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Seasonal Patterns of Soil Water Recharge and Extraction on Semidesert Ranges

DWIGHT R. CABLE

Abstract

Soil water is recharged in the semidesert Southwest during the usual winter precipitation season, and again during the usual summer rainy season. The amount and depth of recharge varies widely depending primarily on the amount of precipitation, and secondarily on storm character, soil texture, vegetation cover, and evapotranspiration. Soil water depletion patterns and amounts differed among species, between plants and bare soil, and between seasons. Compared to evaporation from bare soil, plants extracted water much faster, but at more variable rates. Essentially all available soil water was used by plants or evaporated during most depletion periods.

Essentially all soil water in semidesert areas is either used by plants or is evaporated from the soil surface; relatively little percolates below the reach of plant roots. Evaporation and extraction by plants are so rapid that water is seldom available for more than a few weeks at a time.

The present study was undertaken to determine: (1) seasonal patterns of soil water recharge on the Santa Rita Experimental Range south of Tucson, Arizona, and (2) seasonal patterns of water extraction by seven major native and two important introduced perennial grasses and three native shrubs growing naturally on a variety of soils on the Range.

Methods

Eight sampling locations were selected on which from one to five species were studied. Sites were selected on the basis of optimum growing conditions for the particular species, as evidenced by vigor of the plants. Because each of the 12 species has its individual requirements and limitations of soil and climate, some more stringent than others, the sites represent a wide range of environmental conditions. Maximum distance between sites was 16 km (10 miles). Elevations varied from 884 to 1,312 m (2,900 to 4,300 ft), and average annual precipitation from about 27 to 43 cm (10.5 to 16.8 inches) (Table 1). About 56% of the annual rainfall occurs from July through September; most of the remainder occurs from December through April. The two rainy periods are thus separated by dry periods, with the May-June drought particularly severe. Winter storms are typically extensive, of long duration and low intensity; summer storms are typically localized, intense thunderstorms of short duration.

Soils were mostly sandy loams or gravelly sandy loams in the upper 25 cm, but varied from loamy sands to clays in the subsoil (to 1 m). Sites 7 and 8 had clay loam textures throughout the profile (Table 1).

To sample soil water, 5-cm diameter holes were drilled within 15 to 20 cm of the center of each of four plants of each of the perennial grass species (except only two plants of Lehmann lovegrass (*Eragrostis lehmanniana*)[1] at site 3), and under the crowns of four plants of each shrub species (except only two plants of false-mesquite at site 3). Despite care in selecting healthy medium-size plants, a few plants died during the 3-year period. Values reported for some species and some periods, therefore, are means of 2 or 3, instead of 4 plants. Holes were 1.5 m deep for most grasses and 3 m deep for the two large shrubs, creosotebush and fourwing saltbush. Because of large rocks in the soil at site 3, the false-mesquite holes were stopped at 1 m. Two additional holes were drilled in bare areas at each study site for controls.

Aluminum tubes were installed in the holes for taking soil water measurements. Measurements were taken with a neutron probe at 25-cm depth intervals, starting at 25 cm. The holes were drilled in June 1971. Plant roots were then given 1 year to recover from whatever damage the drilling might have done. Soil water measurements were obtained at approximately 2-week intervals from July 1972 to June 1975.

The neutron probe integrates soil water content in a sphere of soil varying from about 15 to 25 cm radius around the indicated measurement point. However, for ease of presentation, each soil water measurement is assumed to represent the water content of the 25-cm soil layer immediately above the recorded soil depth. The mean of the measurements taken at 25, 50, 75, and 100 cm is assumed to represent the mean water content of the top 1 m of soil.

Vegetation at all study sites, except 4, consisted of essentially pure stands of the study species. Site 4 was a mixture of the five study species and scattered plants of burroweed (*Aplopappus tenuisectus*). In addition, at sites 3, 4, and 5, scattered individuals of velvet mesquite (*Prosopis juliflora* var. *velutina*) were present. Mesquite and burroweed plants whose roots were judged to be within reach of the soil moisture access tubes were killed. The control plots, approximately 2 m in diameter, were maintained in bare condition by periodic application of granular Tandex at the rate of 5.0 kg/ha active ingredient.

Nearly all study plants were on flat or gently sloping ground, away from natural drainageways. However, one plant each of creosotebush (site 6) and fourwing saltbush (site 7) was in or very close to a shallow drainageway (swale position) that carried runoff following rain. Two of the buffelgrass plants (site 8) were located in the shallow pits that impounded water following rain; the other two were on adjacent upland (flat) sites.

