LEAF DYNAMICS, STEMFLOW AND THROUGHFALL WATER AND NUTRIENT INPUTS IN A SUBTROPICAL SAVANNA PARKLAND, TEXAS

A Thesis

by

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AND NUTRIENT INPUTS IN A SUBTROPICAL

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ABSTRACT

Leaf Dynamics, Stemflow and Throughfall Water
and Nutrient Inputs in a Subtropical Savanna
Parkland, Texas (December 1991)
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Chair of Advisory Committee: Dr. Steven R. Archer

Species in mixed-shrub clusters exhibited different patterns of leaf initiation and abscission. Prosopis glandulosa had complete leaf loss leaf loss before January indicating that this species was a deciduous growth form. Diospyros texana, Celtis pallida, and Condalia Hookeri, maintained a percentage of their leaves in the canopy during January-February of the first year when temperatures did not fall below -3 °C, but had complete leaf loss during January of the second year when temperatures were more severe. The species exhibited a facultative evergreen growth form. Leaf loss by Zanthoxylum fagara was not influenced by temperatures, but appeared to be influenced by drought conditions. Zanthoxylum was strongly evergreen, and appeared to be uncoupled from influences of temperature and day length.

Zanthoxylum appears to play the largest role in the transfer of water, nutrients and litterfall because of the large contribution to number of plants and large total canopy area within shrub clusters. Prosopis accounted for a high proportion of cluster canopy area and contributed large quantities of litterfall, but its role in the transfer of nutrients in stemflow appears to be limited because of low relative leaching and low water flux. Celtis had the greatest leaching of nutrients, but water, nutrient and litterfall transfers were limited by relatively few plants and low total canopy area within shrub clusters. Condalia and

Diospyros had low leaching potential, and low total inputs of nutrients and litterfall because of low relative canopy area and plant numbers.

Annual nutrient inputs via throughfall were greatest for K, followed by Mg, P, N and Ca. Annual throughfall and stemflow inputs (both nutrients and water) differed among clusters as a result of differing shrub cluster size, total canopy area, and species composition. Throughfall generally made up 97% of the total input for all nutrients in shrub clusters, whereas stemflow input was generally <3% for all nutrients. Throughfall and stemflow water input was generally 77 and 16% of precipitation, respectively. Canopy interception loss varied among shrub clusters averaging 8% for the year. Implications of nutrient and water input on successional processes are discussed.

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CHAPTER I

INTRODUCTION

In terrestrial ecosystems, the soil receives nutrients via inputs from precipitation, atmospheric dry fallout (Galloway and Parker 1980), and nutrients from plant canopies via litterfall and leaching (Eaton et al. 1973). Quantification of these transfer processes has illustrated the importance of each input to the total cycle of nutrients between the plant and soil, and has aided in estimating recycling rates of certain nutrients, the annual plant uptake of nutrients, and turnover rates of nutrient pools (Parker 1983).

On many landscapes, it may be difficult to ascertain whether patterns of plant distribution and abundance are the cause or result of edaphic heterogeneity. The input of nutrients via throughfall (water passing through a plant canopy), stemflow (water passing through a plant canopy and running down the plant stem)(Parker 1983), and litterfall can lead to high nutrient flux to soils beneath plant canopies. The influence of trees and shrubs on soil properties has been well documented (e.g. Zinke 1962, Zinke and Crocker 1962, Tiedemann and Klemmedson 1973, Barth and Klemmedson 1978, Barth 1980, Virginia and Jarrel 1983, Tiedemann and Klemmedson 1986, and others). Although seldom quantified, the degree of enhancement of soil physical and chemical properties is undoubtedly a function of the length of time a tree or shrub species has inhabited a site. For example, in the Sonoran Desert, nitrogen (N) and organic carbon accumulated at the

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This thesis follows the style of the Journal of Range Management.

rate of 11.2 g/m^2 and 0.11 kg/m^2 per meter of height, respectively, with Prosopis juliflora (Barth and Klemmedson 1982). Luken and Fonda (1983) observed a four-fold increase in soil nitrogen associated with a 54 year Alnus rubra chronosequence. Extensive changes in soil physical and chemical characteristics have also been demonstrated during the course of shrub succession in North American hot deserts (Vasek and Lund 1980). Spatial variability in soil properties beneath tree and shrub canopies and soils in associated interstitial zones have been attributed to decomposition of plant litter and roots beneath the woody canopy (Zinke 1962, Garcia-Moya and McKell 1970, Barth 1980), removal of nutrients from interstitial zones (Tiedemann and Klemmedson 1973), chemical and physical action of stemflow (Gersper and Holowaychuck 1970), and a combination of these effects (Barth and Klemmedson 1982).

Nutrient input and transfers can vary among growth forms within an ecosystem. Evergreen growth forms tend to have leaves that are more resistant to leaching, small but continuous leaf losses, effective nutrient storage in older leaves, and the potential for year round nutrient uptake, thus allowing nutrient conservation on sites which they occupy (Thomas and Grigal 1976, Bryant et al. 1983, Gray and Schlesinger 1983). Conversely, deciduous growth forms generally have leaves less resistant to leaching, produce large pulses of litterfall, and have a dormant period with no carbon gain (Gray and Schlesinger 1983). The assessment of growth form differences (i.e. evergreen vs. deciduous) in patterns of nutrient input and return can be accomplished by monitoring leaf phenology and survivorship, litterfall patterns, leaching of nutrients, and nutrient return pathways, thus providing criteria for organizing plants into groups of functional similarity.

On sandy loam uplands in southern Texas, Prosopis glandulosa establishes in the herbaceous zones, adds vertical structure which attracts birds disseminating seed of other woody plants, and modifies the soils and microclimate to facilitate the ingress and establishment of other woody species (Archer et al. 1988). Over time, woody species numbers increase, forming clusters of shrubs. These shrub clusters are hypothesized to represent an intermediate stage in the conversion of relatively open grassland to subtropical thorn woodland (Archer et al. 1988). As clusters reach advanced stages of development, they can contain as many as 16 species of woody plants which appear to represent different growth forms. The association of these various woody growth forms poses questions regarding strategies of resource acquisition and utilization, mechanisms of coexistence and successional processes. Previous studies have shown that soil nutrient content beneath shrub clusters increases relative to herbaceous interstitial zones as shrub clusters develop over time (Loomis 1989). The seasonal contribution of nutrients, water, and litterfall by the various woody species comprising the cluster to the soil is unknown. In this study, the role of the major shrub species in the contribution of litterfall and nutrients/water via throughfall and stemflow were quantified.

The objectives of this study were to: 1) Quantify leaf phenology patterns of the major shrub species occupying shrub clusters in order to determine the extent to which shrubs could be classified into growth form categories of functional similarity (Chapter III); 2) Assess spatial and temporal variability in quantity of litterfall within clusters at advanced stages of development (Chapter III); 3) Quantify nutrient concentrations and yearly nutrient inputs of precipitation, throughfall and stemflow within shrub clusters

(Chapter IV); and 4) Quantify throughfall and stemflow water inputs and canopy interception loss within clusters at advanced stages of development (Chapter V).

CHAPTER II

STUDY AREA

Field research was conducted at the Texas Agricultural Experiment Station, La Copita Research Area (LCRA), 15 km from Alice, Texas (27° 40'N 98° 12' W) on the eastern portion of the Central Rio Grande Plains. Elevation at the site ranged from 75 to 90 m. Litterfall and plant phenology data were collected within a 5 hectare livestock exclosure established on a sandy loam upland in January 1984. The upland was surrounded on all sides by densely wooded drainages. Descriptions of the major woody species occupying these shrub clusters at advanced stages of development are given in Table 1. The herbaceous zones between clusters were dominated by Aristida spp., Paspalum setaceum, and Bouteloua rigidiseta (Loomis 1989). Soils on the site are of the Miguel and Papalote Series (fine loamy hyperthermic Aquic Paleustalfs, 1-3% slopes).

The climate of the LCRA is subtropical with hot summers and mild winters. Snowfall and extended cold periods are rare. Winter (late December to February) temperatures average 14 °C with an average daily minimum of 7 °C. Average summer (June through August) temperature is 28 °C with an average daily maximum temperature of 35 °C. The growing season ranges from 260 to 300 days with an average of 289 days (USDA 1979). First and last freezes usually occur in December and mid-February, respectively (USDA 1979).

Temperatures were below-average during the winter and above-average during the fall throughout the period of this study; spring and summer temperatures were fairly typical of the long-term average (Figure 1). Light freezing temperatures (0 to -1 °C) occurred during December 1987 (3 days), January

Table 1. Characteristics of shrubs comprising mixed-species clusters in a south Texas subtropical savanna parkland (based on qualitative descriptions in taxonomic guides). Species identified with a "*" were examined in this study.

Species	Growth Form	Leaf Texture	Bark Type	Canopy Architecture	Reference
Honey Mesquite* (<u>Prosopis glandulosa</u> Torr.)	Deciduous	Malacophyllous	Rough, Scaly	Tree or shrub; rounded crown	1,2
Lime pricklyash* (<u>Zanthoxylum fagara</u> L.)	Evergreen/ deciduous	Coriaceous	Smooth	Tree or shrub; rounded crown	1,3
Brasil* (<u>Condalia Hookeri</u> M.C. Johnst.)	Deciduous	Coriaceous	Smooth	Shrub or tree	1,3
Texas persimmon* (<u>Diospyros texana</u> Scheele)	Deciduous/ evergreen	Coriaceous	Smooth	Small tree or large shrub	1,3 1,3
Spiny hackberry* (<u>Celtis pallida</u> Torr.)	Deciduous	Malacophyllous	Smooth	Densely branched shrub	1
Agarito (<u>Berberis trifoliolata</u> Moric.)	Evergreen	Sclerophyllous	Scaly	Small shrub	1,2,3
Desert yaupon (<u>Schaefferia cunefolia</u> Gray)	Evergreen	Coriaceous	Smooth	Densely branch- ed rigid shrub	1

Table 1. continued.

Species	Growth Form	Leaf Texture	Bark Type	Canopy Architecture	Reference
Lotebush (Ziziphus obtusifolia Gray)	Evergreen	Malacophyllous	Smooth	Stiff, spiny much branched shrub	1
Texas colubrina (Colubrina texensis Gray)	Deciduous	Malacophyllous	Smooth	Small shrub; rounded crown	1

[1] 1 = Vines 1984
2 = Box 1981
3 = Correll and Johnston 1979

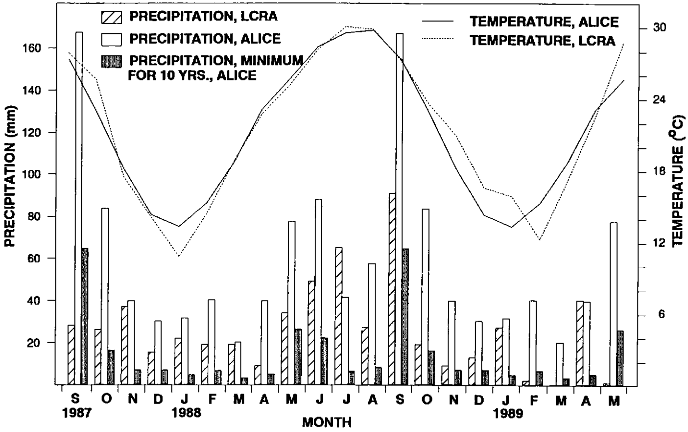


Figure 1. Mean monthly precipitation and temperature during the study period, and long-term means for monthly temperature, precipitation, and minimum precipitation recorded for 10-year periods for Alice, Texas (USDA, 1979).

1988 (3 days), February 1988 (2 days), November 30, 1988, December 20, 1988 (1 day), and January 5 and 6, 1989. Hard freezing temperatures ($\leq$-1 °C) occurred in January 1988 (2 consecutive days) and February 1989 (5 consecutive days).

Long-term average annual precipitation for this area is 716 mm. Seventy percent of the rainfall occurs between April and September. March is usually the driest month with an average rainfall of 20.3 mm (USDA 1979). Long-term average monthly rainfall, minimum precipitation in two years out of ten (i.e. the average minimum monthly precipitation for two years in a decade) for Alice, Texas, and observed precipitation for the LCRA are summarized in Figure 1. Rainfall during this study was below-average for most months and sometimes below the ten-year minimum.

CHAPTER III

LEAF DYNAMICS OF CO-EXISTING SHRUBS IN A SUBTROPICAL SAVANNA PARKLAND

Introduction

Patterns of leaf phenology and survivorship are indicative of plant strategies for resource allocation and the seasonal dynamics of energy flow, primary production and nutrient cycling (Nilsen et al. 1987). However, information regarding differences between woody species in leaf turnover is often scanty, conflicting and based on casual observations. Many generalizations regarding growth form strategies (evergreen vs. deciduous) are static oversimplifications. For example, some species characterized as deciduous maintain small populations of leaves during the unfavorable season and some species classified as evergreens may have complete leaf turnover 6-8 months after leaf initiation (Nilsen and Muller 1981, Westman 1981, Nilsen et al. 1987). Seasonal patterns of litterfall are illustrative of growth form differences in leaf phenology but do not reflect differences in leaf initiation and leaf longevity between species or growth forms. Leaf phenology is one criterion for organizing woody plants into groups of functional similarity, thus simplifying management and ecological modelling efforts (Nilsen et al. 1987)

Seasonal leaf dynamics have important implications for nutrient cycling and primary production. Decomposition of plant litter is a major component of the nutrient cycle. Litterfall can be defined as all plant structural components (leaves, twigs, branches, bark, fruits, flowers, etc.) which accumulate and decompose beneath the plant canopy (Vitousek 1984). The quantity and quality of litterfall determines the magnitude of nutrient flux. Litterfall input is correlated with seasonal patterns of plant phenology (Klinge 1978, Proctor 1983) and can be used to predict aboveground primary production (Bray and Gorham 1964, Klinge 1978, Lim 1978, Ogawa 1978, Proctor 1983).

Woody plant communities of the La Copita Research Area (LCRA) contain as many as 25 species of trees and shrubs which vary in phenology, photosynthetic habit, leaf structure, stature and abundance (Table 1). The seasonal progression of leaf initiation, longevity, and leaf drop for these species is unknown. The objectives of the study were to (1) Quantify leaf initiation and abscission of the key species noted in Table 1; (2) Assess spatial and temporal differences in quantity of litterfall within multi-species shrub clusters on sandy loam upland landscapes; (3) Compare and contrast patterns of leaf phenology with patterns of litterfall to determine species differences; and (4) Determine the extent to which shrub species might be grouped into categories of functional similarity based on these criteria.

Materials and Methods

Leaf Phenology

Seasonal patterns of leaf phenology were determined for Prosopis, Condalia, Zanthoxylum, Celtis and Diospyros. In August 1987 (for Prosopis and Zanthoxylum) and October 1987 (for the others), one leader on each of two plants of each species was tagged and the terminal portion was mapped. In January 1988, the number of leaders was increased to five. Maps denoted locations of leaves, visible buds, reproductive parts, thorns, and leaf scars. Stems were mapped every two to three months through May 1989. A relative leaf number (RLN) was calculated for each plant on each date by dividing the total number of leaves present by the maximum number of leaves observed on the leader during the year (Nilsen et al. 1987).

Litterfall

Three shrub clusters on a sandy loam upland meeting criteria for mature clusters (Archer et al. 1988) were selected for litterfall collection. Litterfall was collected in 50 x 50 x 8 cm frame traps. Edges of the wooden frames were sharpened to created a finite edge so litter would either fall into or out of the trap. Bottoms of the trays were lined with fiberglass mesh to allow drainage. Twelve traps were placed on the soil surface within each shrub cluster; four around the Prosopis glandulosa trunk in the center and eight midway between the center and canopy perimeter of the cluster (Figure 2). Canopies of shrubs within the cluster were elevated such that traps could be easily placed. Litterfall was collected at the end of each month beginning September 1987 through February 1989. Leaves from traps were sorted by species. Miscellaneous litterfall (stems, flowers, and fruits) was pooled across species. Litter was oven-dried at 60 °C and weighed.

Species density and individual plant height, canopy area, and basal diameter were determined in shrub clusters used for litterfall collection. Canopy area was estimated by measuring the horizontal canopy projection and calculating area based on appropriate shape (e.g. circle or ellipse).

Statistical Analyses

Leaf phenology. Analysis of variance was conducted on the RLN means (after arcsin of the square root transformations) using a general linear model (SAS 1987). Fischer's least significant difference (LSD) was used to separate means. Regression analysis was used to explore relationships between RLN and temperature, daylength, and rainfall.

Litterfall. Litterfall data was analyzed as a split-plot design to determine differences between species and

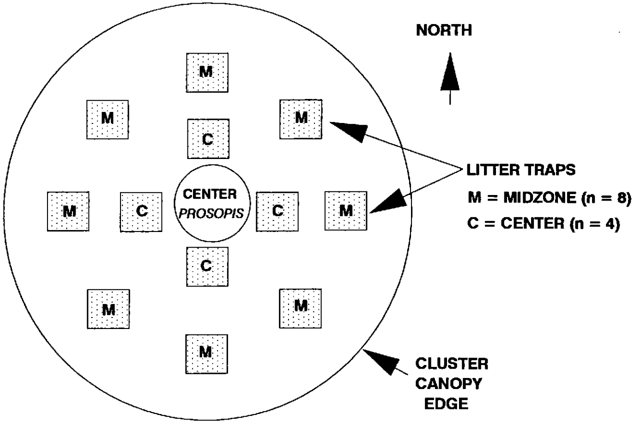


Figure 2. Generalized view of litter trap placement for litterfall collection in mixed-shrub clusters in a south Texas subtropical savanna parkland.

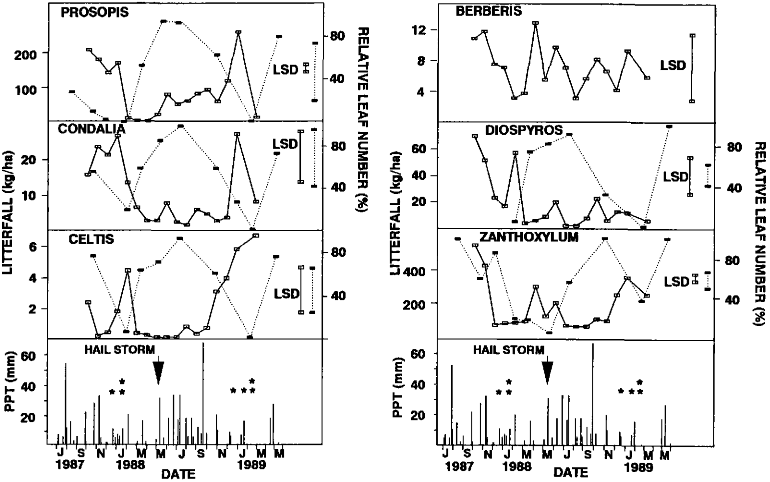
clusters. The main plot variables included species, replication (shrub assemblage) location of litter trap, and the species*location interaction. The sub plot variables were time (month of collection), and time*species interaction. The mean square error (MSE) calculated for the split plot model was used for mean separations (Fischer's LSD) to assess spatial and temporal variability at the shrub cluster level. In a separate analysis of variance model, the litterfall contribution of plant species was assessed using Fischer's LSD and species MSE. Regression models were used to explore relationships between litterfall biomass and temporal variables such as daylength, rainfall patterns, and temperature. For leaf phenology and litterfall analyses, differences are considered significant at $P \leq 0.05$.

Results

Leaf Dynamics: Individual Species

Leaf phenology. Seasonal patterns of leaf initiation and growth were similar for Prosopis glandulosa, Diospyros texana, Celtis pallida and Condalia Hookeri. Leaves were initiated from dormant buds in early to mid-March of both years. Each species had a full complement of leaves by mid-July (Figure 3). Prosopis leaf abscission began in August with complete leaf loss by January of both years (Figure 3). Diospyros, Celtis and Condalia retained a proportion of their leaves during January of the first year when freezing temperatures did not fall below -2 °C (for 2 days); however, during the second year, freezing temperature were more severe (-6 °C for 5 days), and complete leaf abscission occurred (Figure 3). Therefore, the extent to which these species retain leaves during this period, thus appears to be influenced by low temperature extremes. Initiation of flowering was similar for Prosopis, Diospyros, Celtis and

Figure 3. Mean monthly foliar litterfall (kg/ha; solid line) and relative leaf numbers (%; dotted line) for the dominant species in shrub clusters. Note differences in litterfall scale between panels. Single asterisks (*) indicate occurrence of light freezing temperatures (0 - 2 °C) and double asterisks indicate the occurrence of hard freezing temperatures (-3 to -6 °C). Means, standard errors, and LSD rankings are summarized in Appendix Tables 1-7.


PROSOPIS
CONDALIA
CELTIS
BERBERIS
DIOSPYROS
ZANTHOXYLUM
LSD
LITTERFALL (kg/ha)
RELATIVE LEAF NUMBER (%)
PPT (mm)
HAIL STORM
J S N J M M J S N J M M
1987 1988 1989
DATE

Condalia, with each having producing inflorescences during May and June. Prosopis and Diospyros did not produce any fruit on the plants sampled. Low rainfall in May and June may have inhibited seed set by these species. Condalia had continuous flowering and fruit production during June through September and did not appear to be inhibited by moisture conditions. Celtis had fruit maturation in July.

Zanthoxylum fagara differed from other species in its pattern of leaf initiation and loss. Leaf initiation began in late-May and early-June during the first year, almost 60 days after the other species began leaf initiation (Figure 3). The onset of this delayed growth coincided with several rainfall events in May and June 1988. Leaf abscission occurred typically after approximately 30 or more consecutive days since the last rainfall event of >13 mm. Low relative leaf numbers during March and May 1988 occurred during drought periods in excess of 45 days. Zanthoxylum maintained foliage in its canopy throughout both years regardless of temperature (Figure 3). Floral buds originated in October and flowering subsequently occurred during May and June. However, no fruit were produced on any of the plants sampled, perhaps because of low rainfall during May and June. A summary of the phenological characteristics of each species is given in Table 2.

Biomass input. Mean total litterfall for shrubs was greatest for Zanthoxylum, followed by Prosopis, Diospyros, Condalia, Berberis, and Celtis (Table 3). Mean total foliar litterfall from Zanthoxylum and Prosopis was an order of magnitude greater than that of other species reflecting the large canopy area of these species in the clusters. Zanthoxylum contributed a significantly more to annual litterfall biomass than all other species (Figure 3). Annual litterfall from Prosopis was also high except during its

Table 2. A summary of the phenological and growth form characteristics of the major shrub species comprising shrub clusters in southern Texas that were identified in this study.

Characteristic	Species: Celtis	Condalia	Diospyros	Prosopis	Zanthoxylum
Leaf initiation	March	March	March	March	May/June[1]
Canopy Development					
Maximum	July	July	July	July	July/Aug.[1]
Minimum	Jan./Feb.[2]	Jan./Feb.[2]	Jan./Feb.[2]	Jan.	March/June[1]
Growth Form	Facultative Evergreen	Facultative Evergreen	Facultative Evergreen	Deciduous	Evergreen
Initiation of:					
Inflorescence	May	May/June	May	May	May/June
Fruit	July/August	July-Sept	---[3]	---[3]	---[3]
Variable explaining most variation in RLN[5]	Daylength	Daylength	Daylength	Daylength/ Temperature	CDSLR[4]

[1] Variable, depending on rainfall.
[2] Depending on severity of the freeze.
[3] No fruit were formed.
[4] CDSLR = consecutive days since the last rain >13 mm.
[5] RLN = Relative leaf numbers.

Table 3. Means and standard errors (SE) for numbers of plants per cluster, height (m), absolute canopy area (m^2/cluster), relative canopy area (%), and annual foliar litterfall (kg/ha) for selected species comprising mixed-shrub clusters (n=3).

Species	Number of Plants/ Cluster	SE	Height (m)	SE	Absolute Canopy Area (m^2)	SE	Relative Canopy Area (%)	Annual Litter Input (kg/ha)	SE
<u>Berberis trifoliolata</u>	1.5	0.5	1.1	0.2	1.5	0.9	1.8	81	60
<u>Celtis pallida</u>	2.7	0.7	1.5	0.4	2.6	1.9	3.0	20	7
<u>Condalia Hookeri</u>	6.0	4.0	1.3	0.1	4.5	4.0	5.2	114	42
<u>Diospyros texana</u>	3.3	0.9	1.3	0.3	1.6	0.9	1.9	218	131
<u>Prosopis glandulosa</u>	1.0	0.0	5.3	0.7	51.3	3.8	59.0	1010	153
<u>Zanthoxylum fagara</u>	22.7	1.9	1.6	0.1	25.4	3.5	29.2	2116	173

dormant period (January - March). Other species contributed little to total annual litterfall biomass.

Pooled across species, foliar litterfall and total litterfall (leaf litter + other plant parts such as branches, twigs, reproductive parts, etc.) followed a seasonal pattern with peaks in September - October of 1987 and December of 1988 (Figure 4). Leaf litter made up the largest proportion of total litterfall during most months. May 1988 was the exception, when a storm delivered golf ball size hail, resulting in a large pulse of litterfall, particularly of twigs and branches.

Peak litterfall for Prosopis occurred in the fall and early winter months (September - December) of both years (Figure 3). Large peaks occurred in December of both years before freezing temperatures occurred. Condalia peak litterfall occurred during December for both years (Figure 3). Litterfall was low during the late winter and growing season months (February through August) and statistically comparable. The pattern of Condalia litterfall resembled closely that of Prosopis.

Litterfall for Diospyros was high during September, October, and December during 1987 compared to these same months in 1988 (Figure 3). This may reflect dry conditions following a very wet spring and early summer (April through June) in 1987, when Diospyros produced a greater amount of leaf biomass during the wet growing season. It appeared that less biomass was produced in 1988. This may have been caused by frost damage to the buds, or a combination of low rainfall and frost. Mean separations on the monthly data showed no significant differences in litterfall between February 1988 and February 1989, but if the data are relativized to reflect biomass differences in each year, the pattern of litterfall is approximately the same with peak litterfall in September.

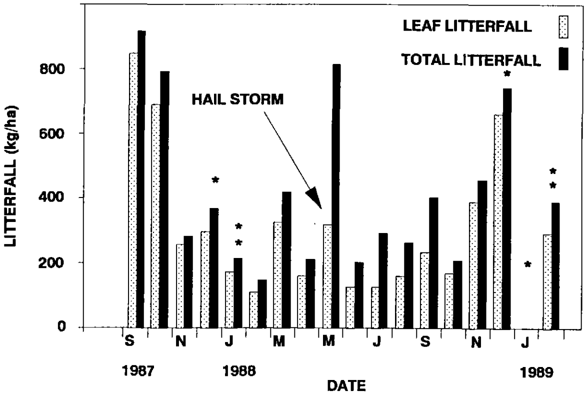


Figure 4. Mean monthly leaf and total (leaves, twigs, reproductive parts, branches, etc.) litterfall (kg/ha) within mixed shrub clusters. Single asterisks (*) indicate occurrence of light freezing temperatures (0 to -2 °C) and double asterisks indicate occurrence of hard freezing temperatures (below -3 to -6°C). Litterfall for February 1989 includes January 1989.

Peak litterfall for Celtis occurred in January of both years, corresponding to hard freezing conditions during these months. Almost no litterfall occurred between May and August.

In contrast to the other species, no consistent seasonal pattern of litterfall input was apparent for Zanthoxylum or Berberis (Figure 3). For Berberis, no significant differences were detected between months, and mean litterfall was 3-10 kg/ha during each month. No peaks in litterfall biomass occurred during months of freezing temperatures. For Zanthoxylum, patterns of litterfall were analogous to those of RLN in that the months with greatest litterfall inputs were generally preceded by extended dry periods (> 30 days). Zanthoxylum appeared to be insensitive to light freezing temperatures. Freezes that occurred during January and February 1988 did not influence litterfall amounts and RLN remained approximately the same (Figure 3).

Regression relationships. Regressions of mean monthly temperature, daylength (photoperiod) and the number of consecutive days since the last rainfall >13 mm on leaf numbers indicated that daylength and temperature explained 43 to 78% of the variance in leaf numbers (Table 4). Multiple regressions using these same variables did not improve the coefficient of determination because of the high correlation between temperature and daylength ($r = 0.86$). Rainfall did not account for a significant proportion of the variation in leaf numbers of these species.

Conversely, Zanthoxylum was poorly correlated with temperature and daylength (Table 4). The number of consecutive days since the last rainfall event >13 mm was highly correlated and explained 76% of the variance in leaf numbers. Zanthoxylum appears to be sensitive to drought conditions.

In contrast to RLN, regression analyses using mean

Table 4. Correlation coefficients (r), coefficients of determination (R^2), and significance levels for simple regression of relative leaf number and litterfall with daylength, mean monthly temperature, and consecutive days without rainfall events >13 mm for species in mixed shrub clusters.

	Relative Leaf Numbers			Litterfall		
Species	r	R^2	Pr.>F	r	R^2	Pr.>F
Variable: Daylength						
Berberis	-	-		0.07	0.00	ns
Celtis	0.74	0.54	**	-0.64	0.41	*
Condalia	0.73	0.53	**	-0.59	0.34	*
Diospyros	0.88	0.78	**	-0.20	0.04	ns
Prosopis	0.75	0.57	**	-0.25	0.06	ns
Zanthoxylum	0.05	0.00	ns	-0.16	0.02	ns
Variable: Mean monthly temperature						
Berberis	-	-		0.20	0.04	ns
Celtis	0.80	0.64	**	-0.55	0.30	*
Condalia	0.71	0.51	**	-0.38	0.14	ns
Diospyros	0.79	0.63	**	-0.08	0.00	ns
Prosopis	0.65	0.43	**	0.14	0.02	ns
Zanthoxylum	0.39	0.16	*	0.07	0.00	ns
Variable: Consecutive days without rain > 13 mm						
Berberis	-	-		0.42	0.17	ns
Celtis	-0.24	0.06	ns	0.34	0.11	ns
Condalia	-0.01	0.00	ns	0.29	0.08	ns
Diospyros	-0.11	0.01	ns	0.15	0.02	ns
Prosopis	0.01	0.00	ns	0.33	0.11	ns
Zanthoxylum	-0.86	0.76	**	0.56	0.31	*

[1] Pr.> F refers to significance of F test for regression model:
** = 0.0001
* = 0.01
ns = not significant (> 0.05)

monthly temperature, daylength, and consecutive days without rain as independent variables to predict litterfall biomass generally had low and non-significant coefficients of determination for all species (Table 4). This may be an artifact of the numerical analysis of absolute versus relativized data and the annual variability in absolute data. It may also reflect the role of stochastic events such as hail in May 1988 and frost influencing litterfall. For Zanthoxylum, consecutive days without substantial rainfall explained a significant amount of the variance in seasonal litterfall (31%) (Table 4). As with RLN, correlations with temperature and daylength were low.

Litterfall Dynamics: Shrub Clusters

In order to determine total inputs of litterfall biomass on the landscape, the individual species must be combined. Statistical analyses using spatial and temporal variables to define variability in foliar litterfall for shrub clusters indicated that individual species, month of collection, and the interaction of these were significant ($P<0.05$) (Table 5). Total litterfall input was statistically comparable between shrub clusters, and seasonal deposition of foliar litterfall within clusters was not influenced by trap location. This presumably reflects the large absolute canopy coverage of Prosopis and Zanthoxylum within the cluster (Table 3). However, spatial heterogeneity of litter deposition within clusters was indicated by a significant interaction between individual species and location of collectors. For Condalia, Celtis, Diospyros, and Berberis, the species-location interaction was significant indicating that plants of these species were not dispersed uniformly throughout the cluster. In contrast, no significant differences in mean litterfall were found at the different trap locations within the cluster for Prosopis and Zanthoxylum.

Table 5. Significance tests for split-plot model used to determine sources of variation in litterfall (kg/ha) collected from shrub clusters (n=3) in a south Texas subtropical savanna parkland. The species, location within the cluster and the shrub cluster variables were tested using the mean square error (MSE) for the Type III sums of squares for the species*location interaction. All other variables and interactions were tested using the full model mean square error.

SOURCE	F Value	Pr>F
Model	28.27	0.0000
Species	406.41	0.0000
Location	2.16	0.0142
Shrub cluster	0.36	0.6975
Species x location	2.82	0.0001
Sampling date	40.50	0.0000
Species x sampling date	24.60	0.0000
Test using MSE for Species x sampling date as error term		
Species	144.18	0.0001
Location	0.76	0.6732

Discussion

Factors Influencing Leaf Dynamics

Factors influencing annual litterfall across a landscape may be chronic, random or predictable (Fyles et al. 1986). Chronic factors include insect and disease activity, random factors are those associated with weather, and predictable factors are seasonal phenomena associated with plant phenology. Each of these factors was apparent for individual species and shrub clusters. Field observations suggest that the low litterfall input by Celtis in April-August 1987 may have been associated with consumption of leaves by the snout butterfly larvae [Libytheana bachmanii var. larvata (Stecker)] which use Celtis as a host. Celtis plants used for RLN escaped herbivory, but other Celtis plants were almost completely defoliated by these larvae. Outbreaks of these larvae and their defoliation of Celtis plants has been observed on several occasions in Southern Texas and may be triggered by drought conditions and the demise of parasites (Dr. Tim Frielander, Texas A&M Univ., pers. comm.).

Random factors. Random factors such as drought, freezing temperatures, and hail storms also influenced litterfall. The pronounced peak in total litterfall in early May 1988 which occurred after a hail storm further illustrates the importance of episodic and catastrophic events on litterfall dynamics (Figure 4).

