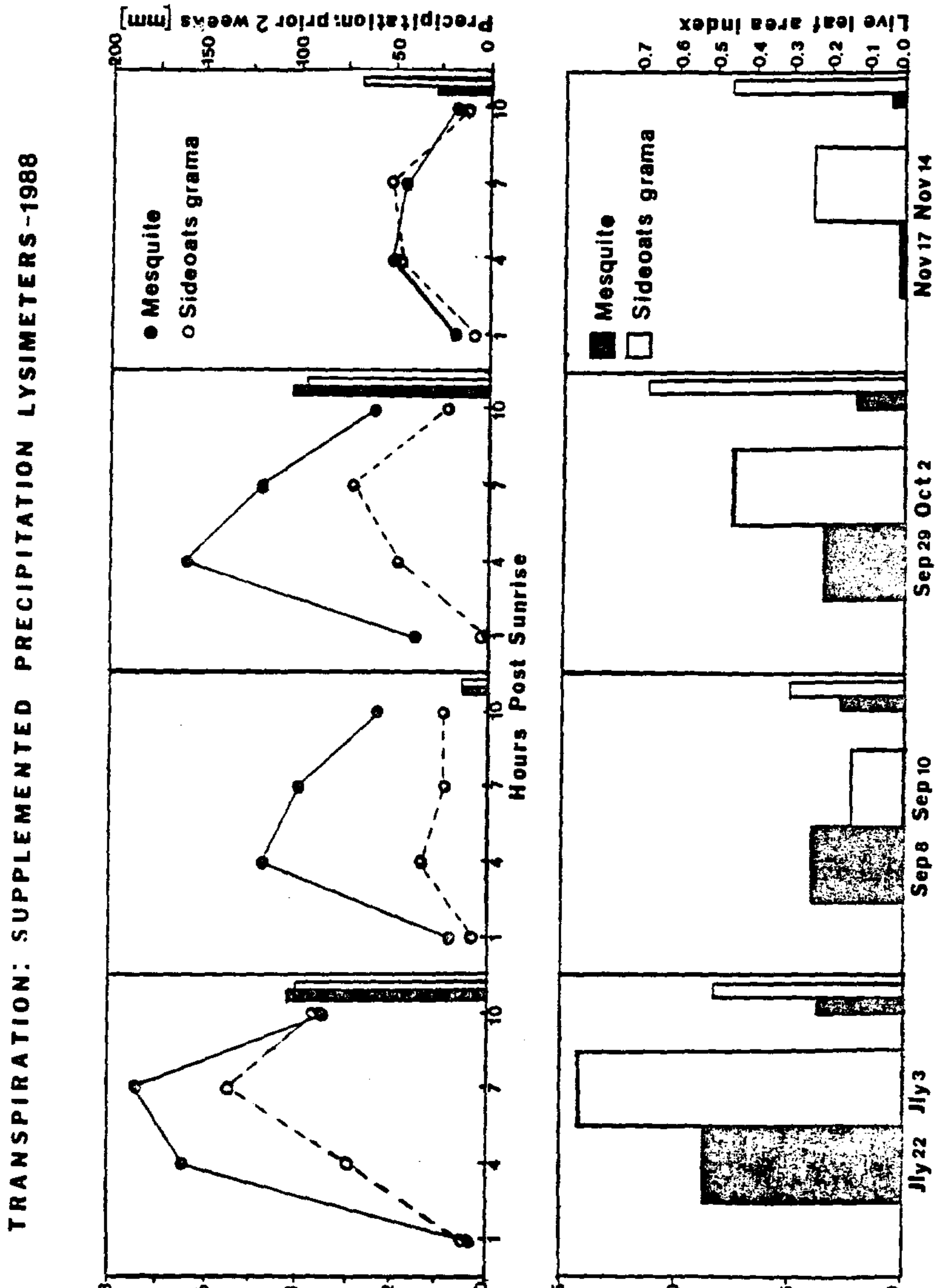


Figure 3(a). Average transpiration, prior rainfall and live leaf area indexes for mesquite and sideoats grama supplementary precipitation lysimeters on each sampling date in 1988.

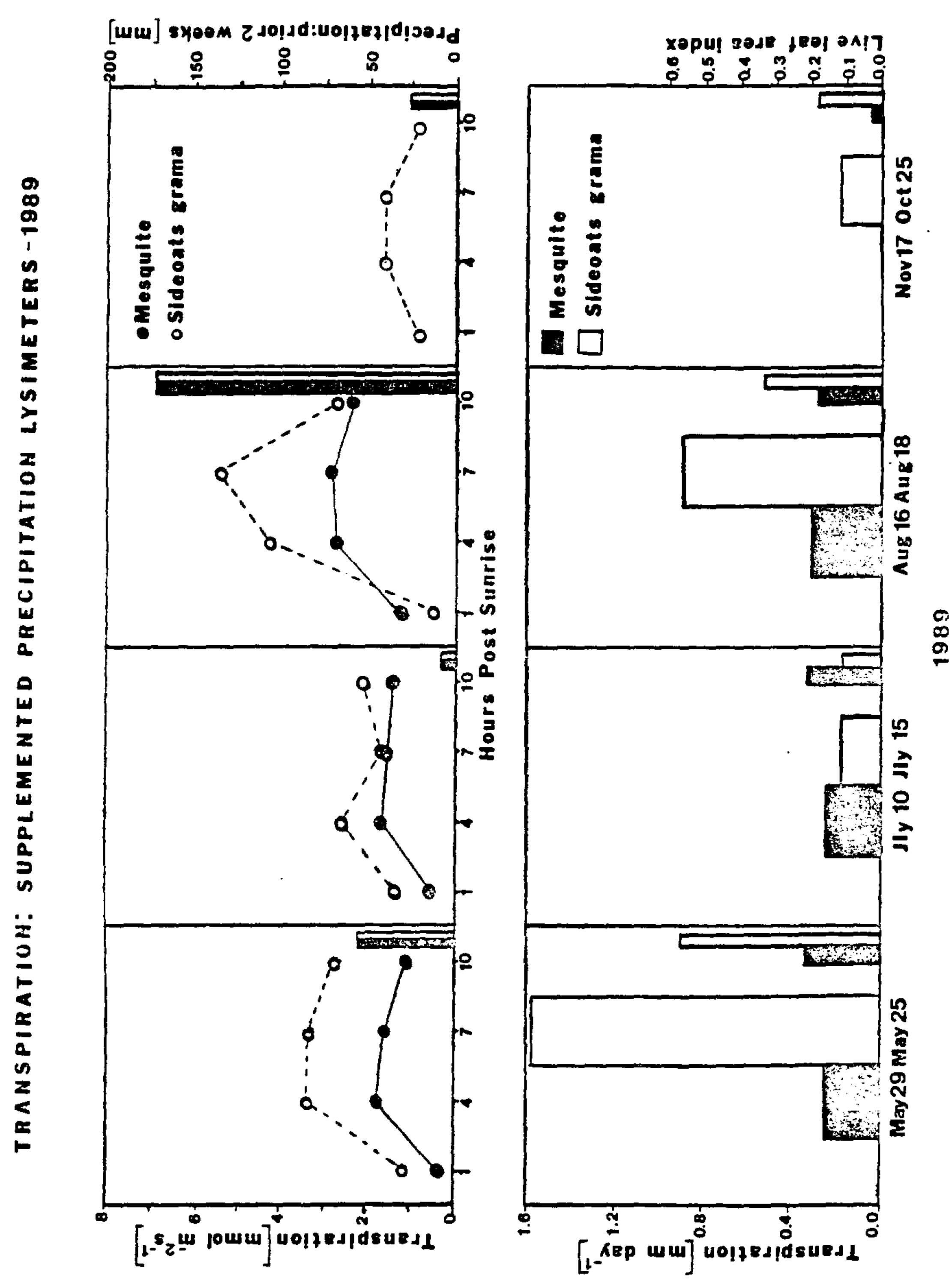


Figure 3(b). Average transpiration, prior rainfall and live leaf area indexes for mesquite and sideoats grama supplementary precipitation lysimeters on each sampling date in 1989.

