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Vegetation Change and Surface Erosion in Desert Grasslands of Otero Mesa, Southern New Mexico: 1982 to 1995

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ABSTRACT.—Desert grasslands that skirt mountain ranges in northern Mexico and the southwestern United States were once common. These grasslands have largely been replaced by shrublands and their soils have become eroded. The most frequently cited causes of these changes are livestock overgrazing, fire and increasing aridity. Studies have not separated grazing and fire from climate effects. Our aim was to determine whether desert grasses are being replaced by shrubs and how rapidly soil surfaces are eroding on unburnt Otero Mesa desert grasslands, where livestock overgrazing has not been a significant factor in historic or recent times. In this article we describe how vegetation and soil surface levels changed from 1982 to 1995 on six permanent transects. Vegetation was measured by charting canopy cover and stem bases of perennial plants in quadrats. Soil surface levels were surveyed in reference to benchmarks placed in nearby bedrock. Vegetation quadrats and surface levels were re-measured in 1995. From 1982–1983 to 1995 the canopy cover of the desert shrubs, *Larrea tridentata* and *Gutierrezia microcephala*, declined by 1.5% and 5.8%, respectively. Canopy cover of the C4 xeric grass *Bouteloua eriopoda* declined by 5.3%. This decline in xeric grass cover was offset by a 1.2% increase in the C4 mesic grass *Bouteloua curtipendula* and a 4.0% increase in the C3 mesic grass *Stipa neomexicana*. From 1983–1984 to 1995 soil surfaces along transects eroded an average of 0.4 mm·y⁻¹. Thus, desert shrubs were not replacing desert grasses, but mesic grass species were replacing xeric species. These changes were associated with a 15-y period of relatively wet cool-seasons and moist warm-seasons from 1981 through 1995. These results document that, even in the absence of livestock grazing and fire, desert grassland vegetation is very responsive to precipitation change over relatively short time periods.

INTRODUCTION

Desert grasslands, also referred to as semidesert grasslands, were once widespread on lower hill-slopes and piedmonts skirting mountain ranges in the southwestern United States and northern Mexico (Schmutz *et al.*, 1991; McClaran, 1995). Although desert grasslands are difficult to define precisely, they have a distinctive flora (Burgess, 1995). The structure of the vegetation is a patchy mix of grasses, subshrubs, succulents, shrubs, shrubby trees and woody rosette-like plants. Not all these lifeforms are equally abundant throughout the desert grasslands. For example, rosette forms are very abundant in desert grasslands of the southern Chihuahuan region, where warm-season rainfall dominates (Valverde *et al.*, 1996), but are less abundant in the colder northern Chihuahuan region

(Cornelius *et al.*, 1991). Because some desert grasslands have scattered small trees, tall shrubs or tall succulents, they are sometimes classed as semiarid savannas (McPherson, 1997).

Today, most desert grasslands have been replaced by shrublands (Brown, 1982; Dick-Peddie, 1993), and only a few examples are currently protected in parks and reserves such as Big Bend and the Central Peloncillos (Peterson and Rasmussen, 1986; Moir and Ludwig, 1991). Desert grasslands once provided the principal habitat for animals such as the pronghorn *Antilocarpa americana*, which is now much reduced in number, and the Arizona prairie dog *Cynomys ludovicianus arizonensis*, which is now extinct (Parmenter and Van Devender, 1995). Several very rare plants, such as the grama grass cactus *Toumeyia papyracantha*, are threatened by loss of desert grassland (Moir and Bonham, 1995).

A complex interaction of factors is probably responsible for the loss of desert grasslands (Humphrey, 1958; Schlesinger *et al.*, 1990; Reynolds *et al.*, 1997, 1999). However, livestock overgrazing, fire and increasing aridity are cited as major causes (Buffington and Herbel, 1965; York and Dick-Peddie, 1969; Gibbens and Beck, 1988; McPherson, 1995; Wondzell and Ludwig, 1995). Grazing impacts on desert grasslands can be subtle. For example, even during favorable climatic periods *Bouteloua eriopoda* declined under light to moderate livestock grazing (Holechek *et al.*, 1994). Fire-induced mortality of grasses is also important. For example, fire-induced replacement of grasses by shrubs was evident in desert grasslands on the Sonoita Plains in southern Arizona (Bock and Bock, 1997) and on the Jornada in southern New Mexico (Cornelius, 1989).