Drought was a major factor influencing leaf loss and initiation by Zanthoxylum. Many tropical and subtropical evergreens, Eucalyptus spp. and Citrus spp. (Zanthoxylum is in the Citrus family), exhibit drought induced leaf loss. Some of these species have greatest leaf loss when soil moisture is replenished, and new leaves are initiated (Kramer and Kowzloski 1979). Leaf initiation and abscision by Zanthoxylum appeared to be strongly coupled to rainfall and independent of photoperiod and temperature. During March through May 1988 when the other species had begun leaf initiation, Zanthoxylum RLN's were at their lowest point and a peak in litterfall occurred. Rainfall during March (19 mm), April (9 mm), and May (34 mm of which 30 occurred in the latter half of the month) was low (Figure 1 and 3). Following a series of rainfall events in late May and June 1988, RLN rose dramatically and litterfall was minimal. Peak Zanthoxylum RLN was thus achieved substantially later in the year than the other species. Zanthoxylum has an extensive lateral root system in the upper 50 cm of the soil profile (Flinn 1986) and predawn xylem water potentials have been observed to be 3.7 to 4.8 MPa lower than that of Prosopis, Condalia, and Celtis. It appears that Zanthoxylum is shallow rooted and coupled closely to near surface moisture conditions. The peaks in litterfall in September 1987 by the other species may have resulted from the hot, dry period during the preceding month. Leaf abscission after hot,dry periods may be caused by withering and death of leaves, or by hormonal changes brought about by water deficits which lead to true leaf abscission (Kramer and Kowzloski 1979).

The influence of sub-freezing temperatures was also apparent for litterfall in mixed-shrub clusters. Diospyros, Condalia and Celtis maintained a proportion of their leaves during January and February of the first year when temperatures did not fall below -3 °C; however, during this same period in the following year, temperatures were more severe and these species exhibited total leaf loss and litterfall peaks.

Predictable Factors. Predictable seasonal events such as phenological patterns for individual species were important in influencing leaf initiation and loss. Plant phenology has both genetically and environmentally regulated components.

Dormancy in trees may be induced by photoperiods, temperature, drought or a combination of these factors (Kramer and Kozlowski 1979). In addition, photoperiodic growth response, time of initiation of dormancy, and chilling requirements of dormant buds can vary between species and populations. For eastern redbud (Cercis canadensis), chilling requirements for breaking bud dormancy increased with latitude, with southernmost populations showing no dormancy or chilling requirements (Doselman and Flint 1982).

Field descriptions of leaf initiation and litterfall on this subtropical site indicated species differences with regard to seasonal and stochastic environmental influences. With the exception of Zanthoxylum and Berberis, leaf initiation of shrubs typically occurred during mid- to late-March during both years of observation, suggesting that by this time air and soil temperatures and photoperiod had exceeded certain threshold values required for bud activation and development (e.g. Van Rooyen et al. 1986). Prosopis, Diospyros, Condalia, and Celtis exhibited rapid leaf production during March through May even though rainfall prior to and during this period was low and below average in both years (Figures 1 and 3). The positive correlation between RLN and daylength and temperature variables (with R^2 values ranging from 43 to 78%) and low correlations with rainfall (R^2 < 6%; Table 4) provide crude indications of the relative importance of these variables. Evidence for Prosopis suggests that the relationship between seasonality of leaf initiation, temperature, and photoperiod is genetically fixed. In common garden experiments, McMillan and Peacock (1964) observed that southern populations of Prosopis exhibited earlier bud activation than northern populations, and suggested that this conferred an advantage at low latitudes where temperatures are more favorable earlier in the year.

Functional Groupings

Prosopis, Diospyros, Condalia, and Celtis generally exhibited similar patterns of leaf initiation and litterfall (Figure 3). However, because Diospyros, Condalia and Celtis maintained a portion of their leaves throughout January and February of the first year when frosts were less frequent and less severe than those in the second year, these species could be classified as tardily deciduous or facultative evergreens (Table 2). The extent of the physiological activity of their foliage during the fall and winter months is unknown. In years when freezing temperatures do not occur (26 out of the last 80 years; Alice, TX historical weather data), these species may conceivably retain substantial amounts of foliage. Prosopis appears to be the only truly deciduous species, exhibiting complete leaf loss and apparent plant dormancy before the onset of freezing temperatures (Table 2).

Conversely, Zanthoxylum behaved as a true evergreen, maintaining leaves in its canopy year round (Table 2). Although data on RLN are not available for Berberis, field observations would indicate that it too was strongly evergreen. Patterns of leaf initiation and litterfall for Zanthoxylum were strikingly different from the other species (Figure 3). Freezing temperatures had some effect on leaf loss, but did not cause complete defoliation during either year. The RLN for Zanthoxylum was relatively stable during months prior to and during freezing temperatures in 1987 (January and March = 16 %). Although RLN was low, this may reflect the influence of low rainfall rather than frost because it continued to drop to 3% in May as dry conditions prevailed and temperatures increased. Zanthoxylum is not, however, cold tolerant. During severe freezes such as those of 1990 (-7 to -13 ^{o}C for 5 days), entire canopies died back to ground level (pers. observations, Lonard and Judd 1985).

Generalizations on the adaptive significance of evergreenness imply that leaf longevity increases plant nutrient use efficiency (Mooney 1972, Orians and Solbrig 1977, Chapin 1980). The longevity of individual leaves of Zanthoxylum during the course of this study would appear to be short because of the extreme drought conditions that prevailed. During years of higher rainfall, the characteristic of rainfall-induced leaf initiation would still occur and leaf longevity would increase. This research was also conducted at the northern-most (coldest) and driest portion of the distribution range for Zanthoxylum (Elias 1980). This species is found mostly in areas that receive more precipitation and where drought is less frequent and less severe.

Prosopis canopies dominate the overstory in shrub clusters. During January through February when Prosopis canopy is devoid of leaves, Zanthoxylum, and to a lesser extent the facultative evergreens, may benefit from increased light availability. These species may experience significant carbon gain when temperatures are suitable for photosynthesis and water is not limiting.

Shrub Cluster Influences.

Litterfall is influenced by spatial and temporal factors (Lowman 1988). Patterns of leaf phenology and litterfall of the individual species described in this study are not detected readily the within shrub clusters because of spatial variability in the species comprising the shrub clusters on the sandy loam upland. Therefore, the magnitude and pattern of litterfall will be skewed by the species or growth form with the greatest canopy area and/or plant numbers. Prosopis had the greatest canopy area followed by Zanthoxylum (Table 3), and the phenological patterns of these two species dictated the pattern of litterfall in shrub clusters on the sandy loam upland landscape.

Annual total litterfall input per cluster was 4660, 4680, 4900 kg/ha (mean $\pm$ SE = 4750$\pm$77 kg/ha), and annual foliar litterfall per cluster was 3780, 3320, 3570 (mean $\pm$ SE = 3560$\pm$132 kg/ha). Meentemeyer et al. (1982) developed equations to predict foliar and total litterfall (kg/ha/yr) amounts based on annual evapotranspiration (AET):

Total leaf litterfall = 5.805(AET mm/yr)-785.5 (3.1)

Total litterfall = 10.070(AET mm/yr)-1839.0 (3.2)

Using their equations and evapotranspiration values for shrub clusters at the LCRA for average and below average rainfall years (from Weltz 1987), total litterfall was predicted to be 6980 kg/ha/yr for total and 4300 kg/ha/yr for foliar litterfall during an average year (AET=876 mm/yr). For a below normal year (AET=543 mm/yr), total litterfall was predicted to be 3630 kg/ha/yr and foliar litterfall was 2370 kg/ha/yr. The values for total and foliar litterfall reported for this study fall within the range predicted by this equation.

Total litterfall values for this area were higher than those reported for other savannas and shrublands (Table 6). Litterfall for a Sahelian Acacia senegal and Balanites aegyptiana savanna (trees only) with rainfall amounts comparable to those in southern Texas was 1200 and 2000 kg/ha/yr respectively (Bernhard Reversat 1982). Litterfall production by Acacia senegal was comparable to that of Prosopis, but Balanites aegyptiana was higher. Litterfall for Acacia albida was higher than that of Prosopis. Litterfall in a pure stand of Ceanothus megacarpus in California chaparral where rainfall was comparable to the LCRA was much higher than values reported here, but coastal sage scrub in the same area and composed of several shrub species produced much less.

Table 6. Foliar and total litterfall in relation to mean annual precipitation (PPT mm) and average annual temperature (TEMP °C), for selected ecosystems. These data represent values for litterfall from trees and shrubs only.

Species/System	PPT (mm)	TEMP (°C)	Foliar Litterfall (kg/ha)	Total Litterfall (kg/ha)	Reference
<u>Acacia</u> <u>senegal</u> Sahelian savanna-Africa (no understory)	300	36.5	1200	-[1]	Bernhard-Reversat (1982)
<u>Balanites</u> <u>aegyptiana</u> Sahelian savanna-Africa (no understory)	300	36.5	2000	-	Bernhard-Reversat (1982)
<u>Acacia</u> <u>albida</u> Zimbabwe savanna-Africa (includes understory)	200	30	1500	-	Dunham (1985)
Chaparral California	540	22	7300	8000	Gray (1983)
Coastal sage scrub California (includes understory)	540	22	1800	1900	Gray (1983)
Caatinga Sobral, Brazil	759	-	-	3300	Kirmse et al. (1987)

Table 6 continued.

Species/System	PPT (mm)	TEMP (°C)	Foliar Litterfall (kg/ha)	Total Litterfall (kg/ha)	Reference
Savanna Nigeria	1232	-	900	-	Hopkins (1966)
Mixed-shrub clusters South Texas savanna	420	28	3560	4760	This study
Prosopis only	420	28	1010		This study

[1]no data available

CHAPTER IV

NUTRIENT INPUTS VIA PRECIPITATION,THROUGHFALL AND STEMFLOW

Introduction

Precipitation constitutes an important flux of nutrients into ecosystems. Although concentrations are comparatively low, annual nutrient inputs from precipitation can be quite large (Likens et al. 1977, Parker 1983). For example, the annual input of nitrogen via precipitation often exceeds that which was fixed biologically (e.g. evergreen shrub communities, Schlesinger and Hasey 1980). Nutrients in precipitation originate from ocean spray, wind-borne dust, gaseous pollutants, and volcanic emissions (Likens et al. 1977). The deposition of nutrients varies with proximity to sources (Miller 1963, Attiwill 1966), prevailing wind direction, and elevation (Schlesinger and Hasey 1980). Changes in nutrient composition of rainfall often occur when precipitation is intercepted by vegetation (Voight 1960, Tukey 1970). In some cases, concentration of certain nutrients in rainfall may decrease after passing through a plant canopy (Voight 1960, Parker 1983). More often, however, concentrations increase as precipitation passes through a leaf canopy (throughfall) and/or moves down plant stems (stemflow).

The extent to which vegetation modifies the chemical composition of incident precipitation varies with plant species and density (Voight 1960, Freedman and Prager 1986), season (Miller 1963, Alcock and Morton 1985), and the amount, duration, frequency, acidity and intensity of incident precipitation (Attiwill 1966, Parker 1983). Factors influencing nutrient composition of stemflow and throughfall include precipitation quality (acidity, nutrient composition), evaporation of moisture, dry deposition on plant surfaces, and plant foliar characteristics and bark texture. Leaf age influences throughfall and stemflow with young leaves having less leaching than old, senescing leaves.

Throughfall is a major transport route for potassium and sodium, often delivering a greater quantity of these elements to the soil than incident precipitation and litter decomposition. Stemflow usually contains higher concentrations of nutrients than throughfall (Voight 1960, Gersper and Hollowaychuck 1970). However, over a period of years, the total nutrient input may be less than that of throughfall (Parker 1983).

Soils beneath trees and shrubs generally have higher nutrient concentrations than herbaceous interstitial zones around the tree or shrub. This increase in nutrients can be attributed to the removal of nutrients by tree/shrub lateral roots from adjacent interstitial zones, greater litter input and decomposition beneath the tree or shrub canopy, as well as stemflow and throughfall nutrient inputs, leading to a higher concentration of nutrients beneath tree and shrub canopies (Zinke 1962, Tiedemann and Klemmedson 1973, Barth and Klemmedson 1978).

Shrub clusters on sandy loam uplands in southern Texas contain up to 16 woody species which vary in growth form attributes (Table 1). Previous studies have shown that nutrient content of the soil beneath the clusters increases relative to herbaceous interstitial zones as clusters develop over time (Loomis 1989). The seasonal contribution to the soil nutrient pool by the woody species comprising these clusters is unknown.

In this study, nutrient inputs via stemflow and throughfall from Prosopis glandulosa, Zanthoxylum fagara, Celtis pallida, Diospyros texana, and Condalia hookerii were compared within clusters at advanced stages of development.

These species were chosen because they had the greatest canopy area and height in the clusters and were also most suitable for stemflow collection. My objectives were to quantify (1) seasonal variation in foliar leaching potential and differences in stemflow nutrient concentration among shrub species and (2) the nutrient concentration and annual nutrient input of incident precipitation, throughfall, and stemflow within multi-species clusters.

Materials and Methods

Precipitation, Throughfall and Stemflow Collection

Five shrub clusters were selected for stemflow and throughfall collection. The shrub clusters chosen met criteria for mature shrub clusters (i.e. large arborescent Prosopis, 8 to 16 species of woody plants; see Archer et al. 1988). Clusters were selected randomly from the available mature clusters within the exclosure.

Bulk precipitation (BPPT) is defined as the nutrient load of incoming precipitation plus dry deposition inputs (Parker 1983). No effort was made to separate dry deposition inputs from incoming precipitation. Bulk precipitation was collected in 1100 mL polypropylene reservoirs using a 16.3 cm diameter funnel mounted into the cap and sealed with silicone rubber. Fiberglass mesh (1 mm) was placed into the funnel to reduce contamination by insects, blowing plant material and soil. The collectors were installed 30 cm above the soil surface herbaceous zones at each of the cardinal directions at a distance of approximately ten meters from the center of each of five shrub clusters.

Bulk throughfall (BTF), defined as the nutrient input via incoming precipitation + dry deposition + leaching from plant canopies (Parker 1983), was collected with inclined plastic gutters (10 cm width) that radiated from the center of each cluster to the drip line in each of the cardinal directions. The troughs, mounted on steel posts approximately 0.5 m above the soil surface, drained into a 25 L reservoir with a funnel mounted to the lid. Fiberglass mesh was placed in the funnel to reduce particulate contamination. The collection reservoir was lined with a polyethylene bag that was replaced after each sample collection. The use of troughs rather than individual throughfall collection stations for BTF minimized disturbance while integrating the horizontal spatial variation in BTF associated with individual plant distribution within the clusters.

Bulk stemflow (BSF) is defined as the nutrient input via incoming precipitation + dry deposition + leaching from plant canopies and stems (Parker 1983). The shrubs selected for BSF collection were Prosopis glandulosa (n=5), Zanthoxylum fagara (n=13), Celtis pallida (n=4), Diospyros texana (n=5), and Condalia hookerii (n=5). The number of individuals selected is roughly proportional to the number of individuals suitable for stemflow collection within the five shrub clusters.

Small shrubs (basal diameter 2.0 to 5.0 cm) were fitted with a pair of pre-cut plastic funnels which were split vertically, wrapped around the lower portion of the main stem (ca. 25 cm above the soil surface), and then pop-riveted along the seams (Figure 5). The seam and rivets were covered and sealed with silicone rubber and the base of the lower funnel was sealed against the plant stem (inside and outside) with butyl rubber caulk. A hole was drilled into the lowest portion of the collector and a piece of Tygon tubing was installed to allow drainage into 1 or 2 l polypropylene reservoirs. A larger diameter funnel was inverted and situated over the collection funnel. Sections of the top portion of this funnel were slit and the plastic

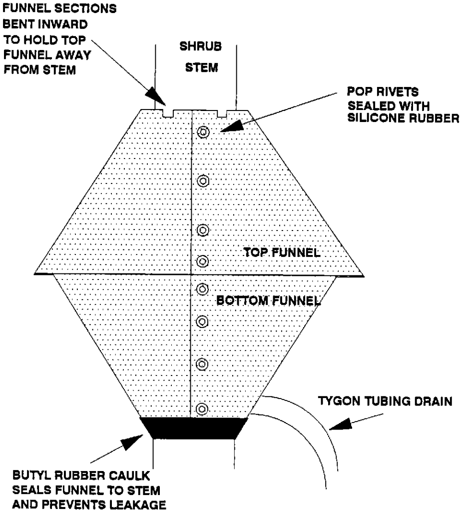


Figure 5. Generalized side-view of stemflow collection apparatus for small shrubs.

bent inward to hold the funnel away from the plant stem. The upper inverted funnel reduced contamination of the stemflow by litter and BTF. For larger shrubs (> 5 cm basal diameter), a collar was made from split rubber tubing (3.0 cm inside diam.). The tubing was nailed in a spiral around the complete circumference of the main stem of large shrubs and sealed against the trunk with butyl rubber caulk. The collar drained into a 20 l plastic collection reservoir.

Sample Collection and Analysis

After each precipitation event, total volume of BPPT, BSF, and BTF was measured. A 200 mL aliquot was withdrawn (when possible) and stored in sterile plastic bags (Whirl-pacs) at -4 °C. The remaining contents were discarded and collectors were washed with 10% HCl solution and triple rinsed with deionized water. Samples were collected within 5 days of each rainfall event.

Calcium (Ca), magnesium (Mg), and potassium (K) concentrations were determined from filtered samples (paper, Whatman #44) using a Perkin-Elmer atomic absorption spectrophotometer. Total nitrogen (N) and total phosphorus (P) were determined after micro-Kjeldahl and persulfate digestion, respectively, on a Technicon II autoanalyzer.

An index for determining whether nutrients were being removed from or added to incident rainfall is the concentration ratio (CR) and was calculated for bulk stemflow and throughfall as:

$$CR = C_t \text{ or } C_s \ / \ C_i \qquad (4.1)$$

where C_t = concentration of bulk throughfall, C_s = concentration of bulk stemflow, and C_i = concentration of bulk precipitation (Parker 1983). Thus. when CR>1 the precipitation has accumulated nutrients from plant canopies and when CR<1, plants canopies have extracted nutrients from the rainfall. Individual storm and mean CR's were calculated only from storms where C_t or C_s was significantly different ($P<0.05$) from C_i.

In this chapter nutrient concentration is defined as the amount of a nutrient per unit of water (i.e. mg/L). Nutrient input or deposition is defined as amount of nutrient deposited by the water flux (BPPT, BTF or BSF) per unit area. Input of nutrients for a given rainfall event was calculated for BPPT and BTF by taking the volume of water (volume of water and water deposition are discussed in Chapter V) collected and dividing it by the collector area (m^2) and multiplying this by the sample concentration (mg/L). For BSF collectors, the canopy area of the instrumented shrub was used for the collection area. Canopy area was determined by measuring horizontal canopy projection along two axes and calculating area based on shape. Therefore, nutrient input via BSF was calculated on a g/m^2 of canopy area for each species. BTF nutrient input was calculated on a g/m^2 of shrub cluster basis.

Mean annual concentrations of BPPT, BTF and BSF (for each species) were determined by averaging concentrations of each nutrient for all storms for the duration of the study period. Total annual input (or deposition) of BPPT, BTF, and BSF (for each species) was determined by summing the input for all rainfall events for each cluster and averaging the year totals of the clusters.

Deposition ratios (DR) were used to compare input of nutrients via throughfall and stemflow to that from precipitation (Parker 1983):

$$DR = D_{t\ or\ s}\ C_{t\ or\ s}\ /\ D_i\ C_i \qquad (4.2)$$

where DR is the deposition ratio, D is the depth of water for bulk throughfall (t), stemflow (s), or precipitation (i) and C is the concentration of the nutrient in water.

Potential Leachability

Seasonal variation in the leachability of leaves and stems for each of the five shrub species were estimated using procedures described by Gray (1983). Five terminal shoots (leafs + stems) from each of the five species were collected from the field and placed cut end up in 200 ml of recently collected rainwater of known nutrient content. The shoots were removed after 12 hours, oven dried, and weighed. The leachate was frozen, stored and subsequently analyzed for Ca, Mg, K, N, and P as described previously. Leaching is expressed as mg nutrient/g shoot biomass.

There are limitations to this technique. Exact recreation of the processes of nutrient removal by rainfall impact cannot be duplicated in the laboratory, and most foliage would not be subjected to rainfall for 12 hours in field conditions. However, this technique does provide an index of the relative leaching potential of nutrient from shoot tissue and allows comparisons among species.

Cluster Attributes

Shrub clusters used for the determination of BTF and BSF nutrient concentrations were characterized by measuring the following attributes of shrubs comprising the cluster: a) height; b) canopy diameter (long axis and perpendicular to long axis); c) basal diameter; d) numbers of stems; e) distance to the central Prosopis plant; and f) direction from the Prosopis plant. These attributes allowed each cluster to be mapped, and the total canopy area, number of plants of each species, and total shrub cluster area were determined. Shrub canopy area was calculated based on horizontal shape of canopy (usually a circle or ellipse). Total shrub cluster area was defined as the area of the landscape occupied by a shrub cluster and was estimated by measurement of diameter along the long axis and perpendicular to the long axis and was computed as an ellipse.

Leaf biomass was estimated using the reference unit method (Andrew et al. 1979, Kirmse and Norton 1985) within an imaginary vertical cube above throughfall trough collectors (dimensions: 12 cm width x collector length x distance to the highest plant canopy above the collector). Sampling was conducted in 1988 during March (start of leaf initiation) and July (peak biomass).

Statistical Analyses

BPPT and BTF chemistry was analyzed using a split plot design with rainfall event and shrub cluster as the main plot variables and trough direction and nutrient flux (BPPT or BTF) as the sub plot variables. The mean square error of the rainfall event by shrub cluster interaction was used as the error term to test significance of rainfall event and shrub cluster in the model. Significance of all other variables and associated interactions were tested using the full model mean square error. Fischer's least significant difference (LSD) procedure was used for mean separations. The LSD was calculated with the error term that was used in the F-test for significance of a given main effect or interaction in the model. Analyses were conducted using the SAS-GLM procedure (SAS 1987). T-tests were used to detect differences in BPPT and BTF means.

The statistical model used for analysis of BSF was a split plot design with rainfall event and shrub cluster as the main plot variables and shrub species and nutrient flux (BPPT or BSF) as the split plot variables. Error terms and LSD's were calculated as described for BPPT and BTF chemistry. All differences in means are considered significant when $P<0.05$.

Stepwise regression and Pearson's correlation analysis (SAS 1987) were used to explore relationships between mean concentrations and depositions of nutrients in BTF and BSF

(Prosopis and Zanthoxylum only) and independent variables such as storm size (mm/event), precipitation intensity (mm/min), monthly litterfall, and consecutive days since the last rainfall event (length of the dry period). Monthly litterfall was determined from collection in shrub clusters adjacent to those used for BTF and BSF collection and are discussed in Chapter III. The litterfall variable was chosen because it indirectly reflects the status of leaf biomass in the cluster canopies. Zanthoxylum litterfall was chosen in the stepwise regression model for BTF concentrations over total cluster litterfall, possibly because this species had the greater biomass above the throughfall collectors and it maintained leaf biomass in the canopy throughout the study period (see leaf phenology, Chapter III). By contrast, Prosopis which also had a large amount of biomass above the collectors did not maintain biomass throughout the study period because of its deciduous nature.

Results

Vegetation Characteristics of Shrub Clusters

Plant abundance and size. Shrub clusters were characterized by a Prosopis overstory and a Zanthoxylum understory. Prosopis plants were few in number but were largest in terms of basal diameter and height (Table 7). Smaller-statured Zanthoxylum plants dominated the understory in terms of both plant numbers (39 per cluster) and total canopy area. Other species targeted for study (Celtis, Condalia and Diospyros) comprised <3% of the total canopy area of clusters.

Biomass above BTF collectors. Leaf biomass above trough collectors was quantified to determine the relative abundance of the species potentially contributing to BTF. Total shrub foliar biomass in clusters averaged 113 ± 10 g/m^3 in March and

Table 7. Mean (±SE) number of plants per cluster, height, number of stems per plant, basal diameter, absolute canopy area, and relative canopy area of species comprising mixed-shrub clusters (n=5) in a south Texas subtropical savanna parkland.

Species	Number of Plants	SE	Shrub Height (m)	SE	Number of Stems	SE	Basal Diameter (cm)	SE	Absolute Canopy Area (m^2)	SE	Relative Canopy Area (%)
Target species											
Celtis	4.0	1.4	1.09	0.23	2.1	0.3	1.8	0.5	3.1	1.5	2.8
Condalia	3.2	1.1	1.07	0.12	1.1	0.1	2.2	0.4	2.0	0.6	1.8
Diospyros	4.8	2.3	0.82	0.15	1.2	0.1	1.5	0.3	4.0	3.4	3.6
Prosopis	1.0		3.57	0.63	2.4	0.6	13.6	3.5	44.3	5.5	39.9
Zanthoxylum	39.6	15.7	1.34	0.06	2.0	0.1	2.3	0.2	43.9	9.5	39.6
Other species											
Berberis	2.6	1.1	0.83	0.12	4.2	1.0	1.1	0.2	2.5	0.8	2.2
Colubrina	6.6	4.4	0.84	0.05	6.5	0.8	0.5	0.0	4.5	2.9	4.0
Lycium	0.2	0.2	1.35	-	1.0	-	2.0	-	0.1	0.1	0.1
Opuntia lep.[1]	1.8	1.1	0.66	0.11	1.0	0.0	0.3	0.1	0.5	0.3	0.5
Opuntia lin.[2]	3.6	1.4	0.78	0.10	0.0	0.0	0.0	0.0	3.4	1.8	3.1
Salvia	1.8	1.4	1.00	0.10	8.2	1.1	1.2	0.3	1.7	1.2	1.5
Schafferia	0.4	0.4	0.67	0.32	7.0	6.0	0.4	0.1	0.2	0.2	0.2
Ziziphus	1.0	0.4	0.90	0.24	2.2	0.7	0.9	0.3	0.7	0.3	0.6

[1] Opuntia leptocaulis
[2] Opuntia lindheimeri

290 ± 20 g/m^3 in July. Zanthoxylum and Prosopis were the primary contributors to leaf biomass for both periods of sampling, followed by Diospyros, Condalia and Celtis (Figure 6). Leaf biomass increased for all species between March and July.

The proportional contribution of shrub species to total leaf biomass was similar between the two collection periods (Zanthoxylum=54%, Prosopis=30%, Diospyros=9%, Condalia=5% and Celtis=1%). It appears that during the growing season the contribution of each species to total leaf biomass is relatively stable. See Appendix Tables 10 and 11 for more detail on individual throughfall collectors and individual shrub cluster biomass.

The vegetation in the clusters was stratified vertically with three to four stratum above the collectors. The upper stratum (>2 m height) was primarily occupied by Prosopis (Table 5). The mid-stratum (1-2 m height) were dominated primarily by Zanthoxylum but also contained Celtis and Diospyros. The lower stratum was occupied by small shrubs (< 1 m height) of all species except Prosopis.

Assessments of leaf biomass during the months when the deciduous and facultative evergreens had lost leaves (December - February) were not made. Data presented in Chapter III indicated that Prosopis had complete leaf loss during this period and that Zanthoxylum maintained 16% of its leaves. Celtis, Diospyros, and Condalia, maintained 4, 5, and 18% of their leaves, respectively. These data suggest that Zanthoxylum would have constituted the largest proportion of the total leaf biomass during the winter months.

Potential Leachability

Artificial leaching trials were conducted to determine if seasonal differences existed in the leaching of nutrients from shoots of different species. The leaching trials were

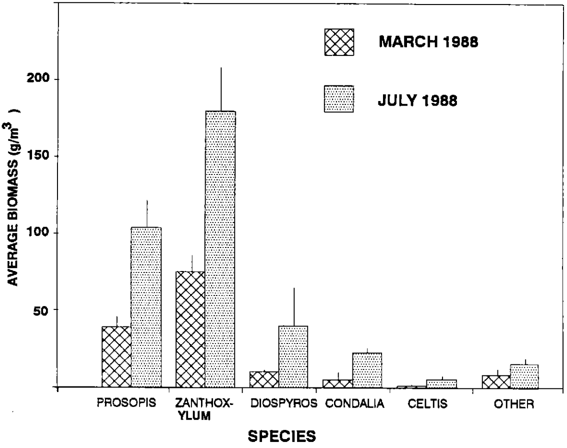


Figure 6. Average biomass (g/m^3) with standard errors (lines on bars) of the shrub species above bulk throughfall collectors for periods representing low (March 1988) and high (July 1988) biomass. Other species include Colubrina, Ziziphus, Berberis, Schafferia and Lycium.

conducted during August 1987, December 1987, and June 1988 to represent different stages of shrub growth. June is a period of rapid leaf growth and canopy development while August is near peak expression of shrub biomass and the time of greatest water stress. December represents the period of leaf senescence and loss.

Results of the analysis of variance significance tests for main effects and interactions for the potential leachability of nutrients from the selected shrubs are summarized in Table 8. Species and date were the main effects. Shrub species was significant for all nutrients, whereas date was significant only for P. The species by date interaction was significant for all nutrients but magnesium.

Shoot retention of nutrients was highest for P (maximum loss of 0.31 mg/g plant tissue) regardless of plant species. Retention of Ca, K, and N was generally lowest (maximum losses = 19.6, 14.0, and 13.2 mg/g of plant tissue, respectively). Mg was intermediate (maximum loss was 2.6 mg/g plant tissue). A pooling of the ion concentrations across species and dates gave the following leaching profile for nutrients: K > Ca = N > Mg > P.

Calcium. Leaching of Ca was greatest for Celtis ($\geq$ 7.2 mg/g) and comparatively low for all other species at each date (< 0.9 mg/g) (Figure 7). Several species exhibited nutrient absorption during the December 1987 trial. Statistical analyses indicated that these were not significantly different from zero.

Ca leachability of Condalia and Zanthoxylum shoots decreased steadily from early summer through winter (Table 9). Leachability of Celtis shoots was comparable in June and August but more than doubled in December. Leachability of Prosopis and Diospyros shoots did not change significantly with season.

Table 8. Significance tests for ANOVA model used to determine sources of variation in ion concentrations of nutrients leached from terminal leaders of five shrub species on three dates in 1987 and 1988.

Source	Calcium		Magnesium		Potassium		Nitrogen		Phosphorus	
	F Value	Pr>F[1]	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F
Model	12.49	**	7.89	**	6.02	**	2.73	**	4.86	**
Species	33.45	**	24.64	**	14.13	**	4.10	**	2.94	*
Date	2.20	ns	1.00	ns	1.49	ns	1.10	ns	6.46	**
Species x Date	4.59	**	1.23	ns	3.10	**	2.46	*	5.42	**

[1] Pr>F indicates significance of the F test for each term in the model as follows:

*** = $Pr>F < 0.0001$ * = $0.01 \leq Pr>F \leq 0.05$

** = $0.0001 \leq Pr>F \leq 0.01$ ns = $Pr>F > 0.05$

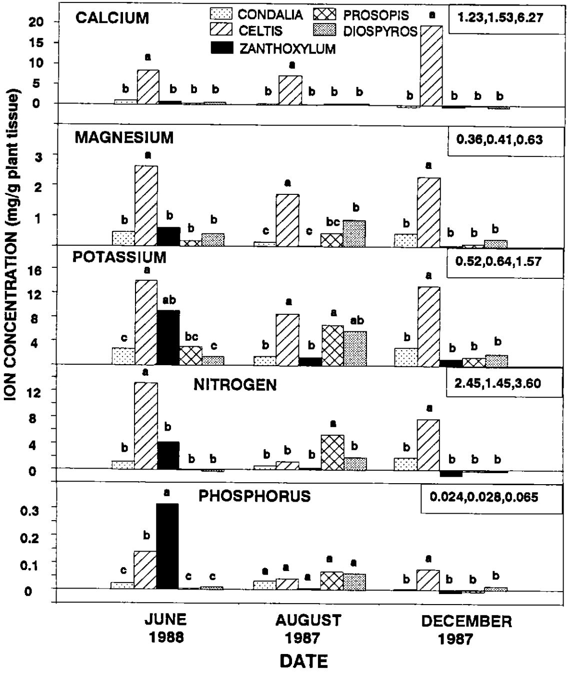


Figure 7. Mean ion concentration (mg/g plant tissue) of nutrients leached from terminal shoots of shrub species on these dates. Means with the same letter within date were not significantly different (P>0.05). Note differences in y-axis scales for each nutrient. Number in boxes in right corner of each graph represent mean concentrations (mg/L) of rainwater used for each leaching trial.

Table 9. Means and standard errors (SE) of calcium, magnesium, potassium, nitrogen, and phosphorus (mg/g of plant tissue) leached from shoots submerged in rainwater for 12 hours. For each species, means with the same letter were not significantly different between dates (P>0.05) based on Fischer's LSD.

Species/Nutrient	June, 1988			August, 1987			December, 1987		
	Mean	SE	Sig.	Mean	SE	Sig.	Mean	SE	Sig.
Calcium									
Condalia Hookeri	1.07	0.26	a	0.20	0.18	ab	-0.43	0.50	b
Celtis pallida	8.43	1.63	b	7.23	1.32	b	19.65	5.75	a
Zanthoxylum fagara	0.84	0.30	a	0.07	0.08	ab	-0.57	0.43	b
Prosopis glandulosa	0.40	0.16	a	0.26	0.23	a	-0.20	0.48	a
Diospyros texana	0.52	0.13	a	0.36	0.14	a	-0.49	0.68	a
Magnesium									
Condalia Hookeri	0.47	0.04	a	0.15	0.05	b	0.43	0.10	a
Celtis pallida	2.63	0.81	a	1.72	0.38	a	2.30	0.56	a
Zanthoxylum fagara	0.61	0.23	a	0.02	0.01	b	0.04	0.03	b
Prosopis glandulosa	0.17	0.11	a	0.44	0.25	a	0.09	0.06	a
Diospyros texana	0.42	0.04	ab	0.87	0.25	a	0.25	0.12	b
Potassium									
Condalia Hookeri	2.73	0.55	ab	1.52	0.25	b	2.96	0.54	a
Celtis pallida	14.02	2.89	a	8.57	2.16	a	13.20	3.21	a
Zanthoxylum fagara	9.06	2.89	a	1.32	0.48	b	1.06	0.33	b
Prosopis glandulosa	3.04	2.07	a	6.70	2.49	a	1.44	0.56	a
Diospyros texana	1.50	0.08	b	5.76	1.55	a	1.98	0.99	b

Table 9. continued

Species/Nutrient	June, 1988			August, 1987			December, 1987		
	Mean	SE	Sig.	Mean	SE	Sig.	Mean	SE	Sig.
<u>Nitrogen</u>									
Condalia Hookeri	1.25	0.52	a	0.62	0.49	a	1.92	0.97	a
Celtis pallida	13.20	8.01	a	1.26	0.63	b	7.79	3.50	a
Zanthoxylum fagara	4.17	1.60	a	0.27	0.30	b	-0.92	0.35	b
Prosopis glandulosa	-0.10	0.15	b	5.33	2.01	a	-0.18	0.12	b
Diospyros texana	-0.26	0.30	b	1.92	0.87	a	-0.26	0.60	b
<u>Phosphorus</u>									
Condalia Hookeri	0.023	0.010	a	0.031	0.018	a	0.003	0.003	a
Celtis pallida	0.140	0.057	a	0.040	0.031	a	0.076	0.027	a
Zanthoxylum fagara	0.316	0.115	a	0.006	0.007	b	-0.011	0.004	b
Prosopis glandulosa	0.005	0.007	ab	0.067	0.035	a	-0.007	0.004	b
Diospyros texana	0.011	0.006	a	0.061	0.035	a	0.014	0.015	a

Magnesium. Celtis shoots exhibited the greatest Mg leachability on each date (> 1.7 mg/g) (Figure 7). Mg leaching from shoots of other species was < 0.9 mg/g and generally did not differ from each other significantly (Figure 7).