Definitions and Units

The terms *soil water losses*, *soil water depletion*, and *evapotranspiration (ET) losses*, refer to soil water that was extracted from the soil during particular periods of time (initial content less final content). Soil water is expressed either as percentage by volume or in centimeters depth. One percent by volume equals 1 cm depth in 100 cm of soil, or 0.25 cm in a 25-cm layer. Available water, as expressed in this paper, is that in excess of the lowest value recorded (3-year minimum), at each point of measurement.

Statistical Analysis

Because of wide differences in soil and climatic characteristics among study sites, statistical treatment of the data is limited largely to within-species responses. Even at site 4, a small area of apparently uniform soil, subsequent soil investigations revealed large differences in water-holding capacity of soils occupied by differed species.

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[1] Scientific names except for buffelgrass (*Cenchrus ciliaris*) from Kearny and Peebles (1951) are shown in Table 1.

Table 1. Physical characteristics of the study sites.

Study site	Elev. (m)	Average annual rainfall (cm)	Soil texture: Surface	Soil texture: Subsoil	Depth sampled (cm)	Study species
1	1,312	42.7	Gravelly sandy loam	Gravelly loamy sand	100	Slender grama *Bouteloua filiformis*
2	1,244	40.4	Gravelly sandy loam	Gravelly sandy loam	100	Lehmann lovegrass *Eragrostis lehmanniana*
3	1,160	38.1	Very gravelly sandy loam	Very gravelly clay	75	Lehmann lovegrass
					100	False-mesquite *Calliandra eriophylla*
4	1,144	34.3	Gravelly sandy loam	Gravelly loamy sand	100	Santa Rita threeawn *Aristida glabrata*
				Variable sandy-clayey	100	Spidergrass *Aristida ternipes*
				Variable sandy-clayey	100	Black grama *Bouteloua eriopoda*
				Variable sandy-clayey	100	Arizona cottontop *Trichachne californica*
				Clay loam	125	Tanglehead *Heteropogon contortus*
5	1,043	32.2	Gravelly sandy loam	Gravelly loamy sand	100	Bush muhly *Muhlenbergia porteri*
6	945	30.5	Sandy loam	Clay loam	300	Creosotebush *Larrea tridentata*
7	906	27.9	Clay loam	Clay loam	300	Fourwing saltbush *Atriplex canescens*
8	884	26.7	Clay loam	Clay loam	125	Buffelgrass *Cenchrus ciliaris*

Between-species comparisons in water use therefore were not feasible. Instead, the data obtained in this study characterize the water use and replenishment regimes for each plant species under naturally occurring soil and climatic conditions.

Results and Discussion

Precipitation and Recharge

The 3-year study included very wet as well as very dry recharge periods (Table 2). There were eight periods when significant amounts of water were added to the soil: three in summer and five in fall-winter-spring. Water reached only to the 25-cm depth following three precipitation periods, to 75 cm and 100 cm in two periods each, and to 150 cm in only one. Although more precipitation usually occurred in summer than in winter, moisture penetrated deeper and lasted longer in winter because of greater infiltration and lower evapotranspiration. The contrast in depth of wetting between warm- and cool-season precipitation was greatest for bare soil and least for soil occupied by tanglehead. For example, total water in the 100-cm profile at maximum recharge after the unusually wet winter, 1972-73, varied only from 8.5 cm for bare soil to 11.5 cm for soil under tanglehead (Table 3). In the wet summer of 1974, however, bare soil at maximum recharge contained less than one third as much water (3 cm) in the 100-cm profile as did soil with tanglehead (9.5 cm) with little wetting below 25 cm in the bare soil (Fig. 1, Table 4). Also, except for tanglehead, the upper 75 cm of bare soil at site 4 recharged about as well in the winter of 1972-73 as did soil under perennial grasses (Fig. 1).

The relatively high effectiveness of winter moisture, especially on bare soil, is attributed to: (1) typically, the intensities for winter precipitation do not exceed the infiltration capacity of the soil whereas the precipitation rates of summer thunderstorms normally do; (2) the small droplets characteristic of winter storms fall at lower velocities and result in less soil splash and sealing of the surface soil than is the case for torrential summer showers (Osborn 1955); and (3) evapotranspiration demands are much lower in winter than in summer.

Increased infiltration capacity due to the presence of vegetation, particularly of fibrous-rooted species, has been reported by Pearse and Wooley (1936) in southern Idaho and by Box (1961) in south Texas and by Osborn (1952) (also see Branson et al. 1972). Lyford and Qashu (1969) found infiltration rates 2.5 to 4 times higher under creosotebush and paloverde plants than in adjacent openings in southern Arizona. In this study the soil with tanglehead recharged to 75 cm about as well in summer as in spring, because the plants were part of a

Table 2. Seasonal precipitation (cm) at the study sites.

