Effects of intense, short-duration grazing on microtopography in a Chihuahuan Desert grassland

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Abstract

We studied the effect of three consecutive years of short duration (<48 h per year), and intense grazing (20–40 yearling cows per hectare) on soil surface microtopography in a Chihuhan Desert grassland. We also studied the effects of shrub removal plus grazing on microtopography. Microtopography was measured in 18 plots (treatments). Treatments were a combination of two factors: (1) three levels of grazing (winter-grazed, summer-grazed, and not grazed), and (2) two levels of habitat structure (shrubs-removed and shrubs-intact). Mesquite (*Prosopis glandulosa*) shrubs were removed from half of the plots (nine out of 18 plots). The average height of the micromounds, the average depths of intermound depressions, and the number of micromounds were significantly reduced on the grazed plots. Shrub removal had no significant effect on the height of the micromounds or the depth of the intermound depressions of ungrazed plots. There were significant differences in average micromound heights and intermound microdepression depths attributable to the season of grazing. Microtopography was significantly reduced on grazed plots from which shrubs were removed, compared to ungrazed plots, and grazed plots with shrubs present. Grass canopy reduction, and destruction of the micromound structure in a short duration, plus intense grazing results in erosion of micromounds and in-filling of intermound depressions. The loss of microtopography coupled with reduction in vegetation height and cover resulting from short-duration intense grazing by cattle exposed soils to an increased risk of soil erosion

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Destruction of the micromound/microdepression topography by cattle changes the spatial patterns of water infiltration, and may homogenize nutrients in desert grasslands.
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1. Introduction

Microtopography (or micro roughness) describes variations in soil surface elevation (mm or cm) for a scale of a few meters of horizontal distance. Small-scale (a few centimeters) changes in vegetation communities synchronized with the elevation differences were observed in drained marsh (Zedler and Zedler, 1969). Vivian-Smith (1997) reported that species richness and evenness were significantly higher in areas characterized by a small-scale heterogeneous microtopography. A soil surface with more mounds and depressions creates a better setting for seed germinations, seedling establishment and growth than that of a homogeneous soil surface (Smith and Capelle,1992). Desert grasslands are characterized by micro-topography that appears to be the result of a long-term accumulation of soil around grass tussocks.

Desertification or degradation of Chihuahuan Desert grasslands has been hypothesized to result from changes in the spatial scale of the distribution of soil resources (Schlesinger et al., 1990). Desert grasslands are characterized by fine-scale patchiness of soil nutrients and water (Schlesinger and Pilmanis, 1998). Soil nutrient-rich patches in desert grasslands are small mounds that are occupied by bunch grasses. The unvegetated depressions between grass tussocks act as microcatchments for water and are responsible for retaining water and nutrients in situ. Mounds and depressions (microtopography or micro roughness) are among other soil surface features that affect water infiltration, soil water storage, and erosion by water and wind. Mounds that support grass tussocks increase water infiltration by stem flow along leaves and tillers (Van Elewijck, 1989) and leaves and tillers trap and immobilize soil particles. Depressions between mounds have finer texture rain crusts, and trap wind-blown organic debris. Depressions serve as temporary water collection areas that enhance ponded infiltration and reduce overland flow (Dunkerley and Brown, 1999; Tongway and Hindley, 2000). Therefore, at a unit surface scale, soil microtopography is an important physical feature that affects wind and water processes. Factors that affect this fine-scale patchiness are hypothesized to be the precursor of coarse scale changes leading to desertification. Livestock grazing has been shown to change the spatial distribution of grasses in the short-grass steppe (Alder and Lauenroth, 2000). They attributed changes in the spatial heterogeneity of the dominant grass, *Bouteloua gracilis*, primarily to grazing effects. A study of changes in microtopography on grazing gradients in the Chihuahuan Desert grassland documented reduction in the abundance, height and depth of mounds and depressions, respectively, as a result of chronic, long-term grazing by domestic

livestock (Nash et al., 2003). The combination of biomass removal by grazers and the compaction and breakdown of mounds by hoof action are the mechanisms by which the fine-scale microtopography is lost.