Determining the relative effects of grazing, fire and precipitation is a challenge because of the difficulty of isolating these factors. One of the few desert grassland areas where livestock grazing and fire have not been significant is the western edge of Otero Mesa in southern New Mexico. Thus, vegetation change in these desert grasslands can be examined in relation to precipitation patterns without the confounding impact of livestock grazing and fire.

As desert grasslands change to shrublands, rates of runoff, soil erosion and nutrient loss during storm events increase (Schlesinger *et al.*, 1999). As soils erode, surface levels change—degrading in some parts of the landscape (rills and gullies) and aggrading in others (alluvial fans) (Parsons *et al.*, 1992; McAuliffe, 1995; Wondzell *et al.*, 1996). Almost all studies of changes in soil surface levels in desert grasslands and shrublands have been on rangelands with a long history of livestock grazing (*e.g.*, Gibbens *et al.*, 1983). Even the 1979–1992 study on soil surface changes in ungrazed grasslands of the Central Peloncillo Mountains (Moir *et al.*, 2000) was in an area where livestock had grazed for over 70 y until 1972. Thus, there is a paucity of data on rates of soil surface change in ungrazed desert grasslands, such as those on the western edge of Otero Mesa.

The aims of this study were to answer three questions: (1) Are ungrazed and unburnt desert grasslands on Otero Mesa changing into shrublands? (2) If vegetation changes are occurring, can they be explained by changes in precipitation patterns? (3) What are rates of soil erosion in the desert grasslands of Otero Mesa in the absence of livestock grazing and fire? Answers to these questions will contribute to a clearer understanding of the rates, causes and kinds of changes that occur in desert grasslands.

STUDY AREA

Otero Mesa is situated in the northern Chihuahuan Desert region of southern New Mexico at 32°30'N, 105°47'W, about 120 km northeast of El Paso, Texas (Fig. 1). Our study area is on the western edge of the plateau of Otero Mesa, which slopes gently to the southeast and a sharp escarpment rises in the west (Gile *et al.*, 1981). The silty cal-

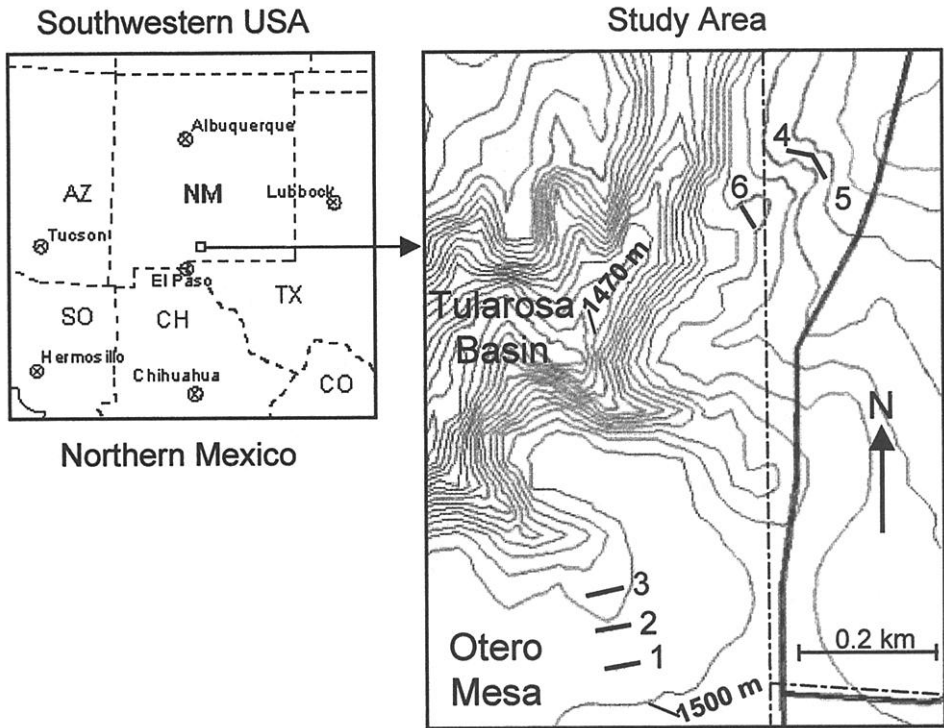


FIG. 1.—The location of the Otero Mesa study area (□) in southern New Mexico and the position of six permanent transects in small drainages on the western edge of Otero Mesa above the Tularosa Basin. Approximate metric elevations for selected contours are shown. Contour interval is 3 m. Dash-dot lines denote pasture fences

careous soils derived from Paleozoic limestone are shallow near the escarpment. The mean annual precipitation of 255 mm falls mainly in the warm season (193 mm, May–Oct.). Frosts are common during the drier cool season (Nov.–Apr.).

