Total Vertical Sediment Flux and PM_{10} Emissions from Disturbed Chihuahuan Desert Surfaces

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Abstract:

Desert surfaces are typically stable and represent some of the longest-lived landforms on Earth. For surfaces devoid of vegetation, the evolution of a desert pavement of gravel and small stones protects the surface from erosion by wind and water and vegetation further protects the surface in arid and semi-arid rangelands. The susceptibility of the land surface to wind erosion is enhanced by mechanical damage to the desert pavement or vegetation losses resulting from fire or grazing. Despite the relatively rich literature on the effects of grazing and fire on plant community composition, land degradation, and the productivity of arid landscapes, little is known about the effects of moderate grazing or fire on the erodibility of soils in desert grasslands and shrublands. Here we investigate the effect of simulated moderate grazing, simulated livestock trampling, and of fire on the resulting wind erodibility and dust emissions of the affected soil surfaces. We surveyed 24 plots of the same size, 6 m X 0.6 m, at a research site in the northern Chihuahuan Desert including 6 plots in a shrub-grass ecotone, 12 plots in an adjacent grassland, and 6 plots in an area that had been burned by a natural wildfire 6 months earlier but had no vegetation recovery due to the time of year and drought. To evaluate the various effects of disturbances on the susceptibility of the surface to wind erosion and dust entrainment, replicates of three plots underwent different treatments including clipping, trampling, fire, and tillage. We subsequently tested each of the treated plots with a portable field wind tunnel run at 12.6 m s^{-1}. We found that moderate grazing and fire did not result in great soil loss in desert grasslands but that shrublands were more seriously affected by grazing and fire. Total removal of vegetation and disturbance of the soil surface did result in greater than order of magnitude increases of vertical sediment flux and greater than three-fold increases of dust emissions.

Keywords: Wind erosion, desert surfaces, rangeland, vegetation disturbance, fire

Abbreviations:

USFWS – U.S. Fish and Wildlife Service

SNWR – Sevilleta National Wildlife Refuge

PFWT – Portable field wind tunnel

TVSF – total vertical sediment flux

PM_{10} – particles smaller than 10 µm diameter

D – plots in which all vegetation was removed, the soil tilled to 15 cm depth, raked smooth, and rolled flat and smooth with a weighted lawn roller. This highly disturbed whole soil is used as the control treatment

6B – treatment plots that were burned by wildfire 6 months prior to testing

6BT – treatment plots that were burned by wildfire 6 months prior to testing and subsequently trampled with artificial hooves

GB – grassland plots that were burned by U.S. Fish and Wildlife Service personnel

GC – grassland plots in which the plant canopies were removed by clipping

GCT – grassland plots that were clipped and trampled with artificial hooves

SC – shrub-grass ecotone plots in which the plant canopies were removed by clipping

SB – shrub-grass ecotone plots that were burned by U.S. Fish and Wildlife Service personnel

1. Introduction

Desert surfaces represent some of the oldest landscapes on earth. The scarcity of water as an agent of geomorphological change has resulted in surfaces that erode and form slowly with wind as the primary erosive agent. In the absence of vegetation, desert pavements form as clasts are lifted to the surface by clays undergoing changes in hydration. This roughened surface encourages further deposition of wind-borne fine sediments (Pelletier et al., 2007; Matmon et al., 2009; Dietze et al., 2016) resulting in older surfaces with more clay and silt from aeolian accretion (Meadows et al., 2006). Periodic surface disturbances can heal in a matter of years if the clasts remain (Wainright et al., 1999) or decades if the clasts are completely removed (Haff and Werner, 1996; Pelletier et al., 2007). In spite of their historical stability, desert surfaces are mechnically fragile and may offer early warning of degradation from increased anthropogenic and macrofaunal activity (Haff, 2001). For instance, Okin and Painter (2004) found that wind-eroded sediment from tilled and abandoned center-pivot agricultural fields greatly exceeded that from adjacent undisturbed desert surfaces and Gillies et al. (2010) found that deep tillage of desert soils resulted in a greater than order of magnitude increase of dust emissions when compared to natural surfaces.