Mg leachability of Celtis and Prosopis shoots was not significantly different through time (Table 9). Significant seasonal differences occurred in other species, but patterns were inconsistent.

Potassium. As with Mg and Ca, Celtis shoots had the greatest amount of K leachability for each date (8.5 to 14.0 mg/g) (Figure 7). In June, Celtis and Zanthoxylum had the greatest leachability for K (14.0 and 9.0 mg/g). Leachability was reduced in all species in August relative to June and the leachability of Celtis, Prosopis, and Diospyros was comparable (5.7 to 8.5 mg/g) and greater than that of Zanthoxylum (1.3 mg/g) and Condalia (1.5 mg/g). Shoot K leachability in December was comparable to lower than that of August.

For Celtis and Prosopis, there were no significant differences in loss of K (Table 9). Condalia had greatest leaching of K in December, whereas Zanthoxylum had greatest leaching of K in June. Leaching of K by Diospyros peaked in August.

Nitrogen. In June, shoot N leachability was greatest for Celtis (13.2 mg/g), while losses from all other species were substantially lower (< 4.1 mg/g). By late summer, leachability of N from shoots was greatest for Prosopis (5.3 mg/g) and lower and comparable for other species (< 1.9 mg/g) (Figure 7). In December, shoot N leachability was greatest for Celtis (7.8 mg/g) and comparably low for other species (< 2 mg/g). As with Ca, Zanthoxylum, Prosopis and Diospyros exhibited nitrogen uptake in December, but only absorption of N by Zanthoxylum was significantly different from zero.

Phosphorus. Leaching of P from shoots was one to two orders of magnitude lower than that of other nutrients. In June, leachability of P from shoots was greatest for Zanthoxylum. No significant differences existed in leaching of P among species during the August trial. During December, Celtis has the greatest leaching of P, whereas the other species showed no significant differences (Figure 7). Zanthoxylum and Prosopis appeared to have absorbed P, but these were not statistically significant from zero.

Comparisons of P leaching for each species over time indicated peak leaching occurred during August for Prosopis and during June for Zanthoxylum (Table 9). No significant seasonal differences in leaching of P was observed for Diospyros, Celtis, and Condalia.

Bulk Precipitation and Bulk Throughfall Chemistry

Nutrient concentrations. The results of the analysis of variance using the split-plot model for nutrient concentrations for main effects and interactions are summarized in Table 10. Storm and shrub cluster were significant main effects for all nutrients but Ca. Direction of collectors and the interaction with storm was significant only for K. Nutrient flux (BPPT or BTF) and its interaction with storm was significant for all nutrients. Individual means, standard errors and LSD's for BPPT and BTF are summarized in Appendix tables 14 through 18 on an event basis.

Bulk throughfall (BTF) concentrations of Ca were significantly different from BPPT for 53% of the rainfall events occurring during the study period (Figure 8). For some small rainfall events (< 8 mm), Ca concentrations in BPPT significantly exceeded amounts in BTF, indicating that Ca was absorbed by the leaves and bark in the cluster canopies. These events had concentration ratios (CR's) that ranged from 0.3 to 0.4. In cases where BTF concentrations of Ca were

Table 10. Significance tests for split-plot model used to determine sources of variation in concentrations of nutrients in bulk precipitation and throughfall (flux), as a function of shrub cluster, trough direction, and rainfall event (storm) and associated interactions. The storm and cluster variables were tested using the mean square error from the type III sums of squares for the storm x cluster interaction. All other variables and interactions were tested using the full model mean square error.

	Calcium		Magnesium		Potassium		Nitrogen		Phosphorus	
Source	F Value	Pr>F[1]	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F
Model	15.8	***	6.1	***	4.6	**	3.0	**	2.9	**
Cluster	2.1	ns	3.5	**	7.6	**	13.5	**	14.7	**
Storm	86.5	***	33.4	***	14.5	**	10.8	**	10.6	**
Storm x Cluster	7.2	**	1.3	*	0.8	ns	1.8	**	1.2	ns
Direction	0.5	ns	1.2	ns	8.1	**	0.8	ns	0.5	ns
Flux	6.1	*	184.7	**	192.7	**	22.2	**	11.4	**
Storm x Direction	0.6	ns	0.8	ns	1.5	**	1.0	ns	1.3	ns
Flux x Direction	2.4	ns	2.8	*	7.0	**	1.2	ns	1.2	ns
Flux x Storm	19.7	***	7.1	**	10.1	**	1.9	**	3.4	**
Test using Storm x Cluster as error term										
Storm	12.0	**	25.7	**	18.7	**	5.9	**	9.2	**
Cluster	0.3	ns	2.7	*	9.8	**	7.4	**	12.7	**

[1] Pr>F indicates significance of the F test for each term in the model as follows:

*** = Pr>F < 0.0001   * = 0.01 ≤ Pr>F ≤ 0.05

** = 0.0001 ≤ Pr>F ≤ 0.01   ns = Pr>F > 0.05

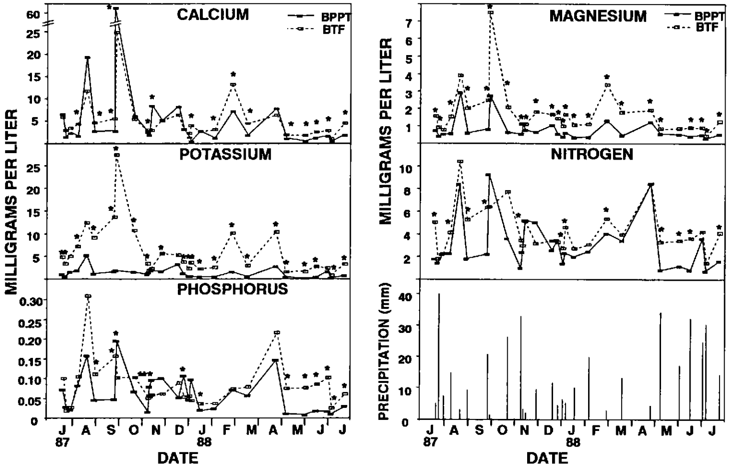


Figure 8. Mean concentration (mg/L) of selected nutrients in bulk precipitation (BPPT) and bulk throughfall (BTF) and precipitation amount for rainfall events occurring from July 1987 through July 1988. Paired means associated with an "*" are significantly different ($P<0.05$) for BPPT and BTF. See Appendix tables 14 through 19 for means and standard errors.

greater than BPPT and significantly different, the Ca concentration ratios ranged from 1.6 to 6.4, with an average of 2.3 (Table 11).

BTF concentrations of Mg were significantly different from BPPT for 85% of the rainfall events occurring during the study period (Figure 8). Highest mean Mg concentrations in BTF typically occurred in rainfall events < 8 mm. When BTF concentrations were significantly different from BPPT, BTF concentration ratios averaged 2.4 and ranged from 1.4 to 3.7 (Table 11).

BTF concentrations of K were significantly different from BPPT for 78% of the collection events during the study period (Figure 8). As with Mg, the peak concentrations of K appeared to occur in small rainfall events. Relative to other nutrients, K had the greatest differences in concentration between BTF and BPPT. K concentration ratios for BTF averaged 5.4, with peaks of 8 to 14, indicating high mobility of this nutrient (Table 11).

N concentrations in BTF differed significantly from BPPT for 42% of the rainfall events (Figure 8). Concentrations of N in BPPT exceeded that of BTF for four storms each of which were <9 mm, but these were not significantly different. When BTF N concentrations were greater than BPPT the average concentration ratio was 2.6 (range = 1.3 to 4.3) (Table 11).

P concentrations in BTF differed from BPPT for 50 % of the rainfall events, but concentrations were much lower than those of other nutrients (Figure 8). For seven of the events, BTF concentrations were lower than that of BPPT, but only three events were significantly lower indicating absorption of P by the shrub canopies. As was the case with Ca and N, these instances coincided with small (< 9 mm) rainfall events. For events where P in BTF was greater than BPPT, BTF concentration ratios averaged 4.2, with a range of 1.8 to 8.4 (Table 11).

Table 11. Percent of bulk throughfall and stemflow events significantly different from bulk precipitation, mean concentration ratio (CR), minimum and maximum concentration ratio for selected nutrients in bulk stemflow and throughfall collected within mixed-shrub clusters in a south Texas subtropical savanna parkland.

Nutrient	Percent Sign. Diff.	Mean CR	Minimum CR	Maximum CR
Bulk throughfall				
Calcium	53	2.3	1.6	6.4
Magnesium	85	2.4	1.4	3.7
Potassium	78	5.4	2.4	14.5
Nitrogen	42	2.6	1.3	4.3
Phosphorus	50	4.2	1.8	8.4
Bulk stemflow - *Prosopis*				
Calcium	60	8.3	2.2	43.0
Magnesium	56	5.7	2.2	10.5
Potassium	56	12.5	6.5	24.1
Nitrogen	52	4.8	2.0	10.9
Phosphorus	39	4.1	2.3	8.0
Bulk stemflow - *Zanthoxylum*				
Calcium	56	3.9	1.9	13.7
Magnesium	65	3.6	1.7	6.6
Potassium	65	7.5	2.1	23.0
Nitrogen	44	3.7	1.7	6.2
Phosphorus	40	3.6	2.0	5.5

Regression relationships. Storm size (mm/event), Zanthoxylum monthly litterfall (kg/ha), and consecutive days since the last rain (CDSLR) combined to account for 65 to 77% of the variance associated with mean nutrient concentrations in BTF (Table 12). Storm size was negatively correlated with concentrations of all nutrients, indicating that concentrations tended to decrease with increasing amounts of precipitation. Monthly Zanthoxylum litterfall was selected by the stepwise analysis over monthly litterfall values for other species, and typically explained the most variance (23 to 67%). Zanthoxylum litterfall was positively correlated with nutrient concentrations, indicating that conditions conducive for litterfall production also increased nutrient concentrations in BTF. Storm intensity was the least important variable in the model, making a significant contribution (9%) only for P. The contribution of CDSLR in explaining variance in BTF nutrient concentrations was 19 and 17% for N and P, but only 3-9% for Ca, Mg, and K.

Bulk Stemflow Chemistry

Nutrient concentrations. The analysis of variance for the split-plot model used to determine significance of main effects and interactions is summarized in Table 13. Shrub cluster and storm main effects were significant for all nutrients. Nutrient flux (BSF or BPPT), species and the interaction of these variables was significant for all nutrient concentrations except P. The nutrient flux*species*storm variable was significant for all variables except for P.

During approximately 33% of the rainfall events, Celtis, Condalia, and Diospyros produced <80 ml of stemflow. Therefore, these species will not be discussed on an event basis, but will be discussed later in this chapter when comparing mean annual concentrations of stemflow. Additional

Table 12. Results of stepwise regression analysis (partial R^2 and model R^2s) and Pearson's correlation coefficients (r values) of variables potentially influencing concentrations (mg/L) of selected nutrients in bulk throughfall within mixed-shrub clusters.

Nutrient	Variables: PPT[a] (mm)	Litter-fall[b] (kg/ha)	CDLSR[c]	Inten-sity[d] (mm/min)	Model r and R^2
<u>Calcium</u>					
r value	-0.57	0.53	0.08	-[1]	0.81
partial R^2	0.33	0.23	0.09	-	0.65
<u>Magnesium</u>					
r value	-0.56	0.68	0.07	-	0.88
partial R^2	0.24	0.47	0.06	-	0.77
<u>Potassium</u>					
r value	-0.42	0.79	0.16	-	0.88
partial R^2	0.12	0.62	0.03	-	0.77
<u>Nitrogen</u>					
r value	-0.43	0.62	0.41	-	0.85
partial R^2	0.15	0.38	0.19	-	0.72
<u>Phosphorus</u>					
r value	-0.29	0.57	0.50	0.31	0.86
partial R^2	0.14	0.34	0.17	0.09	0.74

[a] PPT = Mean rainfall amount for each event.
[b] Litterfall = Mean monthly litterfall for <u>Zanthoxylum</u> <u>fagara</u>.
[c] CDSLR = Consecutive days since last rainfall event.
[d] Intensity = Rainfall intensity for each event.
[1] Indicates this variable was not selected by the stepwise model.

Table 13. Significance tests for split-plot model used to determine sources of variation in concentrations of nutrients in bulk precipitation and stemflow (Flux), shrub cluster, shrub species, and rainfall event (storm) and the associated interactions. The storm and cluster variables were tested using the mean square error from the type III sums of squares for the storm*cluster interaction. All other variables and interactions were tested using the full model mean square error.

Source	Calcium		Magnesium		Potassium		Nitrogen		Phosphorus	
	F Value	Pr>F[1]	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F	F Value	Pr>F
Model	4.72	**	5.26	**	3.59	**	4.06	**	2.65	**
Cluster	12.38	**	3.56	**	8.25	**	17.46	**	22.56	**
Storm	13.19	**	13.97	**	5.62	**	10.45	**	7.18	**
Storm x Cluster	1.80	**	0.79	ns	0.83	ns	2.76	**	2.62	**
Species	12.89	**	8.98	**	5.23	**	5.89	**	1.57	ns
Flux	145.24	**	509.13	***	400.71	**	164.97	**	23.95	**
Species x Storm	1.28	*	2.07	**	1.03	ns	1.02	ns	0.59	ns
Flux x Storm	4.20	**	10.88	**	4.74	**	5.57	**	2.41	**
Flux x Species x Storm	2.83	**	3.08	**	1.68	**	1.46	**	0.59	ns
Test using Storm x Cluster as error term										
Storm	7.33	**	17.70	**	6.80	**	3.79	**	2.73	**
Cluster	6.88	**	4.51	**	9.98	**	6.33	**	8.59	**

[1] Pr>F indicates significance of the F test for each term in the model as follows:

*** = Pr>F < 0.0001	* = 0.01 ≤ Pr>F ≤ 0.05
** = 0.0001 ≤ Pr>F ≤ 0.01	ns = Pr>F > 0.05

information on the nutrient concentrations of BSF for these species are summarized in Appendix tables 19 through 48 on an event basis.

Ca concentrations in BSF of Prosopis were significantly different from BPPT for 60% of the rainfall events where stemflow was collected (Figure 9). Concentrations of Ca in BSF were generally higher than BPPT with greatest differences occurring in September 1987 and January through March 1988. The concentration ratio of Prosopis BSF averaged 8.3 (range=2.2 to 43.0) (Table 11). Concentrations of Ca in BSF of Zanthoxylum differed significantly from BPPT for 56% of the stemflow events (Figure 9). The concentration ratio of Zanthoxylum BSF Ca was generally greater than BPPT with an average of 3.9 (range = 1.9 to 13.7). The greatest differences in Ca concentrations ratios between Zanthoxylum BSF and BPPT occurred during September 1987 and January 1988. Patterns of Prosopis and Zanthoxylum Ca concentrations were comparable. However, concentrations of Ca were generally higher for Prosopis, significantly so from January through March 1988 (Figure 9) the period when no leaves were present in the Prosopis canopy (Chapter III).

Concentrations of Mg in Prosopis BSF differed significantly from BPPT for 56% of the rainfall events (Figure 10). Peaks in BSF Mg concentrations occurred during December 1987 and January 1988. Mg concentration ratios in BSF ranged from 2.2 to 10.5 with a mean of 5.7 (Table 11). Concentrations of Mg in Zanthoxylum BSF differed significantly from BPPT for 65% of the rainfall events, with peaks in September 1987 and January 1988 (Figure 10), coincident with the periods the periods of high (551 kg/ha) and low litterfall (60 kg/ha) periods, respectively. Mg concentrations in Zanthoxylum BSF averaged 3.6 times more than that of BPPT with a concentration ratio range of 1.7 to 6.6 (Table 11).

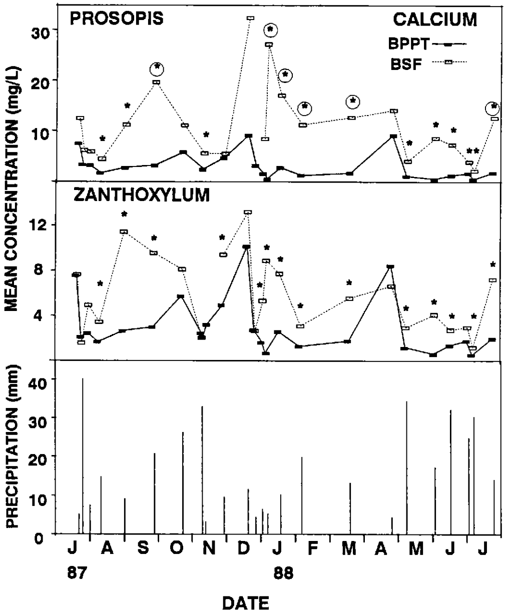


Figure 9. Mean concentration (mg/L) of calcium in bulk precipitation (BPPT) and bulk stemflow (BSF) from Prosopis and Zanthoxylum, and precipitation amount for rainfall events occurring from July 1987 through July 1988. Paired means associated with an "*" are significantly different (P<0.05) for BPPT and BSF. Circled asterisks indicate a significant difference (P<0.05) between Prosopis and Zanthoxylum mean BSF for that date.

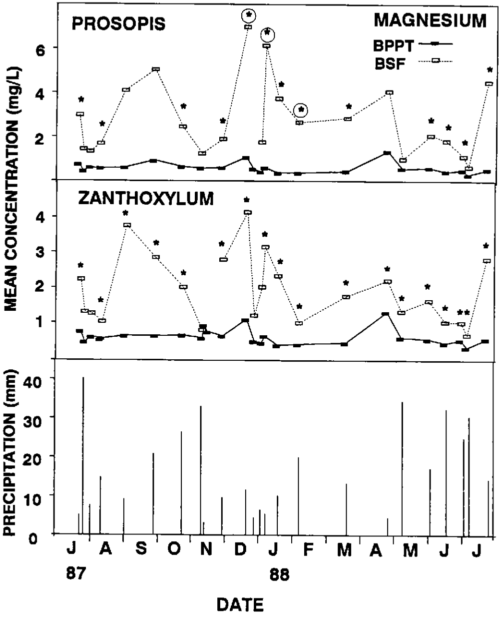


Figure 10. Mean concentration (mg/L) of magnesium in bulk precipitation (BPPT) and bulk stemflow (BSF) from Prosopis and Zanthoxylum, and precipitation amount for rainfall events occurring from July 1987 through July 1988. Paired means associated with an "*" are significantly different (P<0.05) for BPPT and BSF. Circled asterisks indicate a significant difference (P<0.05) between Prosopis and Zanthoxylum mean BSF for that date.

Prosopis and Zanthoxylum BSF Mg concentrations differed significantly on three rainfall events, each of which occurred during winter when Prosopis canopies lacked foliage. Prosopis concentrations were generally higher than Zanthoxylum for each of these events (Figure 10).

Prosopis concentrations of K in BSF differed significantly from BPPT for 56% of the rainfall events (Figure 11). When Prosopis BSF K concentrations were significantly greater than BPPT, the concentration ratios ranged from 6.5 to 24.1, with a mean of 12.5 (Table 11). The greatest CR's for Prosopis K occurred during September 1987, January through March 1988 and June 1988, coincident with a period of high litterfall, a period of no leaves in the canopy and a period of active leaf growth, respectively.

Zanthoxylum concentrations of K in BSF differed from that of BPPT for 65% of the rainfall events (Figure 11), with peaks in September and December 1987. The concentration ratios for K in Zanthoxylum BSF averaged 7.5 (range = 2.1 to 23.0) (Table 11). Prosopis and Zanthoxylum BSF K concentrations differed significantly at 3 precipitation events, with Prosopis concentrations greater for each event (Figure 11).

Mean concentrations of BSF N from Prosopis differed from that of BPPT for 52% of the precipitation events (Figure 12). The greatest deviations occurred during September 1987, December 1987, and June through July 1988, coincident with a period of high Prosopis litterfall, a period of no leaves in the Prosopis canopy, and a period of active leaf growth, respectively. Concentration ratios averaged 4.8 (range: 2.0 to 10.9) (Table 11). N concentrations in Zanthoxylum BSF differed significantly from BPPT for only 44% of the rainfall events. The greatest deviations between BSF and BPPT concentrations occurred during September and December 1987,

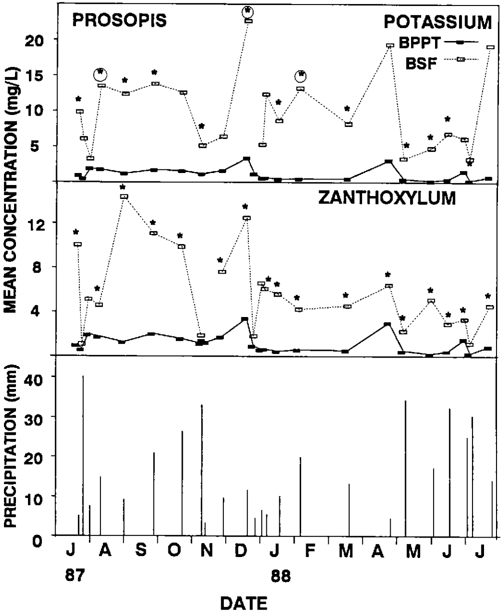


Figure 11. Mean concentration (mg/L) of potassium in bulk precipitation (BPPT) and bulk stemflow (BSF) from _Prosopis_ and _Zanthoxylum_, and precipitation amount for rainfall events occurring from July 1987 through July 1988. Paired means associated with an "*" are significantly different ($P<0.05$) for BPPT and BSF. Circled asterisks indicate a significant difference ($P<0.05$) between _Prosopis_ and _Zanthoxylum_ mean BSF for that date.

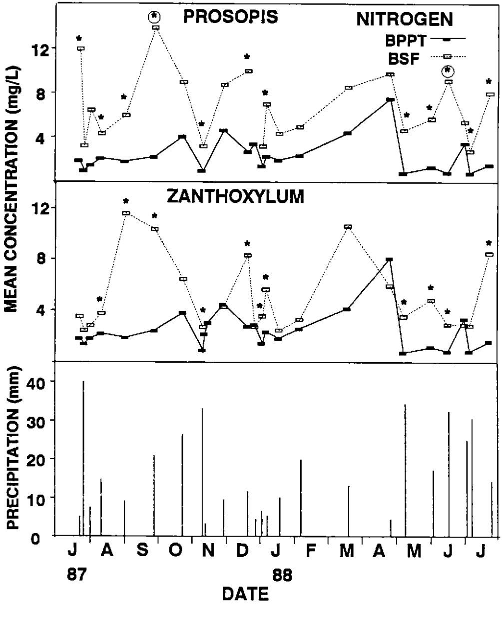


Figure 12. Mean concentration (mg/L) of nitrogen in bulk precipitation (BPPT) and bulk stemflow (BSF) from Prosopis and Zanthoxylum, and precipitation amount for rainfall events occurring from July 1987 through July 1988. Paired means associated with an "*" are significantly different (P<0.05) for BPPT and BSF. Circled asterisks indicate a significant difference (P<0.05) between Prosopis and Zanthoxylum mean BSF for that date.

and late July 1988, approximately the same periods as Prosopis (Figure 12). CR's of Zanthoxylum BSF N ranged from 1.7 to 6.2 and averaged 3.7. Seasonal patterns of BSF N concentrations were comparable for Prosopis and Zanthoxylum. Concentrations differed significantly for only two events, with Prosopis having the greater concentration in each instance (Figure 12).

Mean concentrations of P in Prosopis BSF differed significantly from BPPT for 39% of the rainfall events (Figure 13). The greatest deviations occurred during May through July 1988 period. Concentration ratios of P averaged 4.1 (range = 2.3 to 8.0) (Table 11). Concentrations of P in Zanthoxylum BSF differed significantly from BPPT for 40% of the rainfall events (Figure 13). The range of CR's was relatively small (2.0 to 5.5, mean 3.6) (Table 11). Concentrations of P in Zanthoxylum and Prosopis BSF did not differ significantly from each other (Figure 13).

Regression relationships. Storm size, consecutive days since the last rain (CDSLR), and storm intensity combined to account for 48 to 81% of the variability in Prosopis BSF Ca and P concentrations (Table 14). Mg and K concentrations were correlated with storm size and CDSLR, with these variables explaining 36 to 45% of the variability in BSF concentrations of these nutrients. Storm size, CDSLR, and monthly Prosopis litterfall accounted for 47% of the N concentration variance. Storm size was negatively correlated with concentrations of all nutrients. Storm size explained the most variance for Ca and Mg concentrations (31 to 37%), whereas CDSLR, which was positively correlated, explained the most variance for N and P (30 to 44%). Storm size was a significant variable for only Ca and P concentrations, and explained 10 to 16% of the variability in Prosopis BSF concentrations of these nutrients.

Zanthoxylum BSF Ca and Mg concentrations were correlated with storm size and Zanthoxylum monthly litterfall, with these

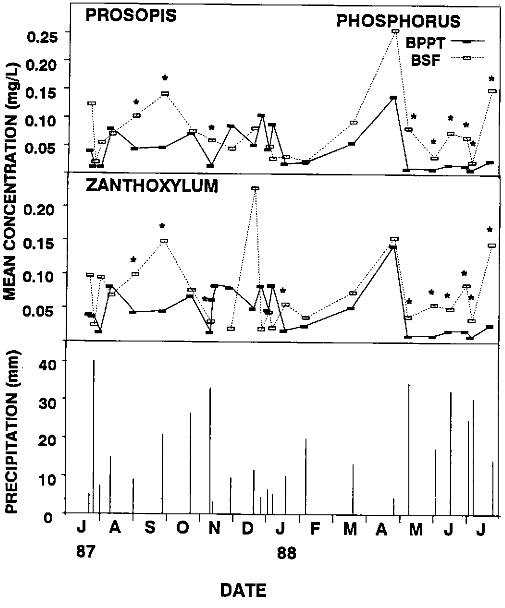


Figure 13. Mean concentration (mg/L) of phosphorus in bulk precipitation (BPPT) and bulk stemflow (BSF) from Prosopis and Zanthoxylum and precipitation amount for rainfall events occurring from July 1987 to July 1988. Paired means associated with an "*" are significantly different (P<0.05) for BPPT and BSF.

Table 14. Results of stepwise regression analysis results (partial R^2s and model R^2s) and Pearson's correlation coefficients (r values) for factors influencing variability in concentrations (mg/L) of selected nutrients in bulk stemflow of Prosopis collected within mixed-shrub clusters.

Nutrient	Variables: PPT[a] (mm)	Litter-fall[b] (kg/ha)	CDLSR[c]	Intensity[d] (mm/min)	Model r and R^2
Calcium					
r value	-0.55	-[1]	0.34	0.38	0.69
partial R^2	0.31	-	0.08	0.10	0.48
Magnesium					
r value	-0.61	-	0.35	-	0.67
partial R^2	0.37	-	0.08	-	0.45
Potassium					
r value	-0.43	-	0.45	-	0.60
partial R^2	0.16	-	0.20	-	0.36
Nitrogen					
r value	-0.35	0.29	0.55	-	0.68
partial R^2	0.09	0.08	0.30	-	0.47
Phosphorus					
r value	-0.45	-	0.66	0.47	0.90
partial R^2	0.19	-	0.44	0.18	0.81

[a] PPT = Mean rainfall amount for each event.
[b] Litterfall = Mean monthly litterfall for Prosopis glandulosa.
[c] CDSLR = Consecutive days since last rainfall event.
[d] Intensity = Rainfall intensity for each event.
[1] Indicates this variable was not selected by the stepwise model.

explaining 47% of the variability in concentrations (Table 15). Storm size explained the greater part of the variance (33 to 34%) for each of these nutrients. BSF K and N concentrations were correlated with storm size, monthly _Zanthoxylum_ litterfall, and CDSLR. Storm size explained more variance in K concentrations (28%), whereas CDSLR accounted for 34% of the N concentration variance. Storm size, CDSLR, and storm intensity explained 41% of the variance in P concentrations. As with _Prosopis_, storm size was negatively correlated with all nutrients, and CDSLR had higher correlations with N and P. The _Zanthoxylum_ monthly litterfall variable accounted for comparable amounts of the variance (13 to 17%) for all nutrients except P.

Mean Annual Concentrations

Bulk throughfall. The mean annual concentration of nutrients found in BTF was significantly greater than that in BPPT for all nutrients except Ca. The mean annual concentration of Ca in BPPT was statistically comparable to that of BTF, primarily because of the extremely high concentration of Ca in BPPT for a rainfall event in late September 1987 (Figure 8). This high concentration cannot be explained readily, but may have resulted from contamination of some samples by bird feces or insects. Exclusion of this data point generated a mean annual concentration of BTF that was slightly higher than BPPT, but not significantly so (Figure 14a; calcium data reflects exclusion of the September storm). Nutrient removal profiles were determined by comparing the magnitude of difference between BTF and BPPT. The term "removal" is used because there is no way to separate leaching from dry deposition effects on concentrations of nutrients. The greater the magnitude of difference in the concentrations of BTF and BPPT for a nutrient, the greater that nutrient was removed from plant canopies (either by leaching or removal of

Table 15. Results of stepwise regression analysis (partial R^2 and model R^2s) and Pearson's correlation coefficients (r values) for factors influencing variability in concentrations (mg/L) of selected nutrients in bulk stemflow of Zanthoxylum collected within mixed-shrub clusters.

Nutrient	Variables				
	PPT[a] (mm)	Litter[b] fall (kg/ha)	CDLSR[c]	Intensity[d] (mm/min)	Model r and R^2
Calcium					
r value	-0.58	0.37	-[1]	-	0.68
partial R^2	0.34	0.13	-	-	0.47
Magnesium					
r value	-0.58	0.36	-	-	0.67
partial R^2	0.33	0.13	-	-	0.46
Potassium					
r value	-0.53	0.41	0.39	-	0.72
partial R^2	0.28	0.17	0.07	-	0.52
Nitrogen					
r value	-0.40	0.55	0.58	-	0.80
partial R^2	0.14	0.16	0.34	-	0.64
Phosphorus					
r value	-0.30	-	0.64	0.33	0.76
partial R^2	0.08	-	0.41	0.09	0.58

[a] PPT = Mean rainfall amount for each event.
[b] Litterfall = Mean monthly litterfall for Zanthoxylum fagara.
[c] CDSLR = Consecutive days since last rainfall event.
[d] Intensity = Rainfall intensity for each event.
[1] Indicates this variable was not selected by the stepwise model.

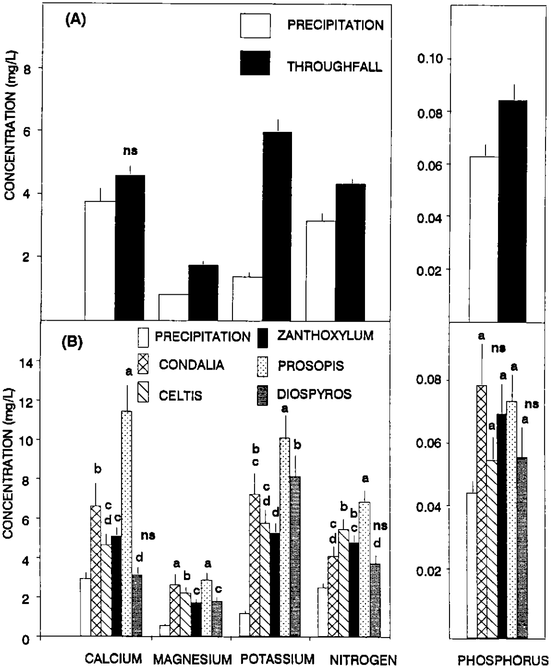


Figure 14. Mean (SE = lines on bars) annual concentrations (mg/L) of nutrients in bulk precipitation, (A) bulk throughfall and (B) bulk stemflow. In (B), species means with the same letter were not significantly different from each other (P>0.05). All means were significantly different from bulk precipitation unless noted with a "ns".

dry deposition from leaf surfaces). The mean annual concentration of K was 4.3 times greater than that of BPPT, indicating the high mobility of this nutrient in plant canopies. Mean annual concentrations of Mg in BTF was 2.1 times that of BPPT. Ca, N and P mean annual concentration ratios in BTF ranged from 1.1 to 1.3 indicating that these nutrients were not as easily removed over time as K and Mg. From these results, a removal profile for BTF in mixed-shrub clusters would be approximately as follows: K > Mg > N = CA = P.

