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Crop Productivity and Surface Soil Properties of a Severely Wind-Eroded Soil

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ABSTRACT

Wind erosion degrades soil quality by modifying soil properties important for optimum plant growth and productivity. In this study we evaluated soil properties and plant productivity of an Amarillo fine sandy loam soil that had been severely wind-eroded for 9 years, causing a loss of about 10 cm (over 1300 mt ha^{-1}) of the soil surface. Cotton, kenaf, and grain and forage sorghum were grown for two years and soil tests were performed on eroded, deposited, and non-eroded areas. The eroded areas produced 34 percent lower cotton boll weights and 40 percent lower lint weights than the non-eroded areas in 1998. Cotton lint yields were not significantly different (P<0.10) in 1997, probably due to severe insect damage. The grain yield of grain sorghum was about 58 percent lower in the eroded area than the non-eroded area. The forage sorghum grain yield in 1998 was 83 percent lower on the eroded area than the non-eroded area. The kenaf yield was an average of about 40 percent lower on the eroded area than the non-eroded area. Erosion had significantly increased (P<0.05) sand content on the deposited area but caused little textural change in the surface of the eroded area compared with the adjacent non-eroded site. The eroded area had significantly less phosphorus, as measured by Bray P1 and P2 methods, than the adjacent non-eroded area. Few differences were found for other plant nutrients among the sites.

INTRODUCTION

There is a considerable body of research on the effects of erosion on soil properties and productivity (Follett and Stewart, 1985; Lal, 1988; Larney et al., 1995; Larson, et al., 1990; Lyles and Tatarko, 1986; McCool, et al., 1985). However, most of the research focuses on the effects of water erosion and not wind erosion. Usually, indirect methods are used to assess the effect of wind erosion on soil properties and productivity. For example, the effects of wind erosion on soil productivity has been associated with yield data (Fryrear, 1981; Eck et al., 1965), rainfall records (Burnett and Moldenhauer, 1957), or estimates of wind erosion (Lyles, 1975) in areas prone to wind erosion. Direct estimates of the effects of erosion on soil properties have been made using comparisons of the properties of dust and *ex situ* bulk surface soil in the laboratory (Hagen and Lyles, 1985) or in the field (Larney et al., 1998; Zobeck and Fryrear, 1986a and 1986b; Zobeck, et al., 1989).

Recent studies of wind erosion used in the development of the Revised Wind Erosion Equation (Fryrear, et al., 1998) and validation of the Wind Erosion Prediction System (Hagen, 1991) have used a unique experimental design consisting of a circular erodible field surrounded by a non-erodible field (Fryrear, et al., 1991). This design allows for the direct comparison of an area with a known amount of wind erosion with a nearby non-eroded soil. Detailed study of such a site eroded for two years in Alberta has been used to determine the effects of limited wind erosion on yields of spring wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.). Changes in productivity on the eroded area due to wind erosion were reflected in wheat yields but not in canola yields (Larney et al., 1998). However, canola yields were slightly higher in the area where saltating soil was deposited than in the eroded field.

A similar site was established at the USDA, Agricultural Research Service, Wind Erosion and Water Conservation Research Unit field station located in Big Spring, Texas in 1988. The site was eroded for nine years and experienced a total soil loss of 1324 mt ha^{-1} (591 t ac^{-1}) (D. W. Fryrear, personal communication). This site provided a unique opportunity to study the effects of severe wind erosion on a sandy soil in the southern High Plains. The objectives of this preliminary two-year study were to quantify the effects of wind erosion on the productivity of several crops grown in the region and evaluate the effects of erosion on surface soil texture and nutrient content.