In naturally vegetated landscapes, especially in humid regions, the vegetation protects the soil by absorbing part of the wind's shear force and reducing impact with the surface (Raupach, 1992; Raupach et al., 1993). Even in semi-arid and arid environments vegetation, although often sparse, protects much of the surface from the erosive forces of wind (Okin, 2008; Wolfe and Nickling, 1993). In addition to removing energy from the wind, vegetation may provide impact points for creeping and cascading sand grains, thus preventing cascades of saltating particles (Bilbro and Fryrear, 1994). The protective effect of vegetation is so great that grasslands in semi-arid and even some arid environments are essentially stable landscapes until some form of disturbance removes the vegetation. Disturbances to vegetation in arid and semi-arid environments often lead to land degradation and decreased environmental quality and appear to be happening with increased frequency (Breshears et al., 2003; Field et al., 2010; Ravi et al., 2011).

Removal of the vegetation by grazing animals is perhaps the most common form of disturbance in desert rangelands and has important implications both on the grazed land and other ecosystems in the region. For example, deposition into alpine lakes in North America increased 5 fold in the early 20th century due to the expansion of grazing on the surrounding bajadas (Neff et al., 2008). This pattern is found throughout much of the Colorado Plateau region (Goldstein et al., 2008). Grazing not only removes the protective cover of the vegetation, but may actually increase the erodibility of the surface by disturbing protective surface soil crusts (Baddock et al.,

2011) and biological crusts (Belnap, 1995; Belnap and Gillette, 1998). Indeed, intensive grazing may also influence the microtopography of desert grasslands (Nash et al., 2004). As disturbance intensity increases, the bare areas between clumps of vegetation may become sources for wind eroded particles and the vegetation clumps create depositional areas. The wind-eroded sediment often contains disproportionate amounts of soil organic carbon and plant nutrients (Zobeck and Fryrear, 1986), leading to the land degradation and redistribution of soil resources, which in turn lead to changes in plant community composition including shrub encroachment (Ravi et al., 2011; D'Odorico et al., 2013). Many degrading grasslands are characterized by an increase in woody plant cover, often referred to as shrub encroachment. Anthropogenic factors like fire suppression and overgrazing may initiate this grassland to shrubland shift, while aeolian processes are thought to play a major role in maintaining and enhancing the heterogeneities in soil and nutrient redistribution (D'Odorico et al., 2013; Okin and Gillette, 2001; Schlesinger et al., 1990).

Heterogeneous shrublands in arid environments are characterized by shrubs surrounded by grasses or, increasingly, by bare areas. Shrubs are particularly efficient at intercepting the finer silt and clay sized aeolian particles and the soil texture is often finer on a mass basis under shrubs than in the surrounding bare areas (Li et al., 2009; Ravi et al., 2007a) leading to the development of nutrient islands (Li et al., 2007; Okin et al., 2008; Schlesinger et al., 1990). Development of these nutrient islands hinders re-establishment of grasses in the bare areas, encourages shrub encroachment, and adds to the heterogeneity of degraded rangelands (van Auken, 2000).

Fire is a natural occurrence in semi-arid and arid rangeland environments and often leads to increased wind erosion (Ravi et al., 2007b; Sankey et al., 2009; Wagenbrenner et al., 2013; Whicker et al., 2002). Fire may also result in the creation and deposition of hydrophobic compounds on the soil surface (Doerr et al., 2000; Ravi et al., 2006, 2009). However, the increased erosion is usually short-term because fire favors the rapid growth of perennial grasses and reduces the survival of shrub seedlings (Ravi et al., 2012; Taylor et al., 2012). For the period between the fire and vegetation recovery, Ravi et al. (2007b) found that wind erosion increased and redistributed the trapped sediments from the nutrient islands under shrubs and clumps of grass. This phenomenon has been described as a negative feedback on land degradation (Ravi et al., 2009) induced by shrub encroachment. Although this process has been observed in post-fire landscapes, there is little information on the increase of erodibility that can be attributed to fire. We initiated this study to determine The extent to which vegetation removal by grazing (clipping of vegetation and trampling of the soil surface) and fire affected the stability of the surface compared to mechanical disturbance of the whole soil for desert grasslands and grass-shrub ecotones typical of rangelands in much of southwestern North America.