Year	Season	Study site 1,2	3	4	5	6	7	8	Mean
1972	Jul-Sep	14.2	13.0	14.3	14.0	16.9	24.2	21.3	16.8
	Oct-Dec	16.2	13.6	16.0	16.6	15.3	18.0	16.4	16.0
	Total	30.4	26.6	30.3	30.6	32.2	42.2	37.7	32.8
1973	Jan-Mar	18.0	13.6	13.3	13.5	11.3	11.8	10.5	13.1
	Apr-Jun	1.9	1.7	1.5	1.7	2.2	2.1	2.2	1.9
	Jul-Sep	8.6	6.9	10.0	8.4	6.0	7.5	6.0	7.6
	Oct-Dec	1.8	1.3	1.3	1.3	1.0	1.2	1.2	1.3
	Total	30.3	23.5	26.1	24.9	20.5	22.6	19.9	23.9
1974	Jan-Mar	6.5	4.6	5.2	5.3	1.7	4.1	3.8	4.7
	Apr-Jun	T	T	0.3	0.4	0.4	0.2	0.2	0.2
	Jul-Sep	31.5	25.4	21.6	22.8	23.5	23.0	22.1	24.3
	Oct-Dec	9.4	6.8	10.6	8.7	7.5	9.6	8.4	8.7
	Total	47.4	36.8	37.7	37.2	35.1	36.9	34.5	37.9
1975	Jan-Mar	6.2	4.6	5.6	5.3	4.2	4.6	3.7	4.9
	Apr-Jun	2.2	1.4	1.6	1.4	0.4	0.7	0.5	1.2
	Total	8.4	6.0	7.2	6.7	4.6	5.3	4.2	6.1
3-yr	Mean	38.8	31.0	33.8	33.1	30.8	35.7	32.1	33.6

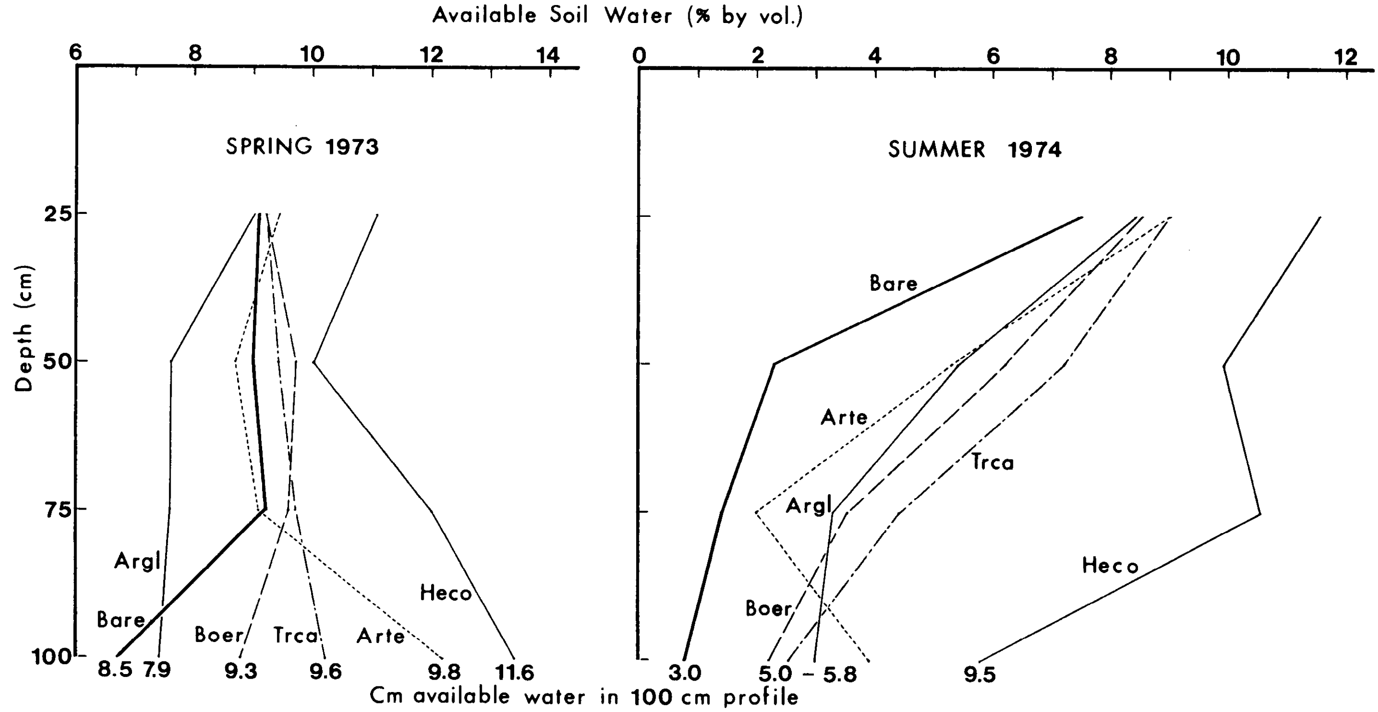

Fig. 1. *Comparison between spring 1973 and summer 1974 in available soil water at maximum recharge at bare soil and plant locations at site 4 (Arg[1] = Santa Rita threeawn, Arte = spidergrass, Boer = black grama, Heco = tanglehead, Trca= Arizona cottontop). Total available water (cm) in the 100-cm profile shown across bottom.*

Table 3. Spring 1973 soil water losses (% by volume) following good winter recharge; averaged over all depths showing recharge.