Otero Mesa desert grasslands are dominated by perennial bunch- and mat-forming grasses such as *Bouteloua curtipendula*, *B. eriopoda*, *B. gracilis* and *B. hirsuta* (Stewart, 1982; Muldavin *et al.*, 1996). Parts of these 'grama grasslands' were grazed by cattle, goats, mules and horses from 1885 to 1954 (Wood *et al.*, 1997), but the remoteness and ruggedness of the western edge meant that the desert grasslands occurring there escaped grazing, or were only very lightly grazed. Between 1954 and 1965 the U.S. Army expanded its McGregor Range facilities at Fort Bliss onto Otero Mesa by purchasing ranches. Under leasing agreements with Fort Bliss and the Bureau of Land Management, some parts of Otero Mesa are still grazed by livestock (BLM, 1990), but since 1965 straight fences along the jagged western edge of Otero Mesa have excluded cattle from all but two of our study transects. These two transects occur in a pasture east of this fence, but are only lightly grazed because they are in a remote corner. Our study sites had droppings indicating some use by deer. Although grass fires occur on Otero Mesa (lightning- and missile-ignited), none of our sites were burnt during the study period (1982–1995).

METHODS

In 1982 and 1983 we selected two sites on Otero Mesa that were typical of desert grasslands in the area and established six transects across small drainages flowing off Otero Mesa into the Tularosa Basin (Fig. 1). Transects were permanently located with steel rods driven into the soil to a depth of 0.75 m or to bedrock on shallower soils. Transects 1, 2 and 3 were 30 m long. They were established in early autumn 1982 and the vegetation along them was measured. Soil surface levels were surveyed on these transects in early autumn 1983. Transects 4, 5 and 6 were 25 m long. They were established in other small drainages in early autumn 1983. Vegetation was measured and soil surfaces were surveyed on these transects in early autumn 1984. Transects 4 and 5 had a common northeast corner and each cut across one of two small drainages which merged into the drainage where transect 6 was located. We remeasured vegetation and resurveyed soil surfaces on all six transects in late summer 1995.

Vegetation was measured by charting (outlining) the canopy of all perennial plant species in 20- by 50-cm quadrats positioned at 1-m intervals along the six transects (starting at 0.5 m)—166 quadrats in total. Quadrats were oriented along transect lines with their long-axis upslope (*see* Ludwig and Moir, 1987). We outlined canopies on a field form showing each quadrat gridded into 100 squares (*i.e.*, each square represented 1%). This form facilitated determination of percent canopy cover of species. In addition, we charted outlines of the bases of all plants rooted within each quadrat.

Chart data also provided information on the turnover of individuals within species. To measure individual turnover rate from 1982–1983 to 1995, transparent overlays of plant canopies and bases were made from the 1995 chart data. These overlays were aligned over the 1982–1983 chart data. Nine of the most common species were scored according to the number of individuals lost, gained or unchanged in each quadrat. A plant was considered the same individual if its charted base in 1995 overlapped the base of an individual charted in 1982–1983. If the basal outlines did not touch they were considered to be separate individuals and were scored as being either lost (present in 1982–1983 but absent in 1995) or gained (present in 1995 but absent in 1982–1983).

Bases of multistemmed shrubs were charted as clusters of dots, each dot representing a separate stem. If the outline of a cluster of stems in 1995 overlapped that of a cluster in 1982–1983, the shrub was scored as unchanged. If a cluster did not overlap it was scored as a gain or loss, depending on the year of occurrence. If the basal outline of a plant charted in 1995 touched or overlapped two separate basal outlines of individuals of the same species charted in 1982–1983, it was assumed that the two plants had coalesced and the number of plants had not changed (both were still alive). If two basal outlines of the 1995 chart overlapped a single outline of the 1982–1983 chart, these two plants were scored as one unchanged (alive from the earlier plant) and one new plant. It was assumed that the plant charted in 1982–1983 had split into two by 1995.