2. Methods

2.1 Study Site

The field study was conducted at the United States Fish and Wildlife Service (USFWS) Sevilleta National Wildlife Refuge (SNWR) in central New Mexico (Figure 1). This area receives 200 mm mean annual precipitation, primarily in the summer monsoon season from late July to September. The mean annual maximum air temperature is 23.7°C ranging from 12.6°C for the winter months of December through February to 34.2°C for the summer months of June through August. The mean annual minimum air temperature is 3.1°C ranging from -6.5°C for the winter months to 13.4°C for the summer months. The study site was located on the east side of the Rio Grande flood plain at an elevation of 1530 m MSL and is typical of northern Chihuahuan Desert grassland and grass-shrub ecotone.

Creosote bush (*Larrea tridentat*a (DC.) Cov.) is the dominant shrub species and is found mostly near rock outcrops, with fewer individuals of Mormon tea (*Ephedra spp.*) and Snakeweed (*Guttierezia sarothrae* (Pursh) Britt. & Rusby) occurring sporadically. The dominant grass species of the area is Black grama (*Bouteloua eriopoda* Torr.) and other grasses include sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), ring Muhly (*Muhlengergia Torryei* (Kunth) Hitchc.), false buffalo grass (*Munroa squarosa* (Nutt.) Torr.), and three awns (*Aristida spp.*). The SNWR has been protected from grazing for over 50 years and has been the location of many investigations into desert ecology including multiple studies of shrub encroachment into grassland (Baez and Collins, 2008).

Vegetative cover of five plots in grassland and four plots in shrub-grass ecotone were determined using the line intercept method implementing 0.5 m lines placed at 0.1 m intervals perpendicular to the direction of intended portable field wind tunnel (PFWT) wind flow over the plots. This method resulted in 60 lines 0.5 m in length or a total of 30 m of line intercept per plot. Shrubs were defined to be woody perennials and forbs were included with the grasses. For the desert grassland, grasses and forbs covered 57.9 ± 8.2% of the soil surface leaving 42.1 ± 9% bare. In the shrub-grass ecotone, shrubs covered 73 ± 15.4%, grass and forbs covered 15.6 ± 9.3%, and

19.8 ± 12.9% of the surface was bare. Bare surface areas were covered with approximately 15% gravel in a desert pavement. A view of a shrub-grass ecotone at SNWR is presented in Fig. 2A.

The soil at the study site is classified as Turney loamy sand (fine-loamy, superactive, mixed, thermic Typic Haplocalcid) with slope of less than 1%. The surface soil has a loamy sand to sandy loam texture with about 15 percent gravel and mean sand, silt, and clay percentages and related standard deviations for the study plots are 80.2 ± 2.7%, 9.6 ± 1.7%, and 10.2 ± 1.5% respectively. Soil texture was determined using the hydrometer method (Gee and Bauder, 1986). Soil surface moisture in the upper 0.5 cm at time of testing was determined gravimetrically (Gardner, 1986) and was less than 1.0% in all cases.

2.2 Plot Preparation Procedures

A total of 24 plots 6 m long and 0.6 m wide were prepared for testing with the PFWT. This number represents 8 experimental conditions or treatments replicated three times each. The treatments were:

1.) Cleared of all vegetation and tilled with a rotary tiller then raked and rolled smooth using a weighted lawn roller. This treatment represented the control treatment as the activity resulted in a homogenized whole soil without the protection afforded by desert pavement or vegetation (D1-3)

2.) Grass only plots clipped using lawn clippers as close to the soil surface as possible without disturbing the soil (GC1-3)

3.) Grass only plots clipped as per GC and then trampled with 2 artificial hooves each consisting of five spaced 3 cm diameter dowel rods 6 cm long (GCT1-3). Pictures of the trampling shoes and the trampling activity are presented in Fig. 3.

