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Soil Movement in Mesquite Dunelands and Former Grasslands of Southern New Mexico from 1933 to 1980

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Abstract

Soil levels were marked on grid and transect stakes in mesquite duneland and grassland areas at 3 sites on the Jornada Experimental Range in 1933 and 1935. Soil levels on one set of transect stakes were remeasured in 1950 and 1955. Remeasurement of soil levels at both transect and grid stakes in 1980 revealed that extensive soil movement had occurred during the intervening years. On a 259-ha site containing large mesquite dunes in 1935, maximum deposition and deflation was 86.9 and 64.6 cm, respectively, in 1980. There was a net gain of 1.9 cm in soil depth over the entire area. On a 259-ha site only partially occupied by mesquite dunes in 1933, there was a net loss of 4.6 cm in soil depth and mesquite dunes had completely occupied the site by 1980. On a transect established across a mesquite duneland-grassland ecotone in 1935, there was a net loss in soil depth of 3.4 cm. Mesquite dunes had completely occupied the former grassland and dune intercept increased from 34.9 m in 1935 to 149.6 m in 1980. Gross erosion rates on wind deflated areas were equivalent to 69 tonnes ha^{-1} yr^{-1} on the area of large mesquite dunes. On the area partially occupied by mesquite in 1935 the gross erosion rate was 52 tonnes ha^{-1} yr^{-1}. At the ecotone transect gross erosion rates were 45, 101, and 40 tonnes ha^{-1} yr^{-1} for 1935-50, 1950-55, and 1955-80 periods, respectively.

Honey mesquite (*Prosopis glandulosa* Torr.) is a plant native to the Southwest, which has spread widely during the historical period. Overgrazing, seed dispersal by domestic livestock and rodents, and periodic droughts have been advanced as causes contributing to the proliferation of mesquite (Buffington and Herbel 1965). The spread of mesquite, primarily into former grassland areas, has caused profound changes in plant communities and in soils and microrelief. Since mesquite makes large demands on a limited soil water supply (Haas and Dodd 1972), herbaceous vegetation between mesquite plants is often reduced in abundance and cover. Baring of the soil surface permits wind erosion and the formation of "coppice dunes" (Melton 1940) as sand is entrapped by mesquite stems. Mesquite dunes now dominate vast areas which once had a relatively flat surface covered primarily by herbaceous vegetation.

The formation of mesquite dunes involves the physics of soil movement by wind, a subject which has been the object of many studies (Bagnold 1941, Chepil and Woodruff 1963, Gillette 1978). An understanding of the processes, i.e., saltation, creep, and suspension, by which soil particles move under the impetus of wind and the influence of surface roughness factors has led to the development of a generalized soil loss equation for wind erosion (Woodruff and Siddoway 1965). This equation has been used in assessing potential wind erosion problems in the United States (Kimberlin et al. 1977). The arid Southwest, where sandy soils predominate and vegetation cover is often minimal, has a high wind erosion potential.

In the early 1930's, scientists at the Jornada Experimental Range were concerned with the spread of mesquite and concomitant wind erosion. As part of their research program, large exclosures and transects were established in mesquite dunelands and on ecotones between grassland and mesquite dunelands. Soil levels were marked on a large number of grid and transect stakes. This far-sighted action provided a unique opportunity to quantify soil movement. Soil levels at the original stakes were remeasured in 1980. Soil movement during the 45 to 47-year period shows that mesquite dunelands, while having an appearance of stability, are actually a dynamic, constantly shifting system.

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Study Area

The Jornada Experimental Range, encompassing 78,266 ha, is located 37 km north of Las Cruces, N. Mex. The elevation ranges from 1,260 m on the relatively level plains to 2,833 m at the crest of the San Andres mountains. Sandy soils predominate on 58,470 ha which constitute the plains portion of the Experimental Range. On the plains, the area covered by mesquite increased from 11,770 ha in 1858 to 37,110 ha in 1963 (Buffington and Herbel 1965). Dunes have formed on most of the mesquite-occupied area.

The average yearly precipitation is 231 mm with 52% occurring during July, August, and September. The summer rains are largely intense, convective storms of localized occurrence. Winds are most frequent and of highest velocity in March and April. These early spring winds blow predominately from the west and southwest and cause the most soil movement.

Specific study sites included 2, 259-ha (640 acres) exclosures built in 1933 and 1934 and a 457.2-m transect established in 1935 across a mesquite-grassland ecotone. The 259-ha exclosures were originally called the "Artificial Revegetation Exclosure" and the "Natural Revegetation Exclosure" but for brevity will henceforth be designated as Site A and B, respectively. The ecotone site will be referred to as Site C.