	Starting available water			Total loss				
Species	% by volume[1]	*t* test[2]	CV[3]	% by volume[1]	*t* test[2]	CV[3]	Loss per day	Profile depth (cm)
Grasses								
Santa Rita threeawn	8.0 ± 0.2		9.4	6.7 ± 0.2	**	9.0	0.066	100
Black grama	9.3 ± 0.4		17.3	7.8 ± 0.4	**	25.0	0.083	100
Spidergrass	9.8 ± 0.8		27.1	8.0 ± 0.4	**	17.7	0.094	100
Tanglehead	11.5 ± 0.4	**	13.2	9.0 ± 0.3	**	10.3	0.092	100
Arizona cottontop	9.7 ± 0.6		24.2	8.2 ± 0.4	**	21.7	0.085	100
Bare soil	8.5± 0.6		20.1	4.6 ± 0.7		41.6	0.048	100
Slender grama	9.3 ± 0.3		14.9	8.2 ± 0.3	**	16.0	0.088	100
Bare soil	8.5 ± 0.5		16.8	6.4 ± 0.4		19.2	0.061	100
Bush muhly	9.9 ± 0.6		24.1	8.5 ± 0.5		25.5	0.083	100
Bare soil	8.7 ± 0.8		26.4	7.1 ± 0.7		27.0	0.060	100
Lehmann lovegrass (site 2)	10.0 ± 0.3	**	12.3	8.7 ± 0.3	**	13.5	0.065	100
Bare soil	8.0 ± 0.6		19.5	3.6 ± 0.3		21.0	0.032	100
Lehmann lovegrass (site 3)	14.0 ± 1.0	*	17.4	12.3 ± 1.0	**	20.6	0.141	75
Bare soil	9.7 ± 1.5		38.8	6.1 ± 1.6		65.3	0.051	75
Buffelgrass (pit)	12.9 ± 0.7		16.7	10.8 ± 0.8	*	22.0	0.120	125
Buffelgrass (flat)	11.2 ± 0.5		12.3	9.6 ± 0.5		14.6	0.116	100
Bare soil (flat)	8.4 ± 1.6		59.6	7.2 ± 1.6		70.2	0.076	125
Shrubs								
False-mesquite	9.0 ± 1.1		29.4	7.7 ± 1.2		39.4	0.104	75
Bare soil	9.7 ± 1.5		38.8	6.1 ± 1.6		65.3	0.051	75
Fourwing saltbush (swale)	10.8 ± 1.6		33.0	8.9 ± 1.8		44.4	0.108	125
Fourwing saltbush (slope)	7.3 ± 1.2		64.2	5.9 ± 1.2		81.2	0.088	125
Bare soil (slope)	11.1 ± 1.8		44.6	9.4 ± 1.8		53.6	0.106	100
Creosotebush (swale)	11.7 ± 1.0		20.1	10.8 ± 1.0		21.2	0.119	125
Creosotebush (slope)	3.8 ± 0.9	**	92.6	2.8 ± 0.8	**	115.0	0.050	125
Bare soil (slope)	9.0 ± 1.9		65.9	7.3 ± 1.6		71.6	0.094	125

[1] Means ± one standard error
[2] $**P \leq 0.01$, $*P < 0.05$, $+ P < 0.10$, for differences between soil with plants and bare soil
[3] Coefficient of variation (%)

Table 4. Summer 1974 soil water losses (% by volume), averaged over all depths showing recharge.