4.) Shrub-grass ecotone plots clipped as close to the soil surface as possible without disturbing the soil. Shrubs were clipped using long-handled pruning shears (SC1-3)

5.) Grass plots burned by USFWS personnel (GB1-3)

6.) Shrub-grass ecotone plots burned by USFWS personnel (SB1-3)

7.) Grass plots at a location 300 m north of the main study site burned by natural wildfire 6 months prior to testing (6B1-3)

8.) Grass plots at a location 300 m north of the main study site burned by natural wildfire 6 months prior to testing and trampled with the artificial hooves (6BT1-3)

with each treated area being slightly wider than the size of the PFWT working section. In addition to the treated tunnel footprint area, an additional 2 m was cleared of shrubby vegetation to accommodate the ground level placement of the flow conditioning section of the field wind tunnel. Each shrub-grass ecotone plots area was selected to include the base and understory area of three shrubs. A picture of a typical plot with the wind tunnel in place for testing is presented in Fig. 2B.

2.3 Wind Tunnel Testing of Prepared Plots

Field operations were conducted between March 2 and April 27 of 2010. The erodibility of the prepared surfaces was tested using the PFWT that tests a surface 6 m long and 0.5 m wide. Details of the design and construction of this PFWT are presented in Van Pelt et. al (2010). The

6 m by 0.5 m test section of the PFWT was carefully set in place over the prepared plots and any gaps between the test section and plot surface were sealed with foam rubber to ensure full wind flow to the end of the test section. The test was initiated with a period of increasing wind speed to a steady flow velocity of approximately 12.6 m s^{-1} measured at the 0.5 m level in the center of the tunnel. This velocity was maintained for a period of 5 minutes for the clipped, trampled, and 6 month post-fire plots and 10 minutes for the plots burned by USFWS personnel and was termed Run 1. During Run 1, the readily erodible sediment was blown off the surface and there was negligible sediment movement at the end of the period. The additional time for the plots burned by USFWS personnel was to collect additional sediment for chemical extraction in support of a companion investigation. Following Run 1, a second test period of 30 minutes (Run 2) was performed at the same wind velocity but with the addition of 14 g m^{-1} s^{-1} of washed quartz abrader sand dropped onto the floor of the flow conditioning section to simulate steady state saltation at critical field length. The final run of the wind tunnel testing was a 10 minute period (Run 3) in which the assumptions of reaching steady state rates of sediment emission could be tested by comparison with data from the last 10 minutes of Run 2.

An isokinetically aspirated vertical slot sampler with opening 3.25 mm wide by 1 m tall was placed at the mouth of the test section to collect an integrated sample of entrained sediment. The slot sampler allowed the entrained sediment to be separated into saltation sized material that was deposited in a pan at the bottom and suspended dust that was trapped on glass fiber filters. An isokinetic sampling line in the duct leading to the filters was sampled optically using a GRIMM model 1.108 particle size analyzer. This particle size sampling resulted in the output of number of particles for each of fifteen different diameter classes every 6 seconds. From this data we were able to calculate the PM_{10} emission rate from the tested surface.

Between each run of the PFWT, the slot sampler was capped and the saltation material was collected from the bottom pan and placed into a labelled soil can. The filter cassettes were also collected in their holders and replaced with clean filters in cassettes. The slot sampler was reassembled and returned to the mouth of the wind tunnel with the slot cover still in place. The time at which the abrader flow to the flow conditioning section was resumed and the cover removed from the slot sampler was recorded and a timer set for the length of the next test. The numbered and previously weighed filters in the cassettes were transferred to an enclosed trailer, were carefully removed from their cassettes, and were placed into static free sealed sleeves for transport to a microbalance. The cassettes were inspected, clean filters installed, and the finished cassettes were placed in dust-proof boxes for the next test segment.