Monthly precipitation data from Nov. 1909 to Oct. 1996 were obtained from Orogrande, New Mexico, which is located 20 km west of our Otero Mesa study area. Over this 87-y period a few months had missing values. These were 'filled' with the 87-y means for the appropriate months. To relate vegetation changes to general precipitation patterns, monthly precipitation data were averaged by cool season (Nov.–Apr.) and warm season (May–Oct.) over 5-y periods. We began with 1951–1955 and ended with 1991–1995, the latter period including the time of remeasurement (Aug. 1995). Mean precipitation data for these 5-y periods were expressed as departures from long-term (1909–1996) cool- and warm-season means, which were 62 mm and 193 mm, respectively.

Along the six line transects, soil surface levels were surveyed using a surveyor's transit and a pole with marks for reading to the nearest mm. Levels were measured at 0.5 m intervals along lines and in reference to a benchmark placed in bedrock (*see* Ludwig and Moir, 1987). This surveying method allowed for a rapid assessment of a large number of surface observations, but the accuracy of these observations depended on the placement of the transect line in exactly the same position in each survey. We took care in the field to achieve exact line placement. However, even with this care, it became obvious from subsequent data tabulation and field notes (*e.g.*, reading taken on top of a rock) that line placements, hence surveyor pole positions, were not always at exactly the same place in 1995 as in 1983–1984. For example, the pole might have been placed at the base of a rock in 1983 but on top of that rock in 1995. These mismatched pole positions were not used in computing soil surface changes.

This surveying method also depended on having an accurate reading to a fixed benchmark to provide a point of elevation for referencing all transect observations. Benchmarks were bolts placed in bedrock as close to transects as possible. For transects 4, 5 and 6 bedrock was within a few meters, but for transects 1, 2 and 3 the nearest bedrock was over 100 m away. Because of heat shimmer and optical limitations in the surveyor's transit we used in 1995, we were unable to accurately remeasure the surface levels of transects 1, 2 and 3 in reference to this distant benchmark. Fortunately, the elevations of the tops of the steel rods used to permanently locate the ends of transects 1, 2 and 3 were also surveyed in reference to this benchmark in 1983. Therefore we could remeasure transect 1, 2 and 3 surface levels in 1995 in reference to the elevations of these rods. We are confident that soil surface changes measured relative to these rods are accurate because the elevations of the top of the rods did not change relative to each other from 1983 to 1995—the rods were deep enough in the ground to be stable.

RESULTS

Canopy cover of two common Chihuahuan Desert shrubs occurring on Otero Mesa transects in 1982–1983, *Larrea tridentata* and *Gutierrezia microcephala*, had markedly declined by 1995 (–1.5% and –5.8%, respectively; Table 1), and more individuals were lost than gained (Table 2). The number of *L. tridentata* individuals involved was few, but losses were 4 in comparison to individuals gained (1) and unchanged (2). There was a large turnover in *G. microcephala* individuals: 45 died, 14 established and only 2 remained unchanged. Canopy cover of other shrubs and subshrubs changed less than 1% (Table 1).

Composition of grasses also changed from 1982–1983 to 1995, with mesic grasses replacing xeric grasses. *Stipa neomexicana*, which is a cool-season, C3 mesic grass (Dick-Peddie, 1993), went from being absent in 1982–1983 to 36 individuals, with a canopy cover of 4.0% in 1995 (Tables 1, 2). The C4 mesic grass *Bouteloua curtipendula* increased in cover by 1.2%, largely by a net gain of 44 individuals. While these two grasses together increased canopy cover by a total of 5.2%, the warm-season, C4 xeric grass *B. eriopoda* had a net loss of 100 plants and declined in canopy cover by 5.3%. The C4 grasses *Aristida purpurea*, *B. gracilis*, *Muhlenbergia arenacea* and *Sporobolus cryptandrus* also had a net loss of plants, but *B. eriopoda* had the greatest net loss.

Over the 25 y from 1951 to 1975 cool-season precipitation (by 5-y periods) was always below its long-term average (Fig. 2). Since 1975 cool-season precipitation has been higher than its long-term average, particularly in the 5-y period before our Aug. 1995 measurements. Warm-season precipitation was above normal in all the 5-y periods since 1965, especially since 1980.