The Site A exclosure was established on an area where mesquite dunes were large and well established. Many seeding and transplanting trials were conducted from 1934-36 in unsuccessful attempts to establish forage grasses and browse species. Drifting sand rendered the exclosure fence ineffective and it was removed in the early 1960's. The predominant soils in the Site A exclosure are deep, loamy sands which are thermic Typic Haplargids of the Onite series; soils of the numerous and large mesquite dunes are thermic Typic Torripsamments of the Pintura series. There are also inclusions of thermic Typic Haplargids of the Dona Ana series (Bullock and Neher 1980).

In 1933, about half of the Site B exclosure was covered with mesquite dunes. Grasses dominated the non-duned portion of the exclosure but mesquite plants were present. The exclosure was established to see if protection from grazing would allow natural plant succession to reestablish a grassland climax. A 1,731-m belt transect with stakes every 15.2 m was established in a north-south direction across the exclosure and projecting beyond the exclosure fence 61 m at either side. The deep, loamy sand soils in the exclosure have been mapped as the Onite-Pintura complex (Bullock and Neher 1980).

The 457-m transect across the former grassland-mesquite duneland ecotone at Site C occurs on shallow (<50 cm to caliche layer), thermic Typic Paleorthids of the Simona series (Bullock and Neher 1980). Dunes large enough to qualify as pedons belong to the Pintura series.

Approximately one-third of the Site B exclosure was sprayed with 2,4,5-T for mesquite control in 1966-68. Further plot treatments were superposed upon the sprayed portion in 1969-72. Approximately 183 m of the Site C transect fell within an area treated with 2,4,5-T in 1973. No herbicides have been applied at Site A.

Methods

To facilitate vegetation type mapping, a 201.1 × 201.1 m (10 × 10 chain) grid was laid out on the site A exclosure. Intersections of grid lines (81 points) were marked by steel fence posts. In February, 1935, the soil level at each grid point post was marked by filing a notch in the post 15.2 cm above the upper face of a 30.5 cm wooden ruler laid on the soil surface in a north-south direction on the east side of the post (Little 1935a).

In 1931, a 201.1 × 100.6 m (10 × 5 chain) grid was laid out on the Site B exclosure. Grid line intersections (153 points) were marked with a 1.2-m length of 3.2-cm pipe. Soil levels were marked, as described above, on the pipes in May, 1933 (Little 1935a). A remeasurement of soil levels at the grid markers was made in February, 1935 (Little 1935b).

A transect was established across the Site B exclosure in 1935. Stakes 66 cm long cut from steel fenceposts were driven 43 cm into the ground at 15.2-m intervals. The transects, which followed a north-south grid line 604 m from the west side of the exlosure, extended 61 m beyond the exclosure fence on the north and south sides. Soil levels were marked, as described above, on the 104 transect stakes in April, 1935. While preparing a map of the vegetation in a 30.5-cm belt along the transect, the extent and height of mesquite dunes intersected by the grid line side of the belt transect were also mapped (Little 1935c).

At Site C, a belt transect (30.5 cm wide) was established in April, 1935. The transect was oriented WSW to ENE, approximately parallel to the prevailing wind direction. The eastern half of the transect was in an area of mesquite dunes and the western half in black grama (*Bouteloua eriopoda* (Torr.) Torr.] grassland. The fence post stakes placed at 15.2 m intervals on the 457.2 m transect were about 48 cm long and driven into the ground 30.5 cm. Soil levels were marked, as described above, in April, 1935 (Little 1935d). Remeasurements of soil levels on this transect were made in 1950 and 1955.[1]

During June and July, 1980, remeasurements of soil levels at the grid and transect stakes were made at all study sites. Grid markers along the fence lines at Site B and the former fence lines at Site A were not measured. A 30.5-cm ruler was positioned in the same manner as in 1935 and the distance to the file mark was determined. Where stakes had been completely excavated by wind erosion, the distance from the file mark to the bottom end of the stake was measured and soil loss recorded as a "greater than" value. A few of the stakes were lying down and buried by sand. In this case, the amount of soil on top of the stake was subtracted from the soil depth lost.

A metal detector was used to locate completely buried stakes. These were carefully excavated, preserving a reference to the current soil surface level. Buried stakes were often badly rusted but the deep file marks were discernible in every case. At Site A 7 of the grid markers were not located. Since this site had been open to livestock for some time, the fenceposts may have been broken off by animals rubbing against them. At the Site C transect 2 stakes close to a road (present in 1935) which bisected the transect were not included.