Two response variables have been chosen for statistical analysis based on their importance to the objectives of the study. The first variable was the total vertical sediment flux (TVSF) measured during 5 minutes of Run 1 for the clipped, trampled and 6 month post-fire plots or 10 minutes of Run 1 for the plots burned by USFWS personnel. During this test, no abrader sand was added to the flow conditioning section and thus all saltation-sized particles collected in the bottom pan of the slot sampler and all suspension-sized sediments trapped on the filters were from the surface being tested. The total weights of TVSF collected through the slot sampler (g) was determined by summing the weight of saltation-sized sediment in the bottom pan with the weight of total suspended sediments collected on the filters, divided by the proportional width of the sampler with respect to the mouth of the wind tunnel (dimensionless), and the soil surface area under the wind tunnel test section (m^2) to calculate the total vertical flux ($g\ m^{-2}$). The second response variable was the steady state PM_{10} emission rate for the tested surface. This was determined from particle diameter data collected with the optical sensor and averaged for the last 3 minutes of Run 2. PM_{10} is respirable dust affecting air quality and environmental health and it is regulated by the U.S. Environmental Protection Agency.

Data sets used in the statistical analyses were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965) in JMP ver. 10 software (SAS, 2012). We tested for differences among means for non-normally distributed data separately using a nonparametric Wilcoxon test (SAS, 2012). Analysis of variance for normally distributed data sets were conducted using Proc. GLM and means were separated with Ryan's Q (SAS, 2013). It is our opinion that levels of probability determining statistical significance are somewhat arbitrary and so we have chosen to present the means along with the fitted probability levels. In this way, the reader may determine which differences are meaningful and which are not.

3. Results and Discussion

3.1. Total Vertical Sediment Flux

Means and standard deviations for the TVSF for the initial wind tunnel run (without added abrader) for all plot preparation treatments are presented in Figure 4. The rate of TVSF production was not constant during the 5 or 10 minute test, but tended to be greater in the beginning and decreased to essentially zero by the end of the 5 or 10 minute test period indicating that all the readily erodible material had been entrained. The results among the replicates tended to be highly variable and coefficients of variation greater than 30% were typical. The highly disturbed tilled and rolled treatment (D) provided a greater than order of magnitude more TVSF than any other plot preparation treatment by producing 1873.71 g m^{-2} compared to 111.09 g m^{-2} for the nearest non-tilled treatment. This clearly demonstrates the importance of vegetative cover, desert pavement, and surface crusting in controlling wind erosion ($p=0.0014$). When the natural non-tilled surfaces are considered by themselves, differences were noted among the treatments ($p=0.0611$) with shrub-grass ecotone burned treatment (SB) producing slightly more TVSF, 111.09 g m^{-2}, than the unburned (SC) treatment, 99.90 g m^{-2}, within the same vegetation type. The clipped grass (GC) treatment produced the next greatest amount of TVSF, 80.36 g m^{-2}, followed by the 6 month post burn un-trampled treatment (6B) that produced 68.60 g m^{-2}, the 6 month post burn trampled treatment (6BT) at 46.83 g m^{-2}, the burned grass treatment (GB) that produced 30.78 g m^{-2}, and finally the clipped and trampled grass treatment (GCT) that produced a scant 25.47 g m^{-2}.

For recently clipped or burned treatment plots, the vegetation type appeared to have the greatest effect on TVSF with the SB treatment out producing the GB treatment by a factor of greater than three ($p=0.0632$). The adjacent clipped treatment plots were not as affected by the clipping as evidenced by the SC treatment producing only a small amount more TVSF than the GC treatment ($p=0.5185$). This may have been due to the protection provided by the litter layer under the shrub canopies. Also, in the grass-shrub ecotone plots there tended to be less grass coverage so when the shrub canopy was removed and the litter layer burned, there is much more bare area than similarly clipped or burned grass treatment plots. Sankey et al., (2010) reported the smoother areas following a fire in a shrub steppe tended to erode while the rougher areas actually became depositional environments. In the grass plots, the effective basal cover probably changed very little by removal of the vegetation due to the dominance of bunch grasses. Thus these plots retained more of their original near-surface roughness than the grass-shrub ecotone plots.

