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SOIL DEPTH EFFECTS ON CHIHUAHUAN DESERT VEGETATION

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ABSTRACT.—We evaluated relationships between soil depth and vegetation standing crop components over a 3-year period on 3 adjoining pastures with similar size, vegetation, and soils on the Chihuahuan Desert Rangeland Research Center in south central New Mexico. Soils on our study pastures are primarily light sandy loams varying from a few centimeters to 1 m or more in depth underlain by a calcium carbonate layer. Study pastures were ungrazed in 1995 and 1996 and conservatively grazed in 1997. Linear regression equations using perennial grass standing crop (kg ha^{-1}) and honey mesquite (*Prosopis glandulosa* Torr.) cover (%) as dependent variables and soil depth as the independent variable were significant ($P < 0.05$) and similar for all 3 pastures. Deep soils had low perennial grass standing crop and high mesquite cover, while the opposite occurred for shallow soils. Within shallow soils, honey mesquite and perennial grass standing crop were not correlated ($P = 0.78$, $n = 18$), but a significant ($P = 0.01$) negative correlation occurred on deep soils ($r = -0.67$, $n = 15$). Perennial grass standing crop differed greatly among years when data were pooled across pastures, ranging from 64 kg ha^{-1} in 1995 to 248 kg ha^{-1} in 1997. Our study shows that soil depth has a major influence on Chihuahuan Desert vegetation. Perennial grasses are favored by shallow sandy soils while deep sandy soils favor honey mesquite.

Key words: rangeland, herbicides, brush control, cattle, grazing.

Site factors such as topography, soil depth, soil texture, and precipitation play a critical role in determining the type of vegetation and its potential productivity for any rangeland area (Holechek et al. 2001). Sound decisions on management practices such as brush control, seeding, and fertilization depend on understanding site potential.

Honey mesquite (*Prosopis glandulosa* Torr.) invasion has been considered a major range management problem in the Chihuahuan Desert of southwestern United States and northern Mexico (Buffington and Herbel 1965, Gibbens et al. 1992). However, long-term monitoring studies in southern New Mexico showed no change in mesquite cover during the period from 1952 to 1999 across 40 sites (McCormick and Galt 1993, Galt et al. 1999). Nearly all sites that were grasslands in the early 1950s still remain grasslands today (Galt et al. 1999). Grazing intensity levels on 80% of these sites were considered to have been light to moderate during most years (Galt et al. 1999).

Mesquite invasion in the Chihuahuan Desert may be closely related to site characteristics such as soil depth and texture. However, studies evaluating how soil factors influence honey mesquite levels are lacking.

The objectives of our study were to evaluate the effects of soil depth on mesquite canopy cover, mesquite density, and perennial grass standing crop during 3 consecutive years in the Chihuahuan Desert of south central New Mexico. The primary null hypothesis tested was that soil depth has no effect on mesquite cover and perennial grass standing crop.

Study Area

The study was conducted during autumn 1995, 1996, and 1997 on the New Mexico State University Chihuahuan Desert Rangeland Research Center (CDRRC), 40 km north of Las Cruces, Doña Ana County, New Mexico. The CDRRC lies in the southern portion of the Jornada del Muerto Plain between the San Andres Mountains and the Rio Grande. The elevation of the study area is 1340 m. Topography is generally level with all slopes less than 5%. The area is arid, with no permanent water except the river and stock watering points supplied by wells and temporary earthen tanks. Annual precipitation during the study period

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varied from 180 to 298 mm. The 63-year average is 230 mm (Table 1). About half of the annual precipitation occurs between July and September, with highest precipitation in August. Wood (1969) described the climate of the area as semidesert, with annual temperatures varying from –23° to 42°C and daily fluctuations of up to 30°C. June is the warmest month and January the coldest.

Soils of the CDRRC study area are mainly light sandy loams varying in depth from a few centimeters to 1 m or more underlain by a calcium carbonate hardpan (caliche; SCS 1980). The soils are classified as fine loamy, mixed, thermic, Typic Haplargids and are in the Simona-Cruces associations (SCS 1980). In areas where groundcover is sparse, sand dunes have formed around mesquite plants (Wood 1969). Over most of the study area, the soil profile is relatively well preserved and stable.