Species	Starting available water: % by volume[1]	t test[2]	CV[3]	Total loss: % by volume[1]	t test[2]	CV[3]	Loss per day	Profile depth (cm)
Grasses								
Santa Rita threeawn	5.0 ± 0.9		65.1	4.1 ± 0.8	+	71.8	0.093	100
Black grama	5.1 ± 0.8		62.3	4.2 ± 0.7	+	70.1	0.080	100
Spidergrass	5.0 ± 1.0		65.4	4.0 ± 0.9		78.0	0.087	100
Tanglehead	9.5 ± 0.8	**	29.1	8.4 ± 0.9	**	36.8	0.157	125
Arizona cottontop	5.8 ± 0.8	*	52.3	4.9 ± 0.7	*	58.2	0.094	100
Bare soil	3.0 ± 1.0		94.7	2.0 ± 0.7		96.7	0.070	100
Slender grama	6.8 ± 1.3	+	52.9	6.1 ± 1.2	*	54.2	0.160	100
Bare soil	3.8 ± 1.1		83.0	2.5 ± 0.8		90.7	0.057	100
Bush muhly	6.0 ± 1.1		61.5	5.0 ± 1.0		69.5	0.105	75
Bare soil	4.4 ± 1.4		79.4	2.8 ±1.2		108.9	0.065	75
Lehmann lovegrass (site 2)	10.2 ± 0.2	**	7.1	8.0 ± 0.2	**	12.4	0.123	100
Bare soil	8.4 ± 0.5		15.9	4.1 ± 0.1		10.0	0.069	100
Lehmann lovegrass (site 3)	13.0 ± 1.6	**	29.6	11.4 ± 1.7	**	36.0	0.220	75
Bare soil	3.0 ± 1.4		118.7	1.6 ± 0.9		138.0	0.028	75
Buffelgrass (pit)	12.0 ± 1.0	**	26.4	10.6 ± 0.9	**	26.8	0.220	125
Buffelgrass (flat)	8.0 ± 1.3	**	44.5	7.5 ± 1.2	**	43.8	0.108	100
Bare soil (flat)	1.8 ± 0.6		94.8	0.5 ± 0.4		227.9	0.007	100
Shrubs								
False-mesquite	3.1 ± 1.2		78.6	1.9 ± 1.2		123.2	0.053	50
Bare soil	4.5± 1.7		77.4	2.4 ± 1.2		98.3	0.042	50
Fourwing saltbush (swale)	14.5 ± 1.9	**	28.6	12.0 ± 2.4	**	43.7	0.177	125
Fourwing saltbush (slope)	4.7 ± 1.4	+	84.0	3.6 ± 1.3	*	103.5	0.104	11
Bare soil	1.9 ± 0.7		100.4	0.6 ± 0.5		213.8	0.012	100
Creosotebush (swale)	6.6 ± 2.6	*	78.6	6.1 ± 2.6	**	84.6	0.074	100
Bare soil (slope)	1.7 ±0.4		75.7	0.6 ± 0.4		186.1	0.049	100
Creosotebush (slope)	4.6 ± 1.8		69.1	3.4 ± 2.1		105.1	0.104	25
Bare soil (slope)	3.7 ± 0.4		15.3	2.3 ± 0.2		12.3	0.049	25

[1] Means ± one standard error
[2] $**P<0.01$, $*P<0.05$, $+P<0.10$, for differences between soil with plants and bare soil
[3] Coefficient of variation (%)

relatively dense colony with a good cover of litter. Recharge of soils occupied by the other four species fell between the extremes of bare soil and soil with tanglehead, but with sharply lower recharge with increasing depth. These plants were in the more open stands where much of the soil was exposed, and high surface runoff in the summer would be expected.

The practical implication of these results is that a ground cover of plants and litter greatly increases the effectiveness of summer precipitation, but increases the effectiveness of cool-season precipitation only moderately. Since 90% of the perennial grass forage on southern Arizona ranges is produced from summer rainfall (Culley 1943) the importance of maintaining an adequate ground cover of forage plants and litter is apparent. In other words, adequate ground cover is not essential for the production of winter-spring annuals, but it is necessary for high yields of warm-season perennial grasses.

Water-holding capacities of the soils were strongly affected by differences in texture, primarily of the subsoils, as would be expected. Amounts of water available at the start of the 1973 spring deletion period for finer subsoils ranged from 10.8 to 14.0% compared to the 8 to 10% for predominantly sandy or mixed subsoils. Finer subsoils were those associated with tanglehead, Lehmann lovegrass at site 3, the pit position buffelgrass, and the swale position fourwing saltbush and creosotebush (Table 4). The contrast between high water-holding capacity of clay subsoils occupied by tanglehead and sandy subsoils occupied by Santa Rita threeawn is particularly