Intense, short-duration grazing is one of the grazing management systems that have been proposed for maintaining productivity of arid rangelands (Savory, 1978; Volesky et al., 1994). Short-duration grazing is hypothesized to increase production of grasses, and intense, short-duration hoof action is generally thought to increase water infiltration and incorporation of litter into the soil (Savory, 1978). We hypothesized that short-duration grazing would have little affect on the micro-topography that is characteristic of desert grassland. We also hypothesized that short-duration grazing during the non-growing season (winter) would have less impact on desert grassland microtopography than intense, short-duration grazing during the growing season (summer).

2. Materials and methods

The experiment was conducted on the Jornada Experimental range approximately 40 km N-NE of Las Cruces, New Mexico. The long-term average annual precipitation is 225 mm year^{-1} with 60% occurring during July through September as connective storms. Maximum temperatures regularly exceed 40°C, and winter minimum temperatures are frequently below 0°C. Eighteen 0.5 ha plots were established in a 1284 ha grassland pasture that had been grazed during winter and spring at an average stocking rate of 259 AUM (Animal Unit Months) per year since 1957 (an AUM is one adult cow for 30 days). The plots were arranged in two rows of nine plots blocked in three blocks of six plots per block along the long axis (Fig. 1).
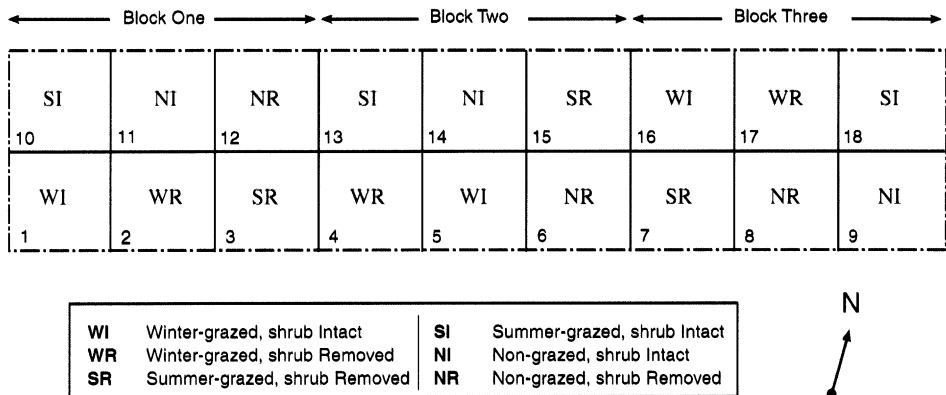

Fig. 1. Multiple Stressor Exclosure plots layout. Number in lower left corner for each plot denotes plot number. WI = Winter-grazed, shrub Intact, WR = Winter-grazed, shrub Removed, SR = Summer-grazed, shrub Removed, SI = Summer-grazed, shrub Intact, NI = Non-grazed, shrub Intact, NR = Non-grazed, shrub Removed.

The treatments were a combination of two factors: (1) removal of the mesquite shrubs [*Prosopis glandulosa* (Torrey) Torrey], and (2) intensive seasonal grazing (winter or summer). These treatments were applied in a randomized complete block design (Fig. 1). The plots were fenced in July–August 1993. Mesquite shrubs were removed from nine plots in January and February 1994 by hand cutting stems at the soil surface and painting the severed stem surfaces with herbicide (Roundup™). Hand cutting did not affect the soil mound around the base of the mesquite plants. Because of the extreme drought, plots were not grazed in the summer of 1994. Plots were winter-grazed in February 1995 and 1996 and summer-grazed in August 1995 and 1996. Stocking rate was adjusted for the estimated forage available in the plots. Plots were stocked with between 20 and 40 yearlings per plot for 24–36 h in order to remove 65–80% of the estimated available forage, This stocking rate produced a grazing intensity approximately 30 × greater than the grazing intensity imposed on the pasture in the previous 40 years.