Stemflow. The mean annual concentrations of Ca in BSF significantly differed from BPPT for all species except Diospyros (Figure 14b). Concentrations of Ca in BSF were greatest in Prosopis followed by Condalia, Zanthoxylum, and Celtis. Mean annual concentrations of Mg in BSF differed significantly from BPPT for all species. Condalia and Prosopis had the highest concentrations of Mg, and Zanthoxylum and Diospyros the lowest. Significant differences existed in the mean annual concentrations of K in BSF for all species when compared individually to BPPT. Prosopis had the highest mean annual concentration, followed by Diospyros, and Condalia. Zanthoxylum had the lowest mean annual concentration of K. With the exception of Diospyros, all species had mean annual concentrations of N significantly greater than BPPT. Prosopis had the greatest concentration, followed by Celtis and Zanthoxylum. The mean annual concentrations of P in BSF was significantly different from BPPT for all species except Celtis and Diospyros. No significant differences existed in the mean annual concentrations of P among species. BSF nutrient removal profiles based on annual concentration ratios are given for each species in Table 16.

Total Annual Input

Precipitation and throughfall. Total annual input (g/m^2)

Table 16. Ranked nutrient removal profiles for bulk stemflow (BSF) and throughfall (BTF) collection as determined by the magnitude of difference between the mean annual concentration of stemflow/throughfall and bulk precipitation.

Source	Removal Profile
Bulk Stemflow	
Celtis	K > Mg > N > Ca = P
Condalia	K > Mg > Ca > P = N
Diospyros	K > Mg > N = P = Ca
Prosopis	K > Mg > Ca > N > P
Zanthoxylum	K > Mg > Ca = N = P
Bulk throughfall	K > Mg > N = Ca = P

of nutrients in BPPT was greatest for Ca, followed by N, K, Mg, and P (Figure 15). The total annual input of nutrients via BTF was greater than BPPT. Mean K deposition from BTF was 3.6 times greater than that from BPPT. As a result, annual input from BTF was greatest for K. The deposition ratios for total annual input of BTF were similar (1.5 to 1.8) for Mg, N and P. The total input of Ca by BTF was only 5% greater than that of BPPT. Figure 16 illustrates the difference in total BTF input of nutrients in two mature shrub clusters whose areal extent bracketed the range of mature clusters sizes on the study site.

Stemflow. Annual input of selected nutrients in BSF from collared shrub species was calculated by multiplying the nutrient concentration by the water volume for each rainfall event. Nutrient inputs for individual plants were expressed per unit of canopy area. On a canopy area basis, Diospyros had the greatest total annual input for all nutrients, and Prosopis the lowest (Figure 15). However, Celtis, Diospyros and Condalia comprised a small fraction of the total canopy area within clusters, relative to Zanthoxylum and Prosopis (Table 7) so their input on a per cluster basis would be diminished. AS a result, differences in annual nutrient inputs between clusters A and B generally mirrored differences in the total canopy area of constituent species (Figure 17).

Relative inputs. Total annual inputs of nutrients via BTF and BSF (by species) for two selected shrub clusters (A and B) are summarized in Table 17. BTF generally comprised 97 to 98% of the total nutrient input regardless of cluster. BSF inputs were dominated by Zanthoxylum which averaged approximately 2% and by Prosopis which averaged about 0.5%.

Rainfall event deposition. Figure 18 depicts nutrient deposition by BPPT and BTF+BSF on a per event basis for an average mature shrub cluster having an area of 49.1 m^2 (mean

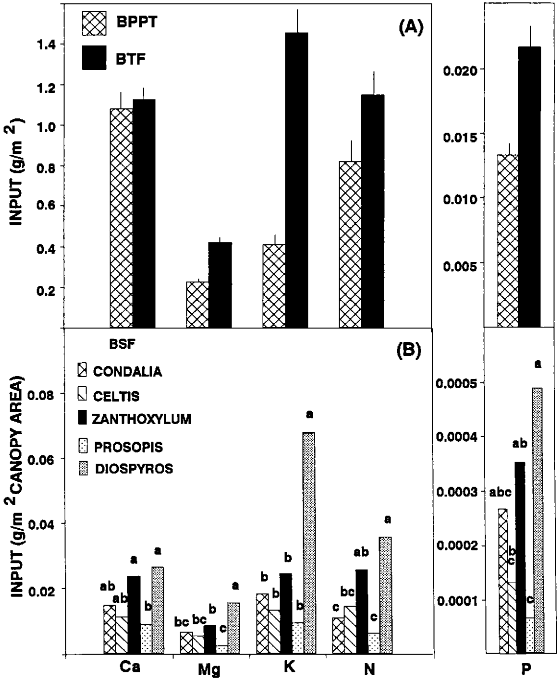


Figure 15. Annual input (g/m^2) for nutrients measured in (A) bulk precipitation (BPPT) and bulk throughfall (BTF) and species (B) bulk stemflow (BSF) within clusters. Means with the same letter were not significantly different from each other (P>0.05).

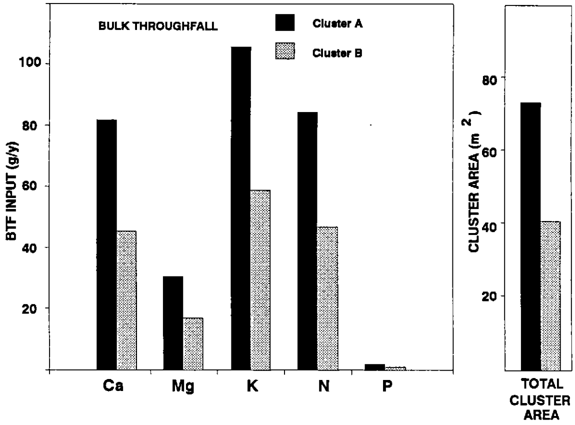


Figure 16. Total annual input (g) of selected nutrients in bulk throughfall within two mixed shrub clusters (A and B) with total cluster areas representing the range in sizes of mature clusters.

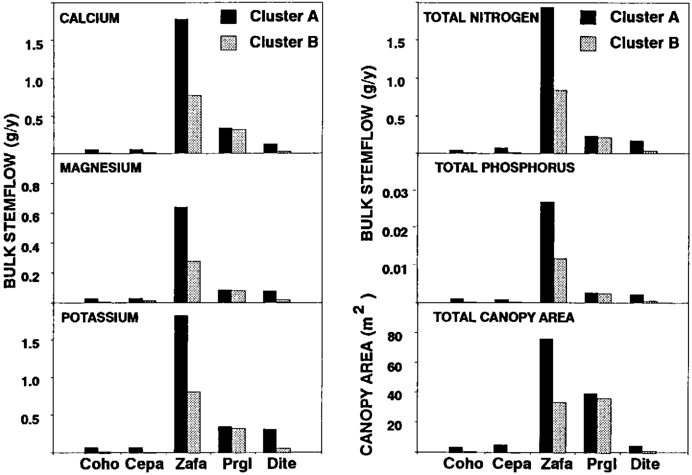


Figure 17. Total annual input of nutrients (g) via bulk stemflow within two mixed-shrub clusters (A and B) for Condalia (Coho) , Celtis (Cepa), Zanthoxylum (Zafa), Prosopis (Prgl) and Diospyros (Dite).

Table 17. Annual input (g) of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorus (P) from bulk throughfall (BTF) and bulk stemflow (BSF) for two mature shrub clusters (A & B) that represent the range of total cluster areas for mature shrub clusters examined.

	Ca	%	Mg	%	K	%	N	%	P	%
CLUSTER A										
BTF	81.76	97.21	30.44	97.31	105.85	97.56	83.95	97.18	1.6060	97.96
BSF										
Condalia	0.05	0.06	0.02	0.07	0.07	0.06	0.04	0.05	0.0010	0.06
Celtis	0.06	0.07	0.03	0.08	0.07	0.06	0.08	0.09	0.0007	0.04
Zanthox.	1.77	2.11	0.64	2.04	1.84	1.70	1.92	2.23	0.0269	1.64
Prosopis	0.34	0.40	0.08	0.26	0.35	0.32	0.23	0.26	0.0026	0.16
Diospyros	0.12	0.15	0.07	0.23	0.32	0.29	0.17	0.19	0.0023	0.14
Total	84.11		31.28		108.49		86.38		1.6395	
CLUSTER B										
BTF	45.36	97.60	16.89	97.84	58.73	98.00	46.58	97.72	0.8910	98.37
BSF										
Condalia	0.01	0.02	0.00	0.02	0.01	0.02	0.01	0.01	0.0002	0.02
Celtis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0000	0.00
Zanthox.	0.77	1.66	0.28	1.62	0.80	1.34	0.84	1.76	0.0117	1.30
Prosopis	0.31	0.67	0.08	0.44	0.32	0.54	0.21	0.44	0.0024	0.26
Diospyros	0.02	0.05	0.01	0.07	0.06	0.10	0.03	0.06	0.0004	0.05
Total	46.48		17.26		59.92		47.66		0.9057	

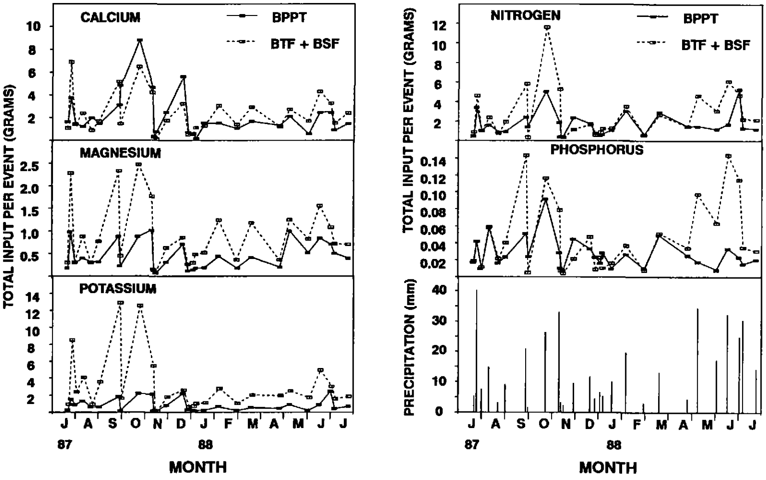


Figure 18. Total input of nutrients per event (grams) for an average mixed shrub cluster and a corresponding herbaceous zone of the same size for the period of July 1987 to July 1988.

shrub cluster area for this study) and a corresponding herbaceous zone of the same area. Herbaceous zones receive nutrient inputs from only BPPT and nutrient input in the cluster would be from BTF+BSF. Stepwise regression analysis chose precipitation amount, total cluster litterfall, and the consecutive days since the last rainfall event (CDSLR) as significant variables influencing deposition of nutrient via combined BTF and BSF. These variables explained >70% of the variation in all nutrient deposition (Table 18).

Precipitation amount was highly correlated with deposition of all nutrients in BTF+BSF. Total monthly cluster litterfall was chosen by the stepwise analysis above that for any species alone. This variable had slightly low correlation coefficients, but explained 10 to 32% of the variability in deposition depending on the nutrient. The CDSLR variable was moderately correlated with deposition of BTF+BSF nutrients, but explained a small (<10%) but significant proportion of the variation in nutrient deposition. The greatest nutrient deposition of Mg, K, N, by BTF+BSF occurred in late September through mid-November, periods characterized by large rainfall events, and high levels of litterfall. Nutrient deposition of P by BTF+BSF was also high during these same months, but was also very high in May and June. This corresponds with the time of high leaching of P by Zanthoxylum seen in the artificial leaching trial. Deposition of all nutrients were very low during the months of December and January, possibly due to the very small amount of precipitation for each of these events.

For several of the small rainfall events, Ca, N, and P deposition of nutrients by BPPT were greater than that of the cluster, indicating possible absorption of these nutrients by the foliage in the canopy.

Table 18. Results of stepwise regression analysis (partial R^2s and model R^2s) and Pearson's correlation coefficients (r values) for factors influencing variability in depositions (g/m^2) of nutrients in bulk throughfall+bulk stemflow collected within mixed-shrub clusters in a south Texas subtropical savanna parkland.

Nutrient	PPT[a] (mm)	Total[b] Cluster Litterfall (kg/ha)	CDSLR[c]	Model r and R^2
<u>Calcium</u>				
r value	0.79	0.25	0.34	0.87
partial R^2	0.62	0.10	0.04	0.76
<u>Magnesium</u>				
r value	0.81	0.32	0.36	0.93
partial R^2	0.66	0.15	0.05	0.86
<u>Potassium</u>				
r value	0.59	0.52	0.35	0.85
partial R^2	0.35	0.32	0.06	0.73
<u>Nitrogen</u>				
r value	0.75	0.28	0.40	0.87
partial R^2	0.57	0.11	0.08	0.76
<u>Phosphorus</u>				
r value	0.71	0.28	0.47	0.86
partial R^2	0.51	0.14	0.09	0.74

[a] PPT = Mean rainfall amount for each event.
[b] Litterfall = Mean monthly litterfall for all species sampled within shrub clusters.
[c] CDSLR = Consecutive days since last rainfall event.

Discussion

Nutrient Mobility

The mobility of nutrients in ecosystems influences the rate of cycling between the plant and soil system. K is a very mobile nutrient with high foliar concentrations (Tukey et al. 1958, Gosz et al. 1973). As a result, recycling of this element within a system can be substantial. In red pine stands, 40% of the foliar K was traced to fertilization of the stand 23 years earlier (Stone and Kszstyniak 1977). High K mobility was apparent in BTF and BSF in shrub clusters. Concentrations of this nutrient in BTF and BSF were generally higher than that of other nutrients examined, and had higher concentration ratios (Figures 8-14; Table 11). Potential leachability of K from shoots was on average two to four times higher than that of other nutrients (Figure 7). Because of the high concentrations of K in BSF and BTF, input per unit area was greater than that of other nutrients.

Mobility of Ca was lower than that of K, but leaching of Ca from plant canopies can be substantial because of accumulation and low retranslocation from apical tissues and leaves (Epstein 1972, Parker 1983). However, potential leachability of Ca was found to be low for all species except Celtis (Figure 7). Concentrations of Ca in BTF and BSF were comparable to or slightly lower than K, but annual concentrations of Ca in BTF were not significantly different from BPPT, further indicating low removal of this nutrient from shrub cluster canopies.

Foliar concentrations of Mg are generally low and the element in not leached easily (Tukey 1970, Parker 1983). However, nutrient removal profiles for BTF and BSF indicated that removal of Mg from shrub clusters was higher than that of all nutrients except K (Table 16), even though the potential leachability of Mg was relatively low (Figure 7). This suggests that Mg in BTF and BSF originated primarily from dry deposition (see later discussion).

Nitrogen removal from shrub cluster canopies was lower than that of K and Mg, but was comparable to Ca and P (Table 16). Although foliar concentrations of N are often high (1-3% D.W.) leaching of N can be quite low (Tukey 1970). The potential leachability of N from species comprising shrub clusters was low for all species except for Prosopis in August and Celtis in July (Figure 7).

Leaching of P is typically quite low because of its immobile organic form within plant tissue (Epstein 1972). P removal profiles indicated that this nutrient had comparable to lower mobility than Ca and N in shrub clusters (Table 16). Concentrations of P in BTF and BSF were the lowest of all nutrients examined. Leachabilty of P from shoots of all species was relatively low and statistically comparable for all dates, with the exception of Zanthoxylum in June.

Leachability of Nutrients from Woody Plant Species

Artificial leaching trials indicated significant differences in retention between species comprising mixed-shrub clusters (Figure 7). Celtis typically leached the greatest amounts of all nutrients other than P throughout the year. Prosopis, the dominant overstory plant, exhibited high levels of retention for all nutrients throughout the year. With the exception of P in Zanthoxylum, leaching potential of other species was generally comparable throughout the year.

Generalizations on the significance of evergreenness as a nutrient conservation adaption would suggest that leaching of nutrients by these growth forms would be low relative to that of deciduous growth forms (Gray 1983). However, leaching of nutrients by the evergreen Zanthoxylum was comparable to or greater than that of other shrub growth forms (Figure 7). This was particularly evident for P in June and was unexpected since evergreen plants are often noted for their phosphorus conservation (Monk 1966, Thomas and Grigal 1976). Zanthoxylum also lost substantial quantities of N and K during this time. The relatively low retention of P by Zanthoxylum and high levels of input via stemflow (Figure 17) may be particularly advantageous to shrubs in the cluster which may potentially fix nitrogen (e.g. Prosopis and Rhannaceous shrubs such as Condalia, Colubrina texensis, and Ziziphus obtusifolia) and thus facilitate their coexistence.

Despite high leaching potentials, the nutrient input by Celtis would appear to be quite low because of low biomass and plant numbers in the cluster (Figure 6, Table 7). This was apparent for total annual input of nutrients via BSF in both shrub clusters examined (Figure 17). Even though the leaching potential of a species may be high to low compared to other species in the cluster, nutrient input via BTF and BSF will be dictated largely by species plant numbers and biomass.

Nutrient Dynamics in Shrub Clusters

Several processes may interact to enhance nutrient concentration of throughfall and stemflow: 1) wet deposition of precipitation (quantity and quality) to the canopy during a rainfall event. The subsequent evaporation of this intercepted water would concentrate nutrients on plant surfaces; 2) removal of dry deposition accumulated upon the leaf and stem surfaces; 3) leaching of nutrients from plant tissues; 4) uptake, sorption or permanent attachments of solutes, gases, or particles by canopy foliage and epiphyllic biota (Parker 1983).

Leaching and dry deposition. Calcium and N annual concentrations in BPPT (4.4 and 3.2 mg/L respectively) at the LCRA were much higher than those reported by Parker (1983) as global averages (Ca= 0.82 mg/L, S.D.= 0.94; N = 0.98 mg/L S.D.= 0.92). Hart and Parent (1974) reported high levels of

Ca (2.44 mg/L) in precipitation in southern Utah and attributed these high levels to dry deposition caused by farming activity on alkaline soils near the study site. The high amount of N in BPPT cannot be explained readily, but might be caused by fixation of N by lightning during convectional thunderstorms that were prevalent during the study period. Mg, K and P were within the range of values for global concentration averages reported by Parker (1983).

Potassium had the highest BTF and BSF concentration and deposition ratios of all nutrients (Tables 8 and 17) and greatest leachability (Figure 7). Given the low concentrations of K observed in bulk precipitation, and the potentially high concentrations of K in leaves, most of the K in throughfall and stemflow would have been derived from leaching of leaf tissue rather than removal of dry deposition (Parker 1983). The high concentrations of K in BSF exhibited by Prosopis during the winter (Figure 11) would indicate possible influences of dry deposition, sap seepage, or latent litterfall in the Prosopis canopy (Enright 1987). Magnesium concentration and deposition ratios for BTF and BSF were lower than K but slightly higher than or comparable to the other nutrients (Tables 11 and 19), but leaching of this nutrient was low (Figure 7). Plant canopies can generally increase deposition of Mg by a factor of 7 relative to precipitation, and 50 to 70% of this enhancement of throughfall is associated with dry deposition of Mg (Parker 1983). The low leaching potential of Mg by the species in this study (Figure 7) indicate that dry deposition of Mg on plant surfaces contributed substantially to Mg levels in BTF and BSF.

The annual BPPT concentration of Ca was comparable to that of BTF causing the concentration ratio for Ca to be lower than that of other nutrients (Table 19). Leaching of Ca was low among species except for Celtis, therefore enhancements in

Table 19. Concentration and deposition ratios based on mean annual concentrations and annual inputs of selected nutrients in bulk throughfall (BTF) and stemflow (BSF) in mixed-shrub clusters in a south Texas subtropical savanna parkland.

Source	Ca	Mg	K	N	P
Concentration Ratios					
BTF	1.1	2.1	4.3	1.4	1.3
BSF					
Celtis	1.6	3.8	4.9	2.2	1.2
Condalia	2.2	4.6	6.1	1.6	1.8
Diospyros	1.1	3.1	7.0	1.5	1.3
Prosopis	3.9	5.0	8.5	2.7	1.6
Zanthoxylum	1.7	3.0	4.5	1.9	1.6
Deposition Ratios					
BTF	1.03	1.8	3.5	1.4	1.6
BSF					
Celtis	0.010	0.022	0.031	0.017	0.010
Condalia	0.013	0.027	0.043	0.013	0.020
Diospyros	0.024	0.066	0.162	0.043	0.037
Prosopis	0.008	0.009	0.022	0.007	0.005
Zanthoxylum	0.021	0.036	0.058	0.031	0.026

nutrient concentrations in BTF and BSF would possibly be augmented by dry deposition. Dry deposition of Ca via sedimentation has been observed near alkali flats (Parent 1972, Hart and Parent, 1974), plowed fields and unpaved roads (Parker 1983). The study site was within 2 km of plowed fields on the prevailing wind side of the area. Four dirt roads, some covered with caliche (calcium carbonate), were located near the exclosure where precipitation, throughfall and stemflow were collected. These could have been significant sources of Ca for dry deposition. Dry deposition of Ca may also be high in coastal areas (Art et al. 1974). The La Copita Research Area is approximately 96 km west of the Gulf of Mexico, where many precipitation events originate. Precipitation originating in air masses directly over the ocean generally have a Ca/Mg ratio approaching that of sea water (0.196), whereas precipitation events originating over land often have greater Ca/Mg ratios (Eaton et al 1973). The average Ca/Mg ratio for rainfall events occurring during the study period was 5.5 (range = 1.0 to 22.8) indicating that the Ca collected was primarily from terrestrial sources.

Nitrogen in BTF exceeded that of BPPT for less than half of the events during the study period. The mean annual concentration ratio was 1.36, indicating that it was not removed as easily as K and Mg from the cluster canopies (Table 19). The artificial leaching trials indicated N was leachable in varying amounts by the species in the clusters, but in the December trial, there was absorption of N by the species biomass which was statistically significant for Zanthoxylum (Figure 7). Total nitrogen removal from precipitation has been reported (e.g. Miller 1963, Carlisle et. al. 1966, Foster and Gessel 1972, Foster 1974, Rolfe et al. 1978, and Jordan et al. 1980), and this may be a mechanism of nitrogen conservation by plants (Parker 1983). Annual deposition of N was exceeded only by K. However, the deposition ratio was lower than that of all nutrients examined (DR =1.4), because of the high concentrations of N in bulk precipitation.

P concentrations in BTF and BSF were lowest of the nutrients examined (Figure 14). Leaching of phosphorus was apparent in the artificial leaching trials, especially by Zanthoxylum during June (Figure 7). Dry deposition of phosphorus via sedimentation can occur, but the phosphorus is not very soluble in precipitation (Parker 1983). Concentration ratios and deposition ratios of P indicated enhancement of bulk throughfall by the shrub canopies (Table 19). This enhancement was possibly due more to leaching of P (especially by Zanthoxylum during June), rather than by dry deposition.

Stemflow deposition. Zanthoxylum generally had the lowest annual concentrations of all nutrients in BSF among the species, but greater nutrient input per unit of canopy area than all species but Diospyros (Figure 14 and 15). Conversely, Prosopis had the highest annual BSF concentrations for all nutrients except P, but deposition per unit of canopy area was the lowest of all species. Condalia and Celtis were generally intermediate in annual concentrations and deposition of nutrients in BSF. Diospyros had BSF annual concentrations of nutrients that were comparable to Zanthoxylum, but total deposition per unit of canopy area was much greater. These differences were caused by the differences in the volume of stemflow produced by the species. For a given rainfall event, Diospyros and Zanthoxylum generally had greater volume of stemflow than the other species (see Chapter V). Even though concentrations of BSF were generally low for Zanthoxylum and Diospyros, the greater volume of stemflow produced by these species led to greater deposition per unit of plant canopy area. Conversely, Prosopis generally had high concentrations of nutrients in BSF, but stemflow volume was less, thus causing lower deposition. Deposition ratios for BSF were always less than 1 (Table 19) indicating that deposition of nutrients via BSF on an area basis was less than that of BPPT because of greater input per unit area by BPPT. The differential water input by the species within the cluster is evident when examining annual deposition ratios. Diospyros, followed by Zanthoxylum, generally had much higher deposition ratios, whereas Prosopis generally had low deposition ratios (Table 19).

Variables Influencing Concentrations and Depositions

For BTF and BSF concentrations (Prosopis and Zanthoxylum only), storm size was always negatively correlated with nutrient concentrations (Tables 10, 12, and 14). This most likely reflects the fact that nutrients are leached or removed most easily during the early stages of plant wetting, and increasing amounts of precipitation have a subsequent diluting effect (Clements et al. 1972). BTF+BSF depositions were positively correlated with storm size indicating that deposition increased as water input increased (Table 18). The consecutive days since the last rainfall event was positively correlated with and explained approximately 17 to 44% of the variability in the concentrations of N and P in BTF and BSF. The length of the dry period could have allowed increased dry deposition of these nutrients. However, N input via dry deposition may be absorbed readily by leaves, whereas that of P is usually in a form not soluble in precipitation (Parker 1983). High concentrations (Figure 8, 12, and 13) of these nutrients relative to precipitation may therefore reflect increased leaching by water stressed-plants.

The greatest CR's for N and P occurred during April, May and June (Figure 8, 12, 13) and leachability of Celtis and Zanthoxylum shoots were greatest during June (Figure 7).

During this period of leaf expansion and canopy development, nutrient concentrations in foliage might be relatively high and cuticular development relatively low. Although Tukey et al. (1965) reported that quick incorporation of nutrients into young plant tissues reduced leaching at this stage of development, results from this study suggest that leaching was relatively high during early stages of leaf expansion and growth. The consecutive days since the last rainfall event was slightly correlated with BTF+BSF depositions, but explained a small (<9%) but significant proportion of the variation in nutrient deposition.

Zanthoxylum monthly litterfall explained 23 to 62% of the variance in concentrations of all nutrients in BTF. The *Zanthoxylum* monthly litterfall variable was selected for each BTF nutrient over monthly litterfall values for the other species and all species combined, reflecting the dominant role of this species in BTF nutrient removal on a seasonal basis. *Zanthoxylum* monthly litterfall was positively correlated for all nutrients indicating higher concentrations of nutrients when litterfall increased. This may reflect increased leaching of nutrients from senescing leaves which may be more permeable because of cuticle breakdown (Thomas 1969). Litterfall from *Zanthoxylum* was important in explaining variability in *Zanthoxylum* BSF concentrations, whereas litterfall from *Prosopis* was not an important variable in explaining *Prosopis* BSF concentrations. *Prosopis* did not maintain foliage in the canopy from late December 1987 to mid-March 1988. Even so, concentrations of Ca, Mg, and K in BSF were significantly elevated above that of BPPT and above that of the foliated evergreen *Zanthoxylum*, reflecting the importance of dry deposition relative to foliar leaching for inputs of these nutrients (Figures 9,10 and 11). Woody plants such as *Prosopis* with rough, reticulated bark may accumulate and store more dry deposited nutrients than smooth bark species (Voight 1960). Total shrub cluster litterfall was selected as a variable influencing deposition of BTF+BSF nutrients over that for any species alone by the stepwise analysis, and explained 10 to 32% of the variance for all nutrients (Table 18), thus indicating the influence of all species on deposition of nutrients.

Landscape Nutrient Inputs

At the LCRA, Prosopis glandulosa establishes in herbaceous zones on sandy loam uplands, adds vertical structure which attracts birds disseminating seed of other woody plants, and modifies the soils and microclimate to facilitate the germination and/or establishment of other woody species (Archer et al. 1988). As the shrub clusters develop, organic carbon and various soil nutrients increase relative to herbaceous zones (Loomis 1989). The data from this study indicate that throughfall and stemflow nutrient inputs play a role in enhancing the nutrient status of the soils associated with shrub clusters.

The mixture of species within the cluster would influence both nutrient removal and input. Clusters used for stemflow and throughfall collection were dominated by Prosopis and Zanthoxylum, each contributing approximately 39% to the total canopy area (Table 7). These species represent contrasting growth forms, with Prosopis being a deciduous species and Zanthoxylum being evergreen. Diospyros, Celtis, and Condalia appear to represent facultative evergreen growth forms (see Chapter III), but these species contributed only small amounts to the total cluster canopy area and numbers of plants. Leaf biomass above throughfall collectors within mature clusters was dominated by Zanthoxylum (51%) (Figure 6). As a result, stemflow and throughfall nutrient input dynamics were largely dictated by this species (Figure 17).

Average yearly nutrient input or deposition in mature mixed-shrub clusters will vary depending on the size of the cluster and its species composition (Figure 16 and 17). Relative to BSF, BTF generally comprises >95% of the cluster nutrient input regardless of cluster size or nutrient (Table 17). Bulk stemflow by Zanthoxylum has the largest relative total inputs (generally about 2%), reflecting the large amount of total canopy area and biomass of this species within the cluster and large water flux.

Although relative inputs of nutrients in BSF were much lower than that of BTF, these inputs are biologically significant and do not necessarily represent a loss to the plant. Stemflow enters the soil in a narrow zone near the base of the tree or shrub (Gersper and Holowaychuck 1971), where infiltration rates are high (Thurow et al. 1987), and small feeder roots may proliferate and reabsorb the nutrients (Young et al. 1984). The nutrient input would be directed to this small area, therefore leading to a concentration of nutrients in this restricted area compared to areas receiving only throughfall. The effect this has on shrub species composition and species comprising the cluster is unknown, but may be important.

Comparisons With Other Systems

The total annual input of nutrients from BPPT and BTF for these mixed shrub clusters in southern Texas were compared to those reported for other ecosystems in Table 20. Many of the references in the table are for forest vegetation types. Few sources were found pertaining to shrublands and savannas.

Calcium and N in BPPT from this study are generally higher than those reported for other systems, except for the Plateau and Valley forests of the Ivory Coast. Mg, K, and P deposition BPPT were intermediate for the areas reported. The high Ca input from BPPT seen in this study lowered the BTF

Table 20. Total annual input of nutrients (kg/ha/yr) via bulk throughfall and bulk precipitation for mixed shrub clusters in a south Texas subtropical savanna and other regions and vegetation types of the world (taken from Parker 1983).

Region	Vegetation type	Flux	Ca	Mg	K	N	P	Citation
South Texas	Prosopis mixed-shrubs	BTF	11.22	4.18	14.51	11.52	0.22	This
		BPPT	10.86	2.30	4.17	8.52	0.13	study
Washington	Douglas fir	BTF	6.50	3.40	21.83	4.65	2.92	Abee et al.
		BPPT	2.09	1.27	0.11	1.30	0.23	1972
Ivory Coast	Plateau forest	BTF	39.50	41.00	65.00	79.50	2.20	Bernhard-
	Valley forest	BTF	46.50	48.50	174.50	81.00	9.80	Renverstat
		BPPT	24.00	4.30	5.80	25.00	1.60	1975
North Carolina	Swamp forest	BTF	15.30	7.60	12.00	10.30	1.60	Brinson
		BPPT	4.80	1.40	3.00	5.80	0.50	et al. 1980
England	Oakwood	BTF	17.18	9.36	28.14	8.82	1.31	Carlisle et
		BPPT	7.30	4.63	2.96	9.54	0.43	al. 1966
Puerto Rico	Tropical evergreens	BTF	27.00	49.10	82.80	-	-	Clements &
		BPPT	6.40	19.80	8.90	-	-	Colon 1975
Northern	Paper birch	BTF	9.06	2.00	11.80	3.59	0.93	Comer-
Minnesota	Red pine	BTF	7.30	1.45	5.45	4.37	0.13	ford and
		BPPT	6.03	0.82	1.92	2.85	0.31	White 1977

Table 20. continued.

Region	Vegetation type	Flux	Ca	Mg	K	Tot. N	Tot. P	Citation
New Hampshire	Northern Hardwoods	BTF	7.62	2.17	30.45	11.71	0.73	Eaton et
		BPPT	0.89	0.17	0.37	1.89	0.05	al. 1973
Southern	Chaparral	BTF	3.10	0.90	9.40	1.90	0.00	Gray 1983
California	Coastal sage scrub	BTF	4.70	1.30	11.40	0.90	0.00	
		BPPT	-	-	-	-	-	
Oklahoma	Post oak-	BTF	12.10	2.77	15.00	14.30	2.07	Johnson and
	Blackjack oak	BPPT	3.90	0.86	4.00	3.90	1.07	Risser 1974
Costa Rica	Tropical forest	BTF	0.37	1.70	1.14	0.13	3.07	McColl 1970
		BPPT	0.56	2.13	0.74	0.00	1.09	
Nevada	Jeffrey pine	BTF	5.17	2.72	6.83	9.61	2.03	Stark 1973
		BPPT	0.36	0.14	0.58	5.10	0.19	

deposition ratio. Therefore deposition of Ca in BTF in mixed-shrub clusters is much lower than that for other vegetation types. Annual inputs for Mg, K, and N in BTF were comparable to those in Post oak-Blackjack oak (Quercus stellata and merilandica) vegetation in Oklahoma, and paper birch (Betula papyrifera) and red pine (Pinus resinosa) in Northern Minnesota. BTF annual deposition of P was lower than that reported for any vegetation type except the chaparral and coastal sage scrub vegetation in Southern California which had levels of P that were undetectable (Gray 1983).

Conclusions

Nutrient input via throughfall and stemflow in mixed-shrub clusters appears to be a very dynamic process, the net outcome reflecting interactions among foliar leaching, foliar absorption, and dry deposition. Bulk throughfall and stemflow contributed >96% and <5% ,respectively, of precipitation-related nutrient deposition. Bulk throughfall and stemflow depositions of nutrients were highest during periods of high litterfall and large rainfall events. Growth form differences were apparent in leaching trials, especially with P for Zanthoxylum, and the influence of growth forms differences between Prosopis and Zanthoxylum were seen in bulk stemflow concentrations and depositions. Zanthoxylum, because of its domination of canopy area and biomass throughout the year within the shrub clusters, had the greatest effect on nutrient input. Precipitation amount played a key role in influencing both concentration and total deposition of nutrients, with larger rainfall events having greater deposition.

The above processes may have implications for succession on sandy loam uplands in southern Texas. In the successional development mixed shrub clusters on sandy loam uplands, Prosopis, a nitrogen fixing plant (Johnson and Mayeux 1990), is the first to establish and modifies the soil and microclimate beneath its canopy, thus facilitating the ingress of other woody species. The role of Prosopis throughfall and stemflow in this modification appears to be minor due to low relative leaching and inputs of nutrients, especially nitrogen. Modification of the N content of soils beneath Prosopis canopies over time would therefore be primarily a result of foliar or root litter decomposition. Zanthoxylum is usually one of the first shrubs to appear beneath the Prosopis canopy in the development of shrub clusters. Results from this study indicate that this species plays a major role in the cycling of phosphorus within the cluster. Leaching and depositions of P by Zanthoxylum may be advantageous to the shrubs having the potential to fix nitrogen in the cluster.