From 1983–1984 to 1995 all six transects lost soil. Mean losses varied from 0.6 to 8.2 mm

TABLE 1.—Mean change in species canopy cover (%) from 1982–1983 to 1995 on six permanent transects in desert grasslands. Species are grouped by lifeform and photosynthetic pathway. Species nomenclature follows Powell (1988, 1994). Means based on N = 166 quadrats

Lifeform—pathway/species	1982–1983	1995	Change
Shrubs—C3			
<i>Ceratoides lanata</i> ¹ (Winter fat)	0.2	0.0	-0.2
<i>Dalea formosa</i> (Feather dalea)	0.4	1.3	+0.9
<i>Larrea tridentata</i> (Creosotebush)	1.9	0.4	-1.5
Subshrubs—C3			
<i>Dyssodia acerosa</i> (Prickleleaf dogweed)	3.1	3.7	+0.6
<i>Gutierrezia microcephala</i> ² (Threadleaf snakeweed)	7.9	2.1	-5.8
Grasses—C3			
<i>Stipa neomexicana</i> (New Mexico feathergrass)	0.0	4.0	+4.0
Grasses—C4			
<i>Aristida purpurea</i> (Purple threeawn)	0.4	0.5	+0.1
<i>Bouteloua curtipendula</i> (Sideoats grama)	7.2	8.4	+1.2
<i>Bouteloua eriopoda</i> (Black grama)	8.4	3.1	-5.3
<i>Bouteloua gracilis</i> (Blue grama)	2.2	2.3	+0.1
<i>Bouteloua hirsuta</i> (Hairy grama)	2.3	1.5	-0.8
<i>Muhlenbergia arenacea</i> (Ear muhly)	1.2	1.6	+0.4
<i>Muhlenbergia arenicola</i> (Sandy muhly)	0.4	0.4	-0.0
<i>Sporobolus cryptandrus</i> (Sand dropseed)	1.0	0.6	-0.4
Perennial forbs—C3			
<i>Croton pottsii</i> (Leatherweed croton)	0.1	0.2	+0.1
Leaf succulents—C3			
<i>Nolina texana</i> (Texas sacahuiste)	2.8	2.9	+0.1

¹ Formerly *Eurotia lanata*

² Formerly *Xanthocephalum microcephalum*

TABLE 2.—Total gains and losses of individuals from 1982–1983 to 1995 for nine common species occurring in the 166 quadrats along six transects in the desert grasslands. The net change in individuals (gain minus loss) is also presented, along with the number of individuals which remained unchanged (extant in the same quadrats) from 1982–1983 to 1995

Lifeform—pathway/species	Turnover of individuals		Net change	Individuals unchanged
	Gain	Loss		
Shrubs—C3				
<i>Larrea tridentata</i> (Creosotebush)	1	4	-3	2
Sub-shrubs—C3				
<i>Gutierrezia microcephala</i> (Threadleaf snakeweed)	14	45	-31	2
Grasses—C3				
<i>Stipa neomexicana</i> (New Mexico feathergrass)	36	0	+36	0
Grasses—C4				
<i>Aristida purpurea</i> (Purple threeawn)	11	14	-3	5
<i>Bouteloua curtipendula</i> (Sideoats grama)	182	138	+44	61
<i>Bouteloua eriopoda</i> (Black grama)	86	186	-100	34
<i>Bouteloua gracilis</i> (Blue grama)	87	101	-14	42
<i>Muhlenbergia arenacea</i> (Ear muhly)	39	78	-39	14
<i>Sporobolus cryptandrus</i> (Sand dropseed)	15	23	-8	2