We selected six ungrazed and six grazed plots to estimate cover and canopy height of the vegetation on the plots. Measurements of cover and bare soil patch sizes were made on 50 m lines using a modification of the line intercept methods (Canfield, 1941). Three 50 m line were established on each plot by selecting three numbers between 1 and 50 to match the lines with the 1 m markers at the perimeter of the plots. We recorded the distance on the tape at the point where a plant canopy intersected the line, and the distance at the point where the plant canopy ended. The average height of each plant intercepted was recorded.

In each plot, 10 subplots were selected randomly for microtopography measurements. To obtain random subplots, each plot was divided into a grid of 90 equally sized cells. Numbers between 1 and 90 representing the numbered cells were drawn at random for microtopography measurements. Microtopography was measured using a modified erosion bridge in each subplot. the bridge consisted of 4 m aluminum pipe with holes drilled at 3 cm intervals along 300 cm of the pipe. Solid metal pins (5 mm diameter) were inserted through each of the holes in the pipe. The height of each pin above the leveled reference pipe was recorded to the nearest mm. These lengths were adjusted for subplot slope by using the first and last pins as zero reference. The ends of the aluminum pipe were fastened into vertical end stands, which were driven into the soil at varying depths until the erosion bridge pipe was level, as indicated by a spirit-level placed on the center pipe. Measurements were recorded from the length of the pins above the center pipe and were adjusted for slope using the first pins as zero reference.

In order to measure the microtopography alone, we removed the slope effect by extracting the residuals from the regression line (Proc Reg; SAS, 1998) of the erosional bridge measurements. Residuals were noisy and needed to be smoothed (Fig. 2) for better visualization and ease of calculating the height and frequency of mounds and depressions. Residuals for each transect were smoothed using local regression (Proc Loess; SAS, 1998) as a non-parametric regression. Microtopography features, and the number and height of depressions/ mounds from the "0" level reference that are ≥ 3 cm were determined (Fig. 2). Based on field observations, the minimum depth of depressions that retained litter following the windy season
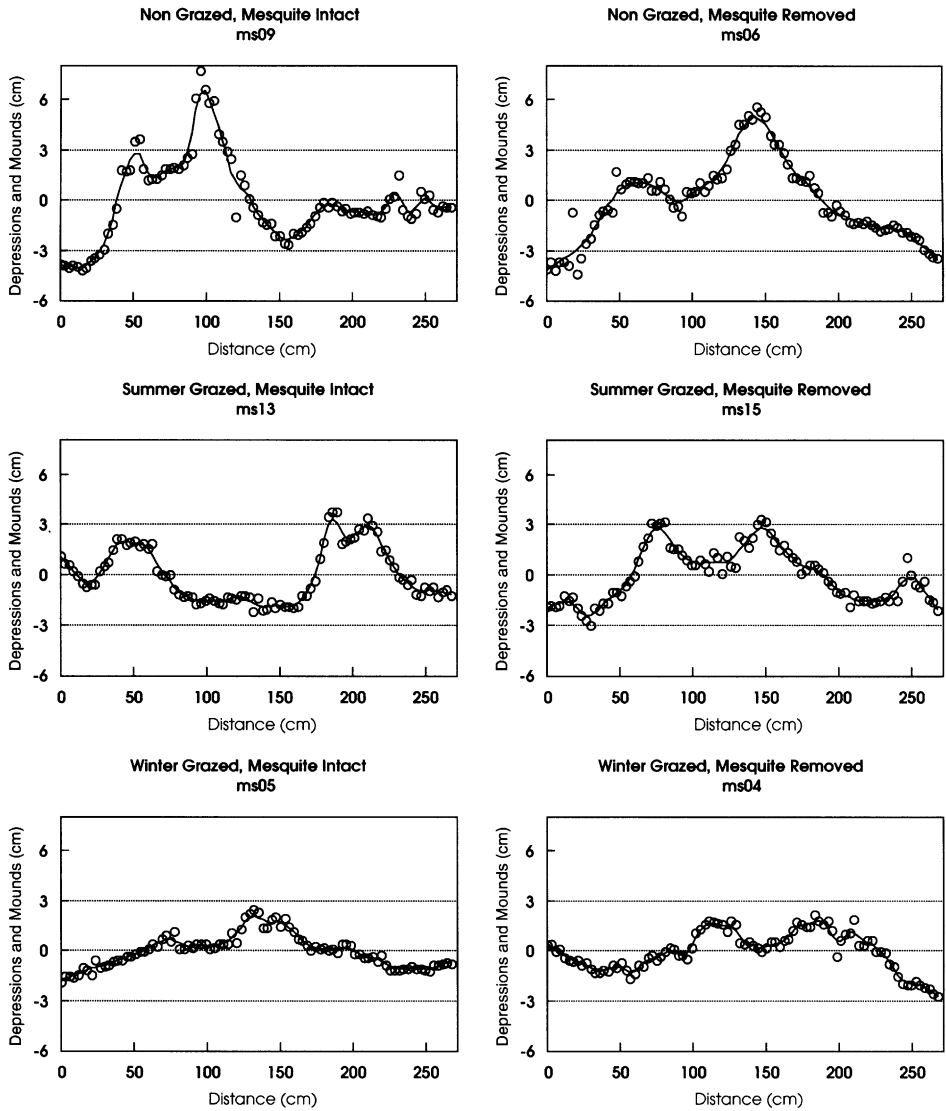
Fig. 2. Microtopography for grazing shrub plots in the multiple stressors. "ms#" denotes the number of the plot in the multiple stressors as related to Fig. 1. The solid line signifies the estimated topography using loess regression for microtopography data (open circle).