CHAPTER V

THROUGHFALL AND STEMFLOW QUANTITY AND CANOPY INTERCEPTION LOSS

Introduction

Water is typically the most limiting resource influencing plant production in arid and semiarid ecosystems. When moisture in the form of precipitation comes in contact with vegetation, it reaches soil via stemflow (water traveling down plant stems) and throughfall (water passing through a plant canopy). Rainfall retained by the canopy leaves and stems may be either evaporated into the atmosphere or absorbed (Hamilton and Rowe 1949) and may lead to a decrease in the amount of water reaching the soil surface (Parker 1983). This reduction in water quantity caused by the plant canopies is termed interception loss.

Plant canopy architecture influences the amount and distribution of throughfall and stemflow water, and thus the amount lost to interception (Parker 1983). Factors such as open spaces in the canopy (Tamm 1951) and crown density (Anderson et al. 1969, Nicholson et al. 1980), influence the quantity of throughfall and stemflow. Canopies that have many open spaces and that have low density of leaves generally produce more throughfall. Canopy storage capacity is a function of leaf area, leaf area index, leaf surface tension forces, storm intensity, and mechanical movement in the canopy (Leonard 1965). Bark texture (Voight 1960, Voight and Zwolinski 1964), stem diameter (Kittredge 1948) and branch angle (Mina 1965, Herwitz 1986) can influence the quantity of stemflow. Trees or shrubs with large crowns and raised branches with smooth bark produce the most stemflow (Parker

1983). Growth form differences can influence the deposition of water beneath plant canopies. Evergreen species generally have greater annual interception losses than deciduous species which drop their foliage during portions of the year (Branson et al. 1972). Studies dealing with throughfall, stemflow, and interception by shrubs are few and have been limited to California chaparral (Hamilton and Rowe 1949), juniper (Juniperus occidenatalis) (Young et al. 1984), live oak (Quercus virginiana)(Thurow et. al. 1987), creosotebush (Larrea tridentata) and tarbush (Florensia cernua) (Tromble 1987). These studies generally indicate that much variability exists in throughfall and stemflow production among shrub species, and interception losses can range from 4 to 30% of the annual rainfall.

Trees and shrubs can augment bulk rainfall input by intercepting and concentrating the rainfall at their stem/trunk base where infiltration rates can be higher than that in areas away from the tree or shrub, thus increasing the amount of rainfall received in this small area. In live oak clusters in the Edwards plateau of Texas, the soil in a 100 mm radius from the bole beneath a single live oak tree can receive 222% of the annual rainfall, whereas the soil more than 100 mm away would only receive 59% of the annual rainfall (Thurow et al. 1987). The drier area away from the trunk would be less conducive for plant growth and establishment (Thurow et al. 1987). Stemflow input from mulga (Acacia anuera) was six times greater within a 45 mm radius of the trunk, and this increased input allowed greater storage of water in the rooting zone of mulga (Pressland 1973). Interception losses are variable among trees and shrubs; however, the shading by tree or shrub canopies may decrease soil temperatures and thus decrease evaporative losses. This may offset losses due to canopy interception. Canopy interception losses are generally a function of storm size, with small storms having greater interception losses than larger storms (Rowe 1948, Hamilton and Rowe 1949). Areas and/or seasons having large percentages of small rainfall events would thus have smaller percentages of incoming rainfall reaching the soil surface beneath plant canopies which could reduce growth and establishment of the plants.

In this study, annual throughfall, stemflow, and interception fluxes within discrete shrub clusters with a Prosopis glandulosa overstory and a mixed-species overstory were quantified in order to ascertain the extent to which bulk rainfall input to soil is modified by these vegetation units. Mixed shrub clusters contain high densities of plants (Archer et al. 1988) and multiple vertical stratum. Prosopis comprises the upper stratum, large Zanthoxylum plants in the second stratum, and medium and small Zanthoxylum and the other species comprising the lower stratum. This layering effect would be expected to influence the amount of precipitation reaching the soil surface as throughfall and stemflow. It was hypothesized that Prosopis glandulosa, because of its large stature and canopy area would have large stemflow inputs within the shrub cluster. Zanthoxylum fagara would also have large stemflow inputs because of the large number of plants and total canopy area within clusters. Diospyros texana, Celtis pallida, and Condalia hookeri would have lower inputs because of low numbers of individual plants and total canopy area. Canopy interception by shrub clusters was hypothesized to be high for shrub clusters because of the high density of the canopies within clusters.

On sandy loam uplands in southern Texas, Prosopis glandulosa establishes in the herbaceous zones, adds vertical structure which attracts birds disseminating seed of other woody plants, and modifies the soils and microclimate to facilitate the ingress and establishment of other woody species (Archer et al. 1988). The role of throughfall, stemflow, and interception losses in the facilitation process may be important for both nutrients (see Chapter IV) and quantity of water reaching the soil surface. The establishment of Prosopis in the herbaceous zones may act to increase and concentrate the quantity of water reaching the soil surface near the base of the shrub, thus increasing soil moisture status which might allow other woody species to have a favorable environment for germination and establishment. Interception loss from the Prosopis canopy in the early stages of cluster development might also be low, further increasing the amount of water reaching the soil beneath the canopy. As new species establish beneath the Prosopis canopy, interception losses would probably increase, but concentration or funneling of water would still be prevalent by all species in the cluster. As clusters mature, canopy interception loss might be substantial because of the density of the canopies and the large amount of canopy area.

Materials and Methods

Precipitation, Throughfall and Stemflow Collection

Bulk throughfall (BTF) and bulk stemflow (BSF) in clusters and bulk precipitation (BPPT) in herbaceous zones were collected as described in Chapter IV. Total quantity of water per unit time was calculated for BPPT and BTF by taking the volume of water collected for each collector during a precipitation event and dividing it by the appropriate area factor (funnel area for BPPT and collection trough area for BTF) to determine surface depth of water (mm). Because of no definite area for stemflow collectors, the canopy area was used as the collector area. Canopy area and plant species numbers for each cluster were determined by measuring canopy projection in two directions to calculate canopy area and by counting individual plant species within the confines of the shrub cluster. Height, basal diameter, and distance from the central Prosopis plant were also noted to further characterize the species within the shrub cluster.

Stemflow was collected from a subset of plants within the shrub clusters. Because of the large number of individual plants per cluster, it would have been impossible to collect stemflow from every plant within the cluster. Therefore, the plants collared for stemflow collection were used to create regression equations in order to extrapolate stemflow input for all plants on a shrub cluster basis, and to determine trends in stemflow amounts among species. Because of the large number of Zanthoxylum plants of varying size within shrub clusters, the stemflow data were analyzed by canopy area classes. Small plants were designated as plants with canopy area $\leq 1.0\ m^2$; medium plants were those with a canopy area 1.0 to 2.0 m^2;, and large plants had a canopy area $>2.01\ m^2$.

Collection of BTF with troughs allowed calculation of throughfall on a per cluster basis. BSF production on cluster basis was determined by applying regression models to individual plants within the cluster. Total BTF and BSF were then subtracted from BPPT to estimate interception loss.

Statistical Analyses

Precipitation and throughfall quantity was analyzed using a split plot design with rainfall event (storm) and shrub cluster as the main plot variables and direction and flux (BPPT or BTF) as the sub plot variables. The mean square error of the storm * cluster interaction was used as the error term to test significance of rainfall event and shrub cluster in the model. The significance of all other variables and associated interactions was tested using the full model mean square error. Fischer's least significant difference (LSD) procedure was used for mean separations (alpha = 0.05 unless otherwise noted). The LSD was calculated using the error term that was used in the F-test for significance of a given variable or interaction in the model. This analysis was conducted using the GLM procedure described in the SAS/STAT guide (SAS 1987). Linear and nonlinear regression was used to determine prediction equations for mean throughfall, stemflow and interception amounts.

Results

Precipitation and Throughfall

Throughfall data were obtained from 28 rainfall events between July 1987 and July 1988. Results of the split-plot analysis of variance for the main effects and interactions influencing BPPT and BTF volume are summarized in Table 21. The interaction of flux (BPPT or BTF) and direction was significant with BTF inside clusters being slightly but significantly greater in the north and east quadrants (Figure 19a). BPPT volume was not influenced by direction (Figure 19a). Although significant differences existed in the fluxes among clusters (Table 21) with two clusters in the western portion of the study site receiving more BPPT than those in the eastern portion, these differences were not reflected in BTF which varied inconsistently between clusters (Figure 19b). An analysis of throughfall directional means within storms indicated that significant differences in directional throughfall generally did not occur until precipitation was >19 mm.

BTF and BPPT were highly correlated in a linear fashion (R^2 = 96%). Variability among shrub clusters existed, but no consistent trends could be detected (Figure 20). Throughfall averaged 76.5% $\pm$ 1.0% of BPPT and was not significantly influenced over the range of storm sizes encountered or among

Table 21. Significance tests for split-plot model used to determine sources of variation in water input (mm) from bulk precipitation and throughfall (Flux), shrub cluster, rainfall event (storm), and direction and the associated interactions of these variables. The storm and cluster variables were tested using the mean square error (MSE) for the Type III sums of squares for the storm x cluster interaction. All other variables and interactions were tested using the full model mean square error.

SOURCE	F Value	Pr>F
Model	81.4	0.0001
Storm	999.9	0.0001
Cluster	12.3	0.0008
Storm x cluster	1.6	0.0001
Flux	659.8	0.0001
Direction	12.2	0.0001
Cluster x direction	4.7	0.0001
Storm x direction	2.3	0.0001
Flux x direction	9.7	0.0001
Storm x flux	17.0	0.0001
Cluster x flux	8.3	0.0001
Storm x flux x direction	1.7	0.0002
Cluster x flux x direction	3.3	0.0001
Test using MSE for Storm x cluster as error term		
Storm	642.5	0.0001
Cluster	7.9	0.0001
Model R^2	0.976	

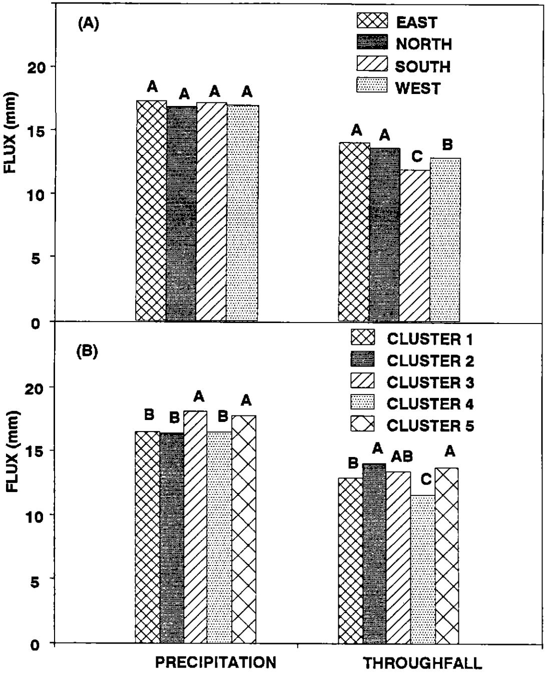


Figure 19. Mean annual precipitation and throughfall fluxes (mm) within mixed shrub clusters. For each variable, means with the same letter were not significantly different (P>0.05).

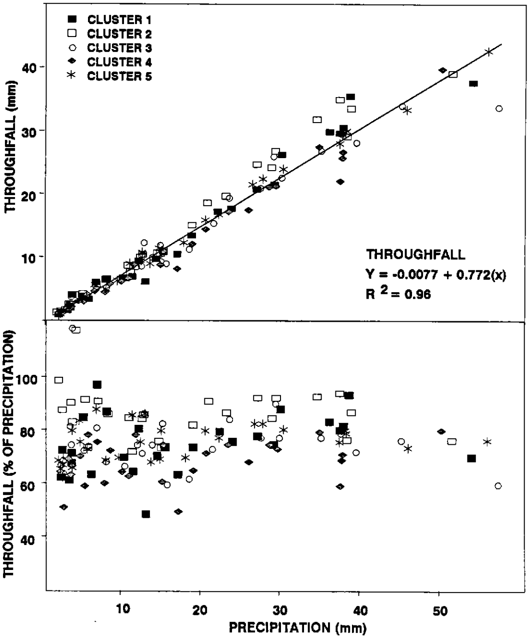


Figure 20. Observed and predicted (Y) throughfall (mm) and throughfall as a proportion of precipitation for shrub clusters. Symbols designate the individual shrub cluster amounts for each storm.

shrub clusters (Figure 20).

Stemflow

Despite substantial differences in size (height, basal stem diameter, and canopy area) and growth forms (Tables 1 and 7) there are few differences with regard to volume of peak stemflow or the size of storm required to induce stemflow (Table 22). Stemflow was typically initiated when BPPT input reached 2.0 to 4.5 mm and the relationship between BSF and BPPT was linear and positive (Figures 21 and 22). Peak BSF input (for the 50 mm precipitation event) ranged from 0.42 mm/plant for Prosopis to 1.87 mm/plant for Diospyros.

Significant differences existed in the slopes of the regression equations used for BSF prediction. The results of these analyses are summarized in Table 23. Diospyros and small Zanthoxylum plants had the largest slope values (Table 22) and were significantly different from all others. Prosopis had the lowest slope (Table 22) and was significantly different from the other species. Celtis, Condalia and large Zanthoxylum plants had comparable slopes (Table 23) and were not significantly different.

Shrub Cluster Throughfall, Stemflow and Interception Loss

The trough collection procedure used for BTF allowed calculation of throughfall on a shrub cluster basis. BSF production on a cluster basis was calculated by applying species-specific regression models in Figures 21 and 22 to individual plants within the cluster. Total BSF and BTF were then subtracted from BPPT to obtain estimated interception loss for each shrub cluster and each rainfall event.

The relationship between species-specific BSF input into cluster soils and BPPT was sigmoidal (Figure 23). The proportion of BPPT entering cluster soils was fairly constant for rainfall events exceeding 20 to 30 mm. Relative contribution of BSF to soil moisture was lowest for overstory

Table 22. Summary of stemflow properties of the five species used for bulk stemflow (BSF) collection in a south Texas subtropical savanna parkland.

Species	Storm size (mm) required to initiate BSF	Peak BSF input (mm)	Regression Slope	R^2
Celtis	2.4	0.50	0.127	0.93
Condalia	4.0	0.65	0.131	0.66
Diospyros	2.5	1.87	0.0513	0.91
Prosopis	4.5	0.42	0.0061	0.81
Zanthoxylum[1]				
Small	4.0	1.50	0.0335	0.89
Medium	4.0	0.68	0.0166	0.84
Large	4.5	0.80	0.0196	0.89

[1] Zanthoxylum sizes correspond with canopy area as follows:
Small = $\leq 1.0\ m^2$
Medium = 1.0 to $2.0\ m^2$
Large = $> 2.0\ m^2$

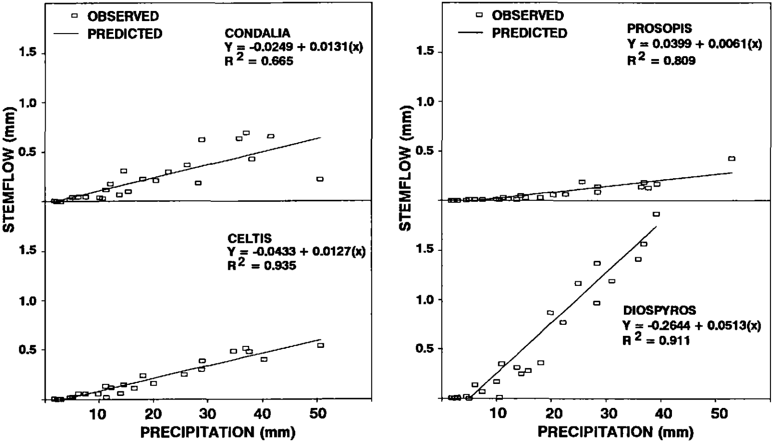


Figure 21. Observed and predicted (Y) stemflow (mm) vs. storm size (X) for selected shrubs comprising mixed shrub clusters in a south Texas subtropical savanna parkland.

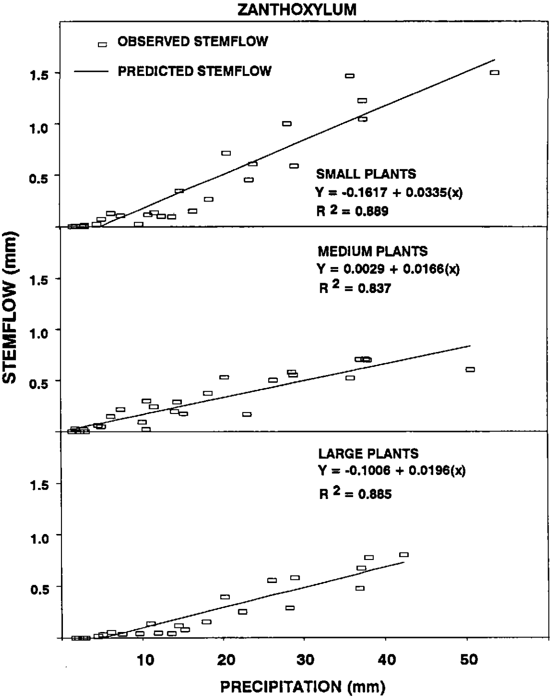


Figure 22. Observed and predicted (Y) stemflow (mm) as related to storm size (X) for Zanthoxylum fagara size classes in mixed shrub clusters in a south Texas subtropical savanna parkland. See table 22 for size class designations.

Table 23. Levels of significance for tests for differences in slopes of regression lines among species used for collection of bulk stemflow (mm) in a south Texas subtropical savanna parkland.

Species	Condalia	Celtis	Zanthoxylum Small	Zanthoxylum Med.	Zanthoxylum Large	Prosopis	Diospyros
Condalia	---	ns[1]	**	*	ns	**	**
Celtis	ns	---	**	**	ns	**	**
Zanthoxylum							
Small	**	**	---	*	**	**	**
Medium	*	**	*	---	ns	**	**
Large	ns	ns	**	ns	---	**	**
Prosopis	**	**	**	**	**	---	**
Diospyros	**	**	**	**	**	**	---

[1] indicates significance of the F test for the corresponding species in the row by column matrix as follows:
*** = < 0.0001 ** = 0.0001 to 0.01
* = 0.01 to 0.05 ns = not significant (>0.05)

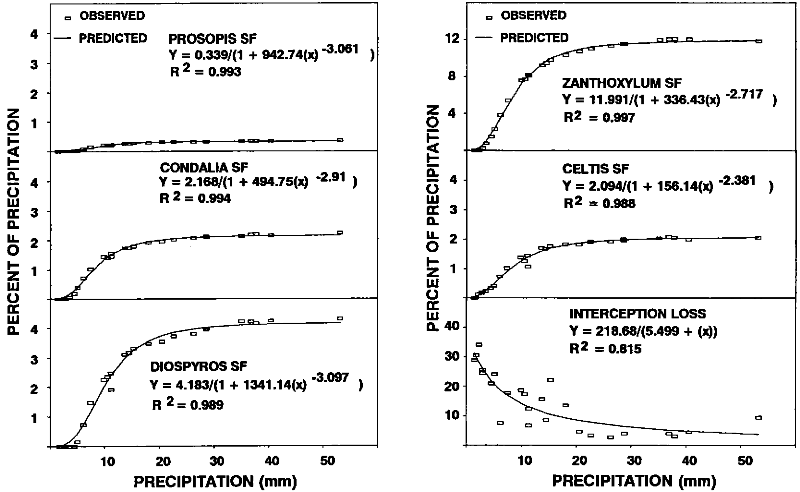


Figure 23. Observed and predicted (Y) stemflow (SF) input and interception loss as a percent of precipitation for shrub clusters as a function of storm size (mm).

Prosopis (<1% BPPT) and greatest for *Zanthoxylum* (1 to 12% for storms 4 to 53 mm). Shrub cluster interception loss expressed as a percent of precipitation was best described with a modified inverse function (Figure 23). Interception losses were fairly constant at approximately 5% of BPPT for rainfall events >20 mm. Cluster-to-cluster differences in the annual input of BPPT, BTF, and BSF are shown in Figure 24. The shrub clusters used in this study differed primarily in the number and size of *Zanthoxylum* plants (Table 24).

Annual BPPT measured at the five clusters averaged 473 mm. Interception losses averaged 34 mm or 7.2% of BPPT (Table 25). Of the 439 mm reaching the soil surface, 77.2% was input as BTF and 15.8% as BSF. BSF inputs were greatest for *Zanthoxylum* and least for *Prosopis*.

Discussion

Average annual throughfall in shrub clusters was 77% of BPPT in southern Texas systems. This value was comparable to live oak clusters in central Texas, and fell within the range of throughfall values reported in other ecosystems (Table 26). Annual stemflow was comparable to that produced by *Ceanothus cuneatus* and *Aesculus californica* (Table 26). Interception loss for shrub clusters was most like that of California chaparral, but was lower than that reported for other systems except lone *Prosopis* plants in northern Texas (Table 26).

Cluster and Flux Differences

Precipitation amounts varied significantly in a directional gradient, with clusters in the western portion of the study area having greater average rainfall than clusters in the eastern portion (Figure 19). The approximate distance from eastern-most and western-most clusters was 400 m. Variation in precipitation amounts at this scale has been reported in other systems (Osborn et al. 1972). However,

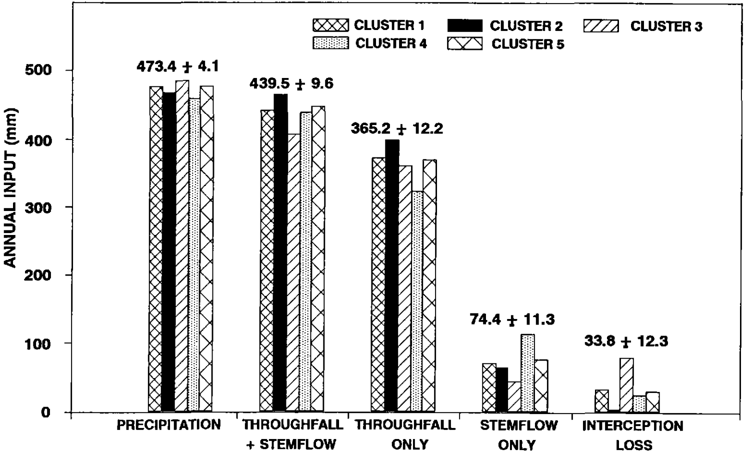


Figure 24. Total annual input or loss (mm) of the selected fluxes within mixed shrub clusters in a south Texas subtropical savanna parkland.

Table 24. Numbers of plants, total canopy area (m^2), and shrub cluster area (m^2) for shrub clusters used to quantify stemflow and throughfall. Data reflects only those plants with height >0.5 m and canopy area greater >0.2 m^2.

	Shrub Cluster				
	1	2	3	4	5
	Numbers of plants				
<u>Prosopis</u>	1	1	1	1	1
<u>Zanthoxylum</u>	21	55	10	11	13
<u>Condalia</u>	1	4	3	1	1
<u>Celtis</u>	0	1	0	3	1
<u>Diospyros</u>	1	1	0	2	1
	Sum of individual plant canopy area (m^2)				
	65.5	91.6	67.8	115.7	127.2
	Total shrub cluster area (m^2)				
	35.8	39.8	51.8	40.6	52.0

Table 25. Distribution of gross precipitation by the various fluxes within mixed shrub clusters in a south Texas subtropical savanna parkland during the study period of July 1987 to July 1988.

Flux	Input (mm)	Percent of Precipitation
Precipitation	473	---
Throughfall	365	77.2
Stemflow		
<u>Condalia</u>	9	1.9
<u>Celtis</u>	5	1.1
<u>Zanthoxylum</u>	49	10.4
<u>Prosopis</u>	1.0	0.3
<u>Diospyros</u>	10	2.1
Interception loss	34	7.2

Table 26. Summary of the percent of annual precipitation for throughfall, stemflow, and canopy interception loss for shrub clusters and trees and shrubs in other ecosystems.

Species/type	Location	Mean Annual (as % of precipitation) Throughfall	Stemflow	Interception Loss	Reference
Shrub clusters	South Texas	77	16	7	This Study
Live oak clusters (<u>Quercus</u> <u>virginiana</u>)	Central Texas	71	3	25	Thurow et al. 1987
<u>Prosopis</u> <u>glandulosa</u>	North Texas	91	5	4	Thompson 1986
Utah Juniper (<u>Juniperus</u> <u>osteosperma</u>)	Arizona	83	-[1]	17	Skau 1964
<u>Ceanothus</u> <u>cuneatus</u>/ <u>Aesculus</u> <u>californica</u>	California	-	16	-	Rowe 1948
Chaparral	California	-	-	8	Rowe and Coleman 1951
Ponderosa pine (<u>Pinus</u> <u>ponderosa</u>)		-	-	32	Connoughton 1934
Hardwoods		-	-	21	Beall 1934

[1] Indicates no data for this flux was reported.

spatial differences in BPPT did not significantly influence BTF (Figure 19). The variation in throughfall within shrub clusters was likely the result of 1) differences in the canopy area of the shrubs within the cluster (Table 23), 2) directional influences (major drip points over some collectors but not others and/or differences in absolute cover above collectors), and/or 3) foliar and branching structure of the shrub cluster canopies. The high density of species and multiple vertical stratum within clusters would be expected to influence water deposition to the soil surface.

The northern and eastern quadrants of the cluster received more throughfall than the western and southern quadrants (Figure 19), reflecting the prevailing direction of storm movement during the study period (personal observation). Similar directional effects for BTF deposition have been reported for pinyon juniper in Arizona (Collings 1966) and for lone Prosopis glandulosa plants in the Texas Rolling Plains (Thompson 1986). In this study, directional differences in BTF input occurred only when BPPT was >19 mm.

Stemflow inputs varied among species and within clusters. Prosopis generally had the lowest production of stemflow (Figure 24). This may be partially attributed to a drooping leaf posture and the rough, corky, reticulated bark on the stems. The Prosopis plants were generally mature, and many of the larger branches were relatively horizontal and had many drip points that would inhibit stemflow production (personal observation). Also, because Prosopis plants occupy the upper stratum, canopy drip from this stratum could be potentially intercepted by lower strata, thus reducing the amount of drip onto lower Prosopis branches. The low BSF input by Prosopis in this study was unexpected because Prosopis inputs were reported to be much higher (2.4 mm of stemflow for 50 mm of precipitation compared to 0.42 mm for the same storm size reported here) in the Rolling Plains of Texas (Thompson 1986). Also, stemflow inputs by mulga (Acacia aneura), a shrub with comparable growth form to Prosopis, ranged from 18 to 40% of annual BPPT in Queensland Australia.

The low input of stemflow water by Prosopis has ecological implications. Because only one Prosopis plant existed in each cluster, its importance to total water input was reduced compared to other species with similar water fluxes (Tables 22 and 25). Nutrient input in clusters over time would be reduced (even though concentrations may be high) because of the low input of water (See Chapter III). Prosopis is hypothesized to facilitate the ingress and establishment of other woody species beneath its canopy (Archer et al. 1988). The data presented in this study would indicate that BSF inputs by Prosopis in mature clusters might have very little effect on providing a more favorable moisture environment beneath its canopy for establishment and growth of other woody species. Early in cluster development, BSF inputs by Prosopis might be greater (per unit area) than in developing and mature clusters because of the lack of lower canopy strata and less rough, reticulated bark on the stems of younger Prosopis plants, thus providing a more favorable moisture environment for ingress and establishment of woody species. As clusters develop and mature, it would appear that the relative role of BSF input on facilitation would be decreased.

Small Zanthoxylum plants had peak stemflow inputs approximately double that of medium and large plants. This may have resulted from a combination of inputs from taller plants in the cluster and the occurrence of fewer drip points in the canopies of these smaller plants. Zanthoxylum has glabrous leaves and smooth bark, and on a per plant basis generated more BSF than other species except Diospyros. Also, high plant density of Zanthoxylum in the cluster (Table 24) combined to dominate stemflow inputs to shrub clusters (Figure 23 and 24). Zanthoxylum, is shallow rooted (Flinn 1986) and leaf numbers and N and P inputs via BTF+BSF appears to be influenced by drought conditions (see Chapter III and IV). Therefore the concentration of large amounts of stemflow at the base of Zanthoxylum plants may be important in nutrient return and relief of stress imposed by dry conditions.

Condalia and Celtis had comparable amounts of BSF input (Figure 21, Table 24). Each of these species has glabrous leaves and their stem bark is slightly rough to smooth. Even though these subordinate species comprise a small proportion of the density and canopy area in shrub clusters, their contribution to stemflow in the whole cluster was greater than that of Prosopis (Figure 23 and Table 25).

Diospyros plants had the greatest stemflow production (Figure 21). This species is characterized by very smooth bark which appears very conducive to stemflow production. Although the density of Diospyros plants was variable between shrub clusters (Table 24), its stemflow inputs were comparable to Condalia (Table 25).

Interception losses in mixed shrub clusters averaged approximately 35 percent of BPPT for small events and approximately 3 to 4% for BPPT amounts >50 mm (Figure 23). In California chaparral, interception for small storms was reported to be 50 to 75 percent and 3 to 6 percent for large storms (Hamilton and Rowe 1949, Rowe and Coleman, 1951). Thurow et al. (1987) reported approximately 40 percent interception loss for small storms and 12 percent interception loss for larger storms in live oak mottes in the Edward's Plateau of Texas. It was hypothesized that interception loss would be substantial in shrub clusters because of the large number of strata and canopy cover within the clusters. Results from this study indicate that interception loss was the lowest of all fluxes within the cluster. The successional implications of this are that interception losses would possibly be low throughout the development and maturation of clusters, and that clusters are efficient water harvesting mechanisms on the landscape.

Storm size class relative frequency distributions from 78 years of rainfall data from Alice, Texas (15 km from the study site) are depicted in Figure 25. Small storms (1-10 mm) had the greatest frequency of occurrence during this period. Storms >70 mm generally had relative frequencies of <1%. Using the number of storms and the mean precipitation amount for each size class, interception loss was calculated and totaled for this period. From this total, percent of total interception loss was determined to compare losses for each storm class. For very small storms (1 to 3 mm) percent of total interception loss was comparable to that of 6 to 15 mm size classes. Percent of total interception loss was greatest for the 3 to 6 mm size class. The large number of storms coupled with the high interception loss for these storm sizes, can lead to substantial losses of water from shrub clusters over time.

Water fluxes within different shrub clusters were found to be variable (Figure 24). This variability is probably caused by the different numbers and sizes of constituent plants within the clusters which behave differently with respect to BTF and BSF. However, the percentages of the fluxes presented here fall within the range of those reported for other systems. The functional relationships derived for BTF and BSF can allow estimation of BTF and BSF for a given shrub cluster when the species composition is known. Thus if the composition of clusters is known for a landscape, BTF and BSF inputs can be projected for various types of rainfall events, and portions of the water budget can be determined.

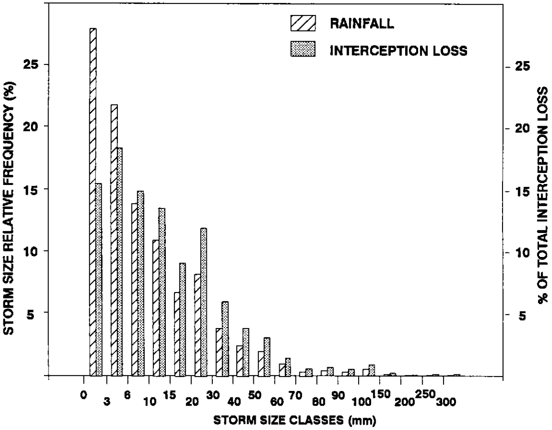


Figure 25. Relative frequency distribution for rainfall events and percent of total interception loss by each size class occurring during the past 78 years in Alice, Texas (15 km from study site).

CHAPTER VI

CONCLUSIONS

The input of water, nutrients, and litterfall within shrub clusters on sandy loam uplands in southern Texas appears to be a very dynamic process. The magnitude of these fluxes seems to be driven by various combinations of growth forms, numbers of woody plants, and size of shrub clusters. A summary of the salient characteristics influencing water, nutrient and litterfall transfers for the major species in this study is given in Table 27. Zanthoxylum fagara, an evergreen, appears to play the largest role in transfer of water, nutrients and litterfall because of its large contribution to total plant numbers and total canopy area within the shrub clusters. Prosopis glandulosa, a deciduous growth form and a nitrogen fixing plant, occupied large portions of the total canopy area within clusters and contributed large quantities to total cluster litterfall; however, its role in the transfer of stemflow nutrients appears to be somewhat limited because of low relative leaching of foliage and low water flux. Celtis pallida, a facultative evergreen, had high relative leaching of nutrients, but nutrient and water transfer was limited by the relatively low numbers of plants and total canopy area within shrub clusters. Condalia hookeri and Diospyros texana, also facultative evergreens, appeared to be limited in their contribution to inputs of water, nutrients and litterfall because of low relative canopy area and plant numbers.

Ecological Implications

In the successional development of multi-species shrub clusters on sandy loam uplands, Prosopis glandulosa is the first to establish and modifies the soils and microclimate

Table 27. A summary of the characteristics of the major shrub species comprising shrub clusters in southern Texas that were identified in this study.

Characteristic	Species: Celtis	Condalia	Diospyros	Prosopis	Zanthoxylum
Leaf initiation	March	March	March	March	May/June[1]
Canopy Development					
Maximum	July	July	July	July	July/Aug.[1]
Minimum	Jan./Feb.[2]	Jan./Feb.[2]	Jan./Feb.[2]	Jan.	March/June[1]
Growth Form	Facultative Evergreen	Facultative Evergreen	Facultative Evergreen	Deciduous	Evergreen
Variable explaining most variance in RLN[4]	Daylength	Daylength	Daylength	Daylength/ Temperature	CDSLR[3]
Mean annual foliar litterfall (kg/ha)	20	110	210	1010	2110
Relative Canopy Area (%)	2.8	1.8	3.6	39.9	39.6
Number of plants/cluster	4.0	3.2	4.8	1.0	39.6
Potential leachability					
Calcium	High	Low	Low	Low	Low
Magnesium	High	Low	Low	Low	Low
Potassium	High	Low	Low	Low	Moderate
Nitrogen	High	Low	Low	Moderate	Low
Phosphorus	High	Low	Low	Low	High

Table 27 continued.