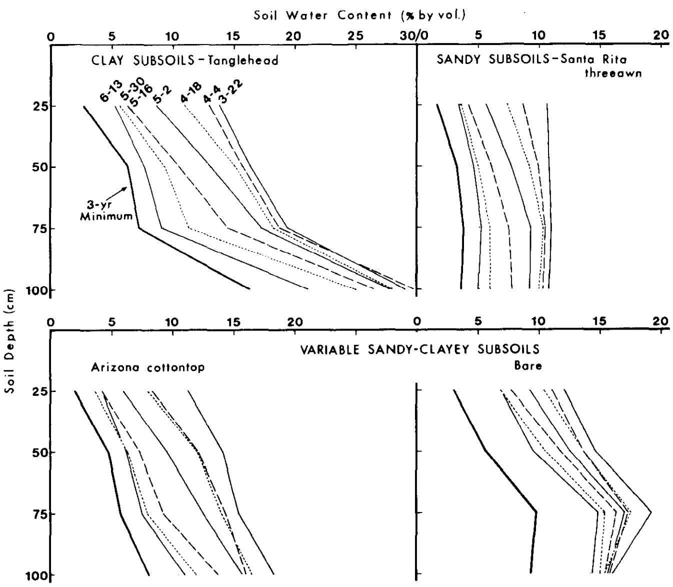

Fig. 2. *Maximum recharge on March 22, 1973, following above-average winter precipitation, as influenced by texture of the subsoil, and subsequent depletion patterns during the dry spring (3-year minimum = lower limit of available water).*

noticeable in both spring and summer at site 4 (Figs. 1 and 2). Clay content of the subsoil with tanglehead increased with increasing depth, as indicated by the rapidly increasing 3-year minimum water content (Fig. 2), whereas the relatively low, but constant, 3-year minimums at all depths for the subsoil with Santa Rita threeawn indicate relatively uniform sandy textures and similar water-holding capacities throughout the profile.

Generally deeper penetration of water due primarily to increased duration of surface flow or ponding made large volumes of available water for plants at the pit and swale positions (Table 4 and 5). Recharge at the swale-position fourwing saltbush plants, for example, reached 150 cm in the summer of 1974 (Fig. 3), with 15.9 cm of available water at maximum recharge (July 25) in the 150-cm profile, compared to penetration to about 75 cm and only 4.4 cm available water at the slope-position plants (July 10). Available water at bare soil locations (August 21) was 3.2 cm with moisture penetrating to only about 25 cm. The relative advantages of pit and swale positions are more marked in wetter than in drier seasons because the amounts of runoff in drier seasons are smaller and less frequent.

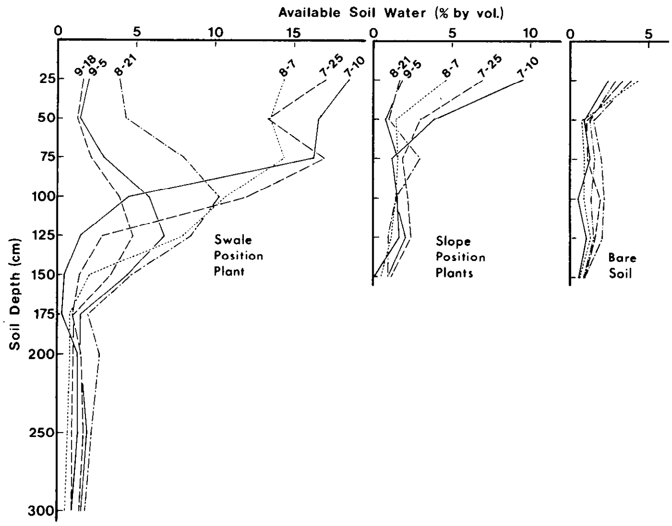

Fig. 3. *Soil water profiles at the time of maximum recharge at 25 cm (July 10, 1974) and during the following depletion period for soil with fourwing saltbush plant in a swale, for plants on an adjacent slope, and for bare soil.*

Depletion Characteristics

The two major periods of soil water depletion in southern Arizona are: (1) the spring growing period, when plants use accumulated cool-season moisture, and (2) the summer growing period, when plants use current precipitation. Depletion patterns differ between spring and summer. Spring depletion starts slowly as warming spring temperatures permit plant growth to begin, increases to a relatively constant high rate during the main period of spring growth (usually 4 to 8 weeks), then tapers off as soil water is depleted. In summer temperatures are high, plant growth is limited by the moisture supply, and evaporation is rapid.

One broad general result of the study was to show that evapotranspiration usually removed all available soil water by the end of each depletion period. This agrees with the view of Wilm (1962) that in arid areas all soil water is lost to evaporation or transpiration whether vegetation is present or not. Consequently, differences in observed evaporation losses between seasons and between kinds and amounts of vegetation were due largely to differences in the amount of soil water available at the start of the depletion periods. For example, following a winter of high recharge, starting available water in the spring of 1973 ranged from 3.8 to 14% and total loss from 2.8 to 12.3% (Table 3). During the relatively wet summer of 1974, initial available water varied from 1.7 to 14.5% and losses from 0.5 to 12.0% (Table 4). Regressions, derived from Tables 4 and 5, indicate that on vegetated plots the initial soil water content was associated with 97% of the variation in loss of winter soil water and with 98% of the summer loss. Comparable values for bare plots were 49% for winter moisture and 89% for summer. The higher correlation in summer is probably due to the fact that available summer moisture in bare soil usually is confined to the upper 25 cm of soil, where it evaporates more rapidly than moisture from deeper layers that contain much of the accumulated cool-season moisture.