The horizontal extent of mesquite dunes intercepted by the transect lines at Sites B and C was measured. These dunes were mapped on mylar sheets at the same scale used in 1935. This allowed the 1980 dune maps to be superimposed over the 1935 maps and changes in dune dimensions determined. A surveyor's level and rod were used to determine dune heights along the transects in April, 1981. Areas of dunes intercepted by the transect were determined from the maps by using a digitizer and computer. Movements in the cardinal directions of dunes which had persisted since 1935 were determined from the maps. An analysis of variance and l.s.d. tests of means were used to determine if dune movements in the cardinal directions differed. Net soil depth gains or losses were calculated from average depths of deposition and erosion, weighted by the proportion of sample points where deposition and erosion occurred. Erosion rates on a weight basis were calculated utilizing the bulk density of soils, depths of soil removal, and time periods of interest.

The possible influence of the stakes upon soil movement had been recognized in 1935. Drifts on the leeward side of stakes or hollowed out areas at the base of stakes were not found in 1980, indicating that the stakes had little influence on soil removal or deposition. The soil movements were so large in depth and horizontal extent that the small vortex swirls created by the stakes had no visible effect.

Results and Discussion

Both wind and water have contributed to soil movement at Site A. The site contains two parallel, low, rounded ridges of sandy soils separated by a broad, flat drainageway with loamy soils. Wind-formed mesquite dunes up to 3.4 m in height cover the ridges. The drainageway shows evidence of alluvial deposition with the deposits cut by small erosion channels. While wind undoubtedly erodes soil from the alluvial flats, there are no wind-formed mounds built up around the shrubs or grasses.

The location of each of the 44 grid posts found was classed as being primarily influenced by wind or water erosion. Nine grid markers were found standing in water-cut gullies or rills or on overflow areas surrounded by alluvial deposits and were classed as being on water-influenced areas. Four showed soil deposition and 5 soil removal with a maximum of 38.4 and 39.6 cm, respectively (Table 1). There was a net loss of 0.5 cm of soil on the water-influenced area.

Wind erosion was the dominant influence at 35 grid posts (Table 1). The maximum deposition (86.9 cm) occurred within a mesquite canopy and the maximum deflation, or soil removal, (64.6 cm) in an interdunal area. No patterns of deposition or deflation in relation to prevailing winds could be detected. Some grid markers occurred on all cardinal dune exposures and both deposition and deflation were found on all exposures.

Based on soil movement at all grid markers, there was a net gain of 1.9 cm in soil depth on Site A during the 45-year period. A net gain of soil is somewhat surprising but the number of sample points is small and maximum deposition considerably greater than maximum deflation. The striking feature is the instability of the soils and the magnitude of the soil movements which have occurred within the area.

Site B is essentially a flat area with no prominent drainageways and wind is the primary erosive agent. Comparisons of soil movement at both grid stakes and transect stakes showed no significant differences ($P>0.05$) between the area used for herbicide trials and the non-sprayed area (Hennessy 1981). The lack of differences between the sprayed and non-sprayed areas may in part be attributed to the fact that dead mesquite stems persist for several years and act as sand traps, just as the naturally defoliated stems do in the windy spring season. Also, the herbicide test strips varied widely in

[1]Field sheets of 1950 and 1955 remeasurements of B-CB-PB belt transect. Jornada Experimental Range files.

Table 1. Soil movement at 44 grid stakes on the 259-ha Site A between 1935 and 1980. Both water and wind function as erosive agents on this site.

Primary erosive force	Soil movement category	Number of points	Maximum (cm)	Minimum (cm)	Mean (cm)	Net Loss (-) or Gain (+) (cm)
Water	Deposition	4	38.4	15.2	25.6	
	Deflation	5	39.6	5.2	21.5	-0.5
Wind	Deposition	17	86.9	2.4	28.8	
	Deflation	18	64.6	3.7	22.2	+2.5
Wind and water combined	Deposition	21	86.9	2.4	28.8	
	Deflation	23	64.6	5.2	22.1	+1.9

mesquite kill and on all but one series of tests it was, in 1980, difficult to distinguish the area which had been sprayed. In the long-term, effective mesquite control can be expected to have an effect on soil movement as denuded dunes melt down and increased interdunal vegetation slows deflation. However, the absence of significant differences between the sprayed and non-sprayed areas led to the decision to combine the 2 areas for the evaluation of soil movement since 1933.