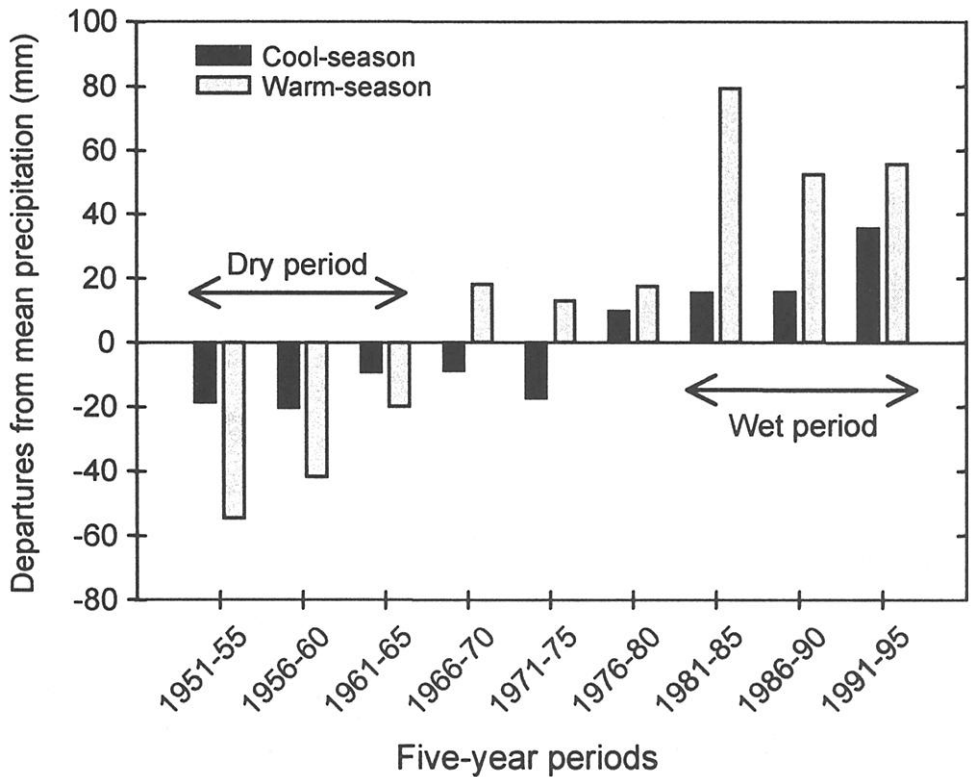


FIG. 2.—Departures from 87-y means for cool- and warm-season precipitation averaged for 5-y periods from 1951 to 1995. The cool-season was defined as Nov.–Apr. and the warm-season as May–Oct.

(Fig. 3). Overall, mean loss was 4.6 mm, which is an average erosion rate of about $0.4 \text{ mm}\cdot\text{y}^{-1}$ over the 11- to 12-y period. Transects 1 and 2 lost more soil than transects 3 to 6. Transects 1 and 2 were located at the head of a small drainage. The other four transects were located lower in drainages where surfaces were rougher and harder (*i.e.*, more gravel, stone and exposed bedrock).

DISCUSSION

From 1982–1983 to 1995 canopy cover of the common desert shrub *Larrea tridentata* declined on our Otero Mesa sites. A similar decline in *L. tridentata* was observed from 1983 to 1994 in the Jornada Basin (Miller and Huenneke, 1996), 90 km west of Otero Mesa. This decline in *L. tridentata* cover was attributed to a decrease in the canopy size of individuals through stem death—no significant change in plant numbers occurred. Similarly, in south-central Arizona, decline of *L. tridentata* cover over a 30-y period largely was due to death of stems (Goldberg and Turner, 1986). On Otero Mesa, the decline in *L. tridentata* was mainly due to death of individual plants. In southeastern Arizona, a decline in *L. tridentata* cover from 1958 to 1981 was attributed to both stem death and plant death (Chew, 1982). It is not clear if this recent widespread decline is due to a short-term climatic oscillation or a long-term climate change (Van Devender, 1995).

