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Soil Sorting by Forty-five Years of Wind Erosion on a Southern New Mexico Range[1]

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ABSTRACT

This paper presents the fractional composition of soil lost from wind erosion for a 45-yr period on mesquite sand dune rangeland in south-central New Mexico. In addition, an equation was developed for defining the soil loss by particle size. Three arbitrarily chosen groups (deposition, noneroded, and eroded) were used to categorize the sampling locations. Net soil loss was in excess of 4.6 cm/ha. Maximum deposition was 78.6 cm and maximum erosion was in excess of 61.9 cm. The sand fraction was divided into three particle size classes. There was a significantly greater amount of the 0.5- to 0.05-mm sand fraction in the deposition site than in either the eroded or non-eroded sites. No net loss of sand from the experimental site was measured. The silt fraction was significantly greater in the non-eroded and eroded sites than in the deposition site, indicating removal of the silt fraction by wind erosion. Wind erosion occurring on the site is resulting in a more sandy textured soil.

Additional Index Words: **soil erosion, arid rangelands, sandy soils, wind, soil movement.**

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WIND EROSION is a common problem on rangelands in the arid Southwest. In southern New Mexico, eolian processes have created large tracts of mesquite (*Prosopis glandulosa*) sand dunes with eroded interdunal areas. The soil from eroded areas may be either deposited in dunes or lost from the site. Because soil texture is an important factor affecting plant growth, it is important to determine which soil fractions are carried off-site, and in what proportions.

In studies comparing sand dunes or drifts with original soils, it has generally been found that drifts or dunes contain less silt and clay than parent soils (Chepil, 1946). In many cases, intermediate grades, including fine sands and silts, were missing from eroded sites (Chepil, 1957). When dune sands were compared with original soils for an area in Saskatchewan, Canada, it was found that the original soil was a sandy loam, whereas the dune soil was a sand (Moss, 1935). A portion of the clay and silt fractions of the parent soil was not deposited in the dunes but was apparently carried off site. A comparison of virgin soils with drifts in the southern High Plains showed that drifts had 22.3% more sand, and 53.1% less silt and clay than virgin coarse soils. The drifts had 31.1% more sand and 20.1% less silt and clay than virgin medium-textured soils (Daniel, 1936).

The objective of this study was to determine the fractional composition of the soil lost over a 45-yr period on a mesquite-duneland range. After determining the fractional composition of soils in mesquite dunes and in noneroded interdunal areas, an equation was developed that defines the soil loss by particle size.

STUDY AREA

The study area is located on the Jornada Experimental Range, 37-km north of Las Cruces, Dona Ana County, New Mexico. Most of the Experimental Range lies in a closed basin with elevations ranging from 1190 to 1375 m. Much of the topographic relief is in the form of broad benches or low playas. Broad areas of sandy soils have been transformed into hummocky terrain by the formation of mesquite dunes up to 150 cm in height.

Soils of the Jornada basin are derived from unconsolidated Pleistocene detritus from surrounding mountains and alluvium from ancestral Rio Grande flooding. They are generally low in organic matter and high in carbonates, with a calcareous layer at depths varying from a few centimeters to 1 m or more. On the study site, interdune soils are coarse-loamy, mixed Typic Haplargids of the Onite series. Dunes tall enough to qualify as pedons are classified as mixed Typic Torripsamments of the Pintura series (Bullock and Neher, 1980). The climate is arid, with low relative humidity, high radiation, and variable precipitation (Paulsen and Ares, 1962). Mean annual precipitation for the period 1916 to 1978 was 230 mm. Rainfall is greatest in August and least in April. Although the average annual wind speed was 0.92 m/s, speeds of 18.5 m/s were frequent, especially in March and April (Paulsen and Ares, 1962).