was 3 cm, therefore 3 cm was considered to be the threshold height or depression required to affect aeolian and fluvial processes in this landscape.

A microtopography index was calculated as (1) the sum of the absolute value of the depressions and mound (Fig. 3a) (2) the frequency of depressions and mounds (Fig. 3b) and (3) the sum of depressions and sum of mounds (Fig. 3c). The
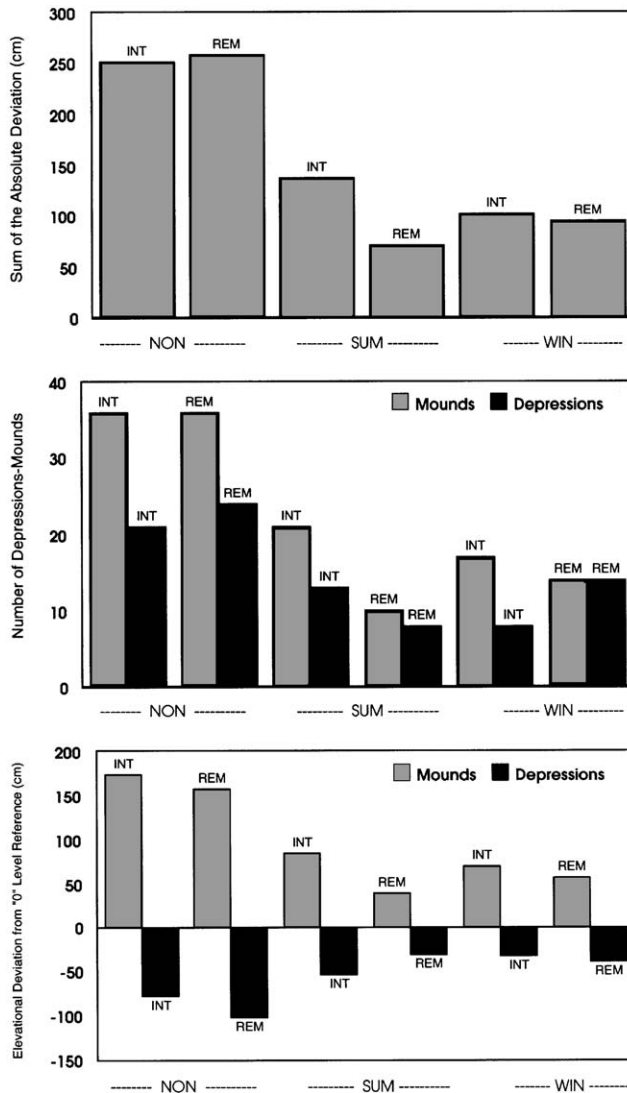
Fig. 3. Comparisons of three indices of microtopography are: the sum of the absolute deviations from the zero reference (cm), the number of depressions and micromounds, and the estimated deviation ($\pm$cm) from the zero reference. NON = non grazed, SUM = summer-grazed, WIN = winter-grazed, INT = shrub (mesquite) intact, and REM = shrub (mesquite) removed.