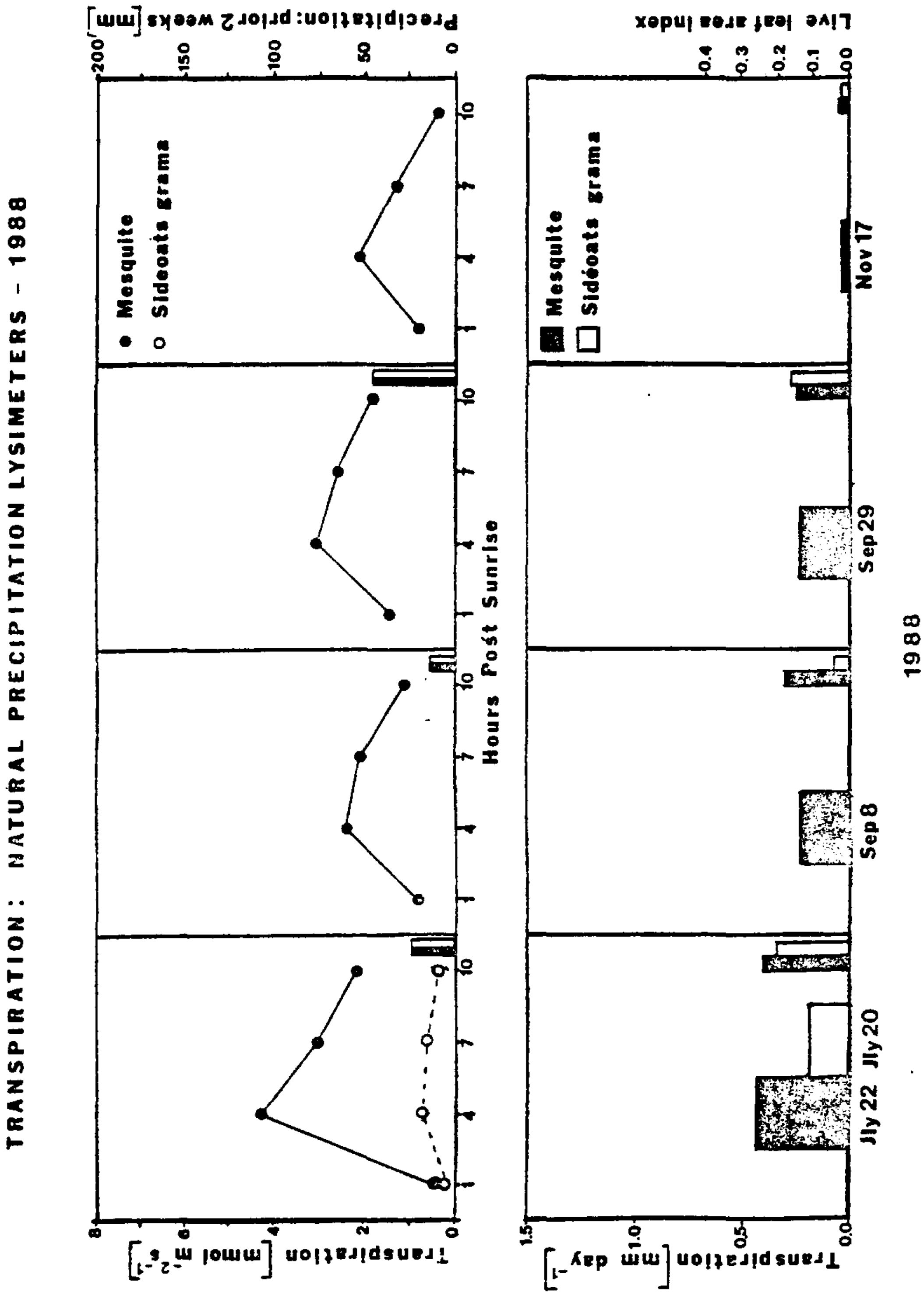
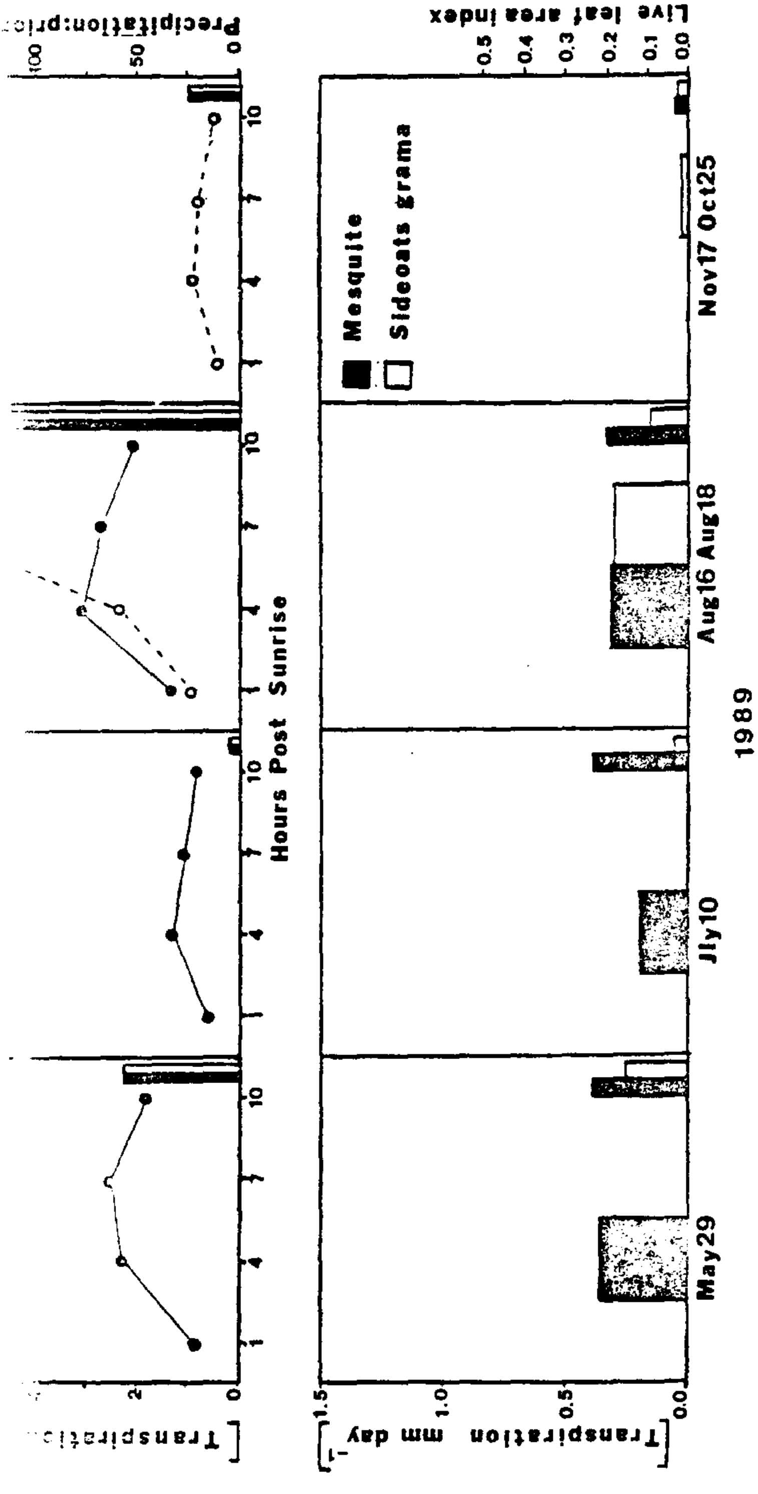


Figure 4(a). Average transpiration, prior rainfall and live leaf area indexes for mesquite and sideoats grama natural precipitation lysimeters on each sampling date in 1988.



, prior rainfall and live leaf area indexes for mesquite and ral precipitation lysimeters on each sampling date in 1989.

RUNOFF FROM MIXED BRUSH DOMINATED WATERSHEDS ON THE LYLES RANCH IN ZAVALA COUNTY

Robert W. Knight and Cherie Fischer

SUMMARY

Very dry conditions during the study period produced limited runoff from the study watersheds. Brush management has the potential to produce increased ground water recharge in the Carrizo-Wilcox recharge area, although no deep drainage was measured during 1988 or 1989. Increased runoff in this area would serve to increase water supply to South Texas, primarily Corpus Christi. Continued study on these watershed for several more years with some favorable moisture conditions are needed to determine the influence of brush on water yield.

METHODS

Nine small watersheds of 0.6 ha were constructed by pushing up a ridge of soil around the edge of the watershed (Fig. 1). The ridge of soil was needed to define the watershed boundary because of the nearly level slope of the area (<1-3%). A 0.6 m H-flume was installed at the lower end of each site and equipped with a FW-1 stage recorder. The stage recorder was used to measure quantity and timing of water movement from the watershed. Rainfall was measured across the site with a network of rain gauges. Rainfall intensities were recorded using a weighing bucket rain gauge.

The watersheds were allowed to calibrate for about 18 months before herbicide treatments were applied in June 1989. Watersheds 2, 4 and 8 had herbicides applied to 100% of their surface area on a grid pattern. Watersheds 1, 6 and 9 had 70% of their surface area treated. The partially treated watersheds had the brush treated in a pattern that would be similar to that used to enhance wildlife habitat.

RESULTS

Precipitation during 1988 was below normal (Table 1). There was only 300 mm of precipitation for the entire year, about ½ of normal, from 29 events. The lower precipitation combined with high temperatures, low humidity and above normal winds all combined to cause extreme drought conditions. There were only 4 rainfall events that produced runoff from some of the watersheds (Table 2). Watersheds 1, 6, 7 and 9 were the only ones to produce any runoff. The highest total runoff for 1988 was from watershed 6 (3.4 mm) and was produced by the October 29 rainfall event.

Total rainfall for 1989 was near normal but there was actually severe drought conditions still present. The total rainfall for 1989 was skewed by one large event on August 7 (170 mm). This storm was very intense and produced runoff from most of the watersheds but did very little to moderate very dry soil conditions. There were only 22 rainfall events in 1989, but they produced 15 runoff events because of their larger size and greater intensities. The largest runoff event for 1989 was the August 7 storm.

Dry conditions following herbicide application delayed the action of the herbicides on the brush. The influence of brush management practices on water yield could not be determined because of the dry conditions and the variability of the data. Continuation of the study for a couple more years will be needed to determine if water yield can be increased in the South Texas mixed brush through brush management.

Table 1. Daily precipitation (mm) at the Lyles Ranch watershed study area main gauge for January 1988 to December 1989.

Date	Rainfall	Total	Date	Rainfall	Total
1988			Dec 7	5.080	
			8	4.064	9.144
Jan 12	19.050				
19	1.778	20.828			300.482
Feb 3	0.457		**1989**		
4	4.572				
9	1.270		Jan 19	37.592	
11	6.096		27	29.464	67.056
29	2.032	18.542			
			Feb 12	1.016	
Mar 17	3.810		16	19.558	20.574
27	1.524	5.334			
			Mar 19	5.080	
Apr 9	32.258		28	8.128	13.208
16	14.986				
30	0.508	47.752	Apr 12	6.604	
			26-29	38.354	44.958
May 14	6.604				
21	11.684		May 12	58.928	
25	5.080	23.368	19	4.318	63.246
Jun 3	6.858		Jun 13	43.688	
6	7.620		24	3.556	47.244
26	3.048	17.526			
			Jul 6	2.794	2.794
Jul 5	0.762				
12	21.844		Aug 7	170.688	
27	5.842		24	2.286	
31	1.524	29.972	25	4.064	177.038
Aug 15	12.700	12.700	Sep 12	7.620	7.620
Sep 7	9.144		Oct 6	27.686	
17	41.910		27	43.434	71.120
29	9.144	60.198			
			Nov 21	1.524	
Oct 29	55.118	55.118	22	4.064	
			29-30	30.734	36.322
					551.180

Table 2. Runoff from Lyles Ranch watershed treatments.