METHODS

The study area was located in the southern Great Plains of west Texas at the USDA-ARS Wind Erosion and Water Conservation Research Unit field station in Big Spring, Texas. The climate is semiarid with a mean annual temperature of 17.1ºC and a mean annual precipitation of 470 mm. The study was conducted on an Amarillo fine sandy loam classified according to Keys to Soil Taxonomy (Soil Survey Staff, 1998) as a fine-loamy, mixed, thermic, superactive Aridic Paleustalf. A typical non-eroded soil profile (Table 1) found in the same field was described for another study by Rolong-Canas (1994).

The field had previously undergone severe wind erosion as part of a nine-year erosion study. In this wind erosion study, a 3-hectare circular field was maintained in a bare, flat, erodible condition. The field was surrounded by ten ridges approximately 0.3 m high and one meter apart. These ridges trapped saltating soil particles coming from the eroding field. The area where the soil particles were trapped is called the deposited area in this paper. The soil immediately adjacent to the deposited area was maintained in a non-erodible condition and is called the non-eroded area

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Table 1. Description of a typical non-eroded Amarillo fine sandy loam evaluated in this study (Rolong-Canas, 1994).

Horizon	Description
Ap1	0 to 13 cm; dark brown[†] (7.5YR 3/4) fine sandy loam; weak medium granular and weak medium subangular blocky structure; very friable; few fine roots; noneffervescent; clear wavy boundary.
Ap2	13 to 28 cm; dark brown (7.5YR 3/4) fine sandy loam; weak medium subangular blocky structure; friable; few fine roots; noneffervescent; abrupt smooth boundary.
Btk1	28 to 38 cm; dark reddish brown (5YR 3/4) sandy clay loam; moderate coarse prismatic breaking to moderate medium subangular blocky structure; friable; common thin, discontinuous clay films; few roots; very slightly effervescent; few films and threads of $CaCO_3$; gradual smooth boundary.
Btk2	38 to 58 cm; reddish brown (5YR 4/4) sandy clay loam; moderate coarse prismatic breaking to moderate medium subangular blocky structure; friable; common thin, discontinuous clay films; few fine roots; strongly effervescent; many films and threads of $CaCO_3$; gradual wavy boundary.
Btk3	58 to 78 cm; yellowish red (5YR 4/6) sandy clay loam; weak medium prismatic breaking to weak medium subangular blocky structure; friable; few thin, discontinuous clay films; few fine roots; strongly effervescent; many films and threads of $CaCO_3$; clear wavy boundary.
Bk1	78 to 100 cm; light reddish brown (5YR 6/4) clay loam; structureless; massive; many fine and medium pinkish white (5YR 8/2) masses of $CaCO_3$; friable; soft to extremely hard segregated concretions of $CaCO_3$; few fine roots; violently effervescent; gradual wavy boundary.
Bk2	100 to 140+ cm; light reddish brown (5YR 6/4) clay loam; structureless; massive; many fine and medium pinkish white (5YR 8/2) masses of $CaCO_3$; friable; soft to extremely hard segregated concretions of $CaCO_3$; few fine roots; violently effervescent.

[†]Colors are for moist soil.

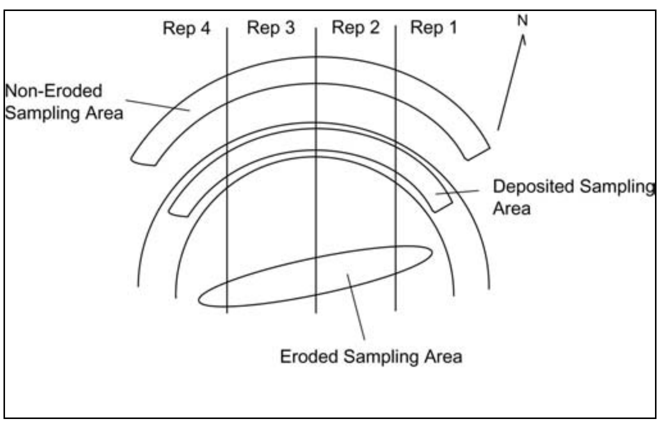

Figure 1. Schematic view of study area. Each rep had cotton, grain sorghum, forage sorghum, and kenaf plots.

in this paper. A detailed description of the erosion study design and the methods for measuring wind erosion were described by Fryrear et al. (1991).