Soil levels at the grid stakes on Site B were measured in 1935, 21 months after the reference marks were established. At that time there had been a net loss of soil equivalent to 0.4 cm (Table 2). By 1980, after 47 years, the net loss of soil was 4.6 cm (Table 2). Since deflation had completely excavated the stakes at 8 grid points, the net loss must be regarded as a minimum value because the amount of soil lost after the stakes fell over is not known. One grid stake was found in a horizontal position under 39.6 cm of sand. Even with the deposition, there was a minimum net soil depth loss of 22.5 cm at this point.

The transect stakes furnish another data base for determination of soil movement but are less precise than the grid markers because the transect stakes were not driven as deeply into the soil (43 cm versus ca. 60 cm). Of the 113 transect stakes, 19 had been completely excavated. With so many minimum values the calculated net soil loss of 3.5 cm is considerably less than the loss calculated from the grid stakes (Table 2).

The total number of dunes intersected by the transect across Site B increased from 71 in 1935 to 108 in 1980. Twelve of the original dunes merged to form 6 dunes and 2 split to form 4 dunes. Total dune intercept increased from 269.5 m in 1935 to 570.0 m in 1980. Average height of the dunes at the plane of interception with the transect was 39 cm in 1935 and 60 cm in 1980. Of the dunes present in 1935, 57 increased in height with a mean deposition of 49 cm. Eight dunes showed a decrease in height ($\bar{x}$=9 cm) and 6 dunes had completely eroded. There were 47 new dunes formed during the 45-year period and these had an average height of 53 cm. The mean maximum height of dunes, regardless of whether that point fell on the transect, was 79 cm in 1981.

Area covered by the dunes intercepted by the transect had increased from 677 m^2 in 1935 to 3,861 m^2 in 1980, or an increase from 10 m^2 to 36 m^2 in average dune area. The growth or shift in the cardinal directions of the 65 dunes persisting since 1935 was determined. The mean movements by direction were: west, 1.95 m; east 2.35 m; south, 3.75 m; and north, 3.84 m. Significant differences (P<.05) were found only between dune movement to the west and movement to the north and south. Thus, dune growth was least on the windward side and tended to be greatest at right angles to the prevailing winds. Whether this north-south extention resembles the wings of parabolic or barcan dunes which form perpendicular to prevailing winds (Bagnold 1941), or is the result of greater mesquite growth in a north or south direction is not known. These dune movements differ markedly from the downwind dune migration rates of 30 to 60 cm per year which Melton (1940) gives for mesquite dunes in southeastern New Mexico.

The Site C transect was established perpendicular to a grassland-mesquite duneland ecotone in 1935. Soil levels were determined at the transect stakes in 1950, 1955, and 1980. Only 27 of the 31 transect stakes were common to all measurements. There was an indicated net soil loss of 2.9 cm from 1935-50 and a nearly equal loss (2.7 cm) in the 1950-55 period (Table 3). The 1950-55 period coincided with what is considered one of the most severe droughts in the Southwest during the past 350 years (McDonald 1956). The drought-induced reduction in vegetation cover probably accounts for the 1950-55 soil loss being nearly equal to that in the preceeding 15 years. From 1955-80 there was a net gain in soil depth (Table 3) but just when the turnaround from loss to gain occurred is not known. The gain in soil depth was greater on the former grassland part of the transect (3.4 cm) than on the mesquite duneland portion (1.4 cm). Since mesquite had largely replaced the grassland by 1955, the mesquite plants were probably trapping off-site sand, resulting in greater deposition. In all time periods, soil depth losses were greater on the original mesquite part of the transect than on the former grassland.

Total dune intercept on the Site C transect increased from 46.7 m in 1935 to 149.6 m in 1980. In 1935, the mesquite duneland portion of the transect had 14 dunes with a mean height of 28 cm on the line. There were 27 dunes on the mesquite portion of the transect in 1981 with a mean height of 31 cm. Of the dunes present in 1935, 9 had increased in height and 4 had decreased in height. On the former grassland portion of the transect there were only 2 small dunes in 1935 (mean height of 15 cm). In 1981 there were 23 dunes

Table 2. Deposition and deflation of soil in 1935 and 1980 at 105 grid stakes on the 259-ha Site B where soil levels were marked in 1933, and 1980 soil levels at 113 transect stakes on Site B on which soil levels were marked in 1935.