Vegetation on the study area is characterized as Chihuahuan Desert grassland with shrubs scattered throughout the area. Large areas have varying cover of honey mesquite (*Prosopis glandulosa* Torr.). Understory vegetation consists largely of black grama (*Bouteloua eriopoda* Torr.), mesa dropseed (*Sporobolus flexuosus* [Thurb.] Rybd.), and spike dropseed (*S. contractus* A. Hitch). Broom snakeweed (*Gutierrezia sarothrae* Greene) dominates a few small areas.

METHODS

We conducted our study on 3 adjoining pastures on the CDRRC having similar soils, topography, and size. These pastures are 992, 1267, and 1219 hectares, respectively. Overall ecological condition of pastures 1 (west) and 2 (center) is late seral, while pasture 3 (east) is in high mid-seral condition (Table 2). Honey mesquite cover and density within each of the 3 pastures show considerable variation. Large portions of each pasture received herbicidal control of brush in the early 1960s (McNeely 1983). Mesquite root kill levels were generally around 65%. Additional herbicidal control was applied in the mid 1980s, but mesquite kill levels were under 5%. Depending on year, these pastures were conservatively to moderately stocked from 1968 to 1994. All pastures were destocked in late July 1994 due to severe drought conditions and were restocked in late November 1996 following procedures of Holechek (1988). Forage use by cattle during 1997 was light to conservative (25–35% use of perennial grasses) in all pastures.

In the fall of 1995, range inventories in the 3 pastures established a baseline databank for intensive evaluation of long-term vegetation trends. We measured total herbage standing crop, forage production, and plant basal cover on all pastures in October 1995, 1996, and 1997. Ten permanent key areas were systematically established for monitoring each of the 3 pastures. We selected these key areas by dividing each pasture into 10 equal parts and then locating the key area near the center of each part. This resulted in key areas being evenly spaced within each pasture. In fall 1996 and 1997, we measured 3 more key areas in sites densely populated with mesquite. One key area was added in pasture 1 and 2 key areas in pasture 3. All key areas were in the center of discreet areas with uniform soils and vegetation. A point-intercept method was used to determine groundcover, plant composition, and trend on all key areas. A transect consisted of 61 m of line located by rebar stakes at each end and another in the center of the line.

TABLE 1. Annual and growing season[1] precipitation (mm) for pastures 1, 2, and 3 from 1995 through 1997 on the Chihuahuan Desert Rangeland Research Center[2].

Pastures	1995 Year total	1995 Growing season total	1996 Year total	1996 Growing season total	1997 Year total	1997 Growing season total
	mm					
1 – West	167	102	197	127	295	139
2 – Middle	175	112	187	120	327	159
3 – East	168	97	230	150	294	138

[1]Growing season is from July through September.
[2]Long-term average precipitation (1930–1993) is 230 mm total and 127 mm during the growing season.

TABLE 2. Vegetation basal cover (%) pooled across years (1995, 1996, 1997) on pastures 1, 2, and 3 on the Chihuahuan Desert Rangeland Research Center in south central New Mexico.

	Pasture		
	1	2	3
	- - - - - - % cover - - - - - -		
Black grama (*Bouteloua eriopoda*)	1.4	1.1	0.1
Mesa dropseed (*Sporobolus flexuosus*)	0.8	0.1	0.4
Threeawn spp. (*Aristida* sp.)	0.2	1.2	0.2
Other grasses	0.4	0.1	0.3
Total perennial grasses	2.8	2.5	1.0
Forbs	0.7	0.7	0.7
Broom snakeweed (*Gutierrezia sarothrae*)	0.4	0.3	0.3
Honey mesquite (*Prosopis glandulosa*)	7.0[a]	4.2[a]	5.2[a]
Other shrubs	0.1	0.1	0.1
Total shrubs	7.5	4.6	5.6
Total vegetation cover	11.0	7.8	7.3

[a]Canopy cover

We measured plant basal cover at 0.61-m intervals using a pin along a tape stretched between the 2 permanent rebars. One hundred observations were taken per transect, and data were recorded by plant species (annual and perennial), litter, rock and gravel, and bare soil. For species composition information, we recorded the nearest plant species in the case of hits on bare ground.