Four crops were grown on this site in 1997 and 1998. The crops included cotton (Gossypium hirsutum L.), grain sorghum [Sorghum bicolor (L.) Moench], forage sorghum [Sorghum bicolor (L.) Moench], and kenaf (Hibiscus cannabinus L.). Cotton and sorghum are commonly grown in this region. Kenaf was tested because it is well adapted to

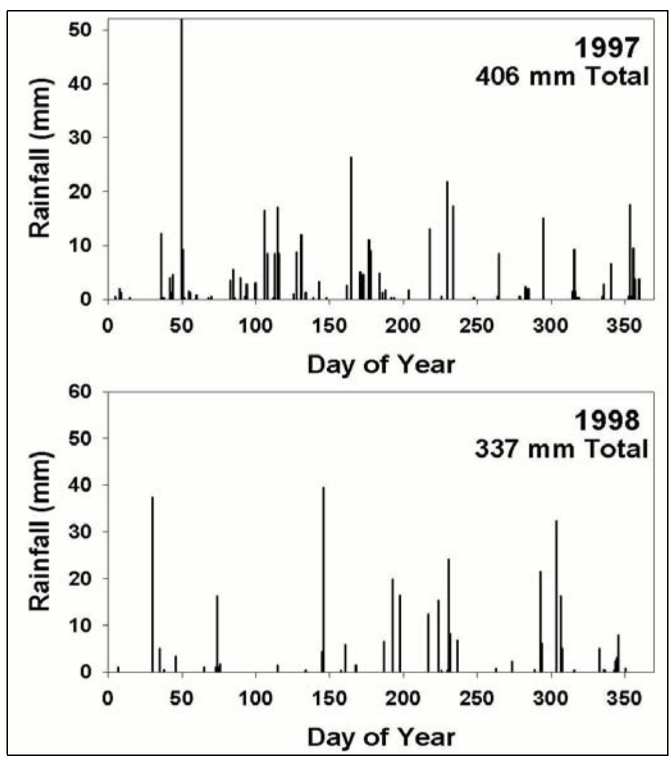

Figure 2. Precipitation of the study area of 1997 and 1998.

the region and has potential as a wind barrier crop. The crops were planted in 4 blocks (replications) that extended across the three test areas (eroded, non-eroded, and deposited) as illustrated in Fig 1. Each block included randomly assigned plots of each crop planted in two sets of 4 rows, separated by one blank row. The row spacing for all crops was one meter. No fertilizers were applied to the plots. At the end of each crop year in 1997 and 1998, a 3-m long area was harvested in one of the interior two rows of each crop in each replication. Grain and total dry matter yield were measured for the grain and forage sorghum. Grain was threshed by hand. Total air-dry boll and ginned lint weight were measured in the cotton. Bolls were hand collected and ginned in a small cotton gin. Total dry matter was measured for the kenaf after leaves were removed in the field.

Three replications were used in 1997, with the exception of the cotton plants. We experienced problems with boll weevils in 1997 and one of the cotton plots was abandoned due to severe infestation. We eliminated the insect problem with proper application of pesticides in 1998 and added another replication. Thus four replications were evaluated for all crops in 1998.

Soil samples were collected from the upper 15 centimeters in each plot to determine the soil texture and nutrient content. The hydrometer method was used to determine the clay content and sieving was used for the sand content. Silt was determined by difference. Nutrient analyses were performed by A & L Plains Agricultural Laboratories, Inc. in Lubbock, Texas. The soil pH was determined in a 1:1 soil:water solution using a platinum electrode. Organic carbon was determined using dichromate oxidation (Nelson and Sommers, 1982). Cation exchange capacity was determined as the sum of exchangeable cations extracted with ammonium acetate (Thomas, 1982) and measured by atomic absorption. Exchangeable cations measured included Mg, K, and Ca. Phosphorus was measured using the weak Bray P1 (Bray and Kurtz, 1945) and strong Bray P2 (NDSU, 1980) methods. Zinc was extracted with DPTA and measured using atomic absorption (Baker and Amacher, 1982).