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge ($l\ s^{-1}$)
1988					
May 25	1	4.826	0.8636	17.9	0.085
	7	4.572	0.2540	5.6	0.082
Sep 17	1	43.180	0.0762	0.2	0.227
	9	40.640	0.1524	0.4	0.057
Oct 29	1	60.198	1.4732	2.5	2.210
	6	50.800	3.4036	6.7	1.420
	7	52.070	2.3876	4.6	0.453
Dec 8	1	4.064	0.7112	17.5	0.085
1989					
Jan 19	1	38.100	1.4478	3.8	0.142
	6	36.830	0.1270	0.3	0.028
	7	38.100	0.6858	1.8	0.077
Jan 27	1	29.464	0.0762	0.3	0.028
	7	29.972	0.1270	0.4	0.028
Feb 12	6	1.016	0.8128	80.0	0.057
Feb 16	1	19.558	0.0508	0.3	0.028
	5	20.320	0.0076	0.1	0.028
	6	20.320	0.0762	0.4	0.113
	7	18.796	0.0102	0.1	0.006
	8	18.796	0.0025	0.1	0.006
	9	18.796	0.0025	0.1	0.009
Mar 19	1	5.080	0.6350	12.5	0.085

Table 2. (continued)

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge ($l\ s^{-1}$)
Apr 26-29	1	38.100	0.1016	0.3	0.368
	2	38.100	0.1270	0.3	0.820
	5	40.640	0.0762	0.2	0.142
	6	40.640	0.6350	1.6	2.270
	8	39.370	0.0762	0.2	0.142
May 12	1	63.500	0.5410	0.9	1.331
	2	63.500	0.8128	1.3	3.030
	3	63.500	0.0051	0.1	0.028
	5	63.500	0.1778	0.3	0.595
	6	63.500	3.0226	4.8	9.830
	8	63.500	0.0762	0.1	0.198
	9	63.500	0.0254	0.1	0.057
May 19	5	4.064	0.1524	3.8	0.057
	6	4.064	0.0127	0.3	0.028
	7	4.572	0.2032	4.4	0.057
Jun 13	1	40.640	0.2540	0.6	0.623
	2	40.640	0.2032	0.5	0.736
	5	47.498	0.2540	0.5	0.255
	6	47.498	1.9304	4.1	6.200
	7	47.498	6.0960	12.8	1.420
	8	47.498	0.0762	0.2	0.142
	9	47.498	0.0178	0.1	0.028
- - - - - - HERBICIDE TREATMENTS APPLIED TO WATERSHEDS[1] - - - - - -					
Aug 7	1	187.960	9.9314	5.3	9.710
	5	167.640	6.9596	4.2	9.940
	6	167.640	10.2616	6.1	10.081
	7	154.940	12.3190	8.0	9.996
	8	154.940	14.4526	9.3	9.713
	9	154.940	2.3876	1.5	6.173
Sep 12	5	8.890	0.1016	1.1	0.255
	6	8.890	0.3302	3.7	1.590
	7	8.128	0.3556	4.4	0.396

Table 2. (continued)

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge (l s^{-1})
Oct 6	5	29.464	0.0762	0.3	0.028
	7	27.686	0.4318	1.6	0.142
Oct 27	1	44.450	0.1016	0.2	0.292
	2	44.450	0.0762	0.2	0.286
	5	44.958	0.4572	1.0	0.453
	6	44.958	0.2032	0.5	0.227
	7	43.688	0.3810	0.9	0.113
	8	43.688	1.5494	3.6	0.227
Nov 22	1	4.572	0.1016	2.2	0.028
	6	4.064	0.0762	1.9	0.040
	7	4.064	0.0762	1.9	0.065
Nov 30	5	30.226	0.0305	0.1	0.028
	6	30.226	0.0762	0.3	0.057
	7	31.496	0.5080	1.6	0.085

[1] Watersheds 2, 4 and 8 had a 100% treatment; watersheds 1, 6 and 9 had a 70% treatment; and watersheds 3, 5 and 7 were left untreated to serve as controls.

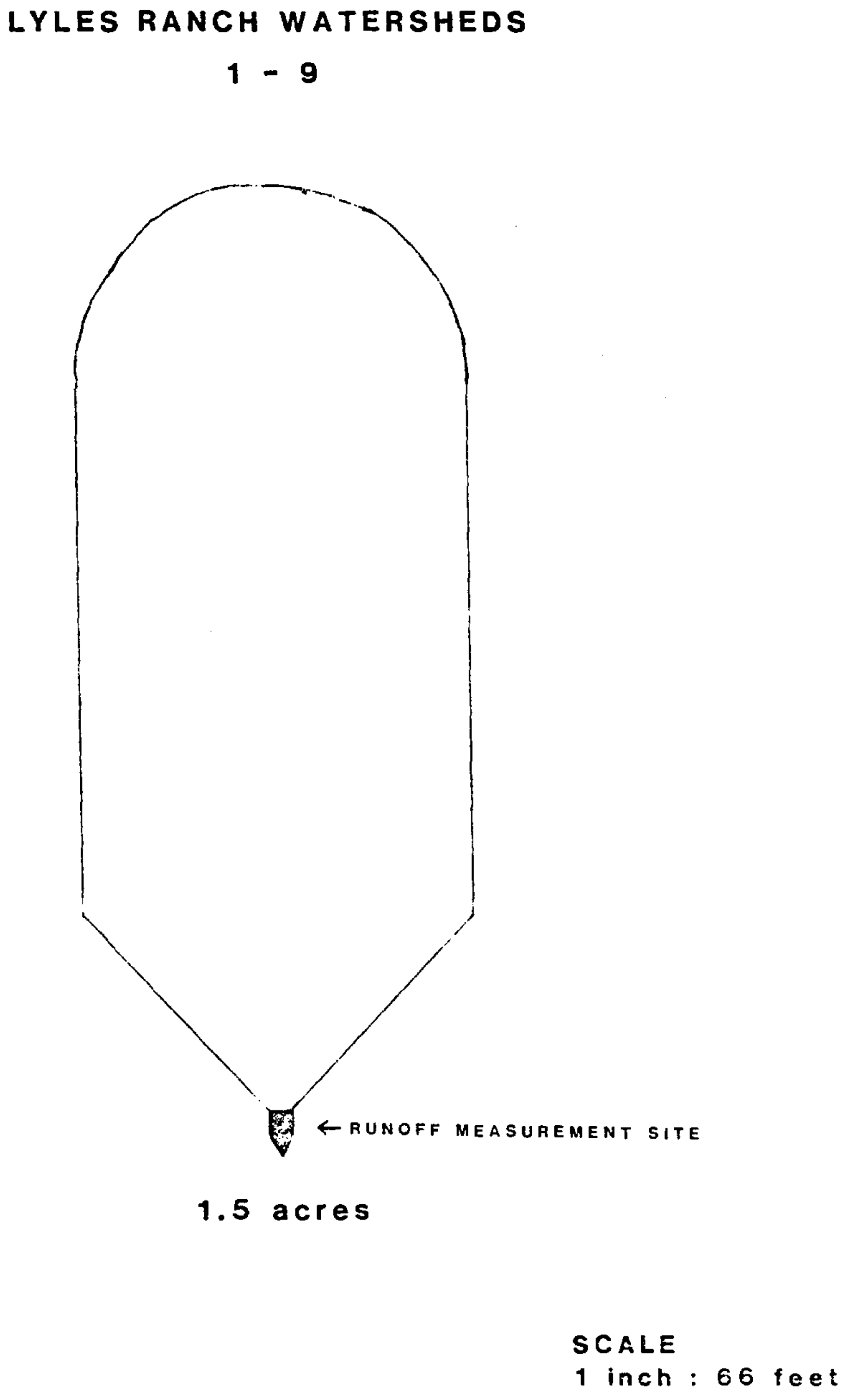
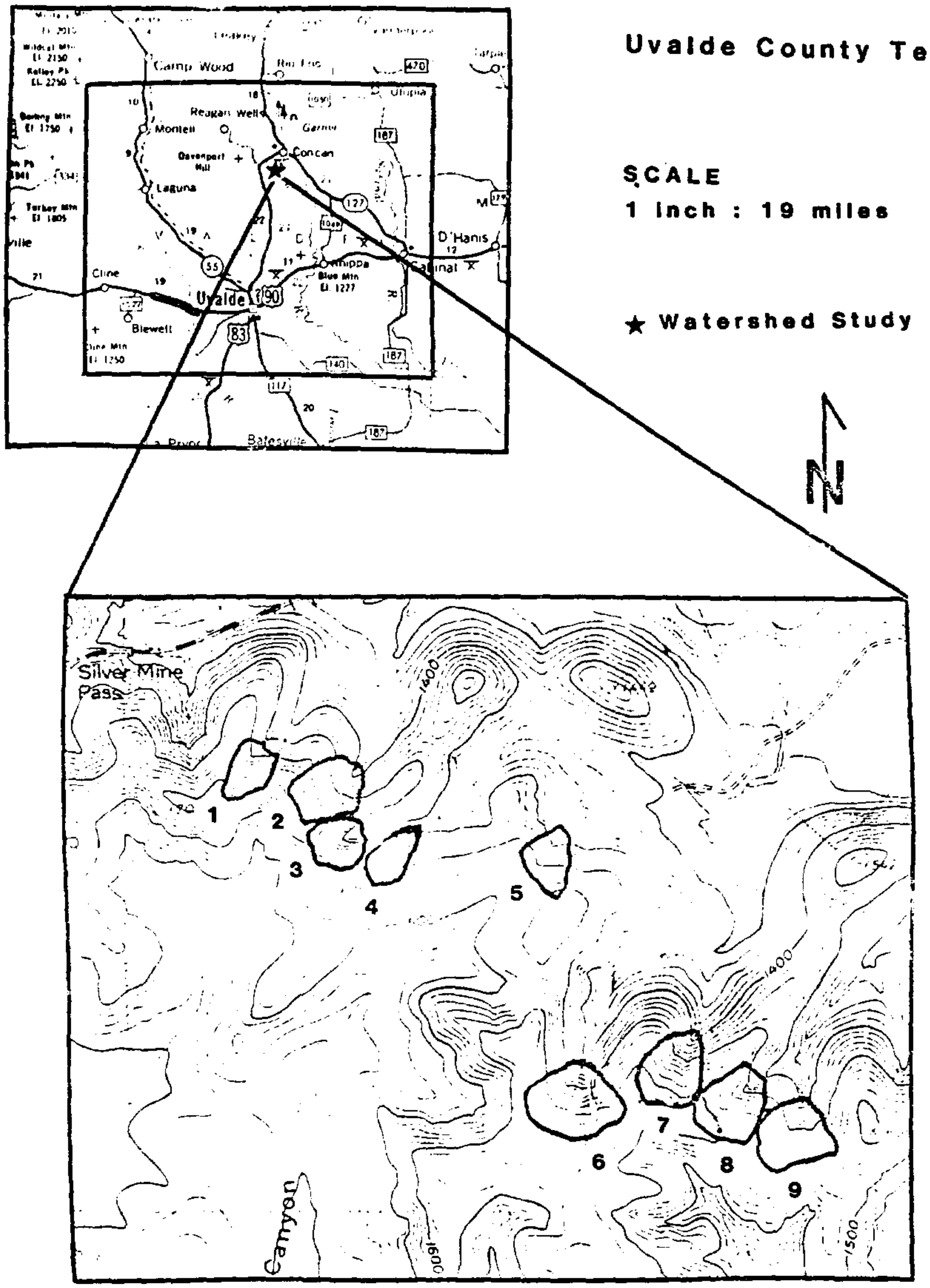


Figure 1. Diagram of watersheds on the Lyles Ranch study area.