Herbage production was evaluated by offsetting the 61-m line by 3.05 m and placing ten 0.5-m square quadrats parallel to the first line at 6.1-m intervals. All plant species were clipped on each plot to ground level, air-dried for 3 days, and then oven-dried for 24 hours at 55°C. In autumn 1997 we adjusted grazed plants to equivalent weight of ungrazed plants by clipping ungrazed plants of similar height and basal diameter outside of quadrats. These adjustments were minimal because very few plants within quadrats showed visible grazing use. Current year's growth was separated from old growth. Standing crop estimates in this study involved only current year's growth. Transects for herbage production were moved 3.0 m each year to avoid clipping in the same spot.

Mesquite canopy cover on key areas was evaluated along the transects previously described by using the line-intercept method (Canfield 1941). Honey mesquite densities on key areas were determined by establishing belt transects. Three 40 × 2-m belt transects were laid out perpendicular to the 61-m line to estimate number of plants per hectare. The belt transects covered a measured area of 240 m^2 on each of the 33 key areas.

Soil depth was determined by digging pits at each of the 33 key areas. Two range sites were encountered (shallow sandy and deep sandy). We considered the shallow sandy range key areas to be those having soils ≤40 cm in depth, and deep sandy range key areas were those having soil depth >40 cm. All 3 pastures had shallow (10–40 cm) and deep soils (41–120 cm). Pasture 1 had 5 shallow and 6 deep key areas, pasture 2 had 8 shallow and 3 deep key areas, and pasture 3 had 5 shallow and 7 deep key areas. Soil depth on each key area was relatively uniform, based on data gathered by driving a steel measuring rod into the ground at various points and recording the depth to the caliche layer.

Statistical Analyses

Using regression and correlation analyses, we evaluated relationships between mesquite cover, mesquite density, soil texture, soil depth, year, and herbage production for individual pastures and across all pastures (Neter and Wasserman 1974). Regression analyses were performed using the Proc Reg Command in SAS. Relationships were evaluated using linear, quadratic, and cuboidal models (SAS 1986).

RESULTS

Mesquite cover and density both showed significant positive correlations (P <0.05) with soil depth across the 3 study pastures (Table 3, Fig. 1). Because the effect of pasture was not significant (P >0.83), data were pooled across pastures for all regression analyses. Results of regression analyses are shown in Tables 4 and 5. In brief, curvilinear regression equations better fit these data than a linear equation.

Black grama and perennial grass standing crops were negatively correlated with soil depth (Table 3, Fig. 2). Curvilinear regression equations appear to better describe the data than a linear equation (Table 4).

Mesquite canopy cover and density on the 33 transects had weak negative (P <0.05) correlations with black grama and perennial grass standing crop (Table 3, Fig. 3). Regression equations fit with linear, quadratic, and cuboidal

TABLE 3. Significant ($P < 0.05$) simple correlation coefficients for associations between mesquite cover (%), mesquite density (kg ha^{-1}), soil depth (cm), black grama standing crop (kg ha^{-1}), and total grass standing crop (kg ha^{-1}) based on 33 transects in 3 pastures for data pooled across years (1995, 1996, 1997).

	Prosopis glandulosa cover		*Prosopis glandulosa* density		Soil depth	
	r	*P*	*r*	*P*	*r*	*P*
Bouteloua eriopoda standing crop	–0.336	0.05	–0.314	0.05	–0.492	0.04
Total	–0.471	0.02	–0.485	0.04	–0.670	0.01
Prosopis glandulosa cover			0.796	0.01	0.873	0.01
Prosopis glandulosa density					0.743	0.01
Soil depth						

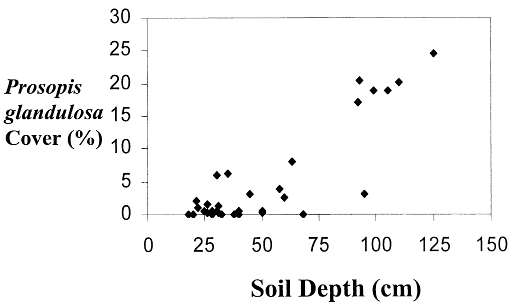

Fig. 1. Relationship between soil depth and mesquite canopy cover on the Chihuahuan Desert Rangeland Research Center in south central New Mexico using data pooled across years (1995, 1996 1997).