	Species				
Characteristic	Celtis	Condalia	Diospyros	Prosopis	Zanthoxylum
Stemflow annual concentration ratios					
Calcium	1.6	2.2	1.1	3.9	1.7
Magnesium	3.8	4.6	3.1	5.0	3.0
Potassium	4.9	3.1	7.0	8.5	4.5
Nitrogen	2.2	5.0	1.5	2.7	1.9
Phosphorus	1.2	3.0	1.3	1.6	1.6
Stemflow annual deposition (g/m2)					
Calcium	0.011	0.014	0.026	0.009	0.023
Magnesium	0.005	0.006	0.015	0.002	0.008
Potassium	0.013	0.018	0.067	0.009	0.024
Nitrogen	0.014	0.011	0.035	0.006	0.025
Phosphorus	0.0001	0.0003	0.0005	0.0001	0.0004
Stemflow input (mm) at 50 mm of rainfall	0.50	0.65	1.87	0.42	0.68–1.50

[1] Depending on rainfall.
[2] Depending on severity of the freeze.
[3] CDSLR = consecutive days since the last rain >13 mm.
[4] RLN = Relative leaf numbers.

beneath its canopy, thus facilitating the ingress and establishment of other woody species. The role of Prosopis throughfall and stemflow water and nutrients in this modification process would appear to be minor due to low relative leaching, stemflow water flux, and inputs of nutrients, especially nitrogen. Nitrogen modification of the soil would then relegated to decomposition of root and foliar litter. The relatively large inputs of litterfall by Prosopis would make this a valid pathway. The low stemflow water flux by this species might have very little effect on providing a favorable environment for establishment and growth of other woody species, indicating stemflow water plays a minor role in the facilitation process.

Zanthoxylum fagara is usually one of the first species to appear beneath the Prosopis canopy in the development of shrub clusters. Results from this study indicate that this species plays a major role in the cycling of phosphorus within the cluster. The increased leaching and deposition of phosphorus may be advantageous to potential nitrogen fixing plants within the clusters, especially since the greatest depositions of phosphorus were at times when species were growing actively. This may further augment modification of the soils in early cluster development. Zanthoxylum, a shallow rooted plant, appears to be sensitive to moisture conditions as evidenced by the variation explained in leaf numbers and concentrations of N and P to the length of the period without significant rainfall. Concentrations of nutrients in cluster throughfall were moderately to highly correlated to litterfall of this species, indicating this species had a major influence on transfer of nutrients in shrub clusters. Stemflow input of water, nutrients and litterfall by Zanthoxylum was greater than that of any other species. These data would indicate that as clusters develop and mature, Zanthoxylum play a major role in the cycling of nutrients within the cluster.

The role of Diospyros, Celtis, and Condalia in the modification of soils beneath clusters and the cycling of nutrients would appear to be minor. The low relative abundance of these species as clusters develop will lead to low relative water and nutrient inputs over time.

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Appendix table 1. Means, standard errors (SE), and corresponding mean separations for Berberis trifoliolata foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	10.89	4.98	abc	a
October	1987	11.79	4.28	ab	a
November	1987	7.54	3.49	abc	a
December	1987	7.12	2.61	abc	a
January	1988	3.13	1.25	c	a
February	1988	3.76	1.23	bc	a
March	1988	12.91	4.50	a	a
April	1988	5.57	1.92	abc	a
May	1988	9.75	3.50	abc	a
June	1988	7.11	2.62	abc	a
July	1988	3.12	1.07	c	a
August	1988	5.71	2.50	abc	a
September	1988	8.21	3.10	abc	a
October	1988	6.66	2.82	abc	a
November	1988	4.20	1.65	bc	a
December	1988	9.30	3.82	abc	a
February	1989	5.90	2.70	abc	a

[1]Litter was collected the last day of each month.

Appendix table 2. Means, standard errors (SE), and corresponding mean separations for Condalia Hookeri foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	15.23	5.88	abc	a
October	1987	23.07	9.26	a	a
November	1987	20.79	7.97	ab	a
December	1987	26.17	10.20	a	a
January	1988	13.14	3.87	abc	a
February	1988	6.21	1.29	c	a
March	1988	2.44	0.83	c	a
April	1988	2.54	1.65	c	a
May	1988	7.43	1.90	bc	a
June	1988	2.12	0.56	c	a
July	1988	1.33	0.38	c	a
August	1988	5.70	1.58	c	a
September	1988	4.39	1.18	c	a
October	1988	2.46	0.66	c	a
November	1988	3.32	0.96	c	a
December	1988	26.67	10.10	a	a
February	1989	7.81	2.36	bc	a

[1]Litter was collected the last day of each month.

Appendix table 3. Means, standard errors (SE), and corresponding mean separations for *Prosopis glandulosa* foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	201.03	11.59	b	b
October	1987	174.78	12.00	c	bc
November	1987	138.01	11.54	d	cd
December	1987	164.93	10.82	c	bc
January	1988	10.71	1.25	h	ij
February	1988	3.90	2.20	h	j
March	1988	2.90	0.97	h	hij
April	1988	21.16	3.16	h	hij
May	1988	77.68	6.51	ef	efg
June	1988	49.61	7.80	g	ghi
July	1988	58.97	4.84	fg	fgh
August	1988	79.79	5.68	ef	efg
September	1988	90.69	7.15	e	ef
October	1988	57.08	4.41	fg	fgh
November	1988	115.61	6.49	d	de
December	1988	251.55	18.06	a	a
February	1989	13.26	1.63	h	ij

[1]Litter was collected the last day of each month.

Appendix table 4. Means, standard errors (SE), and corresponding mean separations for <u>Celtis pallida</u> foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	2.28	1.84	cde	a
October	1987	0.14	0.14	de	a
November	1987	0.37	0.36	de	a
December	1987	1.71	0.87	cde	a
January	1988	4.34	1.08	abc	a
February	1988	0.32	0.21	de	a
March	1988	0.19	0.19	de	a
April	1988	0.00	0.00	e	a
May	1988	0.00	0.00	e	a
June	1988	0.04	0.04	e	a
July	1988	0.74	0.26	de	a
August	1988	0.29	0.23	de	a
September	1988	0.64	0.26	de	a
October	1988	3.00	2.23	bcd	a
November	1988	3.86	1.16	abc	a
December	1988	5.74	1.92	ab	a
February	1989	6.61	1.84	a	a

[1]Litter was collected the last day of each month.

Appendix table 5. Means, standard errors (SE), and corresponding mean separations for Diospyros texana foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	69.75	21.25	a	a
October	1987	51.45	17.40	a	abc
November	1987	23.16	7.40	b	bcd
December	1987	16.90	4.89	b	cd
January	1988	57.31	25.90	a	ab
February	1988	3.96	1.24	b	d
March	1988	5.84	2.06	b	d
April	1988	8.97	5.05	b	d
May	1988	19.89	9.17	b	bcd
June	1988	2.20	0.71	b	d
July	1988	2.16	0.68	b	d
August	1988	7.71	2.71	b	d
September	1988	22.61	6.90	b	bcd
October	1988	5.83	2.08	b	d
November	1988	12.58	3.95	b	cd
December	1988	11.84	3.39	b	cd
February	1989	5.96	2.19	b	d

[1]Litter was collected the last day of each month.

Appendix table 6. Means, standard errors (SE), and corresponding mean separations for Zanthoxylum fagara foliar litterfall (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	551.10	60.20	a	a
October	1987	428.43	40.85	b	b
November	1987	69.48	8.09	fg	gh
December	1987	80.56	7.32	fg	gh
January	1988	82.30	7.24	fg	gh
February	1988	90.36	5.22	fg	gh
March	1988	301.82	18.54	d	d
April	1988	121.43	8.62	f	g
May	1988	203.41	10.73	e	f
June	1988	66.00	9.93	g	h
July	1988	60.53	7.66	g	h
August	1988	61.46	6.74	g	h
September	1988	104.30	9.59	fg	gh
October	1988	92.49	12.68	fg	gh
November	1988	250.97	15.92	de	e
December	1988	357.87	21.16	c	c
February	1989	252.42	15.73	de	e

[1]Litter was collected the last day of each month.

Appendix table 7. Means, standard errors (SE) and mean separations of relative leaf numbers (%) of selected shrub species comprising mixed shrub assemblages in a South Texas subtropical savanna parkland. Mean separations were conducted using Fischer's least significant difference procedure (LSD). Means with the same letter were not significantly different (P>0.05).

Sampling period		Zafa		Prgl		Coho		Cepa		Dite	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
August	1987	100	0 a	28	11 cd	-[1]	-	-	-	-	-
October	1987	58	14 b	8	8 d	58	21 bc	75	3 ab	-	-
December	1987	85	9 a	1	1 d	-	-	-	-	-	-
January	1988	16	0 d	0	0 d	18	17 cd	5	2 c	4	2 d
March	1988	16	1 d	54	17 bc	58	6 bc	62	11 b	74	15 b
May	1988	3	2 e	94	4 a	84	7 ab	70	10 ab	82	10 ab
July	1988	55	6 b	93	5 a	97	3 a	92	5 a	90	5 ab
October	1988	100	0 a	61	16 abc	58	8 bc	60	19 b	31	7 c
February	1989	37	4 c	0	0 d	0	0 d	0	0 c	0	0 d
May	1989	100	0 a	80	20 ab	71	18 ab	75	6 ab	100	0 a

[1]indicates that no data was collected during this sampling period.

Appendix table 8. Means, standard errors (SE), and corresponding mean separations for miscellaneous litterfall (stems, twigs, reproductive parts etc.) (kg/ha). Fisher's least significant difference (LSD) procedure was used for mean separations for the single species only model and the full model which included all variability factors (for more detail on statistical procedures, see Methods section). Litterfall for February 1989 includes litter from January 1989. Means with the same letter were not significantly different (P>0.05).

Date of collection[1]		Mean	SE	Species Model	Full Model
September[1]	1987	66.23	8.16	c	cd
October	1987	103.18	58.64	bc	c
November	1987	23.58	5.28	c	d
December	1987	71.21	21.86	c	cd
January	1988	45.69	6.50	c	d
February	1988	39.19	8.94	c	d
March	1988	94.56	26.73	bc	c
April	1988	53.41	16.56	c	d
May	1988	497.70	59.95	a	a
June	1988	75.29	8.09	c	cd
July	1988	166.37	46.21	b	b
August	1988	100.79	24.54	bc	c
September	1988	172.35	38.54	b	b
October	1988	39.48	5.68	c	d
November	1988	69.92	13.16	c	cd
December	1988	81.20	13.32	c	cd
February	1989	98.33	47.21	bc	c

[1]Litter was collected the last day of each month.

Appendix table 9. Mean monthly litterfall (kg/ha) and annual foliar litterfall for the species comprising mixed shrub assemblages and miscellaneous litterfall on a sandy loam upland in a South Texas subtropical savanna parkland. Litterfall for February 1989 includes litter from January 1989.

Month/year		Species						
		Zanthoxylum	Prosopis	Diospyros	Condalia	Berberis	Celtis	Misc. Litter
September	1987	551.10	201.03	69.75	15.23	10.89	2.28	66.23
October	1987	428.43	174.77	51.45	23.07	11.79	0.14	103.18
November	1987	69.48	138.01	23.12	20.79	7.54	0.37	23.59
December	1987	80.56	164.93	16.90	26.17	7.12	1.71	71.21
January	1988	82.30	10.71	57.31	13.14	3.13	4.34	45.69
February	1988	90.37	3.90	3.96	6.21	3.77	0.32	39.19
March	1988	301.82	2.90	5.84	2.44	12.91	0.19	94.56
April	1988	121.43	21.16	8.97	2.54	5.57	0.00	53.41
May	1988	203.41	77.68	19.89	7.43	9.76	0.00	497.70
June	1988	66.00	49.61	2.20	2.12	7.11	0.04	75.29
July	1988	60.53	58.97	2.16	1.33	3.12	0.74	166.38
August	1988	61.46	79.79	7.71	5.70	5.71	0.29	100.79
September	1988	104.31	90.69	22.61	4.39	8.21	0.64	172.35
October	1988	92.49	57.08	5.83	2.46	6.66	3.00	39.48
November	1988	250.97	115.61	12.58	3.32	4.20	3.86	69.92
December	1988	357.87	251.55	11.84	26.67	9.30	5.74	81.20
February	1988	252.42	13.26	5.96	7.81	5.90	6.61	98.33
$kg/ha^{-1}/yr^{-1}$		2120.00	1010.00	220.00	110.00	80.00	20.00	1200.00

Total $kg/ha^{-1}/yr^{-1}$ = 4760

Appendix table 10. Total leaf biomass (g/m^3) (estimated using reference unit method in a vertical plane above collection troughs) and percent of total biomass of shrub species within each mixed shrub assemblage used for throughfall collection for two sampling periods representing a low (March 1988) and high (July 1988) biomass.

Species	March '88 Biomass	%	July '88 Biomass	%
Shrub cluster 1				
Colubrina texensis	34.7	7	47.2	4
Diospyros texana	7.5	1	2.5	0.2
Prosopis glandulosa	235.0	45	520.2	48
Zanthoxylum fagara	240.1	46	520.9	48
Shrub cluster 2				
Berberis trifoliolata	3.1	1	10.9	1
Celtis pallida	1.1	0.2	10.8	1
Colubrina texensis	7.3	1	9.9	1
Condalia Hookeri	-	-	46.4	3
Prosopis glandulosa	137.3	25	339.7	24
Zanthoxylum fagara	404.8	73	982.1	69
Ziziphus obtusifolia	3.7	1	26.9	2
Shrub cluster 3				
Berberis trifoliolata	1.9	0.4	13.5	1
Colubrina texensis	10.0	2	10.7	1
Condalia Hookeri	0.5	0.1	46.0	5
Prosopis glandulosa	182.4	40	396.7	42
Zanthoxylum fagara	259.0	57	487.1	51
Shrub cluster 4				
Berberis trifoliolata	4.0	1	15.2	1
Celtis pallida	3.7	1	7.7	1
Condalia Hookeri	-	-	20.1	2
Diospyros texana	17.2	4	22.2	2
Prosopis glandulosa	91.9	23	429.1	39
Schafferia cuneifolia	-	-	17.4	2
Lycium berlandieri	-	-	10.8	1
Zanthoxylum fagara	277.2	70	575.0	52
Shrub cluster 5				
Celtis pallida	1.2	0.3	3.4	0.3
Condalia Hookeri	9.6	3	21.4	2
Diospyros texana	23.8	7	176.9	14
Prosopis glandulosa	61.0	18	177.7	14
Zanthoxylum fagara	243.9	72	855.2	69

Appendix table 11. Total leaf biomass (g/m^3) (estimated using reference unit method in a vertical plane above collection troughs) and percent of total biomass of shrub species for each direction within each mixed shrub assemblage for two sampling periods representing a low (March 1988) and high (July 1988) biomass.

Species	Trough Direction	March '88 Biomass	%	July '88 Biomass	%
Shrub assemblage 1					
Zanthoxylum fagara	East	98.3	69	183.3	68
Prosopis glandulosa		37.1	26	84.7	31
Diospyros texana		7.5	5	2.5	1
Prosopis glandulosa	North	118.9	79	254.4	80
Zanthoxylum fagara		13.9	9	36.6	12
Colubrina texensis		17.6	12	25.9	8
Zanthoxylum fagara	South	61.4	81	152.7	74
Prosopis glandulosa		14.4	19	52.7	26
Zanthoxylum fagara	West	66.6	45	148.4	50
Prosopis glandulosa		64.7	44	128.4	43
Colubrina texensis		17.1	11	21.3	7
Shrub assemblage 2					
Zanthoxylum fagara	East	208.8	89	554.8	90
Prosopis glandulosa		26.2	11	62.9	10
Zanthoxylum fagara	North	50.7	59	146.7	52
Prosopis glandulosa		31.3	36	84.3	30
Ziziphus obtusifolia		3.7	4	26.9	10
Condalia Hookeri		0.0		24.1	9
Prosopis glandulosa	South	66.9	53	182.6	55
Zanthoxylum fagara		59.4	47	147.6	45
Zanthoxylum fagara	West	85.8	78	133.0	68
Condalia Hookeri		0.0		22.4	11
Berberis trifoliolata		3.0	3	10.9	6
Prosopis glandulosa		12.9	12	9.9	5
Colubrina texensis		7.3	7	9.9	5
Celtis pallida		1.1	1	10.8	5
Shrub assemblage 3					
Prosopis glandulosa	East	98.4	100	203.1	100
Zanthoxylum fagara	North	110.9	95	195.2	87
Prosopis glandulosa		3.4	3	4.6	2
Berberis trifoliolata		1.9	2	13.5	6
Condalia Hookeri		0.0		11.5	5
Prosopis glandulosa	South	36.7	57	57.4	43

Appendix table 11 continued.

Species	Trough Direction	March '88 Biomass	%	July '88 Biomass	%
Zanthoxylum fagara		17.2	27	30.4	23
Condalia Hookeri		0.5	1	34.5	26
Colubrina texensis		10.0	15	10.7	8
Zanthoxylum fagara	West	130.9	75	261.4	67
Prosopis glandulosa		43.8	25	131.6	33
Shrub assemblage 4					
Prosopis glandulosa	East	51.0	68	245.9	70
Zanthoxylum fagara		22.8	30	89.4	25
Schaefferia cunefolia		0.0		17.4	5
Celtis pallida		1.0	1	0.7	0.2
Zanthoxylum fagara	North	93.5	74	182.6	53
Prosopis glandulosa		33.4	26	133.1	38
Condalia Hookeri		0.0		20.1	6
Lycium berlandieri		0.0		10.8	3
Zanthoxylum fagara	South	99.0	82	175.7	70
Prosopis glandulosa		7.6	6	50.1	20
Diospyros texana		12.0	10	19.0	8
Celtis pallida		2.7	2	7.0	3
Zanthoxylum fagara	West	61.9	87	127.3	82
Berberis trifoliolata		4.0	6	15.2	10
Diospyros texana		5.3	7	3.2	2
Lycium berlandieri		0.0		10.4	7
Shrub assemblage 5					
Zanthoxylum fagara	East	55.7	65	169.9	67
Prosopis glandulosa		20.1	24	61.6	24
Condalia Hookeri		9.6	11	21.4	8
Zanthoxylum fagara	North	114.4	92	446.5	91
Diospyros texana		9.8	8	44.6	9
Zanthoxylum fagara	South	42.9	63	118.6	63
Prosopis glandulosa		24.4	36	65.1	35
Celtis pallida		1.2	2	3.4	2
Zanthoxylum fagara	West	30.8	50	120.2	40
Prosopis glandulosa		16.4	27	51.0	17
Diospyros texana		13.9	23	132.2	44

Appendix table 12. Mean, minimum, and maximum and standard errors (SE) of heights (HT) and total sum of canopy areas of species of shrubs comprising shrub assemblages (n=5) used for throughfall and stemflow collections in a South Texas subtropical savanna parkland.

Species	n	HT Min.	HT Max.	HT Mean	SE	Total Canopy Area
Shrub assemblage 1						
Berberis trifoliolata	2	0.65	0.85	0.75	0.10	1.29
Condalia Hookeri	1	0.90	0.90	0.90	0.00	0.63
Celtis pallida	1	0.22	0.22	0.22	0.00	0.10
Colubrina texensis	2	0.96	1.20	1.08	0.12	1.75
Zanthoxylum fagara	44	0.36	2.15	1.07	0.07	33.19
Prosopis glandulosa	1	6.43	6.43	6.43	0.00	36.21
Diospyros texana	6	0.08	1.41	0.76	0.20	0.86
Opuntia lindhiemerii	5	0.33	1.31	0.67	0.19	2.49
Shrub assemblage 2						
Berberis trifoliolata	1	0.90	0.90	0.90	0.00	2.56
Condalia Hookeri	7	0.55	1.76	1.08	0.16	2.50
Celtis pallida	8	0.04	1.94	0.64	0.20	2.48
Colubrina texensis	23	0.26	1.33	0.83	0.06	15.65
Ziziphus obtusifolia	1	1.78	1.78	1.78	0.00	1.38
Zanthoxylum fagara	99	0.23	4.65	1.32	0.07	51.44
Prosopis glandulosa	1	4.51	4.51	4.51	0.00	34.73
Diospyros texana	3	0.94	1.10	1.04	0.05	0.44
Opuntia leptocaulis	1	0.68	0.68	0.68	0.00	0.11
Shrub assemblage 3						
Berberis trifoliolata	2	1.40	1.44	1.42	0.02	4.30
Condalia Hookeri	3	0.78	1.92	1.17	0.38	2.14
Celtis pallida	1	0.61	0.61	0.61	0.00	0.06
Colubrina texensis	8	0.53	1.04	0.82	0.06	4.99
Zanthoxylum fagara	17	0.20	4.26	1.19	0.22	23.16
Prosopis glandulosa	4	0.94	4.48	2.57	0.73	46.84
Opuntia lindhiemerii	1	0.22	0.22	0.22	0.00	0.04
Salvia spp.	2	0.57	1.00	0.79	0.22	2.33
Optuntia leptocaulis	1	0.54	0.54	0.54	0.00	0.02

Appendix table 12 continued.

Species	n	HT Min.	HT Max.	HT Mean	Total SE	Canopy Area
Shrub assemblage 4						
Berberis trifoliolata	7	0.21	1.40	0.62	0.15	3.99
Condalia Hookeri	4	0.30	0.96	0.78	0.16	0.74
Schafferia cunefolia	2	0.35	0.98	0.67	0.32	0.84
Celtis pallida	6	0.21	2.80	1.65	0.47	7.79
Ziziphus obtusifolia	2	0.41	1.06	0.74	0.33	0.72
Zanthoxylum fagara	21	0.17	3.19	1.37	0.20	41.45
Prosopis glandulosa	1	4.90	4.90	4.90	0.00	64.47
Diospyros texana	13	0.10	1.59	0.58	0.14	1.22
Opuntia lindhiemerii	4	0.30	1.46	0.97	0.26	5.02
Optuntia leptocaulis	6	0.25	1.22	0.61	0.15	1.28
Shrub assemblage 5						
Berberis trifoliolata	1	1.16	1.16	1.16	0.00	0.26
Condalia Hookeri	1	2.00	2.00	2.00	0.00	3.78
Celtis pallida	4	0.30	3.60	1.51	0.72	5.31
Ziziphus obtusifolia	2	0.59	0.68	0.64	0.05	1.38
Zanthoxylum fagara	17	0.14	4.85	2.27	0.30	76.03
Prosopis glandulosa	2	1.13	4.88	3.00	1.87	39.26
Opuntia lindhiemerii	10	0.21	3.46	1.10	0.29	26.93
Salvia spp.	7	0.60	1.45	1.06	0.11	5.94
Optuntia leptocaulis	1	1.05	1.05	1.05	0.00	1.26

Appendix table 13. Means and standard errors (SE) of calcium, magnesium, potassium, nitrogen, and phosphorus leached (mg of nutrient/gram of plant tissue) from twigs submerged in rainwater for 12 hours for each species and trial of the nutrient leachability study. Means with the same letter within trials were not significantly different (P>0.05) using Fischer's LSD procedure.

	August, 1987			December, 1987			June, 1988		
Species/Nutrient	Mean	SE	Sig.	Mean	SE	Sig.	Mean	SE	Sig.
Calcium									
Condalia Hookeri	0.201	0.177	b	-0.434	0.495	b	1.072	0.256	b
Celtis pallida	7.229	1.316	a	19.645	5.750	a	8.425	1.627	a
Zanthoxylum fagara	0.067	0.080	b	-0.574	0.429	b	0.839	0.305	b
Prosopis glandulosa	0.260	0.231	b	-0.204	0.476	b	0.397	0.156	b
Diospyros texana	0.360	0.136	b	-0.492	0.682	b	0.522	0.130	b
Magnesium									
Condalia Hookeri	0.147	0.046	c	0.432	0.095	b	0.473	0.038	b
Celtis pallida	1.723	0.385	a	2.298	0.560	a	2.634	0.815	a
Zanthoxylum fagara	0.018	0.011	c	0.044	0.027	b	0.612	0.230	b
Prosopis glandulosa	0.441	0.251	bc	0.090	0.058	b	0.175	0.109	b
Diospyros texana	0.875	0.246	b	0.249	0.123	b	0.419	0.044	b
Potassium									
Condalia Hookeri	1.520	0.254	b	2.962	0.539	b	2.734	0.552	c
Celtis pallida	8.572	2.155	a	13.201	3.208	a	14.017	2.888	a
Zanthoxylum fagara	1.317	0.484	b	1.065	0.330	b	9.063	2.894	ab
Prosopis glandulosa	6.695	2.486	a	1.439	0.560	b	3.038	2.073	bc
Diospyros texana	5.756	1.549	ab	1.983	0.985	b	1.500	0.082	c

Appendix table 13 continued

Species/Nutrient	August, 1987 Mean	SE	Sig.	December, 1987 Mean	SE	Sig.	June, 1988 Mean	SE	Sig.
Nitrogen									
Condalia Hookeri	0.615	0.488	b	1.918	0.973	b	1.252	0.519	b
Celtis pallida	1.256	0.625	b	7.790	3.498	a	13.196	8.008	a
Zanthoxylum fagara	0.270	0.298	b	-0.915	0.348	b	4.172	1.601	ab
Prosopis glandulosa	5.333	2.014	a	-0.183	0.117	b	-0.100	0.147	b
Diospyros texana	1.920	0.875	b	-0.256	0.598	b	-0.264	0.299	b
Phosphorus									
Condalia Hookeri	0.0310	0.0181	a	0.0032	0.0032	b	0.0231	0.0099	b
Celtis pallida	0.0404	0.0309	a	0.0765	0.0269	a	0.1400	0.0574	b
Zanthoxylum fagara	0.0056	0.0072	a	-0.0105	0.0044	b	0.3161	0.1150	a
Prosopis glandulosa	0.0674	0.0351	a	-0.0075	0.0036	b	0.0049	0.0068	b
Diospyros texana	0.0608	0.0350	a	0.0138	0.0152	b	0.0110	0.0057	b

Appendix table 14. Means and standard errors (SE) of calcium concentrations (mg/L) in bulk precipitation (BPPT) and bulk throughfall (BTF) collected from mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

Date	BPPT Mean	SE	Sig.	BTF Mean	SE	Sig.
July 21, 1987	6.65	2.20	cd	5.90	1.08	cde
July 25	1.53	0.84	ef	2.87	1.00	defg
July 31	2.41	1.61	ef	3.40	0.77	cdefg
Aug. 10	1.76	0.39	ef	4.31	1.33	cdefg
Aug. 22	19.44	3.76	b	11.71	1.39	b
Sept. 1	2.78	0.69	ef	4.58	0.37	cde
Sept. 28	2.85	0.54	ef	5.52	0.45	cde
Sept. 30	62.49	7.55	a	24.75	4.33	a
Oct. 24	6.27	1.55	cd	5.37	0.49	cde
Nov. 11	2.54	0.52	ef	2.79	0.46	efg
Nov. 13	1.90	0.20	ef	3.06	0.43	defg
Nov. 16	8.57	1.62	c	2.88	0.40	defg
Nov. 30	5.13	1.53	cde	5.17	0.89	cde
Dec. 22	8.37	2.30	c	6.38	1.10	c
Dec. 29	3.19	0.81	def	3.14	0.36	cdefg
Jan. 5, 1988	1.45	0.44	e	2.19	0.21	efg
Jan. 8	0.62	0.09	e	3.91	0.50	cdefg
Jan. 20	2.76	1.06	ef	2.60	0.25	efg
Feb. 8	1.23	0.18	e	3.03	0.44	defg
Mar. 3	7.34	0.84	cd	13.22	1.09	b
Mar. 23	1.86	0.26	ef	4.46	0.41	cdef
Apr. 30	7.96	0.94	c	6.34	0.75	cd
May 15	1.15	0.11	e	1.87	0.22	efg
June 7	0.56	0.07	e	1.78	0.21	fg
June 22	1.28	0.22	e	2.54	0.31	efg
July 7	1.76	0.39	ef	2.83	0.33	efg
July 12	0.52	0.07	e	0.99	0.06	g
July 30	1.99	0.23	ef	4.54	1.07	cdef

Appendix table 15. Means and standard errors (SE) of magnesium concentrations (mg/L) in bulk precipitation (BPPT) and bulk throughfall (BTF) collected from mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

Date	BPPT Mean	SE	Sig.	BTF Mean	SE	Sig.
July 21, 1987	0.73	0.12	bcdef	1.57	0.24	def
July 25	0.41	0.05	ef	0.91	0.29	ghi
July 31	0.53	0.08	def	0.78	0.11	hi
Aug. 10	0.56	0.06	def	1.55	0.43	defg
Aug. 22	2.93	0.18	a	3.91	0.66	b
Sept. 1	0.61	0.04	cdef	2.02	0.28	cd
Sept. 28	0.80	0.25	bcdef	2.48	0.25	c
Sept. 30	2.74	0.28	a	7.50	1.08	a
Oct. 24	0.63	0.09	cdef	2.08	0.21	cd
Nov. 11	0.55	0.12	def	1.10	0.15	fghi
Nov. 13	1.13	0.16	bcd	1.13	0.12	fgh
Nov. 16	0.77	0.06	bcdef	1.11	0.17	fghi
Nov. 30	0.65	0.05	bcdef	1.81	0.25	de
Dec. 22	1.06	0.14	bcde	1.67	0.22	def
Dec. 29	0.53	0.06	def	1.44	0.23	efgh
Jan. 5, 1988	0.39	0.04	f	0.99	0.08	ghi
Jan. 8	0.59	0.07	cdef	1.66	0.18	def
Jan. 20	0.35	0.05	f	1.06	0.11	fghi
Feb. 8	0.36	0.04	f	1.11	0.20	fghi
Mar. 3	1.30	0.07	b	3.39	0.39	b
Mar. 23	0.47	0.04	def	1.77	0.30	de
Apr. 30	1.25	0.09	bc	1.92	0.28	cde
May 15	0.55	0.06	def	0.85	0.09	hi
June 7	0.53	0.20	def	0.86	0.10	hi
June 22	0.42	0.05	ef	0.92	0.07	ghi
July 7	0.50	0.03	def	0.91	0.10	ghi
July 12	0.30	0.04	f	0.45	0.03	i
July 30	0.54	0.05	def	1.27	0.27	efgh

Appendix table 16. Means and standard errors (SE) of potassium concentrations (mg/L) in bulk precipitation (BPPT) and bulk throughfall (BTF) collected from mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

Date	BPPT Mean	SE	Sig.	BTF Mean	SE	Sig.
July 21, 1987	1.01	0.21	b	4.95	1.22	fghi
July 25	0.64	0.20	b	3.48	1.13	ghij
July 31	1.56	0.83	b	5.15	2.39	fghi
Aug. 10	1.86	0.76	b	7.28	1.63	ef
Aug. 22	5.25	0.42	a	12.50	2.61	bc
Sept. 1	1.23	0.19	b	9.27	1.51	de
Sept. 28	1.65	0.36	b	13.73	2.09	b
Sept. 30	1.89	0.14	b	27.44	5.79	a
Oct. 24	1.57	0.32	b	10.82	1.83	bcd
Nov. 11	1.12	0.38	b	3.53	0.63	ghij
Nov. 13	1.44	0.22	b	1.97	0.38	ij
Nov. 16	1.88	0.34	b	2.46	0.42	ghij
Nov. 30	1.72	0.29	b	5.70	1.31	fg
Dec. 22	3.31	0.88	ab	5.36	1.13	fgh
Dec. 29	1.20	0.30	b	3.90	0.58	ghij
Jan. 5, 1988	0.62	0.11	b	2.45	0.26	hij
Jan. 8	0.62	0.18	b	3.77	0.58	ghij
Jan. 20	0.49	0.12	b	2.36	0.33	hij
Feb. 8	0.52	0.16	b	2.69	0.36	ghij
Mar. 3	1.61	0.14	b	10.26	1.73	cde
Mar. 23	0.60	0.15	b	3.05	0.39	ghij
Apr. 30	2.82	0.37	ab	10.49	3.11	cd
May 15	0.49	0.06	b	1.73	0.22	ij
June 7	0.21	0.02	b	1.77	0.28	ij
June 22	0.43	0.05	b	2.89	0.52	ghij
July 7	1.68	1.10	b	2.56	0.39	ghij
July 12	0.24	0.03	b	0.99	0.12	j
July 30	0.84	0.28	b	3.43	0.99	ghij

Appendix table 17. Means and standard errors (SE) of nitrogen concentrations (mg/L) in bulk precipitation (BPPT) and bulk throughfall (BTF) collected from mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

Date	BPPT Mean	SE	Sig.	BTF Mean	SE	Sig.
July 21, 1987	1.79	0.34	defg	4.98	0.85	cdefg
July 25	1.45	0.24	defg	1.76	0.37	gh
July 31	2.16	0.76	cdefg	2.21	0.46	gh
Aug. 10	2.26	0.51	cdefg	4.11	0.53	defg
Aug. 22	8.38	1.36	a	10.37	1.72	a
Sept. 1	1.82	0.23	defg	5.21	0.62	cdef
Sept. 28	2.22	0.42	cdefg	6.31	0.78	bcd
Sept. 30	9.25	1.78	a	6.36	0.95	bcd
Oct. 24	3.60	1.33	bcde	7.69	3.30	bc
Nov. 11	0.99	0.14	g	3.41	0.81	efgh
Nov. 13	2.41	0.24	cdefg	2.93	0.47	fgh
Nov. 16	5.20	0.76	b	5.09	1.88	cdef
Nov. 30	5.04	1.27	b	3.10	0.38	efgh
Dec. 22	2.56	0.47	bcdef	3.36	0.62	efgh
Dec. 29	3.47	0.57	bcde	3.25	0.49	efgh
Jan. 5, 1988	1.41	0.52	efg	2.68	0.31	gh
Jan. 8	2.31	0.35	cdefg	4.56	0.78	defg
Jan. 20	1.99	0.46	cdefg	2.66	0.29	gh
Feb. 8	2.45	0.75	cdefg	3.04	0.35	fgh
Mar. 3	4.09	0.30	bc	5.31	0.48	cde
Mar. 23	3.41	1.55	bcdef	3.93	0.50	defg
Apr. 30	8.38	0.56	a	8.43	1.18	ab
May 15	0.81	0.18	g	3.23	0.47	efgh
June 7	1.17	0.31	fg	3.37	0.30	efgh
June 22	0.82	0.14	g	3.57	0.42	efg
July 7	3.62	2.57	bcd	4.17	0.63	defg
July 12	0.79	0.21	g	1.42	0.17	h
July 30	1.65	0.09	defg	4.05	0.64	defg

Appendix table 18. Means and standard errors (SE) of phosphorus concentrations (mg/L) in bulk precipitation (BPPT) and bulk throughfall (BTF) collected from mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

Date	BPPT Mean	SE	Sig.	BTF Mean	SE	Sig.
July 21, 1987	0.071	0.047	bcdef	0.098	0.040	cdef
July 25	0.027	0.011	efgh	0.016	0.002	h
July 31	0.020	0.006	gh	0.025	0.008	gh
Aug. 10	0.082	0.014	bcde	0.102	0.015	cde
Aug. 22	0.158	0.015	a	0.307	0.077	a
Sept. 1	0.045	0.009	defgh	0.108	0.017	cd
Sept. 28	0.046	0.008	cdefgh	0.155	0.026	c
Sept. 30	0.194	0.017	a	0.099	0.021	cdef
Oct. 24	0.065	0.024	bcdefgh	0.100	0.023	cdef
Nov. 11	0.016	0.002	h	0.049	0.008	efgh
Nov. 13	0.078	0.007	bcdef	0.053	0.012	efgh
Nov. 16	0.094	0.011	bcd	0.057	0.008	defgh
Nov. 30	0.100	0.062	bc	0.059	0.006	defgh
Dec. 22	0.050	0.006	cdefgh	0.087	0.030	defg
Dec. 29	0.106	0.027	b	0.051	0.008	efgh
Jan. 5, 1988	0.045	0.015	defgh	0.053	0.021	efgh
Jan. 8	0.096	0.043	bcd	0.041	0.007	fgh
Jan. 20	0.018	0.002	gh	0.033	0.003	gh
Feb. 8	0.023	0.010	gh	0.035	0.007	gh
Mar. 3	0.069	0.008	bcdefg	0.072	0.016	defgh
Mar. 23	0.056	0.016	cdefgh	0.077	0.013	defg
Apr. 30	0.146	0.007	b	0.214	0.056	b
May 15	0.010	0.001	h	0.073	0.013	defgh
June 7	0.009	0.001	h	0.074	0.010	defg
June 22	0.017	0.002	gh	0.083	0.012	defg
July 7	0.017	0.002	h	0.100	0.015	cdef
July 12	0.009	0.001	h	0.023	0.003	h
July 30	0.027	0.003	fgh	0.059	0.010	defgh

Appendix table 19. Minimum, maximum, mean, and standard errors (SE) for calcium concentrations (mg/L) in bulk stemflow collected from Condalia Hookeri within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	2.76	2.76	2.76	-	c
July 31	0	*	*	*	*	
Aug. 10	2	2.37	4.31	3.34	0.97	c
Sept. 1	1	5.52	5.52	5.52	-	c
Sept. 28	2	3.11	27.00	15.06	11.95	b
Oct. 24	3	10.33	32.42	20.45	6.44	ab
Nov. 11	4	0.62	3.19	1.99	0.53	c
Nov. 16	0	*	*	*	*	
Nov. 30	0	*	*	*	*	
Dec. 22	1	27.26	27.26	27.26	-	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	0	*	*	*	*	
Jan. 20	1	6.98	6.98	6.98	-	c
Feb. 8	5	1.14	9.26	3.74	1.48	c
Mar. 23	4	2.06	11.30	6.99	2.68	c
Apr. 30	5	5.64	6.63	6.26	0.31	c
May 15	5	1.14	3.16	2.28	0.38	c
June 7	4	2.01	3.90	2.95	0.94	c
June 22	4	1.43	16.65	7.02	4.83	c
July 7	5	1.58	6.38	3.44	0.82	c
July 12	4	0.52	2.10	1.22	0.38	c
July 30	4	6.84	24.20	16.80	5.17	b

[1]indicates that no samples was collected for this event.