ANNANDALE RANCH STUDY SITE

The Annandale Ranch is located 32 km north of Uvalde near the Frio River and in the recharge area of the Edwards Aquifer (Fig. 1). The study site is located in the Edwards Plateau, which is characterized by rough steep terrain. In much of the study area elevations increase 65 to 125 m within short distances. Normal precipitation for the area is 602 mm; rainfall amounts vary greatly from month to month and from year to year. Annual precipitation varies from a low of 345 mm to a high of 900 mm. Sixty-eight percent of the rain falls between May and October. Maximum precipitation usually falls during late spring and during September. Mean annual lake evaporation is 1778 mm. The average length of the growing season is 256 days. Soils are classified as limestone rock land, which consists of exposed limestone bedrock with the Ector or Kavett soil series found between the exposed bedrock. The site is characterized by a dense overstory of shrubs, mostly juniper and oaks, with a sparse understory of grasses and forbs.

ANNANDALE RANCH STUDY SITE



Uvalde County Texas

SCALE
1 inch : 19 miles

★ Watershed Study Site

SCALE
1 inch : 1575 feet

Figure 1. Location of Annanoaie Ranch watershed study sites.

WATER USE BY LIVE OAK AND BLUEBERRY JUNIPER

M. Keith Owens

SUMMARY

On a rangeland where these species coexist, it appears that although oak trees use more water during wet periods, they transpire less water during dry periods compared to blueberry juniper. Therefore, oak trees would be able to gain carbon and continue growing while using less water than juniper trees during most of the summer.

INTRODUCTION

The amount of water that either runs off into streams or percolates into underground aquifers is extremely important. Water use by native vegetation on rangelands can affect water production. The amount of water used by native trees and how efficiently it is used are not known. This study was designed to help answer these questions.

METHODS

Six live oak trees and six blueberry juniper trees were sampled at monthly intervals on the Annandale Ranch near Concan, TX. The canopy of each tree was divided into three zones based on the amount of light received in each layer. Four leaves were sampled in each zone for carbon uptake and water loss. The density of leaves within each canopy was estimated and used to extrapolate results from single leaves to an entire tree. Two representative canopies were used for presentation purposes. The sparse canopy had a leaf area index of 2.4 (meaning the leaf area was 2.4 times the ground area under the tree), and the dense canopy had a leaf area index of 5.3.

RESULTS

Three results from this study pertain to: (1) water loss from trees, (2) carbon gained by those trees and (3) the efficiency of gaining carbon while using less water.

WATER LOSS

As you might expect, the dense canopy trees lost more water than the sparse trees (Figure 1). Dense canopied oak trees lost 850 gallons of water per day during a wet month. The dense juniper trees lost about 620 gallons during the same time period. In the dry month, however, both trees lost about the same amount of water (244 gallons for oak and 262 for juniper).

CARBON GAINED

Although the dense oak trees used more water, they also gained the most carbon during a 12 hour day. Juniper trees gained only 2/3 of the carbon which the oak trees attained (91 g versus 144 g, Figure 1). In a dry month, the amount of carbon gained was reduced by half for both tree species.

CONVERSION EFFICIENCY

Both tree species had about equal efficiencies during wet periods. They gained about .17 and .15 grams of carbon for each gallon of water lost (Figure 1). Oak trees were better able to adjust their water loss during dry periods. The conversion efficiency increased to .26 grams per gallon of water for oak trees while juniper remained at .15. This represents a 50 percent increase in efficiency for oak trees.

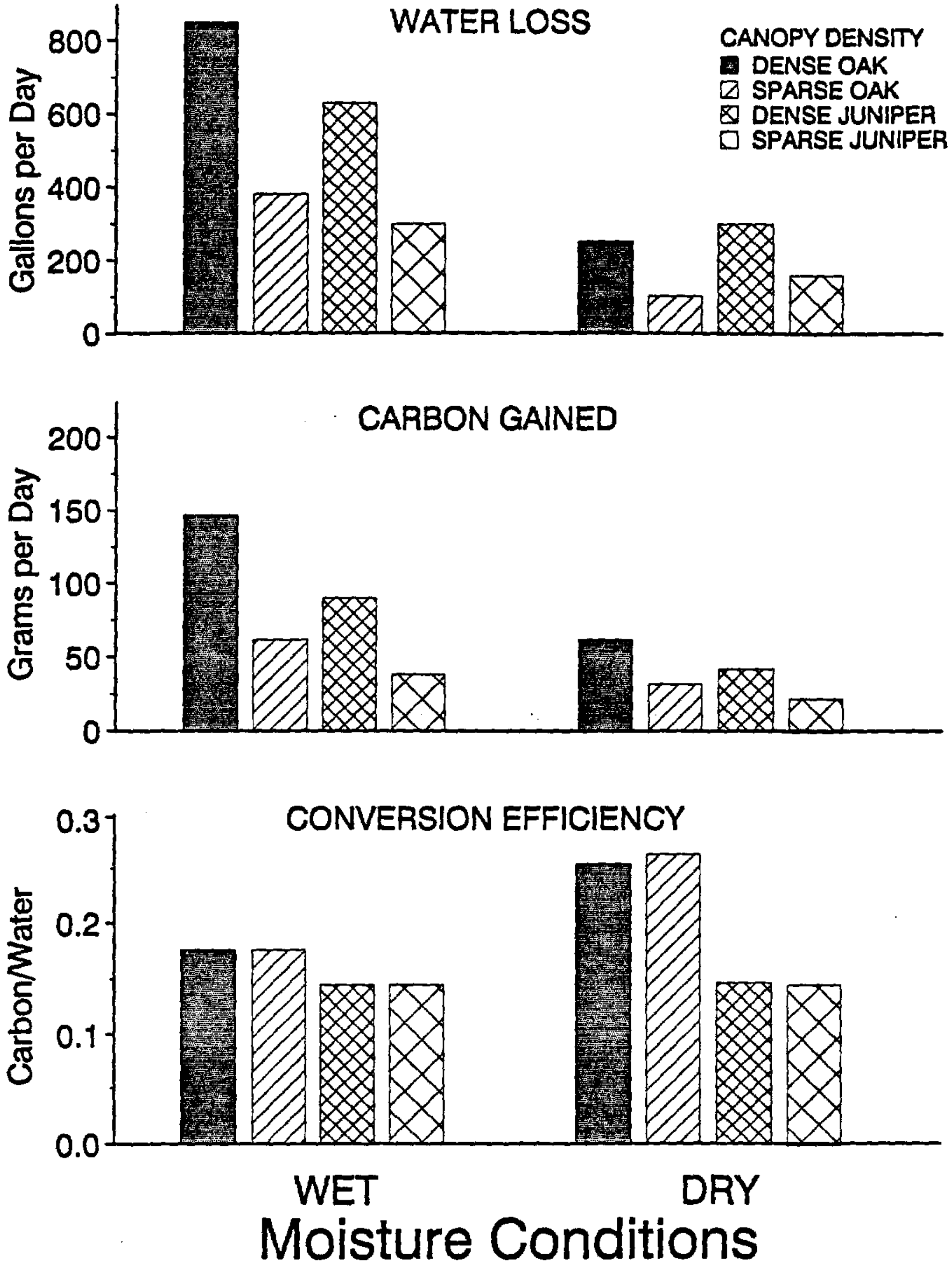


Figure 1. Water loss, carbon gain and conversion efficiency of oak and juniper under two moisture conditions.

RUNOFF FROM THE BRUSH DOMINATED RANGELANDS IN THE EDWARDS AQUIFER RECHARGE AREA

R.W. Knight, C.L. Fischer and M.K. Owens

SUMMARY

Dry conditions limited the number of runoff events. Only one rainfall event in 1988-89 produced runoff from all the watersheds. There is an indication that brush treatment may have increased runoff, but further study must be done to determine the significance and longevity of the treatments.

METHODS

Nine watersheds were instrumented in 1987 in the Edwards Aquifer recharge area on the Annandale Ranch. Topographic maps were developed for each watershed and flumes were located to obtain 3 watersheds each of 4, 5.4 and 6.3 hectares for a total of 9 watersheds (Figs. 1-9). The watersheds were blocked by area for statistical analysis.

Each watershed was instrumented with a 0.9 m H-flume and a FW-1 stage recorder. The stage recorders provided timing and quantity of runoff. A Coshocton wheel sediment sampler was used to obtain integrated sediment samples from the runoff. Pump samplers were used on 2 of the watersheds to obtain samples because of the lack of clearance to install the Coshocton wheel.

Precipitation was measured using a network of rain gauges located across the watershed study area. A weather station located at the base watershed was used to collect detailed weather data including rainfall intensity with a tipping bucket rain gauge.

Brush was treated in June 1989 with picloram. The herbicide was applied in a grid pattern at the recommended rates. Broadcast application was not allowed because of label restrictions for the recharge zone. All areas except the stream channels were treated on watersheds 1, 3 and 9. The stream channel area will be cleared by hand. Watersheds 2, 5 and 7 were treated on 70% of their area leaving a buffer along the stream channels and a pattern that would promote wildlife habitat use.