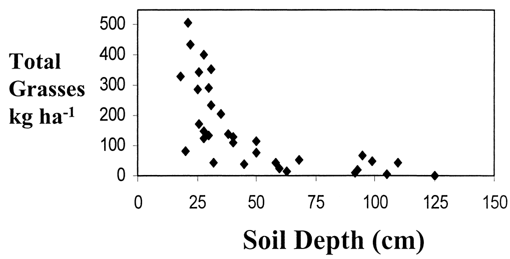

Fig. 2. Relationship between soil depth and total perennial grass production on the Chihuahuan Desert Rangeland Research Center in south central New Mexico using data pooled across years (1995, 1996. 1997).

models appeared to be similar for these relationships ($r^2 \cong 0.22$, Table 5). Although these results suggest that mesquite canopy cover influences grass production, it is important to recognize that high mesquite cover occurred only on deep soils unfavorable for perennial grasses (Fig. 2). No correlatizon ($P = 0.78$) between mesquite cover and total perennial grass standing crop occurred within shallow soils. However, mesquite cover was negatively correlated ($P = 0.01$) with total perennial grass standing crop within deep soils ($r = -0.67$, $n = 15$).

Perennial grass standing crops differed greatly among years. When data were pooled across the 33 key areas, total perennial grass production averaged 64 kg ha^{-1} in 1997, 116 kg ha^{-1} in 1998, and 248 kg ha^{-1} in 1999. Rainfall on the study area during the growing season (July through September) was 16% below average for 1995 but 1% and 16% above average for 1996 and 1997, respectively (Table 1). Perennial grass standing crop in 1997 showed substantial recovery from drought in 1994 and 1996.

We recognize that regression relationships of mesquite cover and soil depth to total grass standing crop could be influenced by year. Therefore, we conducted multiple regression analyses involving year or time in models using soil depth and mesquite cover to predict total grass standing crop. These analyses were conducted using the mixed model procedures of SAS where time was fit as a fixed regression variable and mesquite cover and soil depth were fit as random independent variables (SAS 1996). In these analyses, linear, quadratic, and cubic relationships were tested. The linear term of time and the quadratic term of time were found to be significant ($P < 0.05$) in the model using mesquite cover to predict total grass. However, the actual linear (mesquite cover*time) and quadratic terms (mesquite cover*time*time) were not significant ($P > 0.20$). The coefficient of determination for these models was very weak ($R^2 < 0.14$). Therefore, even though year was significant in the analyses, these regressions were not strong. We took the analyses one step further and analyzed each year independently with the Proc

TABLE 4. Linear, quadratic, and cubic regression equations for predicting grass standing crop (kg ha $^{-1}$) and mesquite cover (%) from soil depth (cm) based on 33 transects in 3 pastures for data pooled across years (1995, 1996, 1997).

Model type	Pasture	Dependent variable	Equation	n	r^2	P
Linear	All	*Prosopis glandulosa*	$y = 0.213x - 5.788$	33	0.75	0.01
Quadratic	All	*Prosopis glandulosa*	$y = 0.0026x^2 - 0.013x + 2.35$	33	0.82	0.01
Cubic	All	*Prosopis glandulosa*	$y = 0.00002x^3 + 0.0007x^2 - 0.035x + 6.1$	33	0.82	0.01
Linear	All	Grass standing crop	$y = -3.1x + 307.5$	33	0.45	0.01
Quadratic	All	Grass standing crop	$y = 0.07x^2 - 11.8x + 517.1$	33	0.58	0.01
Cubic	All	Grass standing crop	$y = 0.001x^3 + 0.26x^2 - 23.4x + 707$	33	0.61	0.01

TABLE 5. Linear, quadratic, and cubic regression equations for predicting grass standing crop (kg ha $^{-1}$) from honey mesquite cover (%) based on 33 transects in 3 pastures for data pooled across years (1995, 1996, 1997).

Model type	Pasture	Dependent variable	Equation	n	r^2	P
Linear	All	Grass standing crop	$y = -8.8x + 195.9$	33	0.22	0.01
Quadratic	All	Grass standing crop	$y = 0.78x^2 - 12.66x + 200.4$	33	0.22	0.03
Cubic	All	Grass standing crop	$y = 0.012x^3 - 0.209x^2 - 9.7x + 198.3$	33	0.22	0.05
Linear	1	Grass standing crop	$y = -10.8x + 237$[a]	11	0.35	0.06
Linear	2	Grass standing crop	$y = -10.3x + 239$[a]	10	0.20	0.09
Linear	3	Grass standing crop	$y = -5.7x + 126$[a]	12	0.27	0.07

[a]Linear regression equations for individual pastures did not differ ($P > 0.10$).