MATERIALS AND METHODS

In the fall of 1931 and spring of 1932, a rectangular grid system 201 by 100.5 m (660 by 330 ft) was laid out on an area 1609.3 by 1609.3 m (1 mile^2). At each of the 153 grid line intersections, a pipe grid marker was driven into the ground.[3] The area was fenced to exclude livestock in 1933. In 1935, a transect was laid out on a north-south grid line located 604 m from the west boundary of the exclosure. The transect extended 61 m beyond the north and south exclosure boundaries and had a total length of 1731.3 m (5680 ft). The transect was marked by 113 metal stakes driven into the ground every 15.2 m (50 ft).

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[3] Little, E.L., Jr. 1935. Report of establishment of belt transect in major exclosure no. 1. Jornada Experimental Range files. Unpublished transcript.

Table 1. Mean volume percent sand, silt, and clay fractions for noneroded soils (V_p), deposition soils (V_d), and eroded soils (V_e) with standard deviations (SD).†

Particle size	Site Noneroded (V_p) ($\bar{X}$ ± SD)	 Deposition (V_d) ($\bar{X}$ ± SD)	 Eroded (V_e) ($\bar{X}$ ± SD)
mm	%		
2.00–1.0	0.014		
1.0 –0.5	7.38a‡ ± 4.00	5.37a ± 4.74	8.94a ± 5.10
0.5 –0.05	79.13b ± 4.78	86.77a ± 5.22	77.77b ± 4.46
0.05–0.002	8.08a ± 1.90	3.17b ± 1.66	8.79a ± 1.75
<0.002	5.40a ± 1.09	4.69a ± 0.78	4.65a ± 0.76

† Each mean value represents 11 observations.

‡ Means for each soil fraction with the same letter are not significantly different ($P < 0.05$).

Soil levels were marked on all grid markers in 1933 and on transect stakes in 1935. Soil levels were recorded from these stakes in 1980. Because the fencelines probably influenced soil deposition, grid markers along fencelines were excluded, and soil movement was determined only at the 105 interior grid stakes. The grid markers, because of their distribution and the depth to which they were driven into the ground (approximately 62 cm), furnished a better data base for calculating net soil loss than the transect stakes, which were driven into the ground about 45 cm. Net soil loss from the area was equivalent to a value >4.6 cm/ha (Gibbens et al., 1983). Maximum deposition at grid and transect stakes was nearly identical with 78.3 and 78.6 cm deposition, respectively. Maximum erosion >61.9 cm could not be determined because some grid markers and transect stakes were completely excavated by erosion. The transect stakes were more easily relocated for purposes of soil sampling than were the grid markers; therefore, the soil movement from 1935 to 1980, measured at the transect stakes, was used to categorize these stake areas into one of the following arbitrarily chosen groups:

1. Deposition site (V_d)—all stakes with >1.8-cm deposition.
2. Parent site (V_p)—stakes between and including 2.7-cm erosion and 1.8-cm deposition.
3. Eroded site (V_e)—all stakes with >2.7-cm erosion.

Sample size was determined by the number of stakes (11) categorized as parent sites. A sample of 11 was drawn at random from deposition and eroded sites. Three soil samples were taken at each of 11 points in each group in April 1984. Soil levels at the parent sites had not changed since 1980. All samples were from the surface to the 15.2-cm depth and were taken at a point near the respective stake. Sand, silt, and clay fractions of oven-dried (105°C) 40-g subsamples were determined by the Bouyoucos hydrometer method (Day, 1965). The means of the three determinations of soil fractions at each sampling point were used in calculations.

RESULTS AND DISCUSSION

The textural differences between soils of parent, deposition, and eroded sites were due, in part, to different horizons being sampled, because different horizons were exposed to the surface as a result of soil removal. Some difference can also be attributed to textural change resulting from soil lost from the area. To determine the fractional constitution of soil lost by erosion, it was necessary to make several assumptions because no fractional analysis was made in 1935 with which to make a direct comparison. These assumptions were:

1. The interdune points that showed the least gain or loss, those between +1.8 cm and −2.7 cm, were assumed to be representative of 1935 interdunal surface soils.
2. Dunes were assumed to be the inverse of interdunal blowouts in terms of soil, except for that portion lost from the area. Thus, the top 15 cm of the interdunal soil, when eroded, would make up the first (or bottom) 15 cm of a new deposit, though some loss would occur in the process. The next 15-cm layer of interdune, when eroded, would make up another 15-cm layer on the depositional surface, etc.
3. Leaching of soil particles through dune soils was assumed to be nonsignificant over the past 45 yr.
4. Soil loss was spread evenly across the deflation profile. This means that the 4.6 cm/ha loss that occurred was spread evenly down to the maximum deflation point of >61.9 cm, or a loss of approximately 0.9 cm from each 15-cm segment of the profile.

Percentage composition for each fraction is shown in Table 1. The differences in volume percentages of the soil fractions between dune and interdune were assumed to be due to the amounts of each of the fractions that had been lost during dune formation.

To determine the fractional loss, it was necessary to develop an equation that would relate such loss to the fractions as found in parent, and, after erosion, dunal soil (Hennessey, 1981). The development of the equation is as follows

$$\mathrm{Sa_p} = \mathrm{Sa_d} + \Delta\mathrm{Sa} \qquad [1]$$

where

$\mathrm{Sa_p}$ = total amount of sand, available for movement,

$\mathrm{Sa_d}$ = total amount of sand moved but remaining on site, and

$\Delta\mathrm{Sa}$ = total amount of sand removed from the site.

Similarly, for all other fractions:

$$\mathrm{Si_p} = \mathrm{Si_d} + \Delta\mathrm{Si} \qquad [2]$$

$$\mathrm{Cl_p} = \mathrm{Cl_d} + \Delta\mathrm{Cl} \qquad [3]$$

where

$\mathrm{Sa_p}$, $\mathrm{Si_p}$, and $\mathrm{Cl_p}$ = total amount of sand, silt, and clay available for movement,

$\mathrm{Sa_d}$, $\mathrm{Si_d}$, and $\mathrm{Cl_d}$ = total amount of sand, silt, and clay moved, but remaining on site, and

$\Delta\mathrm{Sa}$, $\Delta\mathrm{Si}$, and $\Delta\mathrm{Cl}$ = total amount of sand, silt, and clay removed from the site.

Combining Eq. [1], [2], and [3] we obtain:

$$\mathrm{Sa_p} + \mathrm{Si_p} + \mathrm{Cl_p} = \mathrm{Sa_d} + \mathrm{Si_d} + \mathrm{Cl_d} + \Delta\mathrm{Sa} + \Delta\mathrm{Si} + \Delta\mathrm{Cl}\,. \qquad [4]$$

Pintura and Onite soils both have a bulk density of 1.4 g/cm^3 to a depth >80 cm (Gile and Grossman, 1979); therefore, rewriting Eq. [4] in volumetric terms gives

$$V_p = V_d + \Delta V \qquad [5]$$

or

$$V_d = V_p - \Delta V \qquad [6]$$

where

V_d = the volume of all fractions in the depositional or dune soil,

V_p = the volume of all fractions in the parent soil, and

ΔV = the volume for all fractions removed from the site.

Then let

X = the depositional soil fraction in percent (i.e., Sa_d, Si_d, Cl_d),

Y = the parent soil fraction in percent (i.e., Sa_p, Si_p, Cl_p), and

Z = the soil fraction removed from the site in percent (i.e., ΔSa, ΔSi, ΔCl).

For a given volume of soil and for each soil fraction, Eq. [6] can be written as

$$XV_d = YV_p - Z\Delta V \qquad [7]$$

and by substituting Eq. [8] into Eq. [7]

$$X(V_p - \Delta V/V_p) = Y - Z(\Delta V/V_p) \qquad [8]$$

The volumes V_d, V_p, and V are reduced to the depth of soil sampled, (D_d, D_p, and D) for a unit area (e.g., ha), therefore: V_d is replaced by D_d (the depth of soil deposited), V_p is replaced by D_p (the depth of soil fractions in the parent soil), and ΔV is replaced by ΔD (the depth of soil removed from the site.)