Analysis of variance for each test variable was performed as a randomized complete block design using SAS version 6 (SAS, 1990). Analyses were performed using $P<0.10$ for tests of crop yields and $P<0.05$ for tests of soil texture and nutrient content.

RESULTS AND DISCUSSION

Since this study was performed under dryland conditions, rainfall amount and distribution played an important role in shaping the results. Rainfall for both years of this study was below the long-term mean rainfall of 470 mm. A total of 406 mm of precipitation was recorded in 1997 and 337 mm in 1998 (Fig. 2). The rainfall during planting was more abundant in 1997 than that in 1998, resulting in greater plant germination and higher plant populations in 1997 than in 1998 (Table 2). Conversely, there was more rainfall in July and August in 1998 than in 1997.

Crop Yields

Cotton boll and lint weights were generally lower in 1997 than in 1998, even though the plant populations were considerably higher in 1997 than in 1998 (Fig 3). The difference in yields among years may have been due to differences in rainfall distribution or pests. Although we eliminated 2 cotton plots due to weevil infestation in 1997, the plots remaining may have also been somewhat affected. We did not evaluate the effect of boll weevils on the remaining plots. In addition, the July and August rainfall of 1998 may also been important in significantly increasing the yields of the few bolls that were available. These questions will be explored more fully in future analyses of the data.

Cotton boll and lint weights were always greater ($P<0.10$) on the deposited sites than the eroded areas (Fig 3). There was no statistical difference in cotton yield between the non-eroded and eroded areas in 1997. However, the eroded areas produced 34 percent lower cotton boll weights and 40 percent lower lint weights than the non-eroded areas in 1998.

Grain sorghum and forage sorghum produced similar

Table 2. Number of plants sampled in 3 m plot by crop.

		Mean Number of Plants[□]			
		Deposited	**Non-Eroded**	**Eroded**	**Mean**
Cotton	1997	47.5	45	48.5	47.0
	1998	10.8	13.8	13.25	12.6
Grain Sorghum	1997	40.3	41.7	45.3	42.4
	1998	14	13.5	15	14.2
Forage Sorghum	1997	85.7	69	85	79.9
	1998	15.8	16.3	18	16.7
Kenaf	1997	66.7	71	69.7	69.1
	1998	28.5	32.3	34	31.6

[□]Two replications were sampled for cotton in 1997, three reps were sampled for other crops in 1997, and 4 reps were used for all crops in 1998.