Appendix table 20. Minimum, maximum, mean, and standard errors (SE) for calcium concentrations (mg/L) in bulk stemflow collected from <u>Celtis pallida</u> within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	9.03	9.03	9.03	-	abc
July 31	2	6.60	12.43	9.52	2.91	ab
Aug. 10	4	3.08	4.58	3.71	0.45	bc
Sept. 1	0	*	*	*	*	
Sept. 28	0	*	*	*	*	
Oct. 24	4	3.26	8.63	5.72	1.57	bc
Nov. 11	4	1.97	6.32	3.14	1.06	bc
Nov. 13	0	*	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	4.11	5.43	4.77	0.66	bc
Dec. 22	1	4.96	4.96	4.96	-	bc
Dec. 29	1	7.77	7.77	7.77	-	abc
Jan. 5, 1988	1	3.83	3.83	3.83	-	bc
Jan. 8	1	17.21	17.21	17.21	-	a
Jan. 20	4	4.44	5.06	4.75	0.31	bc
Feb. 8	4	0.24	6.00	2.94	1.28	bc
Mar. 23	3	5.65	6.87	6.10	0.38	bc
Apr. 30	1	4.94	4.94	4.94	-	bc
May 15	4	1.18	6.44	3.35	1.59	bc
June 7	3	2.85	6.43	4.37	1.07	bc
June 22	3	1.88	2.85	2.41	0.28	bc
July 7	4	1.75	2.71	2.11	0.30	c
July 12	4	0.93	1.72	1.38	0.23	c
July 30	3	4.29	12.43	8.36	4.07	abc

[1]indicates that no samples was collected for this event.

Appendix table 21. Minimum, maximum, mean, and standard errors (SE) for calcium concentrations (mg/L) in bulk stemflow collected from Zanthoxylum fagara within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	6	1.05	16.68	7.56	3.69	bcd
July 25	5	0.75	2.15	1.53	0.41	fg
July 31	6	1.87	7.69	4.84	1.55	bcdefg
Aug. 10	11	1.52	4.79	3.36	0.33	cdefg
Sept. 1	6	11.00	11.69	11.34	0.35	ab
Sept. 28	6	7.25	12.35	9.49	1.23	ab
Oct. 24	11	2.95	19.95	8.05	1.62	b
Nov. 11	11	0.99	3.18	1.99	0.24	efg
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	11	3.85	18.12	9.34	2.77	ab
Dec. 22	11	6.82	24.20	13.11	2.78	a
Dec. 29	7	1.18	4.04	2.61	1.43	efg
Jan. 5, 1988	9	2.30	9.94	5.23	1.34	bcdefg
Jan. 8	11	4.70	19.35	8.81	2.71	ab
Jan. 20	10	4.32	12.25	7.64	1.70	bc
Feb. 8	11	1.19	5.60	3.03	0.45	defg
Mar. 23	11	1.91	8.44	5.44	0.90	bcdef
Apr. 30	11	3.44	10.98	6.55	1.05	bcde
May 15	11	1.05	6.73	2.86	0.61	efg
June 7	10	1.90	10.76	4.00	0.99	bcdefg
June 22	11	1.00	5.36	2.68	0.47	efg
July 7	11	1.38	8.58	2.91	0.66	efg
July 12	9	0.39	2.32	1.12	0.24	g
July 30	11	2.43	12.88	7.19	1.49	bcd

[1]indicates that no samples was collected for this event.

Appendix table 22. Minimum, maximum, mean, and standard errors (SE) for calcium concentrations (mg/L) in bulk stemflow collected from Prosopis glandulosa within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	3	10.95	13.78	12.36	1.42	def
July 25	1	6.08	6.08	6.08	-	
July 31	2	3.23	8.46	5.85	2.61	fgh
Aug. 10	5	1.87	6.22	4.34	0.96	gh
Sept. 1	5	6.81	18.21	11.08	2.49	ef
Sept. 28	5	10.86	33.52	19.54	4.09	c
Oct. 24	5	1.28	27.69	11.00	4.54	ef
Nov. 11	5	3.20	8.22	5.53	1.06	gh
Nov. 30	5	1.32	8.46	5.42	1.26	gh
Dec. 22	5	5.05	79.11	32.29	12.75	a
Jan. 5, 1988	4	2.05	22.64	8.35	4.85	efg
Jan. 8	5	3.28	65.41	27.05	11.06	b
Jan. 20	5	6.10	23.99	16.97	3.13	cd
Feb. 8	5	5.42	17.77	11.12	3.02	ef
Mar. 23	4	6.72	19.62	12.56	2.76	def
Apr. 30	4	9.02	18.93	13.98	4.95	de
May 15	5	1.43	6.10	3.96	0.75	gh
June 7	4	4.88	11.87	8.52	1.70	efg
June 22	5	5.51	12.24	7.27	1.26	fg
July 7	5	2.04	5.34	3.88	0.68	gh
July 12	5	1.08	3.32	2.09	0.48	h
July 30	5	6.18	20.53	12.55	2.37	def

Appendix table 23. Minimum, maximum, mean, and standard errors (SE) for calcium concentrations (mg/L) in bulk stemflow collected from Diospyros texana within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 31, 1987	2	3.94	4.29	4.11	0.17	a
Aug. 10	1	1.38	1.38	1.38	-	a
Sept. 1	1	4.11	4.11	4.11	-	a
Sept. 28	3	2.33	4.86	3.60	1.27	a
Oct. 24	3	1.31	9.14	4.80	2.30	a
Nov. 11	4	0.76	4.57	2.15	1.22	a
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	1.26	4.10	2.75	0.82	a
Dec. 22	3	4.20	8.32	6.26	2.06	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	1	2.62	2.62	2.62	-	a
Jan. 20	4	2.17	2.52	2.34	0.18	a
Feb. 8	4	1.20	2.51	1.97	0.39	a
Mar. 23	4	2.64	7.22	4.33	1.45	a
Apr. 30	1	7.31	7.31	7.31	-	a
May 15	3	0.67	6.42	3.13	1.71	a
June 7	4	0.79	4.90	3.44	0.91	a
June 22	4	1.86	3.50	2.57	0.49	a
July 7	4	1.18	1.31	1.23	0.04	a
July 12	4	0.36	1.75	0.88	0.30	a
July 30	4	2.00	6.52	4.16	0.93	a

[1]indicates that no samples was collected for this event.

Appendix table 24. Minimum, maximum, mean, and standard errors (SE) for magnesium concentrations (mg/L) in bulk stemflow collected from Condalia Hookeri within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	0.90	0.90	0.90	-	fg
July 31	0	*	*	*	*	
Aug. 10	2	0.54	0.88	0.71	0.17	fg
Sept. 1	1	3.03	3.03	3.03	-	def
Sept. 28	2	1.08	11.19	6.13	5.05	c
Oct. 24	3	4.16	11.76	8.09	2.20	b
Nov. 11	4	0.72	1.21	0.97	0.11	fg
Nov. 16	0	*	*	*	*	
Nov. 30	0	*	*	*	*	
Dec. 22	1	13.76	13.76	13.76	-	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	0	*	*	*	*	
Jan. 20	1	4.51	4.51	4.51	-	cde
Feb. 8	5	0.84	3.90	1.79	0.56	fg
Mar. 23	4	1.30	10.94	5.18	2.94	cd
Apr. 30	5	1.97	3.68	2.90	0.50	ef
May 15	5	0.78	1.94	1.27	0.21	fg
June 7	4	1.00	2.07	1.54	0.53	fg
June 22	4	0.61	2.86	1.61	0.66	fg
July 7	5	0.90	2.36	1.51	0.26	fg
July 12	4	0.28	0.75	0.56	0.10	g
July 30	4	1.70	2.10	1.89	0.12	fg

[1]indicates that no samples was collected for this event.

Appendix table 25. Minimum, maximum, mean, and standard errors (SE) for magnesium concentrations (mg/L) in bulk stemflow collected from Celtis pallida within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	3.16	3.16	3.16	-	bcde
July 31	2	2.81	3.42	3.12	0.30	bcde
Aug. 10	4	1.51	2.17	1.77	0.21	cdef
Sept. 1	0	*	*	*	*	
Sept. 28	0	*	*	*	*	
Oct. 24	4	1.70	2.78	2.39	0.35	bcdef
Nov. 11	4	0.86	2.29	1.38	0.32	def
Nov. 13	0	*	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	1.90	5.45	3.68	1.78	bc
Dec. 22	1	3.48	3.48	3.48	-	bcd
Dec. 29	1	4.40	4.40	4.40	-	b
Jan. 5, 1988	1	2.16	2.16	2.16	-	bcdef
Jan. 8	1	10.77	10.77	10.77	-	a
Jan. 20	4	2.66	3.20	2.93	0.27	bcde
Feb. 8	4	0.32	2.11	1.22	0.39	def
Mar. 23	3	2.61	4.28	3.21	0.53	bcd
Apr. 30	1	2.09	2.09	2.09	-	bcdef
May 15	4	0.85	2.01	1.39	0.34	def
June 7	3	1.43	3.32	2.08	0.62	bcdef
June 22	3	0.87	1.63	1.22	0.22	def
July 7	4	0.73	1.21	0.96	0.14	ef
July 12	4	0.55	0.80	0.70	0.07	f
July 30	3	1.64	3.42	2.53	0.89	bcde

[1]indicates that no samples was collected for this event.

Appendix table 26. Minimum, maximum, mean, and standard errors (SE) for magnesium concentrations (mg/L) in bulk stemflow collected from Zanthoxylum fagara within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	6	0.76	4.52	2.21	0.88	bcd
July 25	5	0.39	2.81	1.29	0.77	def
July 31	6	0.61	2.45	1.24	0.41	def
Aug. 10	11	0.66	1.30	1.00	0.08	ef
Sept. 1	6	3.72	3.74	3.73	0.01	ab
Sept. 28	6	1.98	3.87	2.82	0.34	bc
Oct. 24	11	0.73	3.70	1.99	0.27	cde
Nov. 11	11	0.41	1.32	0.77	0.09	f
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	11	1.27	4.25	2.77	0.59	bc
Dec. 22	11	2.42	10.35	4.12	1.05	a
Dec. 29	7	0.59	1.77	1.18	0.59	def
Jan. 5, 1988	9	0.68	5.20	2.00	0.71	cde
Jan. 8	11	1.90	4.33	3.13	0.46	ab
Jan. 20	10	1.71	2.97	2.31	0.26	bcd
Feb. 8	11	0.18	1.73	0.98	0.15	ef
Mar. 23	11	0.50	3.00	1.73	0.34	cde
Apr. 30	11	1.19	3.18	2.18	0.31	bcd
May 15	11	0.50	2.75	1.30	0.23	def
June 7	10	0.92	2.83	1.60	0.22	def
June 22	11	0.48	1.76	1.00	0.15	ef
July 7	11	0.47	1.46	0.98	0.10	ef
July 12	9	0.34	0.93	0.63	0.08	f
July 30	11	0.83	3.86	2.79	0.43	bc

[1]indicates that no samples was collected for this event.

Appendix table 27. Minimum, maximum, mean, and standard errors (SE) for magnesium concentrations (mg/L) in bulk stemflow collected from Prosopis glandulosa within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	3	2.55	3.39	2.97	0.42	defg
July 25	1	1.41	1.41	1.41	-	ghi
July 31	2	1.06	1.53	1.29	0.23	ghi
Aug. 10	5	0.39	2.95	1.67	0.42	ghi
Sept. 1	5	1.47	10.35	4.07	1.60	cde
Sept. 28	5	1.78	12.41	5.04	1.91	bc
Oct. 24	5	0.83	4.64	2.44	0.73	gh
Nov. 11	5	0.57	1.88	1.21	0.33	ghi
Nov. 30	5	0.67	3.23	1.87	0.45	ghi
Dec. 22	5	1.28	13.72	6.98	2.44	a
Jan. 5, 1988	4	0.74	3.63	1.74	0.67	ghi
Jan. 8	5	2.26	10.66	6.12	1.84	ab
Jan. 20	5	1.16	4.91	3.72	0.69	def
Feb. 8	5	1.63	4.91	2.64	0.77	fgh
Mar. 23	4	1.66	3.91	2.82	0.52	fg
Apr. 30	4	2.43	5.67	4.05	1.62	cdef
May 15	5	0.29	1.33	0.97	0.18	i
June 7	4	1.21	2.96	2.06	0.36	ghi
June 22	5	1.40	2.25	1.81	0.16	ghi
July 7	5	0.68	1.31	1.10	0.14	hi
July 12	5	0.33	1.21	0.62	0.16	i
July 30	5	1.50	9.99	4.48	1.46	cd

Appendix table 28. Minimum, maximum, mean, and standard errors (SE) for magnesium concentrations (mg/L) in bulk stemflow collected from Diospyros texana within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 31, 1987	2	1.79	1.84	1.82	0.03	abcd
Aug. 10	1	1.41	1.41	1.41	-	abcd
Sept. 1	1	3.80	3.80	3.80	-	ab
Sept. 28	3	2.35	2.54	2.44	0.09	abc
Oct. 24	3	0.92	3.45	2.49	0.79	abc
Nov. 11	4	0.84	1.79	1.22	0.29	cd
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	1.05	3.81	2.07	0.87	abcd
Dec. 22	3	1.47	6.70	4.08	2.61	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	1	1.66	1.66	1.66	-	abcd
Jan. 20	4	1.65	1.95	1.80	0.15	abcd
Feb. 8	4	1.13	1.59	1.40	0.14	bcd
Mar. 23	4	0.59	1.84	1.28	0.37	cd
Apr. 30	1	4.29	4.29	4.29	-	a
May 15	3	0.51	1.32	0.83	0.25	cd
June 7	4	0.84	3.05	2.01	0.47	abcd
June 22	4	1.03	1.31	1.21	0.09	cd
July 7	4	0.60	1.58	0.99	0.30	cd
July 12	4	0.33	1.02	0.60	0.16	d
July 30	4	1.15	3.54	2.29	0.66	abc

[1]indicates that no samples was collected for this event.

Appendix table 29. Minimum, maximum, mean, and standard errors (SE) for potassium (mg/L) in bulk stemflow collected from Condalia Hookeri within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	6.85	6.85	6.85	-	c
July 31	0	*	*	*	*	
Aug. 10	2	5.98	13.73	9.85	3.87	bc
Sept. 1	1	17.93	17.93	17.93	-	b
Sept. 28	2	4.51	10.46	7.48	2.98	c
Oct. 24	3	7.51	29.58	16.12	6.82	b
Nov. 11	4	1.22	6.58	3.87	1.12	c
Nov. 16	0	*	*	*	*	
Nov. 30	0	*	*	*	*	
Dec. 22	1	33.53	33.53	33.53	-	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	0	*	*	*	*	
Jan. 20	1	10.40	10.40	10.40	-	bc
Feb. 8	5	1.58	18.51	9.13	3.41	bc
Mar. 23	4	1.44	19.61	7.87	5.88	c
Apr. 30	5	3.04	20.34	9.25	5.56	bc
May 15	5	0.94	2.63	1.85	0.30	c
June 7	4	1.66	5.38	3.52	1.86	c
June 22	4	1.02	9.94	4.54	2.74	c
July 7	5	3.42	9.68	5.95	1.33	c
July 12	4	0.52	1.55	0.95	0.25	c
July 30	4	5.60	6.05	5.83	0.13	c

[1]indicates that no samples was collected for this event.

Appendix table 30. Minimum, maximum, mean, and standard errors (SE) for potassium (mg/L) in bulk stemflow collected from Celtis pallida within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	13.63	13.63	13.63	-	abc
July 31	2	6.07	11.58	8.83	2.76	bcd
Aug. 10	4	5.00	8.19	6.77	0.93	cd
Sept. 1	0	*	*	*	*	
Sept. 28	0	*	*	*	*	
Oct. 24	4	5.12	11.57	7.38	2.10	bcd
Nov. 11	4	2.21	13.20	5.34	2.63	cd
Nov. 13	0	*	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	6.40	8.28	7.34	0.94	bcd
Dec. 22	1	6.04	6.04	6.04	-	cd
Dec. 29	1	17.07	17.07	17.07	-	ab
Jan. 5, 1988	1	5.19	5.19	5.19	-	cd
Jan. 8	1	20.90	20.90	20.90	-	a
Jan. 20	4	3.71	6.70	5.20	1.50	cd
Feb. 8	4	0.15	6.24	3.08	1.28	d
Mar. 23	3	4.20	7.42	5.99	0.95	cd
Apr. 30	1	4.14	4.14	4.14	-	cd
May 15	4	0.68	7.26	3.15	2.07	d
June 7	3	3.52	5.61	4.59	0.60	cd
June 22	3	1.36	3.15	2.31	0.52	d
July 7	4	2.44	2.84	2.66	0.12	d
July 12	4	0.42	2.72	1.52	0.67	d
July 30	3	5.53	11.58	8.56	3.03	bcd

[1]indicates that no samples was collected for this event.

Appendix table 31. Minimum, maximum, mean, and standard errors (SE) for potassium (mg/L) in bulk stemflow collected from Zanthoxylum fagara within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	6	1.77	19.67	10.02	4.52	abc
July 25	5	0.74	1.47	1.06	0.22	g
July 31	6	1.90	10.86	5.10	2.09	cdefg
Aug. 10	11	1.87	9.35	4.55	0.78	defg
Sept. 1	6	5.67	23.06	14.36	8.69	a
Sept. 28	6	3.76	17.21	11.08	2.48	ab
Oct. 24	11	2.86	25.91	9.87	2.23	abc
Nov. 11	11	0.49	4.06	1.84	0.38	fg
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	11	1.71	12.34	7.61	2.16	abcd
Dec. 22	11	4.05	36.77	12.47	4.45	a
Dec. 29	7	1.19	2.40	1.80	0.60	fg
Jan. 5, 1988	9	1.67	19.52	6.58	2.74	bcde
Jan. 8	11	2.92	8.56	6.04	1.05	bcdef
Jan. 20	10	2.71	9.92	5.59	1.55	bcdefg
Feb. 8	11	0.65	10.18	4.21	0.82	defg
Mar. 23	11	0.63	11.90	4.53	1.41	defg
Apr. 30	11	2.79	10.76	6.41	1.38	bcdef
May 15	11	0.49	5.13	2.24	0.51	fg
June 7	10	1.63	11.48	5.10	1.26	cdefg
June 22	11	0.57	7.06	2.89	0.70	efg
July 7	11	0.72	8.87	3.33	0.72	defg
July 12	9	0.14	2.82	1.11	0.39	g
July 30	11	0.90	7.66	4.52	0.84	defg

[1]indicates that no samples was collected for this event.

Appendix table 32. Minimum, maximum, mean, and standard errors (SE) for potassium (mg/L) in bulk stemflow collected from _Prosopis glandulosa_ within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	3	9.07	10.63	9.85	0.78	cd
July 25	1	6.05	6.05	6.05	-	d
July 31	2	2.39	4.16	3.28	0.89	d
Aug. 10	5	0.91	26.60	13.51	4.97	bc
Sept. 1	5	4.73	16.73	12.36	2.51	bc
Sept. 28	5	7.17	30.95	13.77	4.42	bc
Oct. 24	5	2.83	38.07	12.56	6.56	bc
Nov. 11	5	1.61	9.02	5.17	1.63	d
Nov. 30	5	0.95	12.03	6.46	2.28	d
Dec. 22	5	3.18	46.61	22.67	8.07	a
Jan. 5, 1988	4	0.93	16.63	5.33	3.79	d
Jan. 8	5	3.71	32.73	12.31	5.43	c
Jan. 20	5	1.07	15.64	8.63	3.17	cd
Feb. 8	5	3.31	28.80	13.20	5.86	bc
Mar. 23	4	2.51	15.92	8.22	3.25	cd
Apr. 30	4	7.32	31.35	19.33	12.02	ab
May 15	5	0.57	5.61	3.34	0.96	d
June 7	4	1.64	7.56	4.76	1.30	d
June 22	5	3.86	12.74	6.82	1.59	d
July 7	5	1.38	9.76	6.18	1.81	d
July 12	5	0.43	6.15	3.30	1.22	d
July 30	5	4.92	59.40	19.20	10.34	ab

Appendix table 33. Minimum, maximum, mean, and standard errors (SE) for potassium (mg/L) in bulk stemflow collected from Diospyros texana within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 31, 1987	2	14.36	15.01	14.69	0.33	bc
Aug. 10	1	19.09	19.09	19.09	-	ab
Sept. 1	1	25.64	25.64	25.64	-	a
Sept. 28	3	12.50	15.47	13.98	1.49	bcd
Oct. 24	3	2.20	19.83	12.11	5.21	bcde
Nov. 11	4	1.05	14.03	5.98	4.06	defg
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	2.80	14.02	7.61	3.34	cdefg
Dec. 22	3	5.30	26.52	15.91	10.61	ab
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	1	4.24	4.24	4.24	-	efg
Jan. 20	4	3.49	3.53	3.51	0.02	fg
Feb. 8	4	3.44	6.33	5.15	0.88	efg
Mar. 23	4	3.23	12.76	7.95	2.75	cdefg
Apr. 30	1	18.45	18.45	18.45	-	ab
May 15	3	0.81	26.02	9.91	8.08	bcdef
June 7	4	0.89	14.01	6.92	2.93	defg
June 22	4	2.78	5.75	3.81	0.97	fg
July 7	4	1.14	4.81	2.53	1.15	g
July 12	4	0.30	3.78	1.89	0.83	g
July 30	4	4.66	14.50	7.83	2.31	cdefg

[1]indicates that no samples was collected for this event.

Appendix table 34. Minimum, maximum, mean, and standard errors (SE) for nitrogen (mg/L) in bulk stemflow collected from Condalia Hookeri within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	3.08	3.08	3.08	-	cde
July 31	2	0.58	3.59	2.08	1.51	de
Aug. 10	2	2.04	3.91	2.97	0.93	cde
Sept. 1	1	5.38	5.38	5.38	-	bcde
Sept. 28	2	2.39	12.22	7.31	4.92	bc
Oct. 24	3	5.55	7.51	6.66	0.58	bcd
Nov. 11	4	0.37	3.37	1.81	0.62	e
Nov. 16	0	*	*	*	*	
Nov. 30	0	*	*	*	*	
Dec. 22	1	16.70	16.70	16.70	-	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	0	*	*	*	*	
Jan. 20	0	*	*	*	*	
Feb. 8	5	1.30	5.51	2.61	0.80	de
Mar. 23	4	5.97	7.94	6.96	0.99	bcd
Apr. 30	5	4.41	12.52	8.00	2.38	b
May 15	5	1.02	4.87	3.12	0.67	cde
June 7	4	2.53	5.90	4.22	1.68	bcde
June 22	4	1.87	3.06	2.52	0.35	de
July 7	5	0.49	7.35	3.15	1.16	dce
July 12	4	0.12	2.59	1.38	0.61	e
July 30	4	5.08	5.38	5.23	0.15	bcde

[1]indicates that no samples was collected for this event.

Appendix table 35. Minimum, maximum, mean, and standard errors (SE) for nitrogen (mg/L) in bulk stemflow collected from Celtis pallida within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	6.74	6.74	6.74	-	abcdef
July 31	2	2.96	10.53	6.74	3.78	abcdef
Aug. 10	4	2.80	4.85	4.12	0.66	cdef
Sept. 1	1	12.72	12.72	12.72	-	a
Sept. 28	1	11.05	11.05	11.05	-	ab
Oct. 24	4	4.30	9.60	7.42	1.60	abcde
Nov. 11	4	0.53	3.59	2.62	0.70	f
Nov. 13	0	*	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	4.19	6.86	5.52	1.34	bcdef
Dec. 22	1	9.41	9.41	9.41	-	abcd
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	1	3.70	3.70	3.70	-	cdef
Jan. 8	1	2.64	2.64	2.64	-	ef
Jan. 20	1	0.49	0.49	0.49	-	f
Feb. 8	4	2.42	6.31	4.27	0.81	cdef
Mar. 23	3	3.27	9.03	5.76	1.71	bcdef
Apr. 30	3	7.35	8.43	7.89	0.54	abcde
May 15	4	2.99	14.79	7.42	3.71	abcde
June 7	3	5.81	7.55	6.44	0.56	bcdef
June 22	3	2.41	3.00	2.71	0.29	ef
July 7	4	3.04	4.15	3.76	0.36	cdef
July 12	4	1.45	4.63	3.42	0.99	def
July 30	1	9.64	9.64	9.64	-	abc

[1]indicates that no samples was collected for this event.

Appendix table 36. Minimum, maximum, mean, and standard errors (SE) for nitrogen (mg/L) in bulk stemflow collected from Zanthoxylum fagara within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	6	1.83	6.96	3.51	1.18	def
July 25	5	0.18	5.29	2.41	1.21	f
July 31	6	1.68	3.47	2.80	0.39	ef
Aug. 10	11	0.88	6.28	3.75	0.61	def
Sept. 1	6	7.04	16.14	11.59	4.55	a
Sept. 28	6	6.52	15.96	10.35	1.77	a
Oct. 24	11	1.91	14.02	6.46	1.33	bc
Nov. 11	11	0.37	6.32	2.67	0.50	f
Nov. 13	3	*[1]	*	*	*	
Nov. 16	3	*	*	*	*	
Nov. 30	11	1.45	7.22	4.27	1.27	cdef
Dec. 22	11	1.07	16.62	8.32	2.14	ab
Dec. 29	7	1.67	3.71	2.69	1.02	f
Jan. 5, 1988	9	1.05	5.04	3.55	0.61	def
Jan. 8	11	2.04	9.70	5.65	1.62	bcde
Jan. 20	10	0.00	7.34	2.43	1.63	f
Feb. 8	11	1.32	6.23	3.28	0.43	ef
Mar. 23	11	1.50	41.47	10.64	5.29	a
Apr. 30	11	0.00	9.58	5.95	1.51	bcd
May 15	11	1.06	7.72	3.50	0.60	def
June 7	10	1.98	9.51	4.83	0.66	cdef
June 22	11	0.00	5.84	2.88	0.70	ef
July 7	11	0.62	5.35	2.86	0.54	ef
July 12	9	0.08	12.21	2.77	1.21	f
July 30	11	4.11	15.07	8.47	1.59	ab

[1]indicates that no samples was collected for this event.

Appendix table 37. Minimum, maximum, mean, and standard errors (SE) for nitrogen (mg/L) in bulk stemflow collected from Prosopis glandulosa within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	3	8.92	14.40	11.98	1.61	ab
July 25	1	3.25	3.25	3.25	-	ef
July 31	2	3.18	9.74	6.46	3.28	cdef
Aug. 10	5	2.60	5.79	4.34	0.62	ef
Sept. 1	5	4.22	8.00	6.01	0.65	def
Sept. 28	5	7.45	17.22	13.92	1.73	a
Oct. 24	5	3.92	17.71	9.01	2.64	bcd
Nov. 11	5	0.43	4.51	3.23	0.73	f
Nov. 30	5	1.31	30.71	8.76	5.54	bcd
Dec. 22	5	2.41	13.25	10.04	2.02	bc
Jan. 5, 1988	4	0.98	5.19	3.23	0.93	f
Jan. 8	5	2.75	10.50	7.02	1.41	cde
Jan. 20	5	1.52	5.86	4.37	0.97	ef
Feb. 8	5	1.14	7.07	4.98	1.05	ef
Mar. 23	4	5.38	11.77	8.57	3.19	cde
Apr. 30	4	8.70	10.60	9.79	0.57	bc
May 15	5	1.37	7.21	4.68	1.14	ef
June 7	4	2.19	9.34	5.70	1.48	def
June 22	5	2.51	16.41	9.15	4.02	bcd
July 7	5	3.93	7.70	5.44	1.15	def
July 12	5	1.38	5.18	2.79	0.67	f
July 30	5	5.16	12.76	8.01	1.36	cde

Appendix table 38. Minimum, maximum, mean, and standard errors (SE) for nitrogen (mg/L) in bulk stemflow collected from Diospyros texana within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 31, 1987	2	2.16	5.16	3.66	1.50	bc
Aug. 10	1	6.22	6.22	6.22	-	ab
Sept. 1	1	10.28	10.28	10.28	-	a
Sept. 28	3	3.30	4.71	4.01	0.71	bc
Oct. 24	3	1.17	5.76	2.76	1.50	c
Nov. 11	4	0.84	10.25	4.88	2.80	abc
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	3.41	4.93	4.17	0.76	abc
Dec. 22	3	4.24	6.09	5.16	0.93	abc
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	1	2.28	2.28	2.28	-	c
Jan. 20	4	1.15	3.16	2.15	1.01	c
Feb. 8	4	0.67	4.52	2.69	1.12	c
Mar. 23	4	2.30	3.54	2.92	0.62	c
Apr. 30	4	4.38	13.08	8.73	4.35	ab
May 15	3	1.51	9.26	4.16	2.55	bc
June 7	4	1.67	3.95	2.67	0.67	c
June 22	4	0.96	3.51	2.54	0.55	c
July 7	4	1.59	3.61	2.65	0.59	c
July 12	4	1.40	2.10	1.67	0.15	c
July 30	4	2.26	6.23	4.41	0.87	abc

[1]indicates that no samples was collected for this event.