first and second indices can be used to describe the degree of the overall roughness (homogeneity) in soil surface, whereas the third index is a quanti-fication of the height of mounds and depth of depressions, separately, that can be used to discriminate in the physical and biological function between mounds and depressions.

We examined the differences in microtopography between treatments by analysis of variance. Treatments were a combination of two factors: (1) three levels of grazing (winter-grazed, summer-grazed and not grazed), and (2) two levels of habitat (shrubs-removed and shrubs-intact). Treatment plots were placed randomly in three blocks (see Fig. 1). Measurements were repeated within the plots (10 subplots). Split plot analysis of variance was used to find the differences in microtopography indices as effected by grazing, shrub and the combined effect of grazing and shrub (Proc GLM; SAS, 1998). The multiple comparison of mean height of mounds and mean depth of depressions were accomplished by using GLM with the least-square means option.

3. Results

There were large differences in canopy cover, average height of plant canopies, and size of bare, intermound spaces between the grazed and ungrazed plots (Table 1). The most important differences in vegetation affecting microtopography of the grazed and ungrazed plots were the percent cover of live vegetation and the average canopy height of grass tussocks.

Microtopographic relief was reduced in grazed plots compared that in ungrazed plots (Fig. 2). Numerous mounds and depressions that were than 3 cm in height or depth respectively characterized the microtopography of ungrazed plots. Differences between maximum mound height and maximum depth of adjacent depressions were more than 5 cm. These differences in elevations and with frequent adjoining mounds created a fine-scale landscape pattern that had more micro-water catchments and more depressions containing litter fragments than grazed plots (Fig. 2). In summer and winter-grazed plots, the mounds and depressions were within ± 3 cm resulting in a relatively flat surface. Soil from the mounds had filled in the depressions as the mound heights were reduced by hoof action.

The degree of roughness in soil surface measured by the sum of the absolute deviation for the "0" level in ungrazed plots was higher than that in grazed, shrub-removed plots (Fig. 3). In grazed plots, the number and deviation of depressions and mounds from the zero level was greater than that in grazed plots (Figs. 2 and 3).