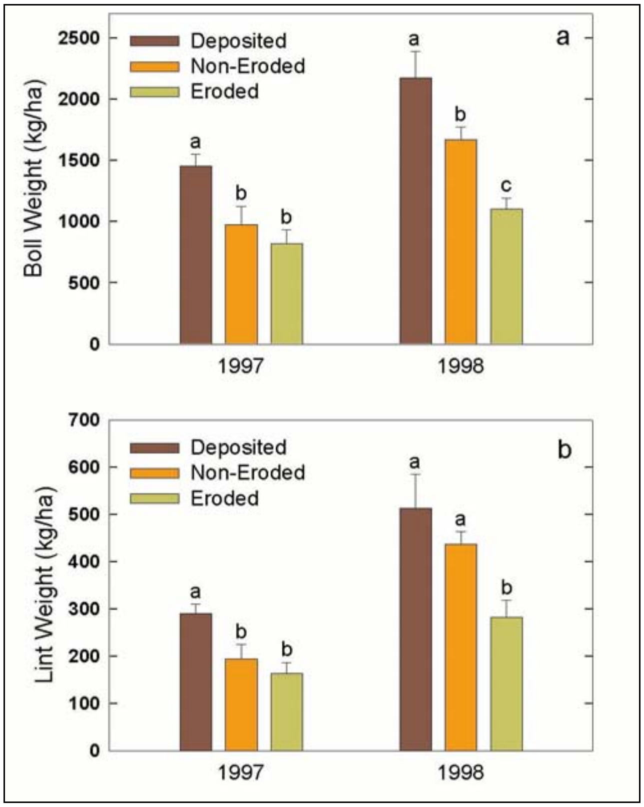

Figure 3. Cotton boll and lint weight, by area, for 1997 and 1998. Means in the same year followed by the same letter are not significantly different at the P=0.10 probability level.

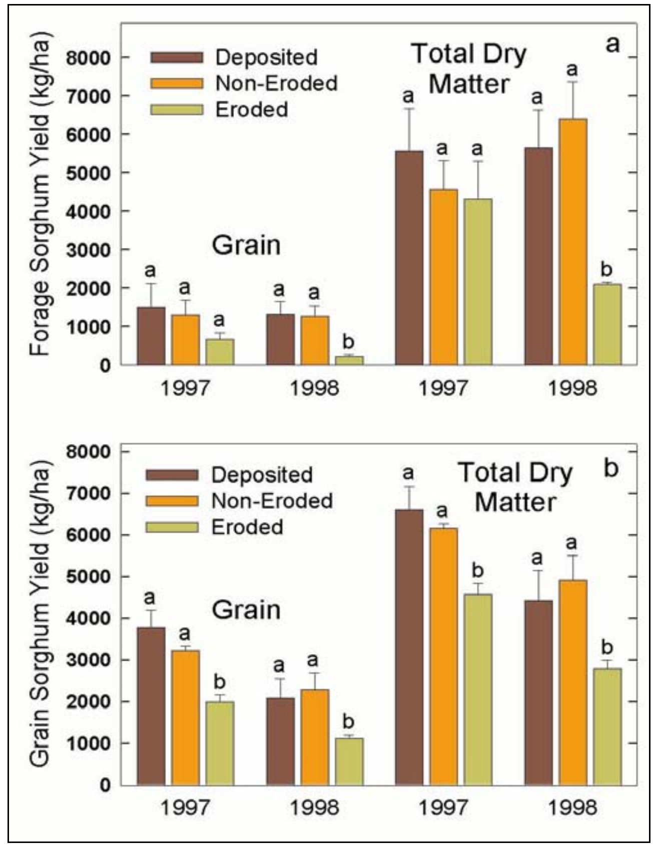

Figure 4. Forage and grain sorghum yields, by area, for 1997 and 1998. Means in the same year followed by the same letter are not significantly different at the P=0.10 probability level.

results, with the exception that no significant differences in yields were found in forage sorghum in 1997 (Fig 4). In every comparison, the deposited and non-eroded areas produced similar yields that were significantly greater than the yields of the eroded areas. The grain yield of grain sorghum over the two-year study period was about 58 percent lower in the eroded area than in the non-eroded area.

The forage sorghum grain yield in 1998 was 83 percent lower in the eroded area than the non-eroded area. The effect of erosion had similar results on total dry matter (TDM) production of grain and forage sorghum. The eroded area had an average of 34 percent lower total TDM for grain sorghum and 65 percent lower TDM for forage sorghum than the non-eroded area in 1998.

The kenaf yields (stem weights) were much greater in 1997 than 1998 (Fig 5). The reason is not certain, but we believe the greater plant populations in 1997 (Table 2) were able to take advantage of the greater moisture in 1997 than in 1998. The other crops did not show this trend. In 1997 the kenaf yields were in the order: deposited > non-eroded > eroded. The yield of the deposited area was the same as that of the non-eroded area in 1998. The kenaf yield was an average of about 40 percent lower on the eroded area than the other areas.