Total water losses from soil with plants were significantly higher than those from bare soil at most grass sites. Fewer such differences were significant at shrub sites because of fewer plants and higher standard errors (Tables 3 and 4). Deviations of soil water depletion rates from regression indicate that slender grama, buffelgrass, and tanglehead extracted water faster than other species during the wet summer of 1974, and that Lehmann lovegrass extracted water more slowly.

Depths to which the soil was recharged were about the same for grasses in summer as in spring; but depths of recharge at shrub locations were only a little more than half as deep in the summer as in the spring, because the finer textured relatively bare soils at the shrub locations had lower infiltration rates and they sealed over quickly during summer thunderstorms.

Bare soil lost less water than vegetated soils in both seasons—one-fifth less in spring, but two-thirds less in summer. This difference between seasons was particularly marked for bare locations with clayey subsoils, which recharge very poorly in summer and thus had less water available (Tables 3 and 4). In all seasons, losses from bare soil tended to be slower and at more uniform rates than from vegetated soil. For example, ET loss from clay soil with Lehmann lovegrass plants at site 3

Table 5. Evapotranspiration losses (cm) during wet and dry spring and summer depletion periods, by depths, averaged over all species at all locations.

	Wet spring 1973		Wet summer 1974		Dry spring 1974		Dry summer 1973	
Depth	Plants	Bare	Plants	Bare	Plants	Bare	Plants	Bare
25	2.34	2.32	2.08	0.92	1.48	1.57	0.79	1.03
50	2.13	1.98	1.65	0.41	0.35	0.26	0.38	0.62
75	1.98	1.53	1.15	0.19	0.03	0.14	0.33	0.59
100	1.57	0.86	0.66	0.17			0.39	0.48
125	0.18	0.15	0.10	0.01			0.18	0.16
150	0.04	0.07						0.15
Total	8.24	6.91	5.64	1.70	1.86	1.97	2.07	3.03
Available at start	10.25	9.19	7.31	3.28	2.15	2.48	2.31	3.51

essentially exhausted available moisture from the upper 75 cm of soil within 2 weeks after maximum recharge in the summer. Bare soil lost water at much lower rates for 6 weeks but mainly from the upper 25 cm layer because deeper soil layers were not wet. The period of rapid soil water depletion in the summer of 1974 varied from 2 to 6 weeks among species and depths. Similar rapid extraction of soil water during the summer was reported for Arizona cottontop and burroweed in an earlier study (Cable 1969).

The ability of semidesert plants to extract water rapidly when it is available is crucial to their survival because soil water that is not picked up quickly by plant roots is soon lost by evaporation.

Subsoil Texture Effects

Differences in subsoil texture strongly affected soil water-holding capacities and amounts of soil water available to plants, as would be expected. At site 4, 22 soil water sampling tubes were installed on an apparently uniform area of about 25-meter radius to sample soil water changes for five perennial grass species and bare soil. Subsoil textures varied from loamy sand to gravelly clay; available soil water at maximum recharge varied from 8.3% by volume in the upper 100 cm of sandy loams and loamy sands at the Santa Rita threeawn plants, to 12.8% in the gravelly clay subsoils at the tanglehead plants. For the other three species, maximum available water varied from 10.0 to 10.3% by volume. These values of maximum available water agree well with those reported for similar soil textures for other environmental situations by Lassen et al. (1952) and Hoover (1962). These data show that subsoil textures, and thus relative amounts of available water, can vary considerably within a relatively small area and suggest that the distribution of species on such an area is strongly affected by soil conditions. Some species apparently are more adaptable than others to soils of varying texture and water-holding capacity. The subsoil-species distribution relationships at site 4 and depletion characteristics during the spring depletion period of 1973 (Fig. 2) show that: (1) clay subsoils, as expected, held the most available soil water, sandy subsoils the least, and the variable subsoils intermediate amounts; (2) ET losses from bare soil were less than from soil with plants and decreased uniformly with increasing depth; (3) in soil with plants, water was extracted most rapidly at the shallower depths early in the depletion period and at successively greater depths as the period advanced, which probably indicates decreasing root densities with increasing depth (Hillel 1971); (4) by June, available soil water was reduced to from 2 to 3% for the three grasses, but the bare soil held noticeably more available water because of lower rates of loss; and (5) the relatively uniform total depletion within the upper 100 cm of soil for each species indicates that the root systems of all three reach to at least 100 cm. Limited data from 125 and 150 cm indicate that the taller grasses extracted some water at 125 cm but little or none at 150 cm.