RESULTS

Precipitation was below normal for July-December 1987, and all of 1988 and 1989. There were 25 precipitation events in 1988 and 27 events in 1989 (Table 1). Eight runoff events occurred in 1988 and 15 events in 1989 (Table 2). There was only one date when there was sufficient rainfall over the entire area to produce runoff from all the watersheds. There is an indication in the runoff from July to December that there was increase runoff from the treated watersheds. The increase on the 100% treatment watershed was about 1% of the precipitation. The amount of runoff was only 1-2% of the rainfall amounts during this drought period. Runoff of about 5% of the precipitation might be expected in a normal year.

The study will be continued to determine if the effects of the brush management practices are significant and continue over several years. There has not been enough runoff events at this time to determine statistical significance of the data.

Table 1. Daily precipitation (mm) at the Annandale Ranch watershed study area for September 1987 to December 1989.

Date	Rainfall	Total
1987		
Nov 5	28.956	28.956
Dec 2	4.572	
18-19	51.054	
21	17.018	
24	1.270	
26	4.064	77.978
		106.934
1988		
Jan 6	3.556	
17	3.810	7.366
Feb 5	6.858	
10	2.286	
19	3.556	12.700
Mar 1	15.748	
17-18	21.336	37.084
Apr 12	2.286	2.286
May 4	8.890	
11	2.032	
21	35.560	46.482
Jun 1	8.890	
3	13.970	
26	130.302	153.162
Jul 6	17.526	
12	67.056	
21	29.972	
29	3.810	118.364
Aug 3	3.810	
14	22.352	26.162
Sep 7	6.350	
17	57.658	
29	5.080	69.088
Oct 29	25.400	25.400
Dec 7	7.620	7.620
		505.714
1989		
Jan 6	2.540	
19	32.512	
23	2.540	
26	57.150	94.742
Feb 15-17	44.196	44.196
Mar 19	3.556	
28	24.638	28.194
Apr 12-13	15.244	
26	13.716	
29	9.652	38.608
May 12	25.400	25.400
Jun 9	13.970	
12	39.370	
24	2.794	56.134
Jul 23	13.970	13.970

Table 1. (continued)

Date	Rainfall	Total	Date	Rainfall	Total
Aug 1	6.604				
7-8	85.090				
24	4.826				
25	9.398	105.918			
Sep 7	6.350	6.350			
Oct 11	19.050				
28	45.720				
29	46.990				
30	12.192	123.952			
Nov 15	16.510				
21	7.620				
30	25.400	49.530			
		596.994			

Table 2. Runoff from Annandale Ranch watershed treatments.

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge ($l\ s^{-1}$)
1988					
May 21	2	34.798	0.0254	0.1	0.170
	3	32.258	0.1524	0.5	2.379
	4	32.258	0.0254	0.1	0.255
	5	35.560	0.1270	0.4	0.311
	7	29.972	0.0254	0.1	0.538
Jun 3	3	11.176	0.0254	0.2	0.425
	5	13.970	0.0254	0.2	0.311
	7	15.240	0.0508	0.3	0.566
Jun 26	1	127.000	0.4826	0.4	5.805
	3	120.650	1.0414	0.9	6.598
	4	120.650	0.3048	0.3	3.285
	5	130.302	0.5080	0.4	2.174
	6	123.190	1.7780	1.4	13.564
Jul 6	7	17.780	0.0254	0.1	0.142
Jul 12	1	67.564	1.1176	1.7	15.801
	2	67.564	6.5278	9.7	72.746
	3	71.882	1.4732	2.0	7.249
	4	71.882	0.5080	0.7	5.125
	5	67.056	1.3462	2.0	2.945
	6	62.230	2.1590	3.5	17.981
	7	62.230	2.6162	4.2	34.292
	8	65.532	1.6002	2.4	14.895
	9	65.532	0.0508	0.1	0.850
Jul 21	6	46.736	0.0762	0.2	0.453
	7	46.736	0.0508	0.1	0.255
Aug 14	5	22.352	0.0762	0.3	0.198
	7	12.192	0.0508	0.4	0.170
Oct 29	5	25.400	0.0508	0.2	0.085

Table 2. (continued)

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge $(l\ s^{-1})$
<u>1989</u>					
Jan 26	1	58.420	0.0254	0.1	0.878
	2	58.420	0.4064	0.7	0.906
	3	60.960	0.3556	0.6	4.134
	6	55.880	0.4826	0.9	4.446
Feb 15-17	3	41.656	0.0508	0.1	0.057
Mar 28	1	26.670	0.0254	0.1	0.255
	3	25.654	0.0508	0.2	0.368
	5	24.638	0.0254	0.1	0.198
Apr 26	3	14.224	0.0254	0.2	0.708
May 12	3	23.368	0.0254	0.1	0.311
	7	31.750	0.0508	0.2	0.198
Jun 12	2	35.560	0.0254	0.1	0.113
	3	41.148	0.0508	0.1	0.651
	7	39.370	0.0254	0.1	0.113
- - - - - - HERBICIDE TREATMENTS APPLIED TO WATERSHEDS[1] - - - - - -					
Jul 23	3	16.510	0.0254	0.2	0.311
Aug 8	2	84.328	2.2606	2.7	6.032
	3	81.280	0.5842	0.7	5.493
	6	76.200	0.6096	0.8	3.681
	7	76.200	0.8890	1.2	2.718
Oct 11	3	22.860	0.0762	0.3	0.227
Oct 28	3	110.236	0.2032	0.2	3.002
	5	119.380	0.0254	0.1	0.255
	6	141.478	0.0762	0.1	1.501
	7	141.478	0.1524	0.1	1.331

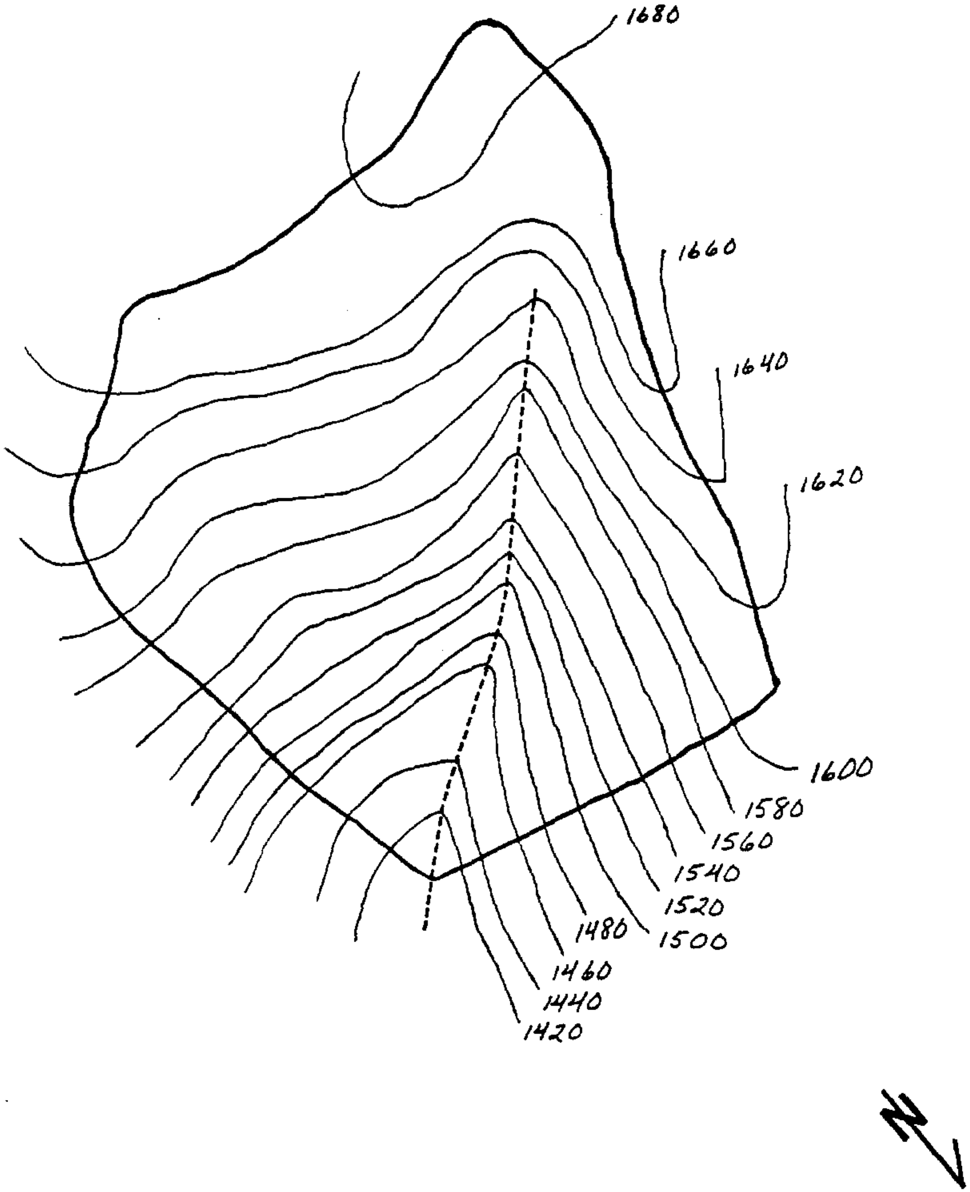
Table 2. (continued)

Storm Date	Watershed	Precipitation area (mm)	Runoff area (mm)	Runoff as a % of Precipitation (%)	Peak rate of Discharge ($l\ s^{-1}$)
Oct 29	2	110.236	6.9088	6.3	47.742
	3	110.236	1.0160	0.9	4.984
	4	110.236	0.1778	0.2	1.189
	5	119.380	1.2192	1.0	4.587
	6	141.478	1.6256	1.1	12.290
	7	141.478	2.1844	1.5	14.895
	8	143.510	1.3208	0.9	9.458
	9	143.510	0.2286	0.2	3.511
Oct 30	3	12.192	0.0762	0.6	0.283
Nov 15	3	16.510	0.1016	0.6	1.113
	5	16.510	0.0254	0.2	0.311
Nov 21	3	29.972	0.0508	0.2	0.198
Nov 30	3	25.400	0.2032	0.8	0.255

[1] Watersheds 1, 3 and 9 have a 100% treatment; watersheds 2, 5 and 7 have a 70% treatment; and watershed 4, 6 and 8 were left untreated to serve as controls.