Fire as an effect was not as predictable as vegetation type. Although the SB treatment produced only slightly more TVSF than the SC treatment (p=0.7582), the GC treatment produced considerably more TVSF than the GB treatment (p=0.1138). This lack of increased post-fire TVSF production in the desert grassland treatment plots contrasts with most of the published literature (e.g. Ravi et al., 2011). It is possible that the dominance of the bunch grasses affected the post fire sediment transport or that the sandy texture of the surface affected this lack of fire effects as suggested by Sankey et al (2009). Water repellency has recently been invoked to explain the post-fire increased soil susceptibility to wind erosion (Ravi et al., 2009b). Immediately after the controlled burn, a test for water repellency was conducted and the soil under the shrub canopies was water repellant while the soil in the desert grassland plots was not. Further, during the fire a residue resembling a very thin layer of sticky tar from the pyrolysis of the grass was deposited on the soil surface. This layer may have served to cement the surface soil and armor it against movement by wind.

Trampling had a negative effect on TVSF production regardless of whether the plots were clipped or burned 6 months earlier. In the freshly clipped plots, the GC treatment produced more than three times as much TVSF as the GCT treatment (p=0.0655). In the plots burned 6 month prior to testing, the 6B treatment produced less than 50% more TVSF than the 6BT treatment (p=0.5533). Trampling broke the smooth crust in both cases and increased the surface roughness, thus limiting the cascade effect commonly seen on smooth bare surfaces. Cattle trampling on a crusted clay surface has been shown to increase total sediment flux (Baddock et al., 2011), but clay crusts typically have very little or no readily entrainable material on the surface whereas the soil crusts at this location have loose sand on the surface that is easily entrained by wind.

The time since burning had a positive effect on total TVSF. The 6B treatment produced more than twice the TVSF than the GB treatment (p=0.3382). The low significance of the differences was due to the very high variabilities noted in the TVSF production for these two treatments with both treatments having standard deviations of 2/3 the means or greater. The trampled plots came much closer to classic levels of significance with the 6BT treatment producing slightly less than a two-fold increase of TVSF production over the GCT treatment (p=0.0836). The effect of time since burn on the increased TVSF production is in contrast to other reports (Ravi et al., 2012; Sankey et al,. 2009; Wagenbrenner et al., 2013). It is apparent that the post-burn soil surfaces at the Sevilleta NWR are less supply limited than those elsewhere such as the silty soils in southern Idaho (Sankey et al, 2009; Wagenbrenner et al., 2013). This effect of greater sediment production at some time after the fire may also be due to breakdown of the pyrolysis product noted immediately after the controlled burn in the grass plots.

3.2. PM_{10} Emission Rates

Steady state emission rate means and associated standard deviations for PM_{10} are presented in Figure 5. As with the TVSF, the D treatment resulted in much more PM_{10} emission than any of the non-tilled treatments ($p=0.0008$). Among the non-tilled treatment plots, treatment related differences were found ($p<0.0001$) and the results among replicates of individual treatments were also less variable than noted for the TVSF. As with the TVSF, the shrub-grass ecotone treatment plots produced the greatest mean PM_{10} and the SB plots emitted 502 mg m^{-2} sec^{-1} compared with 0.453 mg m^{-2} s^{-1} for the SC treatment plots. For treatment plots in the desert grassland community, the GB treatment produced the most PM_{10} at 0.360 mg m^{-2} s^{-1}, followed by the 6BT treatment producing 0.257 mg m^{-2} s^{-1}, the 6B treatment at 0.247 mg m^{-2} s^{-1}, the GCT treatment producing 0.181 mg m^{-2} s^{-1} and, finally, the GC treatment at 0.165 mg m^{-2} s^{-1}. Emissions of PM_{10} did not scale with TVSF or even follow the same order of decrease. This could be attributed to minor differences in fine particles in the surface soil among plots.