Dry-Season Depletion

In growing periods with deficient precipitation, such as the spring of 1974 and the summer of 1973, available soil water supplies were very low. Recharge usually was limited mainly to the upper 25 cm or so of soil. For example, in the dry spring of 1974, 80% of the total ET losses from both bare soil and soil with plants came from the upper 25 cm, indicating very little recharge below 25 cm (Table 5). In the dry summer of 1973, however, small amounts of soil water were present throughout the profile as carryover from the preceding unusually wet winter. Carryover moisture was significantly greater ($P<0.01$) for bare soil than for plant locations. Depletion patterns during droughty growing periods appear to be similar on bare and vegetated areas. During such periods, perennial grasses use water that would be lost by evaporation if the plants were not present, since they produce some green foliage even in the driest seasons. After prolonged dry periods (e.g., summer 1973), essentially no available water was left in the soil. Available water was reduced to between 1 and 2% by volume at all depths by the end of most depletion periods (Table 6).

Management Implications

The productivity of semidesert ranges depends on the supply and disposition of available soil water. The supply of soil water depends on: (1) precipitation amounts, (2) water holding capacity of the soil, as determined by soil depth and texture, and (3) surface condition of the soil, as it affects infiltration and surface runoff. Precipitation and soil characteristics set the upper limits on the amount of available water and are not amenable to control. Infiltration rates, however, can be influenced considerably by manipulating the vegetation cover. Vegetation can increase infiltration not only by protecting the surface from the puddling actions of raindrops, but also by the action of roots in maintaining a friable open soil, more receptive to the infiltration and downward movement of water.

The importance of vegetation in promoting infiltration was particularly evident in the wet summer 1974, when 7.3 cm of water was available at maximum recharge in soil with plants, and only 3.3 cm at bare locations (Table 5).

Once in the soil, available water on semidesert ranges either evaporates or is used by plants. Plants and litter shade the soil, thereby reducing the temperature and air movement at the soil surface and retarding the rate of evaporation. The only way to prevent the eventual loss of all soil water to evaporation is to use part of the moisture for plant growth. A plant can only use moisture that is within reach of its roots; consequently, all moisture in soil that is not occupied by plant roots will be lost by evaporation. Evaporation also takes a part of the moisture from soil that is occupied by plant roots. Plant growth, therefore, is made during relatively short periods between soil wettings and times when evaporation and transpiration have removed all readily available water. Evaporation losses are minimized and forage production is maximized when the roots of forage plants occupy as much of the soil profile as possible and when there is enough litter to cover the soil surface between plants.

A major objective in the management of semidesert range is to get maximum use of precipitation. This requires getting as much water as possible into the soil and using that water as rapidly as possible for plant growth—before it evaporates. The most effective means for doing this is by maintaining a dense ground cover of valuable perennial grasses. Most native semidesert grasses are primarily summer growers. Water losses to runoff and evaporation are especially critical for such grasses because these losses are greatest during the summer rainy season.

Summary and Conclusions

Soil water recharged to greater depths from cool-season rainfall than from summer rainfall and lasted longer. Bare soil recharged almost as well as vegetated soil in winter; but summer recharge of bare soil was only one-third that of vegetated soil, and there was little recharge below 25 cm.

Well-vegetated soil recharged about as well in summer as in winter. In the summer of 1974, more than twice as much water was available at vegetated locations as in bare soil. Perennial grass cover increased the soil water supply in summer by increasing infiltration, decreasing runoff, and slowing evaporation. Furthermore, perennial grasses make productive use of water that otherwise would be lost by evaporation.

Because of differences in infiltration capacity, microrelief, and texture of subsoils, available soil water at specific locations varied from 3.5 to 13.5 cm in the spring of 1973 and from 0.8 to 15.0 cm in the summer of 1974—five times as great at some locations as at others in spring and 19 times as great in summer.

There was rarely any carryover moisture from one rainy season to the next because all available water usually transpired or evaporated by the end of each depletion period. Total soil water loss during depletion periods depended primarily on the amount of available soil water when the period began. Evaporation losses from bare soil, however, tended to be slower and at relatively more uniform rates than evapotranspiration losses from soils occupied by plants. The period of major depletion on vegetated soils lasted 4 to 8 weeks in spring and 2 to 4 weeks in summer.

The root systems of perennial grasses quickly absorb soil water during the relatively short periods when it is available in the summer. Slender grama, buffelgrass, and tanglehead extracted water faster than other species during the summer; and Lehmann lovegrass at the sandy site extracted water more slowly. On a clayey site, however, Lehmann lovegrass essentially exhausted soil water within 2 weeks following summer recharge.

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