ANNANDALE RANCH

Watershed 1



13 acres

SCALE
1 inch : 200 feet

Figure 1. Topographic map of watershed 1 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 2

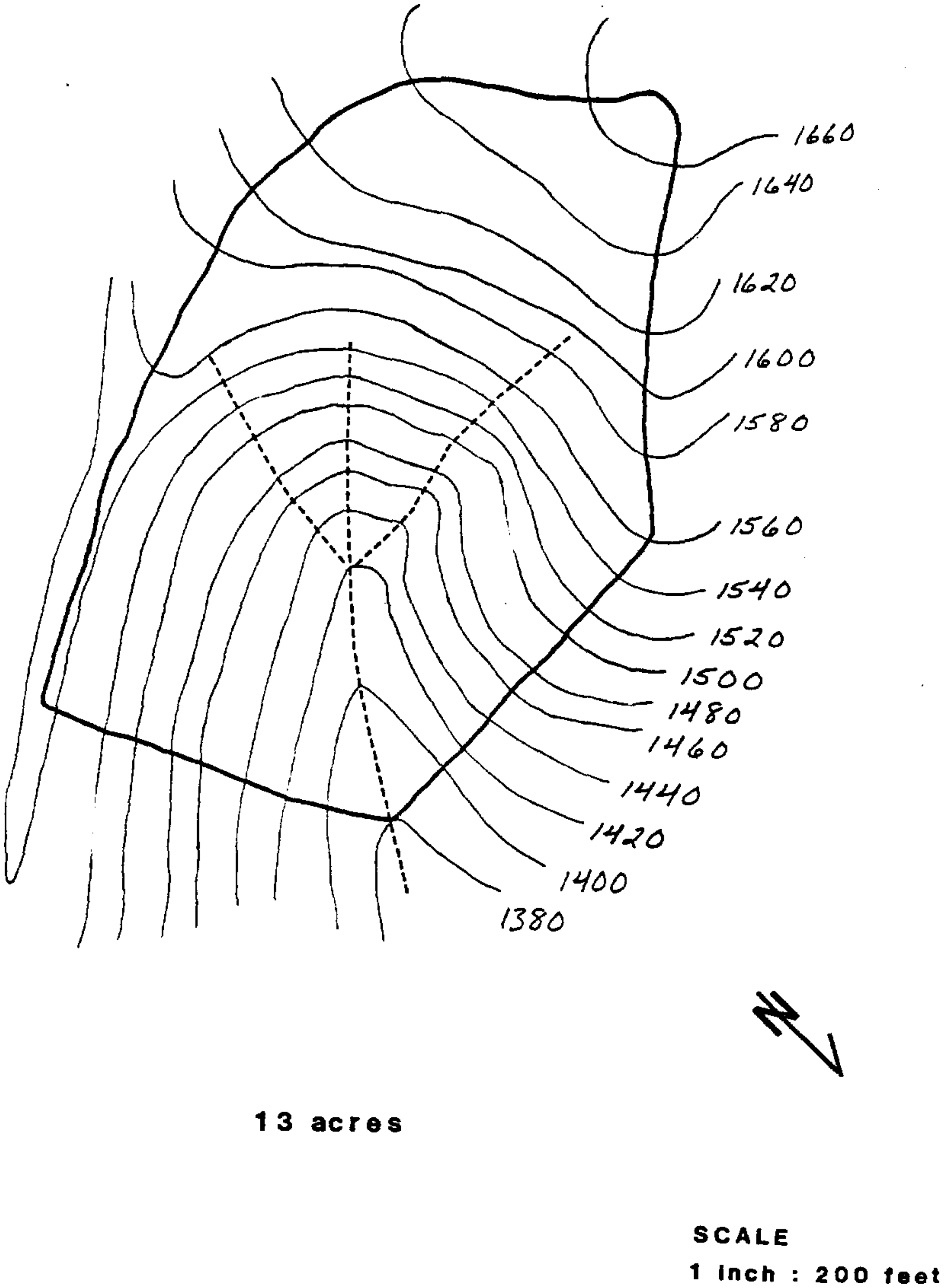
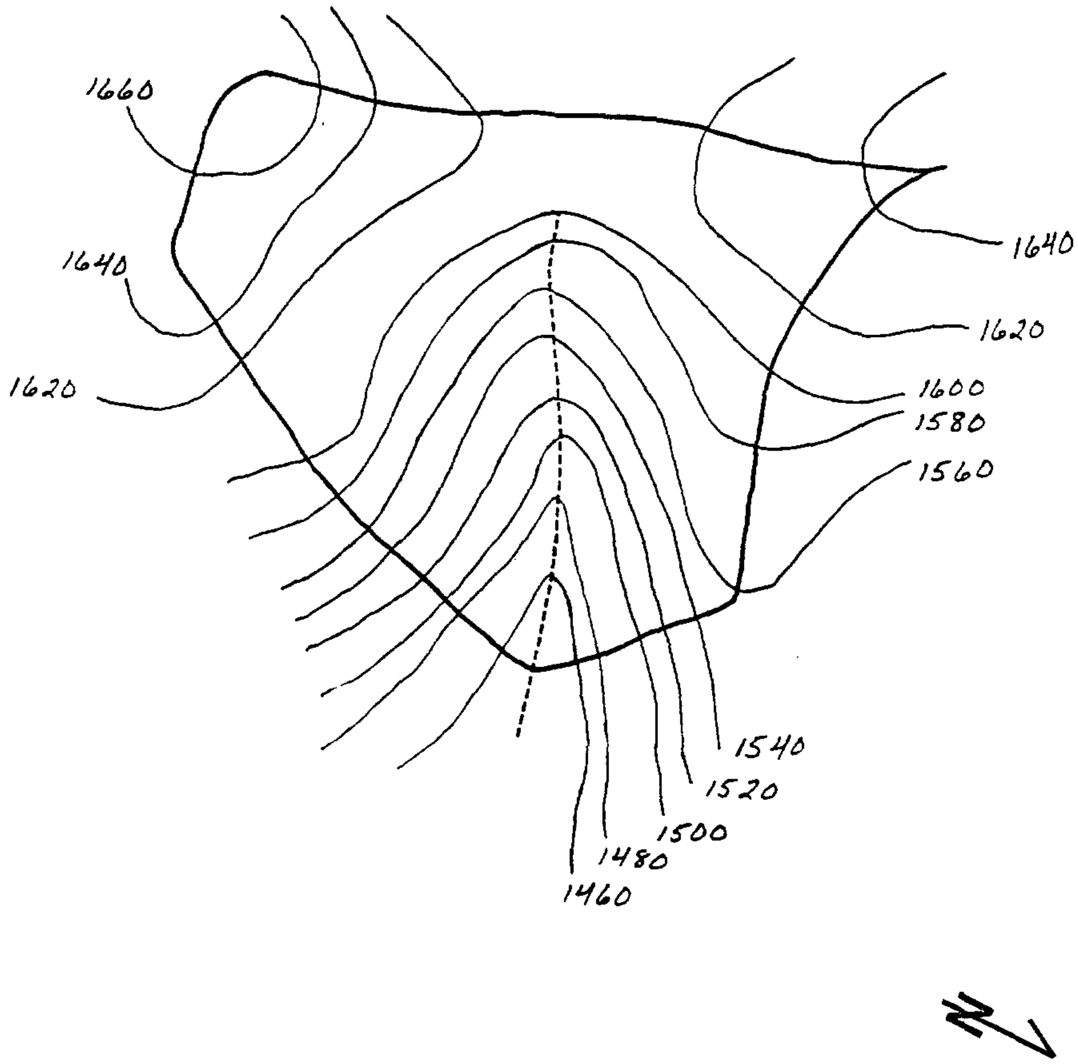


Figure 2. Topographic map of watershed 2 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 3



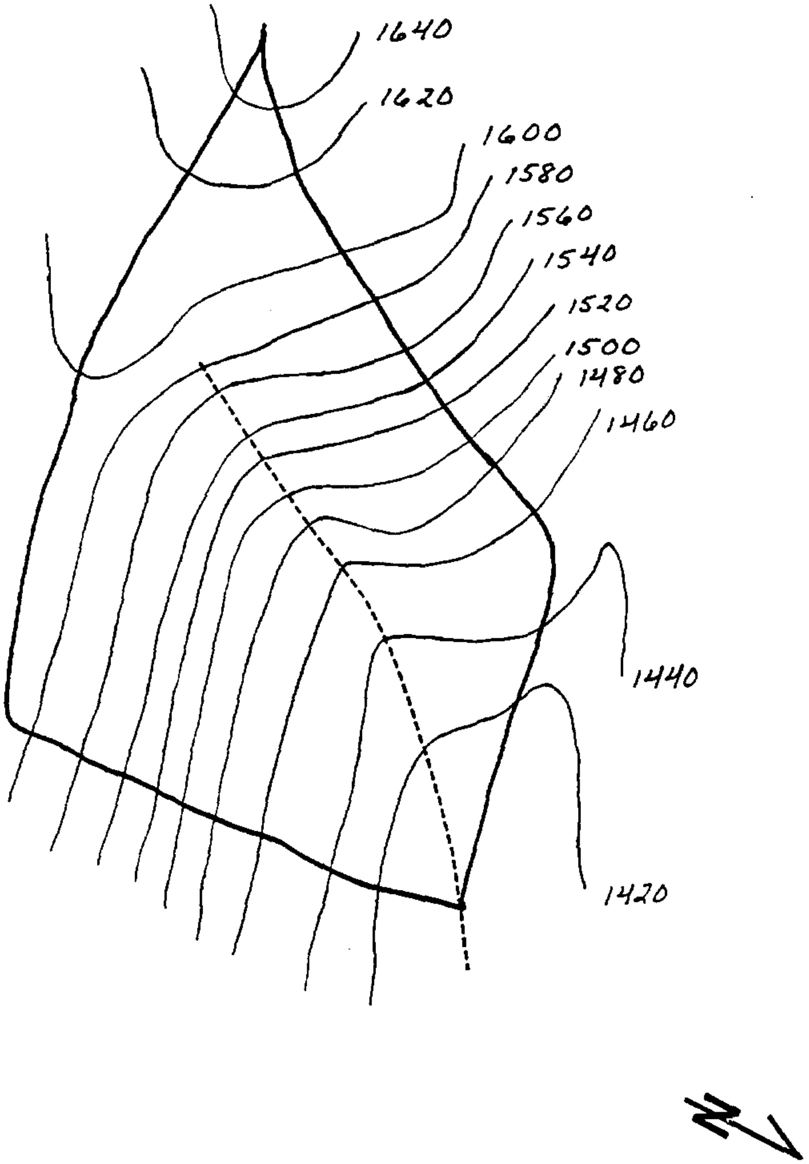
9.5 acres

SCALE
1 inch : 200 feet

Figure 3. Topographic map of watershed 3 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 4



9.5 acres

SCALE
1 inch : 200 feet

Figure 4. Topographic map of watershed 4 at the Annandale watershed study site.