Table 1
Comparison of vegetation cover and height $\pm$ standard deviation on grazed and ungrazed plots

Vegetation or soil surface parameter	Grazed	Ungrazed
Percent cover—bare soil (%)	90.8 ± 4.4	79.6 ± 5.3
Average size of bare soil patch (cm)	142.2 ± 93.6	64.0 ± 3.5
Percent cover of live grass (%)	0.8 ± 1.5	17.4 ± 2.8
Percent cover of dead grass (%)	2.3 ± 4.7	1.4 ± 0.9
Average live grass height (cm)	3.5 ± 2.2	16.3 ± 6.2
Percent cover of sub-shrubs (%)	6.5 ± 4.1	1.8 ± 1.6
Average canopy height of sub-shrubs (cm)	15.8 ± 2.6	10.8 ± 1.8

Average elevation deviation from the zero level was significantly different for mounds resulting from grazing and removal of mesquite ($p < 0.05$). The mean mound heights in ungrazed plots (3.73 cm) were significantly higher ($p \leq 0.0007$) than those of mounds on winter- and summer-grazed plots (1.8 cm). With mesquite removal, the mean height of mounds in mesquite-intact plots was "marginally" significantly higher (2.75 cm) than those in the shrub-removed plots 2.14 cm; $p = 0.052$). While there were no differences in average height of mounds between shrub removal and ungrazed plots, there were significant differences between grazed and ungrazed plots ($p \leq 0.04$; Fig. 4). In summary, whether mesquite shrub was removed or not, the mean height of mounds were larger in the ungrazed plots than that of the grazed plots. Seasonal grazing (winter or summer) had similar effects on the height of mounds ($p \geq 0.32$; Fig. 3). Short duration grazing in the non-growing (winter) and growing seasons (summer) had a similar impact on soil microtopography, hence rejecting our null hypothesis.
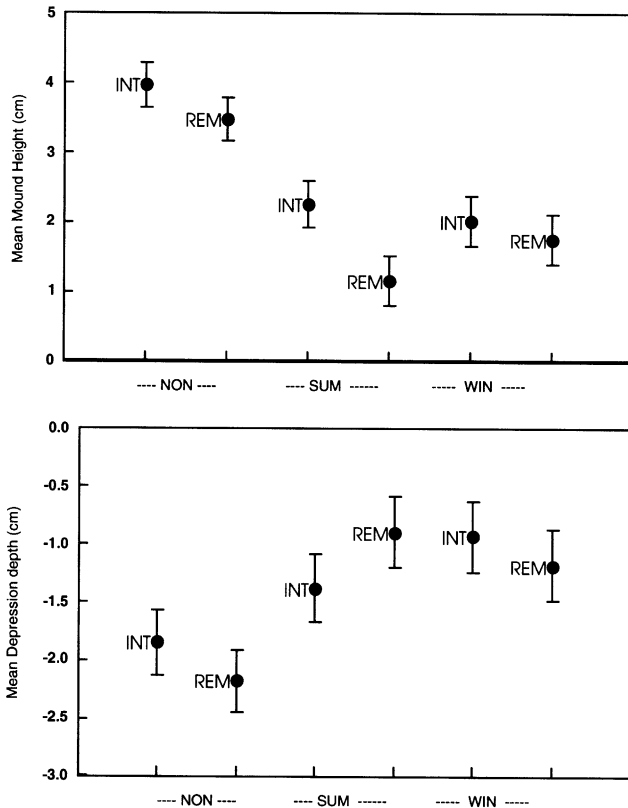

Fig. 4. Mean heights of micromounds and mean depths of depressions on grazing plots in the Chihuahuan Desert grassland. NON = non-grazed, SUM = summer-grazed, WIN = winter-grazed, INT = shrub (mesquite) intact, and REM = shrub (mesquite) removed. Closed circle is the average and the vertical line is the standard error.

The differences in depression depths were smaller than in mound height (Fig. 4). The average depths of depressions resulting from grazing were significantly different ($p = 0.01$) but were not different as a result from the removal of mesquite ($p = 0.90$). The mean depression depth values in ungrazed plots (-2.01 cm) were significantly higher ($p < 0.03$) than those of winter- and summer-grazed plots (-1.1 cm). Mean depression depths were similar in both growing (summer) and non-growing seasons (winter; $p = 0.97$). The combined effect of grazing and shrub-removed showed no differences in the mean depression depths between shrub-removed ungrazed plots ($p = 0.41$; Fig. 4). Seasonal grazing (winter or summer) had a similar effect on depression depths.