By substitution:

$$X[(D_p - \Delta D)/D_p] = Y - Z(\Delta D/D_p)\,. \qquad [9]$$

Using the 15-cm soil sample as the initial depth and the approximately 0.9-cm loss/15 cm of soil as the depth of soil lost (Gibbens et al., 1983), and using Eq. [9], we obtain:

$$X[(15 - 0.9)/15] = Y - Z(0.9/15)\,. \qquad [10]$$

Since X, Y, and Z are percentages, Eq. [10] can be applied to depth, volume, or mass. Using Eq. [10] and the volume percentage values from Table 1, we calculated that −1, 85, and 16% of the soil lost was in the sand, silt, and clay size fractions, respectively. These values seem quite reasonable in terms of erosion physics. The silt fraction, being highly erodible, should constitute most of the loss (Beasley, 1972; Chepil, 1945; Daniel, 1936). Fine silt is the most mobile soil fraction and is carried the farthest. This was confirmed by Chepil (1957), who found missing fractions to be in dust particles comprised of fine silts and sands, which are carried at a height about 60 cm off the ground.

The sand fraction was subdivided into three particle size classes (Table 1). The diameter of the sand particles was <2.0 mm on all three sites. Only the parent site had sand particles >1.0 mm.

There was no significant difference between sites for the 1.0- to 0.5-mm sand fraction. Also, there was no significant difference between the parent and erosion site for the 0.5- to 0.05-mm sand fraction, but a significantly greater amount on the deposition site.

The silt fraction was significantly less in the disposition site than in either the parent or the erosion sites. This indicates that the silt fraction was removed from the area by suspension, and the 0.5- to 0.05-mm sand fraction was deposited in the deposition site. The clay fraction was uniformly distributed over all these sites and no significant differences were detected.

Sand-sized particles probably moved by creep and saltation. Creep is a very slow process, which would lead to little, if any, net loss. Saltation probably accounted for most of the sand movement. The study area is surrounded by mesquite dunelands, which extend for several miles in the direction of the prevailing westerly winds. While saltation undoubtedly moved some sand off the study site, it is logical to assume that an equal or greater amount of sand moved on to the site. Because dunes on the study site are constantly increasing in size, indications are that some moving sand would be trapped and immobilized in the dunes, causing some net gain in the sand fraction, as is indicated by the equation.

Suspension, the chief means of silt and clay particle movement, could be expected to carry particles much farther than would processes of creep or saltation. Deposition of the eroded silt and clay probably occurred at a substantial distance from the study site.

Under continued erosion, soil on the study site will become much more sandy, and even more erodible (Gillette, 1977). Removal of clays and silts will have major influences on such properties as waterholding capacity, cation exchange capacity, soil structure, infiltration and aeration, leaching, and nutrient presence and availability (Gillette, 1977; Russell, 1973). These changes will, in turn, influence the kind and amount of vegetation the area will support.

SUMMARY AND CONCLUSIONS

By marking soil levels on permanent transect stakes, farsighted research workers provided a unique opportunity to examine erosion processes on a southern New Mexico mesquite duneland. After 45 yr there was a net loss of soil from the site, and specific sites could be classed into noneroded, eroded, and depositional areas. Textural analyses were made of soils from each of the three areas. An equation was developed that determined the amounts of sand, silt, and clay lost from the site. Silts (85%) and clays (16%) accounted for all of the soil lost from the site. Sands showed a small net gain (1%). The equation may be used in the prediction of the textural composition of future soil loss from the study site, and may be useful in determining the composition of soil lost from other sites.

The high percentage losses of silt and clay show that wind erosion is leading to more sandy soil texture. Changes in soil properties were accompanied by extensive changes in vegetation on the site during the 45-yr period (Hennessey et al., 1983). Because the mesquite dunelands are annually subjected to wind erosion, soil losses will continue, and further changes in soil properties and vegetation may be expected.

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