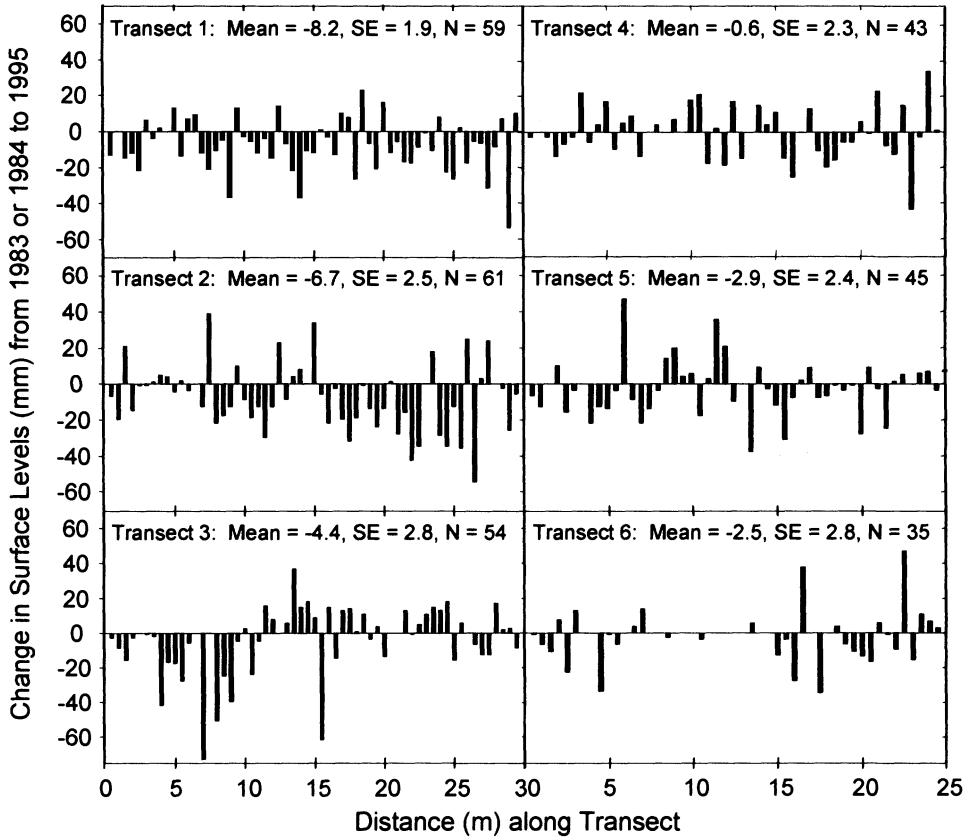


FIG. 3.—Changes in soil surface levels (mm) from 1983–1984 to 1995 along six permanent transects. Observations are for 0.5 m intervals along each transect. The number of observations (N) used for means and standard errors differ between transects because we required as much certainty as possible that surfaces were measured at precisely the same transect positions in 1983–1984 and 1995, so any readings that were obvious mismatches were discarded. In addition, soil surface levels measured on hard surfaces such as rock did not change during the study

The northern Chihuahuan Desert in southern New Mexico is characterized by variable but consistent summer rains and inconsistent winter precipitation (Neilson, 1987). The amount of winter precipitation may be a critical factor in the establishment, growth and survival of perennial lifeforms. In the Jornada Basin, C3 shrubs such as *Gutierrezia sarothrae* successfully establish during periods with wet winters when interference from perennial grasses is reduced by grazing (Neilson, 1986). However, on the ungrazed desert grasslands of Otero Mesa, *Gutierrezia microcephala* and *Larrea tridentata* declined during a period of wet winters.

During droughts with very dry winters, shrubs have high stem senescence and plant mortality rates (Hennessy *et al.*, 1983). However, some shrubs recover quickly during brief wet-winter periods within droughts (Uechert, 1979). Evidence from Arizona also supports the hypothesis that winter precipitation and grazing primarily drive shrub-grass dynamics

in desert grasslands. The grazing-tolerant shrub *Haplopappus tenuisectus* died during dry winters but greatly increased with wet winters (Bock and Bock, 1997).

In the Jornada Basin, *Bouteloua eriopoda* declined markedly during severe drought periods occurring between 1915 and 1979, especially during the 1951–1956 drought (Herbel *et al.*, 1972; Gibbens and Beck, 1988). As a C4 xeric grass *B. eriopoda* has the ecophysiology and morphology that favors its growth and spread during wet summers and dry winters (Senock *et al.*, 1994). This is because the C4 photosynthetic pathway is most efficient under warm, moist and high sunlight conditions (Solbrig and Orians, 1977). Production of new tillers by *B. eriopoda* follows rapidly with inputs of water in summer months (Stephens and Whitford, 1993). *Bouteloua eriopoda* rarely produces seedlings, yet seven such 'seedling years' occurred in the Jornada Basin when a dry winter was followed by above normal rains in late summer-early autumn (Neilson, 1986).

Cool-season and mesic plants are known to be favored when winters are wet (Kemp, 1983). Thus, cool-season C3 grasses such as *Stipa neomexicana* and C4 mesic grasses such as *Bouteloua curtipendula* might be expected to establish and spread during periods with wet-winters. This was evident in our Otero Mesa data where *S. neomexicana* and *B. curtipendula* both increased from the early 1980s to 1995 when winter precipitation was well above normal. These mesic grasses replaced the more xeric or arid grass *Bouteloua eriopoda*.