Reg procedures of SAS (SAS 2000) and found great similarity for each year analyzed. Therefore, based upon these analyses, we feel that pooling the data across years for the relationship of mesquite cover and total grass is an appropriate analysis and presentation of the data. In the multiple regression analyses using soil depth to predict total grasses, similar results to the relationship of mesquite cover and total grass were found (i.e., linear and quadratic terms of time were significant, but the terms involving soil depth were not). The coefficient of determination using soil depth to predict total grass was somewhat stronger across years (r^2 ranging from 0.3 to 0.4). However, these coefficients of determination are still modest for prediction equations, and the regression equations for each individual year are very similar for the 3 years studied. Results of these analyses indicate that the data are best described by curvilinear or quadratic equations, but the similarities found across years suggest that pooling of data across years is a justifiable presentation. Therefore, we believe that the data are best presented pooled across years.

DISCUSSION

It has been commonly postulated that deep, coarse-textured soils facilitate downward water infiltration and retain little moisture near the soil surface (Holechek et al. 2001). Theoretically, this benefits shrub species (such as honey mesquite) having extensive, coarse root systems. In contrast, most moisture is retained near the soil surface by clay soils and sandy soils having a shallow, restrictive (caliche) layer. This should favor grasses with dense, short, fibrous root systems such as black grama. Our data provide evidence supporting these statements. Furthermore, Buffington and Herbel (1965) found that honey mesquite abundance in the Chihuahuan Desert is greatest on deep sandy soils. Herbel and Gibbens (1996) found low black grama and perennial grass standing crops on deep sandy soils on the Jornada Experimental Range in south central New Mexico. The most productive black grama stands occurred on shallow loamy or shallow sandy soils.

On our 6 deep sandy sites where mesquite cover exceeded 15%, perennial grass standing

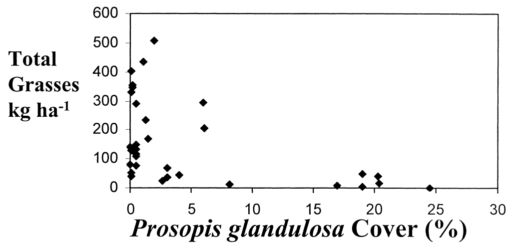

Fig. 3. Relationship between total perennial grass production and mesquite canopy cover on the Chihuahuan Desert Rangeland Research Center in south central New Mexico using data pooled across years (1995, 1996, 1997).

crops were low (<50 kg ha^{-1}) in all 3 years of study (Fig. 3). Scifres and Polk (1974) found little to no increase in forage production on mesquite control areas where mesquite canopy cover had been less than 15–20%. However, there is evidence from Arizona (Glending 1952), Texas (McDaniel et al. 1982), and New Mexico (Warren et al. 1996) that when mesquite canopy cover exceeds 15–20%, it adversely impacts perennial grass production.

MANAGEMENT IMPLICATIONS

Our 3-year study on the Chihuahuan Desert Rangelands Research Center showed perennial grasses are favored by shallow sandy soils while honey mesquite is favored by deep sandy soils. A 47-year study involving 40 sites well distributed across the Chihuahuan Desert of southern New Mexico showed that conservatively to moderately grazed grassland areas had little invasion of honey mesquite from 1952 to 1999 (Galt et al. 1999). Soil depth appears to largely explain why some parts of the Chihuahuan Desert are now dominated by honey mesquite while other areas remain as grasslands. Deep sandy soils with good remaining perennial grass cover are the sites most vulnerable to honey mesquite invasion from drought and heavy livestsock grazing. Care should be taken to ensure these sites receive light to conservative livestock grazing. Burning and/or herbicidal control of mesquite may be necessary to prevent its invasion on deep sandy sites after extended droughts such as occurred in the 1950s. However, these treatments are unlikely to be cost effective for ranchers at today's cattle prices because of the low forage production potential associated with deep sandy sites.

Mesquite invasion does not appear to be a threat on most shallow sandy sites if sound grazing practices are applied. Range improvements such as seeding and brush control will be much more cost effective on degraded sites with shallow soils than those characterized by deep sands.

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