Soil surface roughness measured by the sums of the absolute deviation was more homogenous in grazed than that in ungrazed plots ($p = 0.0002$), whereas the removal of shrubs had no significant effect ($p = 0.27$) on soil microtopography. The average values were higher in ungrazed plots (5.74 cm) than that in winter-summer-grazed plots (3.0 cm, $p \leq 0.0004$). Differences in the sum values between shrub-intact plots (4.14 cm) and shrub-removed plots (3.67 cm; $p = 0.28$) were small. The combined effect of grazing and shrub removal indicated that while there were no differences attributable to shrub removal in ungrazed plots, there were significant differences between grazed and ungrazed plots ($p \leq 0.05$). Differences in microtopography attributable to seasonal grazing ($p > 0.05$) were small.

In ungrazed plots, the effect of shrub removal on mean depth of depressions and mean height of mounds was statistically not significant in this study. Differences may be larger and the effect may be significant if measurements were done on a longer term experiment.

4. Discussion

The results of this study clearly document the virtual elimination of the fine-scale microtopography by intense (high stocking rate), short-duration (1.5 days per year for three consecutive years) activity of domestic livestock. Shrub removal exacerbates the effects of livestock on the micromounds and microdepressions. Hence, our hypothesis of little effect from short duration of grazing on soil microtopography is rejected. On plots with mesquite shrubs present, cattle apparently avoided the shrubs, and therefore had less impact on the microtopography in the vicinity of the shrubs. The combination of grass canopy removal and hoof-action by livestock resulted in mortality or reduction in the canopy areas of the grasses. Intense hoof action resulted in lateral movement of soil from the micromounds into the intermound depressions. Removal of canopy by grazing reduced the area of soil protected by vegetation to very low values. Live grass canopy cover on the grazed plots was only 5% of that on ungrazed plots, and the average grass canopy height on grazed plots (3.5 cm) was only 20% of the average grass height on ungrazed plots (16.3 cm). Micromounds that were largely unprotected because of the reduced height of the grazed tussocks became extremely vulnerable to wind and water erosion. One of the most important factors affecting threshold

velocities for wind erosion is vegetation height (Moss, 1989; Van de Ven et al., 1989). Reduction in vegetation cover and height also affects stemflow in grasses (Van Elewijck, 1989) and water infiltration (Schlesinger et al., 2000). Wind erosion decreases the rooting depth and water-holding capacity. Consequently, soil quality and productivity decline (Leys, 2002). Wind erosion of micromound soils left grass tussock roots exposed to sunlight and to the abrasive force of saltating sand grains. This contributed to the death of the tussock stubble and contributed directly to the microtopographic homogeneity of the grazed plots. Reduction of grass canopy by intense grazing exposed more of the micromound soils to splash erosion (Whitford, 2002). The destruction of the mound/depression microtopography eliminates the micro-watersheds that are important for the maintenance of desert grassland (Schlesigner and Pilmanis, 1998).

The reduction of microtopographic relief plus the reduction in cover and height of vegetation provided longer fetch distances and reduction in surface roughness. These two factors (fetch and roughness) directly affect threshold velocities for entrainment of sand grains and the initiation of wind erosion processes (Skidmore, 1986). In grazed plots where mesquite shrubs were present, there has been accretion of sand at the base of the multi-stemmed shrubs. The reduction in microtopography is a contributing factor to the development of the mesquite coppice dune systems that have replaced desert grasslands in many areas of the Chihuahuan Desert. This study demonstrates that dramatic changes in microtopography, and vegetation cover and height can result from very brief, intense grazing episodes by livestock. Earlier studies documented similar changes in soil surfaces microtopography and vegetation cover and height as a result of chronic grazing pressure by large numbers of livestock (Nash et al., 2003).

Note

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