Data base	Year of measurement	Soil movement category	Number of points	Maximum (cm)	Minimum (cm)	Mean (cm)	Net Loss (-) or Gain (+) (cm)
Grid stakes	1935	No change	9				
		Deposition	36	6.0	0	1.1	
		Deflation	60	4.9	0	1.4	-0.4
	1980	Deposition	33	78.3	1.8	23.8	
		Deflation	72	61.9†	0.9	17.4	-4.6†
Transect stakes	1980	Deposition	43	78.6	0.6	2.5	
		Deflation	70	45.1†	0.9	2.1	-3.5†

†Represent minimum values because one stake was completely excavated by wind erosion.

Table 3. Deposition and deflation of soil at transect stakes on Site C where soil levels were marked in 1935 and remeasured in 1950, 1955, and 1980. Values given show change from one measurement to the next for 27 stakes common to all measurements.

Time period	Soil movement category	Number of points	Maximum (cm)	Minimum (cm)	Mean (cm)	Net Loss (-) or Gain (+) (cm)
1935-1950	No change	2				
	Deposition	4	3.2	0.6	5.1	
	Deflation	21	30.5†	0.6	4.8	-2.9†
1950-1955	No change	2				
	Deposition	3	3.0	0.9	1.7	
	Deflation	22	10.5	0.6	3.6	-2.7
1955-1980	Deposition	18	25.1	1.2	7.0	
	Deflation	9	34.6†	0.3	7.1†	+2.3
1935-1980	Deposition	8	35.1	0.6	10.7	
	Deflation	19	61.0†	0.6	9.3†	-3.4†

†Represent minimum values because on stake was completely excavated by wind erosion.

with a mean height on the transect of 20 cm.

The area covered by the dunes intercepted by the transect increased from 96 m^2 to 493 m^2 from 1935 to 1980 on the mesquite portion of the transect. There was no significant difference ($P>0.05$) in the directional growth of dunes present in 1935 although, as at Site B, growth was least on the west or windward side. On the grassland portion, the area covered by intercepted dunes increased from 8 m^2 in 1935 to 122 m^2 in 1980. During the 45 years mesquite dunes completely replaced the former grassland and black grama is no longer present on the area.

Kimberlin et al. (1977) state that lands reported as damaged by wind erosion are those that lose soil at rates of 33.6 tonnes ha^{-1} yr^{-1}. For the Onite and Simona soils, with a bulk density of 1.4 g/cm^3 in the surface horizons (Gile and Grossman 1979), a loss of 33.6 tonnes is equivalent to a soil depth loss of 0.24 cm ha^{-1} yr^{-1}. Net soil losses on the 3 study sites exceeded this rate only during the 1950-55 drought period on Site C. However, wind erosion is usually considered as a gross loss of soil moved by creep, saltation, and suspension (Wilson 1975). In the mesquite dune situation, creep and saltation fractions are trapped by the mesquite plants and remain on site. Therefore, gross soil loss can be best approximated by considering losses on areas of deflation only.

Losses from the Site A wind deflated areas amounted to 69 tonnes ha^{-1} yr^{-1} for the 45-year period. Using the data from the grid points at Site B, the deflation areas lost 52 tonnes ha^{-1} yr^{-1} for a 47-year period. Losses on deflation areas at Site C were 45, 101, and 40 tonnes ha^{-1} yr^{-1} for the 1935-50, 1950-55, and 1955-80 periods, respectively. Wilson (1975) applied the wind erosion equation to 765,604 ha in Eddy County in southeastern New Mexico and calculated a gross soil loss of 101 tonnes ha^{-1} yr^{-1}. This value is somewhat higher than the long-term yearly losses indicated above but is certainly not excessive for drought periods. As Wilson points out, the application of the site-specific wind erosion equation on a regional basis involves many approximations. The yearly loss rates probably have little real meaning. In the mesquite dunelands soil loss rates will vary widely between years due to fluctuations in vegetative cover on the interdune areas and in the erosive wind energy.

The magnitude of soil movement within the mesquite dunelands indicates that considerable degradation of the soils as a plant growth medium has occurred. Other studies have identified the soil components lost in suspension as being predominately from the silt and clay fractions (Chepil 1946, Gillette 1977). The constant loss of silt and clay as the dunelands are "churned" by wind erosion could have a major influence on soil properties such as water holding and cation exchange capacities. Loss of silts and clays by wind erosion would also reduce the soil binding properties imparted by these two size fractions, and the remaining fraction would be even more susceptible to wind erosion. In this arid environment appreciable changes in water holding capacity alone could be a factor causing shifts in vegetation associated with the mesquite dunes and in potential site productivity. Identification of the soil fractions lost from the mesquite dunelands is the object of continuing studies.

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