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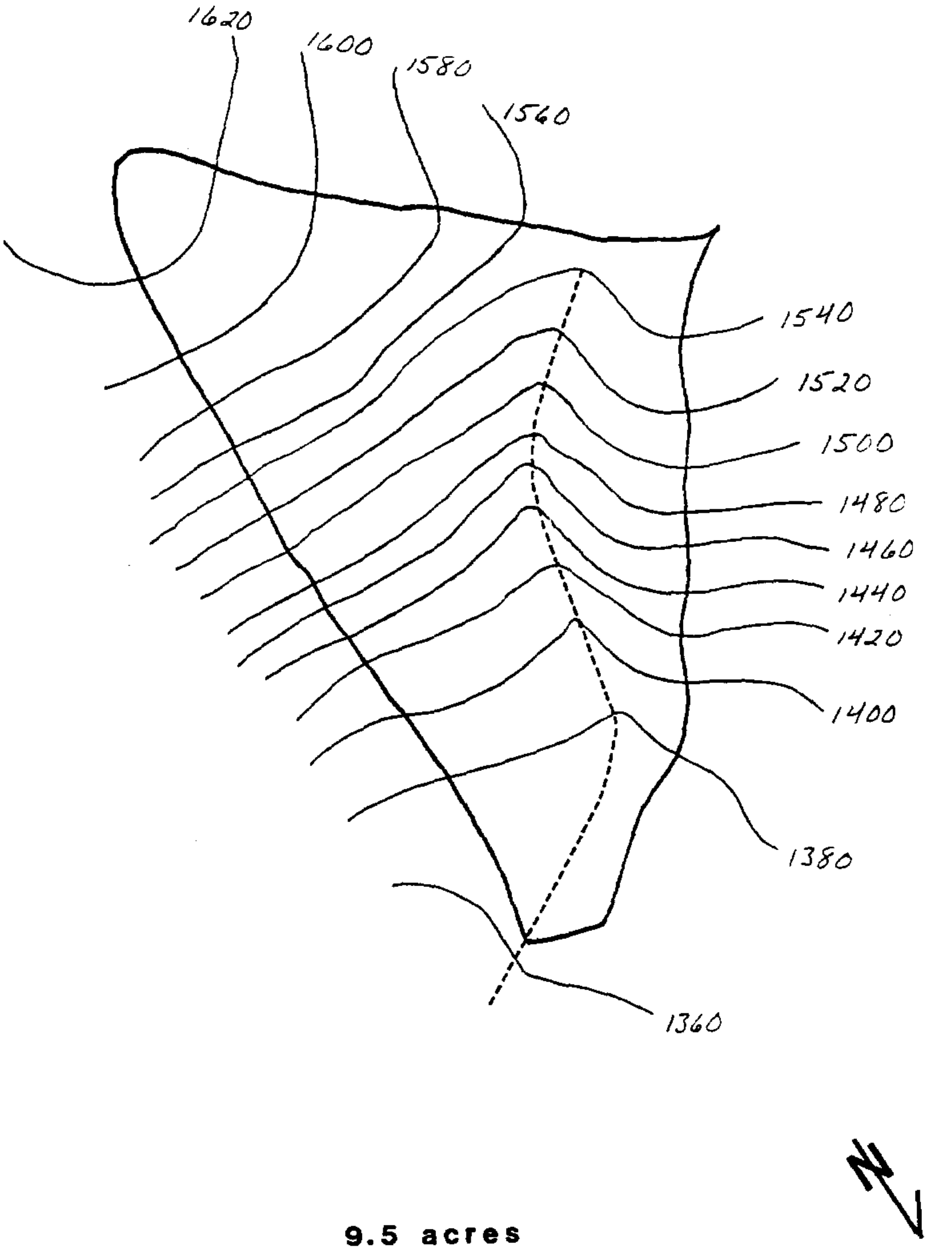
Watershed 5



SCALE
1 inch : 200 feet

Figure 5. Topographic map of watershed 5 at the Annandale watershed study site.

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Watershed 6

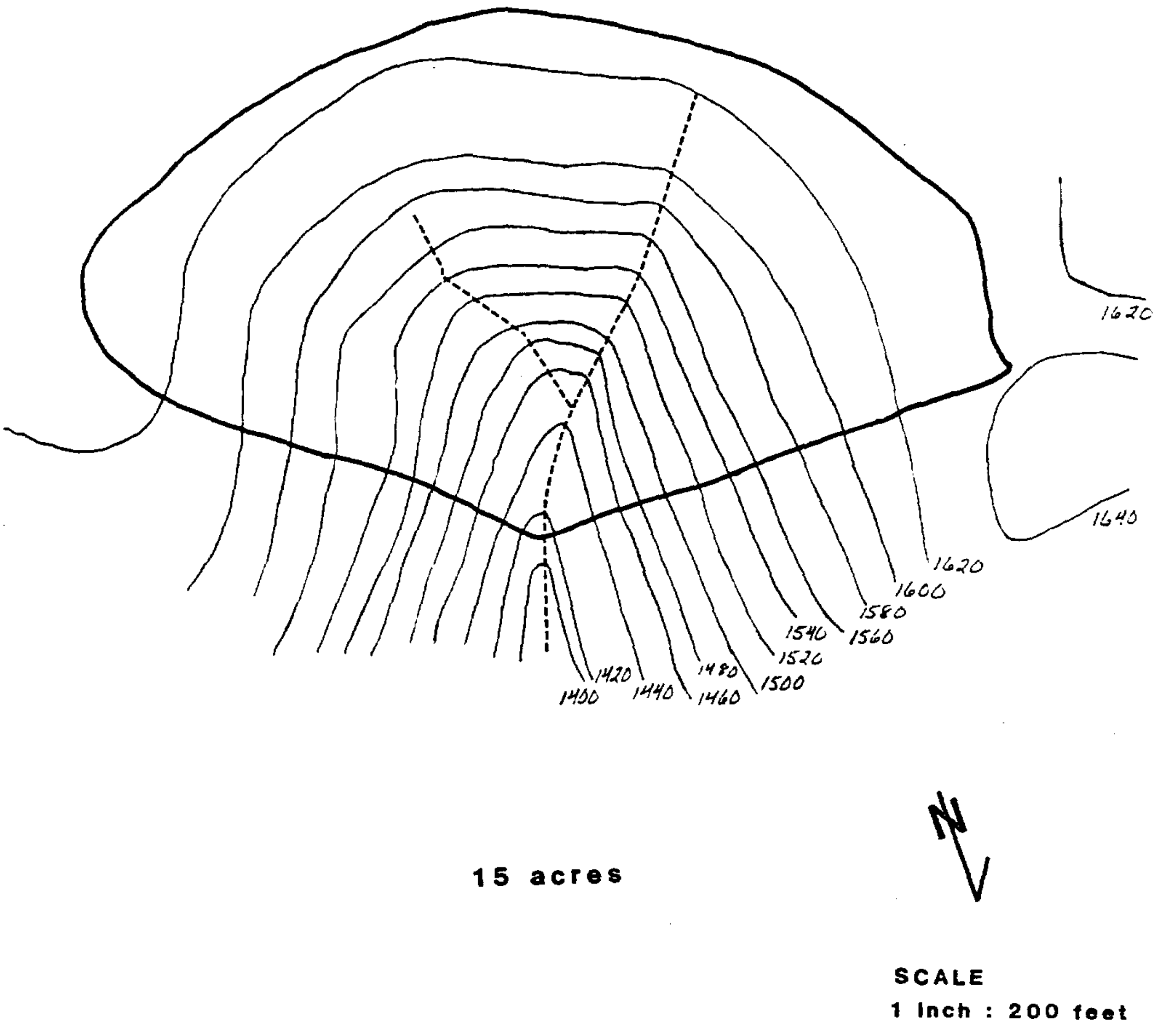
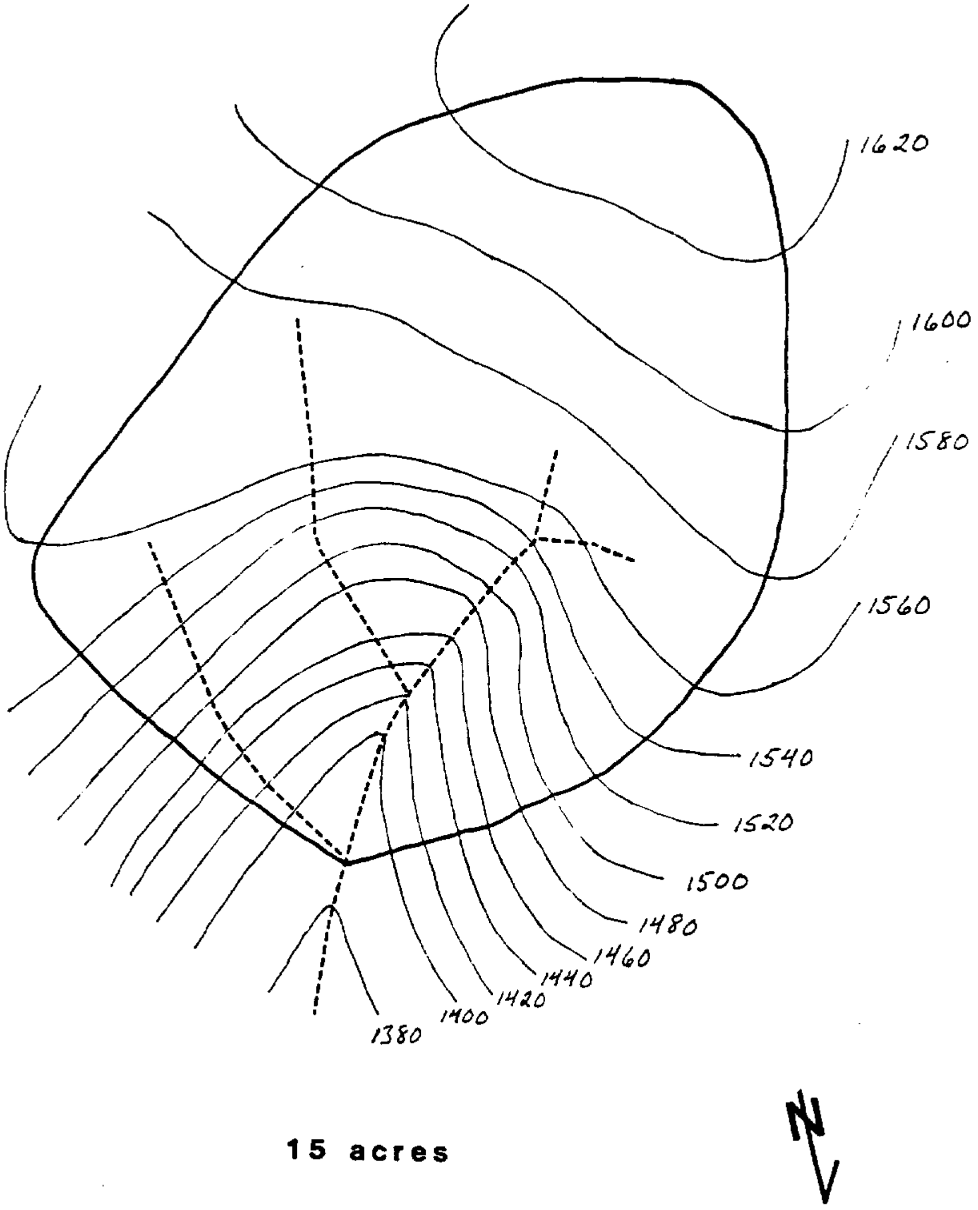