Appendix table 39. Minimum, maximum, mean, and standard errors (SE) for phosphorus (mg/L) in bulk stemflow collected from <u>Condalia Hookeri</u> within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	0.020	0.020	0.020	-	cd
July 31	2	0.027	0.126	0.077	0.050	abcd
Aug. 10	2	0.095	0.186	0.141	0.046	abc
Sept. 1	1	0.164	0.164	0.164	-	abc
Sept. 28	2	0.047	0.125	0.086	0.039	abcd
Oct. 24	3	0.025	0.113	0.076	0.026	abcd
Nov. 11	4	0.033	0.074	0.050	0.009	cd
Nov. 16	0	*	*	*	*	
Nov. 30	0	*	*	*	*	
Dec. 22	1	0.159	0.159	0.159	-	abc
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	0	*	*	*	*	
Jan. 20	0	*	*	*	*	
Feb. 8	5	0.013	0.075	0.042	0.012	cd
Mar. 23	4	0.026	0.339	0.183	0.157	a
Apr. 30	5	0.041	0.396	0.164	0.116	ab
May 15	5	0.026	0.061	0.040	0.007	cd
June 7	4	0.028	0.032	0.030	0.002	cd
June 22	4	0.079	0.120	0.106	0.014	abc
July 7	5	0.028	0.373	0.118	0.065	abc
July 12	4	0.006	0.020	0.013	0.003	d
July 30	4	0.032	0.077	0.055	0.023	bcd

[1]indicates that no samples was collected for this event.

Appendix table 40. Minimum, maximum, mean, and standard errors (SE) for phosphorus (mg/L) in bulk stemflow collected from Celtis pallida within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	0	*[1]	*	*	*	
July 25	1	0.046	0.046	0.046	-	a
July 31	2	0.018	0.029	0.024	0.006	a
Aug. 10	4	0.038	0.054	0.046	0.005	a
Sept. 1	1	0.060	0.060	0.060	-	a
Sept. 28	1	0.108	0.108	0.108	-	a
Oct. 24	4	0.067	0.167	0.125	0.030	a
Nov. 11	4	0.018	0.057	0.035	0.009	a
Nov. 13	0	*	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	0.045	0.131	0.088	0.043	a
Dec. 22	1	0.099	0.099	0.099	-	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	3	0.011	0.011	0.011	-	a
Jan. 8	4	0.035	0.035	0.035	-	a
Jan. 20	1	0.018	0.018	0.018	-	a
Feb. 8	4	0.019	0.094	0.050	0.018	a
Mar. 23	3	0.055	0.086	0.075	0.010	a
Apr. 30	3	0.081	0.203	0.142	0.061	a
May 15	4	0.019	0.146	0.063	0.042	a
June 7	3	0.017	0.046	0.029	0.009	a
June 22	3	0.023	0.029	0.026	0.003	a
July 7	4	0.017	0.042	0.032	0.008	a
July 12	4	0.018	0.034	0.024	0.005	a
July 30	1	0.076	0.076	0.076	-	a

[1]indicates that no samples was collected for this event.

Appendix table 41. Minimum, maximum, mean, and standard errors (SE) for phosphorus (mg/L) in bulk stemflow collected from Zanthoxylum fagara within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	6	0.058	0.177	0.097	0.027	bcd
July 25	5	0.010	0.045	0.024	0.008	d
July 31	6	0.009	0.283	0.094	0.064	bcd
Aug. 10	11	0.028	0.208	0.068	0.017	d
Sept. 1	6	0.062	0.136	0.099	0.037	bcd
Sept. 28	6	0.035	0.213	0.148	0.035	bc
Oct. 24	11	0.015	0.245	0.076	0.022	d
Nov. 11	11	0.010	0.048	0.030	0.004	d
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	11	0.009	0.038	0.019	0.005	d
Dec. 22	11	0.005	1.213	0.227	0.166	a
Dec. 29	7	0.015	0.023	0.019	0.004	d
Jan. 5, 1988	9	0.006	0.140	0.044	0.022	d
Jan. 8	11	0.006	0.036	0.020	0.006	d
Jan. 20	10	0.016	0.103	0.056	0.020	d
Feb. 8	11	0.003	0.093	0.036	0.008	d
Mar. 23	11	0.008	0.255	0.074	0.032	d
Apr. 30	11	0.052	0.299	0.154	0.039	b
May 15	11	0.020	0.067	0.038	0.007	d
June 7	10	0.014	0.118	0.055	0.010	d
June 22	11	0.026	0.132	0.050	0.011	d
July 7	11	0.024	0.338	0.085	0.031	cd
July 12	9	0.011	0.092	0.033	0.009	d
July 30	11	0.038	0.487	0.145	0.059	bc

[1]indicates that no samples was collected for this event.

Appendix table 42. Minimum, maximum, mean, and standard errors (SE) for phosphorus (mg/L) in bulk stemflow collected from Prosopis glandulosa within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 21, 1987	3	0.055	0.231	0.123	0.055	bc
July 25	0	0.020	0.020	0.020	-	e
July 31	2	0.018	0.092	0.055	0.037	cde
Aug. 10	5	0.019	0.115	0.070	0.024	bcde
Sept. 1	5	0.041	0.145	0.102	0.018	bcd
Sept. 28	5	0.077	0.231	0.141	0.027	b
Oct. 24	5	0.039	0.161	0.076	0.022	bcde
Nov. 11	5	0.010	0.082	0.059	0.014	cde
Nov. 30	5	0.009	0.141	0.045	0.024	cde
Dec. 22	5	0.013	0.168	0.081	0.033	bcde
Jan. 5, 1988	4	0.010	0.154	0.049	0.035	cde
Jan. 8	5	0.014	0.034	0.027	0.003	de
Jan. 20	5	0.015	0.046	0.031	0.007	de
Feb. 8	5	0.011	0.038	0.023	0.005	e
Mar. 23	4	0.048	0.138	0.093	0.045	bcde
Apr. 30	4	0.118	0.497	0.257	0.121	a
May 15	5	0.012	0.133	0.081	0.024	bcde
June 7	4	0.017	0.058	0.031	0.009	de
June 22	5	0.048	0.110	0.075	0.018	bcde
July 7	5	0.021	0.089	0.066	0.023	bcde
July 12	5	0.013	0.032	0.022	0.003	e
July 30	5	0.034	0.241	0.151	0.034	b

Appendix table 43. Minimum, maximum, mean, and standard errors (SE) for phosphorus (mg/L) in bulk stemflow collected from Diospyros texana within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter were not significantly different (P>0.05) using Fischer's LSD procedure.

DATE	n	Min.	Max.	Mean	SE	Sig.
July 31, 1987	2	0.022	0.061	0.042	0.020	a
Aug. 10	1	0.084	0.084	0.084	-	a
Sept. 1	1	0.138	0.138	0.138	-	a
Sept. 28	3	0.047	0.068	0.058	0.011	a
Oct. 24	3	0.022	0.119	0.057	0.031	a
Nov. 11	4	0.009	0.187	0.090	0.052	a
Nov. 13	0	*[1]	*	*	*	
Nov. 16	0	*	*	*	*	
Nov. 30	4	0.101	0.184	0.143	0.042	a
Dec. 22	3	0.051	0.053	0.052	0.001	a
Dec. 29	0	*	*	*	*	
Jan. 5, 1988	0	*	*	*	*	
Jan. 8	1	0.025	0.025	0.025	-	a
Jan. 20	4	0.028	0.046	0.037	0.009	a
Feb. 8	4	0.010	0.080	0.038	0.021	a
Mar. 23	4	0.027	0.039	0.033	0.006	a
Apr. 30	4	0.051	0.130	0.091	0.040	a
May 15	3	0.016	0.101	0.049	0.026	a
June 7	4	0.008	0.012	0.009	0.001	a
June 22	4	0.016	0.030	0.024	0.003	a
July 7	4	0.027	0.054	0.038	0.008	a
July 12	4	0.007	0.068	0.027	0.014	a
July 30	4	0.029	0.367	0.118	0.083	a

[1]indicates that no samples was collected for this event.

Appendix table 44. Mean calcium concentrations (mg/L) of bulk stemflow from Condalia Hookeri (Coho), Celtis pallida (Cepa), Zanthoxylum fagara (Zafa), Prosopis glandulosa (Prgl), and Diospyros texana (Dite) collected within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter for each date (across rows) were not significantly different (P>0.05) using Fischer's LSD.

Date	Coho Mean	Coho Sig.	Cepa Mean	Cepa Sig.	Zafa Mean	Zafa Sig.	Prgl Mean	Prgl Sig.	Dite Mean	Dite Sig.
July 21,1987	*[1]		*		7.56	a	12.36	a	*	
July 25	2.76	a	9.03	a	1.53	a	6.08	a	*	
July 31	*		9.52	a	4.84	a	5.85	a	4.11	a
Aug. 10	3.34	a	3.71	a	3.36	a	4.34	a	1.38	a
Sept. 1	5.52	a	*		11.34	a	11.08	a	4.11	a
Sept. 28	15.06	a	*		9.49	b	19.54	a	3.60	c
Oct. 24	20.45	a	5.72	bc	8.05	bc	11.00	b	4.80	bc
Nov. 11	1.99	a	3.14	a	1.99	a	5.53	a	2.15	a
Nov. 13	*		*		*		*		*	
Nov. 16	*		*		*		*		*	
Nov. 30	*		4.77	a	9.34	a	5.42	a	2.75	b
Dec. 22	27.26	a	4.96	b	13.11	b	32.29	a	6.26	b
Dec. 29	*		7.77	a	2.61	a	*		*	
Jan. 5,1988	*		3.83	a	5.23	a	8.35	a	*	
Jan. 8	*		17.21	b	8.81	bc	27.05	a	2.62	c
Jan. 20	6.98	b	4.75	b	7.64	b	16.97	a	2.34	b
Feb. 8	3.74	b	2.94	b	3.03	b	11.12	a	1.97	b
Mar. 23	6.99	b	6.10	b	5.44	b	12.56	a	4.33	b
Apr. 30	6.26	b	4.94	b	6.55	b	13.98	a	7.31	a
May 15	2.28	a	3.35	a	2.86	a	3.96	a	3.13	a
June 7	2.95	a	4.37	a	4.00	a	8.52	a	3.44	a
June 22	7.02	a	2.41	a	2.68	a	7.27	a	2.57	a
July 7	3.44	a	2.11	a	2.91	a	3.88	a	1.23	a
July 12	1.22	a	1.38	a	1.12	a	2.09	a	0.88	a
July 30	16.80	a	8.36	bc	7.19	c	12.55	ab	4.16	c

[1]indicates no samples were collected for this event.

Appendix table 45. Mean magnesium concentrations (mg/L) of bulk stemflow from Condalia Hookeri (Coho), Celtis pallida (Cepa), Zanthoxylum fagara (Zafa), Prosopis glandulosa (Prgl), and Diospyros texana (Dite) collected within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter for each date (across rows) were not significantly different (P>0.05) using Fischer's LSD.

Date	Coho Mean	Coho Sig.	Cepa Mean	Cepa Sig.	Zafa Mean	Zafa Sig.	Prgl Mean	Prgl Sig.	Dite Mean	Dite Sig.
July 21, 1987	*[1]		*		2.21	a	2.97	a	*	
July 25	0.90	a	3.16	a	1.29	a	1.41	a	*	
July 31	*		3.12	a	1.24	b	1.29	a	1.82	a
Aug. 10	0.71	a	1.77	a	1.00	a	1.67	a	1.41	a
Sept. 1	3.03	a	*		3.73	a	4.07	a	3.80	a
Sept. 28	6.13	a	*		2.82	b	5.04	a	2.44	b
Oct. 24	8.09	a	2.39	b	1.99	b	2.44	b	2.49	b
Nov. 11	0.97	a	1.38	a	0.77	a	1.21	a	1.22	a
Nov. 13	*		*		*		*		*	
Nov. 16	*		*		*		*		*	
Nov. 30	*		3.68	a	2.77	a	1.87	a	2.07	a
Dec. 22	13.76	a	3.48	c	4.12	b	6.98	c	4.08	c
Dec. 29	*		4.40	a	1.18	a	*		*	
Jan. 5, 1988	*		2.16	a	2.00	a	1.74	a	*	
Jan. 8	*		10.77	a	3.13	c	6.12	b	1.66	c
Jan. 20	4.51	a	2.93	a	2.31	a	3.72	a	1.80	a
Feb. 8	1.79	ab	1.22	b	0.98	b	2.64	a	1.40	a
Mar. 23	5.18	a	3.21	b	1.73	cd	2.82	bc	1.28	d
Apr. 30	2.90	a	2.09	a	2.18	a	4.05	a	4.29	a
May 15	1.27	a	1.39	a	1.30	a	0.97	a	0.83	a
June 7	1.54	a	2.08	a	1.60	a	2.06	a	2.01	a
June 22	1.61	a	1.22	a	1.00	a	1.81	a	1.21	a
July 7	1.51	a	0.96	a	0.98	a	1.10	a	0.99	a
July 12	0.56	a	0.70	a	0.63	a	0.62	a	0.60	a
July 30	1.89	b	2.53	b	2.79	b	4.48	a	2.29	b

[1]indicates no samples were collected for this event.

Appendix table 46. Mean potassium concentrations (mg/L) of bulk stemflow from Condalia Hookeri (Coho), Celtis pallida (Cepa), Zanthoxylum fagara (Zafa), Prosopis glandulosa (Prgl), and Diospyros texana (Dite) collected within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter for each date (across rows) were not significantly different (P>0.05) using Fischer's LSD.

Date	Coho Mean	Sig.	Cepa Mean	Sig.	Zafa Mean	Sig.	Prgl Mean	Sig.	Dite Mean	Sig.
July 21, 1987	*[1]		*		10.02	a	9.85	a	*	
July 25	6.85	a	13.63	a	1.06	b	6.05	a	*	
July 31	*		8.83	ab	5.10	b	3.28	b	14.69	a
Aug. 10	9.85	ab	6.77	b	4.55	b	13.51	a	19.09	a
Sept. 1	17.93	ab	*		14.36	b	12.36	b	25.64	a
Sept. 28	7.48	a	*		11.08	a	13.77	a	13.98	a
Oct. 24	16.12	a	7.38	b	9.87	b	12.56	ab	12.11	ab
Nov. 11	3.87		5.34	a	1.84	a	5.17	a	5.98	a
Nov. 13	*		*		*		*		*	
Nov. 16	*		*		*		*		*	
Nov. 30	*		7.34	a	7.61	a	6.46	a	7.61	a
Dec. 22	33.53	a	6.04	c	12.47	c	22.67	b	15.91	bc
Dec. 29	*		17.07	a	1.80	b	*		*	
Jan. 5, 1987	*		5.19	a	6.58	a	5.33	a	*	
Jan. 8	*		20.90	a	6.04	b	12.31	ab	4.24	b
Jan. 20	10.40	a	5.20	a	5.59	a	8.63	a	3.51	a
Feb. 8	9.13	ab	3.08	c	4.21	c	13.20	a	5.15	bc
Mar. 23	7.87	a	5.99	a	4.53	a	8.22	a	7.95	a
Apr. 30	9.25	bc	4.14	c	6.41	c	19.33	a	18.45	ab
May 15	1.85	b	3.15	b	2.24	b	3.34	b	9.91	a
June 7	3.52	a	4.59	a	5.10	a	4.76	a	6.92	a
June 22	4.54	a	2.31	a	2.89	a	6.82	a	3.81	a
July 7	5.95	a	2.66	a	3.33	a	6.18	a	2.53	a
July 12	0.95	a	1.52	a	1.11	a	3.30	a	1.89	a
July 30	5.83	b	8.56	b	4.52	b	19.20	a	7.83	b

[1]indicates no samples were collected for this event.

Appendix table 47. Mean nitrogen concentrations (mg/L) of bulk stemflow from *Condalia Hookeri* (Coho), *Celtis pallida* (Cepa), *Zanthoxylum fagara* (Zafa), *Prosopis glandulosa* (Prgl), and *Diospyros texana* (Dite) collected within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter for each date (across rows) were not significantly different (P>0.05) using Fischer's LSD.

Date	Coho Mean	Sig.	Cepa Mean	Sig.	Zafa Mean	Sig.	Prgl Mean	Sig.	Dite Mean	Sig.
July 21, 1987	*[1]		*		3.51	a	11.98	a	*	
July 25	3.08	a	6.74	a	2.41	a	3.25	a	*	
July 31	2.08	a	6.74	a	2.80	a	6.46	a	3.66	a
Aug. 10	2.97	a	4.12	a	3.75	a	4.34	a	6.22	a
Sept. 1	5.38	b	12.72	a	11.59	ab	6.01	b	10.28	ab
Sept. 28	7.31	b	11.05	ab	10.35	b	13.92	a	4.01	c
Oct. 24	6.66	a	7.42	a	6.46	a	9.01	a	2.76	b
Nov. 11	1.81	a	2.62	a	2.67	a	3.23	a	4.88	a
Nov. 13	*		*		*		*		*	
Nov. 16	*		*		*		*		*	
Nov. 30	*		5.52	ab	4.27	b	8.76	a	4.17	b
Dec. 22	16.70	a	9.41	bc	8.32	bc	10.04	b	5.16	c
Dec. 29	*		*		2.69	a	*		*	
Jan. 5, 1987	*		3.70	a	3.55	a	3.23	a	*	
Jan. 8	*		2.64	a	5.65	a	7.02	a	2.28	a
Jan. 20	*		0.49	a	2.43	a	4.37	a	2.15	a
Feb. 8	2.61	a	4.27	a	3.28	a	4.98	a	2.69	a
Mar. 23	6.96	abc	5.76	bc	10.64	a	8.57	ab	2.92	c
Apr. 30	8.00	ab	7.89	ab	5.95	b	9.79	a	8.73	ab
May 15	3.12	b	7.42	a	3.50	b	4.68	ab	4.16	ab
June 7	4.22	a	6.44	a	4.83	a	5.70	a	2.67	a
June 22	2.52	b	2.71	b	2.88	b	9.15	a	2.54	b
July 7	3.15	a	3.76	a	2.86	a	5.44	a	2.65	a
July 12	1.38	a	3.42	a	2.77	a	2.79	a	1.67	a
July 30	5.23	a	9.64	a	8.47	a	8.01	a	4.41	a

[1]indicates no samples were collected for this event.

Appendix table 48. Mean phosphorus concentrations (mg/L) of bulk stemflow from Condalia Hookeri (Coho), Celtis pallida (Cepa), Zanthoxylum fagara (Zafa), Prosopis glandulosa (Prgl), and Diospyros texana (Dite) collected within mixed shrub clusters in a South Texas subtropical savanna parkland. Means with the same letter for each date (across rows) were not significantly different (P>0.05) using Fischer's LSD.

Date	Coho Mean	Sig.	Cepa Mean	Sig.	Zafa Mean	Sig.	Prgl Mean	Sig.	Dite Mean	Sig.
July 21, 1987	*[1]		*		0.097	a	0.123	a	*	
July 25	0.020	a	0.046	a	0.024	a	0.020	a	*	
July 31	0.077	a	0.024	a	0.094	a	0.055	a	0.042	a
Aug. 10	0.141	a	0.046	a	0.068	a	0.070	a	0.084	a
Sept. 1	0.164	a	0.060	a	0.099	a	0.102	a	0.138	a
Sept. 28	0.086	a	0.108	a	0.148	a	0.141	a	0.058	a
Oct. 24	0.076	a	0.125	a	0.076	a	0.076	a	0.057	a
Nov. 11	0.050	a	0.035	a	0.030	a	0.059	a	0.090	a
Nov. 13	*		*		*		*		*	
Nov. 16	*		*		*		*		*	
Nov. 30	*		0.088	ab	0.019	b	0.045	b	0.143	a
Dec. 22	0.159	ab	0.099	b	0.227	a	0.081	b	0.052	b
Dec. 29	*		*		0.019	a	*		*	
Jan. 5, 1988	*		0.011	a	0.044	a	0.049	a	*	
Jan. 8	*		0.035	a	0.020	a	0.027	a	0.025	a
Jan. 20	*		0.018	a	0.056	a	0.031	a	0.037	a
Feb. 8	0.042	a	0.050	a	0.036	a	0.023	a	0.038	a
Mar. 23	0.183	a	0.075	b	0.074	b	0.093	ab	0.033	b
Apr. 30	0.164	ab	0.142	b	0.154	b	0.257	a	0.091	b
May 15	0.040	a	0.063	a	0.038	a	0.081	a	0.049	a
June 7	0.030	a	0.029	a	0.055	a	0.031	a	0.009	a
June 22	0.106	a	0.026	a	0.050	a	0.075	a	0.024	a
July 7	0.118	a	0.032	b	0.085	a	0.066	a	0.038	a
July 12	0.013	a	0.024	a	0.033	a	0.022	a	0.027	a
July 30	0.055	a	0.076	a	0.145	a	0.151	a	0.118	a

[1]indicates no samples were collected for this event.

Appendix table 49. Mean, standard error (SE), maximum and minimum stemflow (mm) of Condalia Hookeri averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	0.020	0.0072	0.000	0.044
July 25	1.190	0.2907	0.504	2.136
July 31	0.164	0.0467	0.081	0.346
Aug. 10	0.250	0.0662	0.103	0.448
Aug. 22	0.000	0.0000	0.000	0.000
Sept. 1	0.149	0.0367	0.079	0.276
Sept. 28	0.457	0.1203	0.175	0.828
Sept. 30	0.000	0.0000	0.000	0.000
Oct. 24	0.608	0.1624	0.228	1.117
Nov. 11	0.833	0.2171	0.330	1.527
Nov. 13	0.000	0.0000	0.000	0.000
Nov. 16	0.000	0.0000	0.000	0.000
Nov. 30	0.142	0.0413	0.050	0.261
Dec. 22	0.236	0.0671	0.092	0.434
Dec. 29	0.009	0.0046	0.000	0.027
Jan. 5, 1988	0.076	0.0218	0.032	0.138
Jan. 8	0.044	0.0142	0.007	0.079
Jan. 20	0.174	0.0497	0.067	0.335
Feb. 8	0.544	0.1433	0.217	1.011
Mar. 3	0.000	0.0000	0.000	0.000
Mar. 23	0.344	0.0938	0.133	0.634
Apr. 30	0.002	0.0016	0.000	0.008
May 15	0.811	0.2138	0.324	1.488
June 7	0.400	0.1026	0.158	0.723
June 22	0.871	0.2089	0.405	1.555
July 7	0.602	0.1543	0.251	1.095
July 12	0.754	0.1896	0.329	1.355
July 30	0.275	0.0727	0.101	0.468

Appendix table 50. Mean, standard error (SE), maximum and minimum stemflow (mm) of Celtis pallida averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	0.021	0.0109	0.009	0.043
July 25	1.096	0.4999	0.556	2.095
July 31	0.121	0.0162	0.089	0.140
Aug. 10	0.243	0.1058	0.113	0.453
Aug. 22	0.003	0.0031	0.000	0.009
Sept. 1	0.135	0.0355	0.086	0.204
Sept. 28	0.433	0.2029	0.193	0.836
Sept. 30	0.000	0.0000	0.000	0.000
Oct. 24	0.574	0.2740	0.252	1.119
Nov. 11	0.781	0.3673	0.364	1.514
Nov. 13	0.005	0.0049	0.000	0.015
Nov. 16	0.000	0.0004	0.000	0.001
Nov. 30	0.138	0.0575	0.055	0.248
Dec. 22	0.234	0.1052	0.100	0.441
Dec. 29	0.015	0.0116	0.000	0.038
Jan. 5, 1988	0.076	0.0210	0.040	0.113
Jan. 8	0.045	0.0102	0.025	0.059
Jan. 20	0.162	0.0623	0.073	0.282
Feb. 8	0.505	0.2261	0.239	0.955
Mar. 3	0.006	0.0059	0.000	0.018
Mar. 23	0.330	0.1503	0.146	0.628
Apr. 30	0.009	0.0073	0.000	0.023
May 15	0.770	0.3645	0.358	1.497
June 7	0.374	0.1675	0.174	0.707
June 22	0.810	0.3492	0.447	1.508
July 7	0.567	0.2568	0.277	1.079
July 12	0.718	0.3277	0.363	1.373
July 30	0.272	0.1336	0.111	0.537

Appendix table 51. Mean, standard error (SE), maximum and minimum stemflow (mm) of Zanthoxylum fagara averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	0.117	0.0207	0.069	0.183
July 25	6.299	0.5730	5.209	8.249
July 31	0.914	0.1380	0.551	1.364
Aug. 10	1.368	0.1448	0.959	1.748
Aug. 22	0.000	0.0000	0.000	0.000
Sept. 1	0.819	0.0549	0.710	0.995
Sept. 28	2.492	0.2507	1.831	3.181
Sept. 30	0.000	0.0000	0.000	0.000
Oct. 24	3.309	0.3363	2.400	4.231
Nov. 11	4.572	0.4103	3.429	5.665
Nov. 13	0.007	0.0008	0.005	0.009
Nov. 16	0.000	0.0000	0.000	0.000
Nov. 30	0.755	0.1083	0.492	1.081
Dec. 22	1.266	0.1424	0.850	1.589
Dec. 29	0.068	0.0076	0.048	0.085
Jan. 5, 1988	0.406	0.0421	0.277	0.524
Jan. 8	0.239	0.0282	0.156	0.326
Jan. 20	0.925	0.0963	0.657	1.223
Feb. 8	2.976	0.2632	2.230	3.727
Mar. 3	0.008	0.0009	0.006	0.011
Mar. 23	1.861	0.1904	1.323	2.354
Apr. 30	0.027	0.0070	0.012	0.046
May 15	4.447	0.4126	3.247	5.463
June 7	2.202	0.2247	1.625	2.892
June 22	4.883	0.3565	3.998	5.570
July 7	3.321	0.2966	2.473	4.090
July 12	4.214	0.4172	2.993	5.261
July 30	1.505	0.2018	1.032	2.051

Appendix table 52. Mean, standard error (SE), maximum and minimum stemflow (mm) of Prosopis glandulosa averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	0.0014	0.0009	0.0000	0.0045
July 25	0.1899	0.0313	0.0862	0.2611
July 31	0.0242	0.0046	0.0125	0.0356
Aug. 10	0.0376	0.0067	0.0168	0.0524
Aug. 22	0.0000	0.0000	0.0000	0.0000
Sept. 1	0.0222	0.0041	0.0097	0.0346
Sept. 28	0.0700	0.0123	0.0324	0.0938
Sept. 30	0.0000	0.0000	0.0000	0.0000
Oct. 24	0.0932	0.0159	0.0443	0.1242
Nov. 11	0.1295	0.0214	0.0611	0.1715
Nov. 13	0.0000	0.0000	0.0000	0.0000
Nov. 16	0.0000	0.0000	0.0000	0.0000
Nov. 30	0.0200	0.0044	0.0091	0.0304
Dec. 22	0.0345	0.0064	0.0162	0.0512
Dec. 29	0.0004	0.0004	0.0000	0.0019
Jan. 5, 1988	0.0101	0.0022	0.0040	0.0157
Jan. 8	0.0049	0.0014	0.0016	0.0090
Jan. 20	0.0248	0.0046	0.0121	0.0340
Feb. 8	0.0837	0.0138	0.0399	0.1112
Mar. 3	0.0000	0.0000	0.0000	0.0000
Mar. 23	0.0516	0.0090	0.0244	0.0713
Apr. 30	0.0000	0.0000	0.0000	0.0000
May 15	0.1256	0.0205	0.0595	0.1650
June 7	0.0617	0.0107	0.0281	0.0807
June 22	0.1395	0.0231	0.0623	0.2001
July 7	0.0935	0.0153	0.0433	0.1233
July 12	0.1185	0.0187	0.0541	0.1516
July 30	0.0418	0.0084	0.0176	0.0615

Appendix table 53. Mean, standard error (SE), maximum and minimum stemflow (mm) of Diospyros texana averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	0.007	0.0074	0.000	0.022
July 25	2.287	1.1225	0.148	3.946
July 31	0.216	0.1007	0.021	0.357
Aug. 10	0.457	0.2399	0.028	0.858
Aug. 22	0.000	0.0000	0.000	0.000
Sept. 1	0.249	0.1192	0.012	0.391
Sept. 28	0.842	0.4409	0.055	1.579
Sept. 30	0.000	0.0000	0.000	0.000
Oct. 24	1.127	0.5888	0.074	2.110
Nov. 11	1.577	0.8009	0.100	2.853
Nov. 13	0.000	0.0000	0.000	0.000
Nov. 16	0.000	0.0000	0.000	0.000
Nov. 30	0.224	0.1337	0.016	0.473
Dec. 22	0.426	0.2342	0.025	0.836
Dec. 29	0.000	0.0000	0.000	0.000
Jan. 5, 1988	0.110	0.0615	0.006	0.219
Jan. 8	0.044	0.0294	0.002	0.101
Jan. 20	0.278	0.1497	0.018	0.537
Feb. 8	1.000	0.5060	0.065	1.802
Mar. 3	0.000	0.0000	0.000	0.000
Mar. 23	0.626	0.3315	0.039	1.187
Apr. 30	0.000	0.0000	0.000	0.000
May 15	1.554	0.7922	0.097	2.821
June 7	0.728	0.3729	0.049	1.335
June 22	1.715	0.8292	0.098	2.842
July 7	1.145	0.5744	0.071	2.036
July 12	1.484	0.7343	0.093	2.588
July 30	0.507	0.2843	0.034	1.017

Appendix table 54. Mean, standard error (SE), maximum and minimum input of throughfall and stemflow (mm) averaged across all mature mixed shrub cluster and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	3.86	0.100	3.60	4.21
July 25	48.21	2.432	40.08	53.49
July 31	9.90	1.100	6.83	11.96
Aug. 10	13.22	0.335	12.35	14.26
Aug. 22	1.51	0.124	1.16	1.78
Sept. 1	8.79	0.543	7.58	10.52
Sept. 28	21.88	0.530	20.29	23.19
Sept. 30	1.05	0.068	0.93	1.31
Oct. 24	29.48	0.734	27.23	31.15
Nov. 11	36.72	1.594	32.29	42.00
Nov. 13	2.19	0.133	1.80	2.58
Nov. 16	1.24	0.098	0.97	1.56
Nov. 30	8.10	0.493	7.06	9.76
Dec. 22	11.55	0.301	10.83	12.43
Dec. 29	3.60	0.254	2.84	4.35
Jan. 5, 1988	6.14	0.381	5.34	7.09
Jan. 8	5.70	0.268	5.04	6.45
Jan. 20	10.49	0.350	9.25	11.35
Feb. 8	25.56	0.876	23.63	28.61
Mar. 3	2.18	0.124	1.87	2.57
Mar. 23	15.60	0.824	12.84	17.64
Apr. 30	3.67	0.228	2.89	4.15
May 15	35.50	1.414	32.65	40.69
June 7	19.61	0.691	17.30	21.39
June 22	38.72	0.989	36.44	41.92
July 7	27.63	0.734	25.65	29.23
July 12	35.51	1.293	30.41	37.18
July 30	11.95	0.472	10.24	12.83

Appendix table 55. Mean, standard error (SE), maximum and minimum input of throughfall (mm) averaged across all mature mixed shrub clusters and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	3.70	0.094	3.40	3.99
July 25	38.50	1.448	33.68	42.56
July 31	8.59	1.102	5.71	10.39
Aug. 10	11.14	0.246	10.56	11.85
Aug. 22	1.50	0.123	1.16	1.78
Sept. 1	7.57	0.553	6.00	8.99
Sept. 28	18.09	0.598	16.64	19.62
Sept. 30	1.05	0.068	0.93	1.31
Oct. 24	24.45	1.136	21.07	26.73
Nov. 11	29.77	1.540	26.45	35.51
Nov. 13	2.18	0.131	1.79	2.56
Nov. 16	1.24	0.098	0.97	1.56
Nov. 30	6.96	0.450	6.24	8.70
Dec. 22	9.61	0.353	8.68	10.69
Dec. 29	3.52	0.255	2.73	4.25
Jan. 5, 1988	5.54	0.405	4.41	6.51
Jan. 8	5.36	0.270	4.54	6.08
Jan. 20	9.11	0.280	8.46	10.00
Feb. 8	21.05	1.159	17.34	24.61
Mar. 3	2.17	0.121	1.86	2.54
Mar. 23	12.77	0.688	11.23	15.11
Apr. 30	3.63	0.233	2.84	4.10
May 15	28.72	2.077	21.82	34.82
June 7	16.28	0.741	14.27	18.52
June 22	31.31	1.560	25.54	33.90
July 7	22.59	0.637	20.93	24.10
July 12	29.10	0.920	26.74	31.67
July 30	9.66	0.514	8.08	10.96

Appendix table 56. Mean, standard error (SE), maximum and minimum input of precipitation (mm) averaged across all interspace zones around mature mixed shrub clusters and precipitation events occurring during the study period in a South Texas subtropical savanna parkland.

Date	Mean	SE	Minimum	Maximum
July 21, 1987	5.08	0.056	5.00	5.29
July 25	53.21	1.316	49.63	56.62
July 31	11.29	0.850	7.90	12.41
Aug. 10	14.44	0.082	14.27	14.70
Aug. 22	2.28	0.151	1.88	2.61
Sept. 1	10.62	0.538	9.28	11.85
Sept. 28	22.65	0.269	21.68	23.25
Sept. 30	1.47	0.045	1.31	1.59
Oct. 24	28.58	0.389	27.14	29.51
Nov. 11	37.90	0.287	37.22	38.91
Nov. 13	2.89	0.031	2.82	2.96
Nov. 16	1.79	0.025	1.75	1.88
Nov. 30	9.95	0.306	8.91	10.72
Dec. 22	13.68	0.224	13.13	14.34
Dec. 29	4.56	0.021	4.49	4.61
Jan. 5, 1988	7.47	0.045	7.32	7.54
Jan. 8	6.16	0.047	5.99	6.26
Jan. 20	11.25	0.212	10.62	11.81
Feb. 8	26.26	0.285	25.30	26.98
Mar. 3	2.93	0.042	2.82	3.04
Mar. 23	18.05	0.188	17.35	18.31
Apr. 30	3.59	0.206	3.11	4.11
May 15	36.93	0.048	36.86	37.10
June 7	20.54	0.302	20.00	21.52
June 22	40.52	1.815	37.10	45.29
July 7	28.77	0.303	27.95	29.51
July 12	35.17	0.641	33.97	37.46
July 30	15.35	0.474	14.09	16.50

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