In a recent study of the productivity of spring wheat and canola after two years of wind erosion on a clay loam soil in Alberta, Larney et al. (1998) reported a canola yield of the eroded area about 11 percent lower than in the deposited area. Although the wheat yields showed a linear decrease as distance from the upwind side of the field increased, wheat yields on the deposited area were not reported. Perhaps the crop yields of our study that best compare the yields of the Larney et al. (1998) study were our sorghum yields (Fig 4). As stated above, grain sorghum yields of the eroded areas were an average of 58 percent lower than the deposited areas over the two-year study period. The differences among the studies may be attributed to many factors such as differences in soils, climatic factors, and amount of erosion.

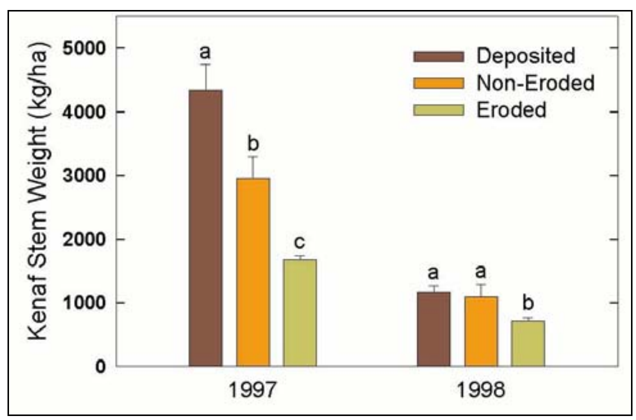

Figure 5. Kenaf yields, by area, for 1997 and 1998. Means in the same year followed by the same letter are not significantly different at the P=0.10 probability level.

Soil Properties

The overall effect of the 1324 mt ha^{-1} (132.4 kg m^{-2}) soil loss on soil properties was not dramatic. Particle size analyses of the surface soil showed no significant differences in the particle size distribution and resulting texture between the eroded and non-eroded areas ($P<0.05$, Fig 6a). The deposited area was similar to the non-eroded area with the exception that it contained greater total sand and very fine sand. The difference was great enough to cause the deposited area to be classified as a loamy sand and the other areas as fine sandy loams (Soil Survey Division Staff, 1993).

The minimal effect of erosion on soil texture observed in this study has a simple explanation. Prior to the erosion study, this area was under cultivation for at least 50 years and had developed a rather thick plow layer (Table 1). Assuming a bulk density of 1.3 Mg m^{-3} (1300 kg m^{-3}), the eroded soil represents an average soil loss of about 10 cm. Removal of 10 cm from the surface of the eroded soil still leaves about 20 cm of fine sandy loam surface soil above the heavier sandy clay loam subsoil, suggesting some but not excessive mixing of the subsoil into the plow layer. Thus, although the clay content of the eroded soil surface was statistically not significantly greater than that of the non-eroded soil surface, the trend was for higher clay content in the eroded soil surface (Fig 6a). The deposited area was made sandier by the deposition of sandy saltating sediment upon the surface that was subsequently mixed into the surface during tillage.

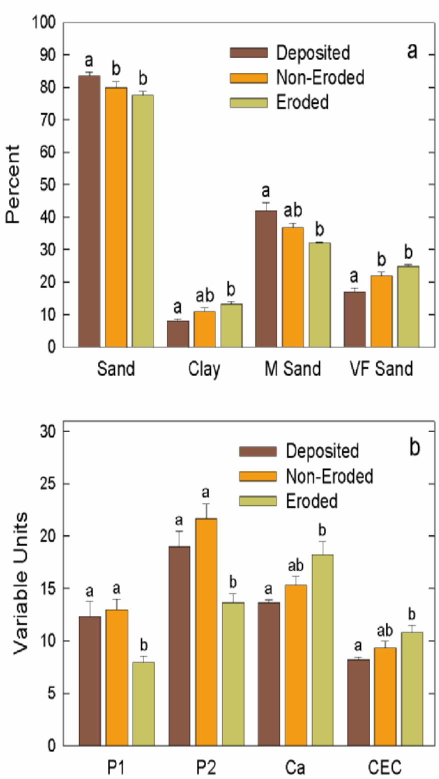

Figure 6. Soil texture (a) and nutrient content (b), by area, for 1997 and 1998.