Are these vegetation changes simply fluctuations in response to short-term climatic oscillations, as hypothesized for southeastern Arizona (Bahre and Shelton, 1993), or will the xeric grass *Bouteloua eriopoda* recover if there is a return to a more arid climatic period? It has been argued that answers to these questions require an understanding of landscape processes such as how water and nutrients are spatially distributed and conserved (Schlesinger *et al.*, 1990; Reynolds *et al.*, 1997). Field and modeling studies suggest that *B. eriopoda* desert grasslands are unlikely to reinvade shrublands (Reynolds *et al.*, 1999). Once desert shrubs invade grasslands, several landscape patch-scale processes operate to favor shrub persistence. Soil and organic matter tend to accumulate under shrubs, enhancing infiltration during rains and concentrating nutrients, while intershrub spaces become bare and provide runoff that transports soil, litter and seeds to shrub patches (Schlesinger *et al.*, 1996, 1999; Connin *et al.*, 1997). These positive feedback processes maintain shrublands as patchy landscapes in which shrubs patches function as resource islands.

Although more patchy than desert grasslands, desert shrublands still function to conserve water and nutrients (Schlesinger *et al.*, 1999). Net primary productivity of these desert shrublands does not differ significantly from nearby desert grasslands (Huenneke, 1996). This does not mean that these shrublands and grasslands are stable—they can change species composition with short-term changes in precipitation patterns (Reynolds *et al.*, 1999), as confirmed by our study, or with long-term climate change (Grover and Musick, 1990; Minnick and Coffin, 1999).

On our six transects in ungrazed desert grasslands of Otero Mesa, we measured an average soil surface loss of $-0.4 \text{ mm}\cdot\text{y}^{-1}$ from 1983–1984 to 1995. Although transects varied in the level of surface change, there was a net loss on each of the six transects. There is a paucity of comparative data on rates of soil surface change in other ungrazed desert grasslands. One similar study, in the desert grasslands of the Peloncillo Mountains in southwestern New Mexico, which has been ungrazed since 1972, Moir *et al.* (2000) found an average rate of surface accumulation of $0.8 \text{ mm}\cdot\text{y}^{-1}$ on 10 transects measured over 9–13 y. However, rates varied greatly between transects. For example, one transect lost $1.4 \text{ mm}\cdot\text{y}^{-1}$ while another transect, located on the same hillslope and only 13 m higher in elevation, gained $2.5 \text{ mm}\cdot\text{y}^{-1}$. These variations did not appear to be related to past livestock grazing

but to a complex interaction between position in the landscape, and surface steepness, roughness and cover (vegetation, litter, stone).

On the Jornada in southern New Mexico livestock grazing has impacted desert grassland vegetation and soil surfaces. For example, Gibbens *et al.* (1983) used 27 permanent reference stakes along a transect to measure soil surface changes and found a net surface loss of 34 mm ($-0.8 \text{ mm}\cdot\text{y}^{-1}$) from 1935 to 1980. Most of this loss occurred before 1955 (-57 mm after 20 y). The transect crossed an ecotone from desert grassland to mesquite *Prosopis glandulosa* duneland. After 1955 the transect was completely covered by duneland and soil deposition occurred to 1980 ($+23 \text{ mm}$). These results illustrate that soil surfaces can greatly change when grazing induces shrublands to replace grasslands, whereas our study provides an estimate of soil erosion rates for ungrazed desert grassland that did not change to shrubland. However, these rates of soil surface change are not directly comparable because of differences in factors such as topography, soils and time.

Our study has shown, however, that even in the absence of livestock grazing and fire, desert grasslands are not static but very dynamic. A change from xeric to mesic grass dominance and a loss of desert shrubs occurred over a relatively short 12–13 y period (1982–1983 to 1995) on Otero Mesa and was associated with a period of well above average cool-season and warm-season precipitation. The average rate of soil erosion was $0.4 \text{ mm}\cdot\text{y}^{-1}$ over the 1983–1984 to 1995 period. This information about vegetation change and soil erosion will provide a useful baseline for monitoring, and better understanding, the dynamics of desert grasslands.

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