Figure 6. Topographic map of watershed 6 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 7

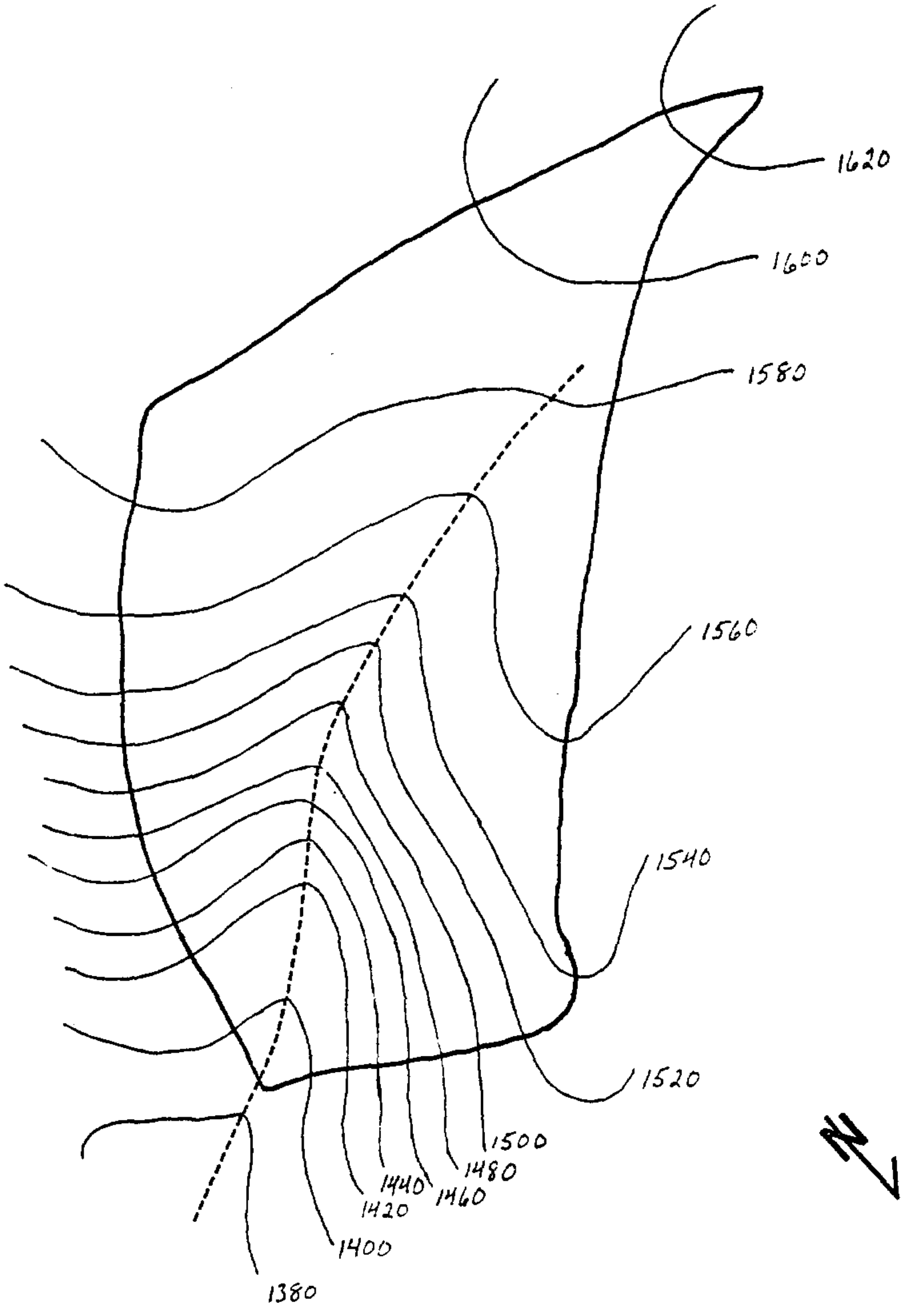


SCALE
1 inch : 200 feet

Figure 7. Topographic map of watershed 7 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 8



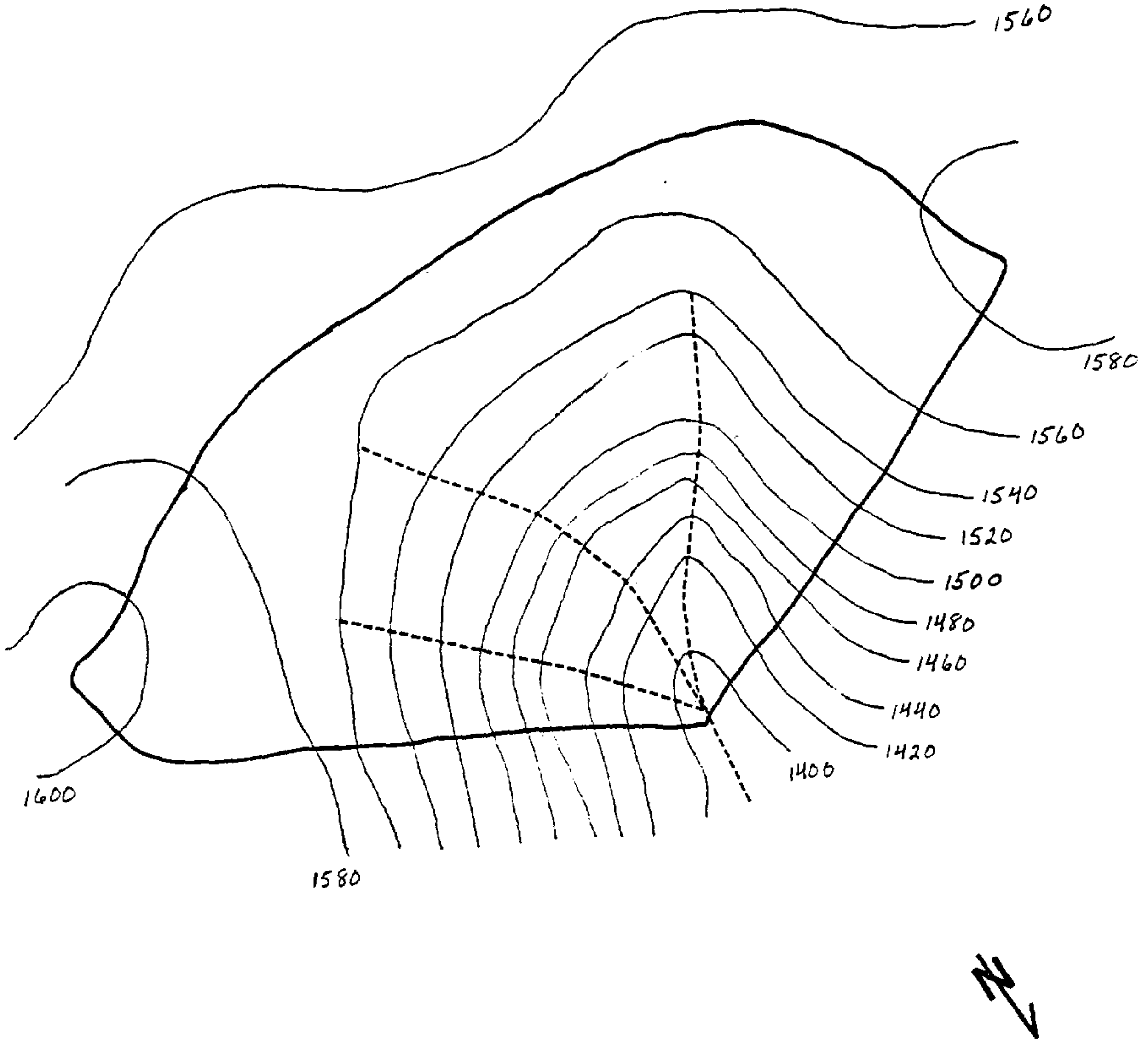
13 acres

SCALE
1 inch : 200 feet

Figure 8. Topographic map of watershed 8 at the Annandale watershed study site.

ANNANDALE RANCH

Watershed 9



15.5 acres

SCALE
1 inch : 200 feet

Figure 9. Topographic map of watershed 9 at the Annandale watershed study site.