The nutrient variables that produced significant differences among areas are shown in Fig 6b. No significant differences were observed among any areas for organic carbon, pH, Zn and exchangeable K, Mg, and Ca. There were also no significant differences between the deposited and non-eroded areas for any nutrients tested. Of all nutrients tested, only the phosphorus, as measured by the Bray P1 and P2 methods, had significantly lower levels in the eroded areas than in the non-eroded areas (Fig 6b). Phosphorus levels were also enriched of the deposited area in a similar study of a clay loam soil in Alberta (Larney, et al., 1998). The phosphorus level of the deposited area was about double that found in the eroded area (about 3.8 ug g^{-1}) in the Canadian study. In our study, the phosphorus level of the depositional area was about 60 percent greater than that observed in the eroded area (8.0 ug g^{-1}) . The reason for the differences in the enrichment of phosphor among the studies is not clear. In our study, the deposited and non-eroded areas had the same level of phosphorus that was significantly greater than the eroded area. This suggests removal of phosphorus by erosion but does not demonstrate the enrichment of the deposited area by erosion. Although, data for the non-eroded area was not available in the Canadian study, dust collected at a height of 25 cm in 1991 and 1992 showed no phosphorus enrichment compared to the 0-2.5 cm deep layer of the eroded soil (Larney et al., 1998).

It is unclear why apparently only phosphorus was removed by wind erosion in our study. It is possible that the phosphorus was bound to soil particles found very near the soil surface while the other nutrients were more evenly distributed throughout the plow layer. More detailed studies of this phenomenon are planned.

The lack of significant differences in organic carbon among the areas was somewhat unexpected. Larney et al. (1998) found 25 percent more organic carbon in a the deposited area in their study of a clay loam soil in Alberta, Canada. However, the initial organic carbon content of the Alberta soil was 1.5 percent, almost six times the organic carbon content of the soil used in this study (0.26 percent). It appears that the low levels of organic carbon of the non-eroded fine sandy loam soil in our study did not provide enough carbon loss or enrichment to significantly change the organic carbon of either the eroded or deposited area.

CONCLUSIONS

In this preliminary study, productivity of dryland cotton, grain sorghum, forage sorghum, and kenaf was measured in 1997 and 1998 on a field that had been severely wind eroded, on an adjacent area where saltating particles were deposited, and on an adjacent non-eroded soil. In most cases, with the exception of forage sorghum and cotton yields in 1997, the severely eroded soil produced lower yields than the non-eroded soil ($P<0.10$). The amount of reduction in yield varied with crop and specific yield parameters but ranged from an average reduction of 28 percent for grain sorghum total dry matter in 1997 to an 83 percent reduction in forage sorghum grain yield in 1998. Yield differences between years was attributed to differences in rainfall amount and distribution as well as insect pressure.

The effect of erosion on soil properties was not as dramatic as that observed for crop yields. There were no significant differences ($P<0.05$) in soil texture or amounts of particles in individual particle size classes among the eroded and non-eroded areas. The deposited area did accumulate enough sand to be classified as a loamy sand. The non-eroded area was a fine sandy loam. Very few differences in nutrients were observed between the eroded and non-eroded areas. Only phosphorus as measured by the Bray P1 and P2 method was significantly lower on the eroded area than on the non-eroded area. Future studies are needed to further define and evaluate differences among areas in other soil properties, such as soil porosity and water holding capacity differences with depth.

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