As with TVSF, vegetation type appeared to be the most important treatment effect on determining PM_{10} emission rates. The SB treatment produced more PM_{10} than the GB treatment ($p=0.0194$). The clipped plots had a very similar pattern with the SC plots emitting more PM_{10} than the GC ($p=0.0299$). When comparing the plant communities, the PM_{10} emission rates do approximately scale the TVSF. Another factor that may lead to greater PM_{10} emission rates for the shrub-grass ecotone plots is the probability of finer soil particle size distributions under the shrub canopies as noted for shrub-grass ecotones at other locations in the Chihuahuan Desert (Li et al., 2009; Ravi et al., 2007a).

Fire increased PM_{10} emission rates in both plant communities. In the shrub-grass ecotone, the SB treatment emitted more slightly PM_{10} than the SC treatment ($p=0.6039$) and in the desert grassland, the GB treatment emitted more PM_{10} than the GC ($p=0.0065$). This finding is in agreement with the recent findings of Wagenbrenner et al. (2013) who noted increases in PM_{10} emissions following fire in southern Idaho. With these recently burned treatments however, we cannot dismiss the possibility that some of the measured PM_{10} may be from ash or from abraded charcoal.

Differently than TVSF, trampling had a positive, albeit slight effect on PM_{10} emission rates. The GCT treatment emitted slightly more PM_{10} than the GC treatment (p=0.7478) and the 6BT emitted more PM_{10} than the 6B (p=0.7299). Even though trampling roughened the plots, it may also have exposed illuviated fines below the soil crust and made them available for entrainment. This finding is in agreement with Baddock et al. (2011).

Time since burn had mixed effects on PM_{10} emission rates. The GB treatment emitted almost 50% more PM_{10} than the 6B treatment (p=0.0101), but the 6BT treatment emitted > 40% more PM_{10} than the GCT (p=0.0978). It is unclear why this discrepancy was observed, but may be related to previous winnowing of the 6 month post-burn area and the replenishment of soil fines by the trampling or may simply be due to the contribution of ash in the recently burned treatment plots.

4. Conclusions

Our results indicate that naturally evolved desert surfaces, even though disturbed, are less erodible and less dust emissive than the whole soil subtending them . Grazing, as simulated by clipping the vegetation to near the soil surface, trampling, and fire did not appear to result in great amounts of erosion or emissions of PM_{10} at our site in the Chihuahuan Desert. The pedestals of the perennial bunch grasses appear to be very effective in limiting the cascading sand grains and keeping soil loss minimal even after moderate grazing or fire. Severe overgrazing could however result in the total loss of vegetation in which case the resulting surface would be expected to behave like the tilled and rolled plots with great increases in soil erodibility and dust emissions likely. Totally denuded areas are common in grazed lands around water sources and holding pens. Sustainability of grazing lands mandates that such degraded areas be kept to a minimum by effective management of domestic livestock. Shrub encroachment may also be unduced by overgrazing and disturbances to shrub dominated rangelands such as wildfire will result in increases of wind erosion and dust emissions. Shrub dominated landscapes take longer to recover post-disturbance than grasslands, resulting in longer periods or disturbance windows during which the soil surface is susceptible to wind erosion.

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Figure Captions

Figure 1: Location of the Sevilleta National Wildlife refuge in New Mexico, USA. The star marks location of wind tunnel study plots.

Figure 2: A) Landscape and vegetation of the study site B) Portable field wind tunnel deployed on a clipped (unburnt) shrub (SC) plot.

Figure 3: View of the trampling shoes detailing construction and picture of the clipped grass plots being trampled.

Figure 4: Means of total vertical flux and standard deviations of sediment produced from the surfaces during the first period of the wind tunnel testing. The tilled plot preparation (D) was statistically different from all the other (non-tilled) surfaces, but no statistically significant differences were noted among the non-tilled surfaces.

Figure 5: Means of steady-state PM10 emission rates and associated standard deviations for the tested surfaces. The tilled plot preparation (D) was statistically different from all the other (non-tilled) surfaces. In addition, significant differences were noted among the non-tilled surfaces. Bars containing the same letter are not significantly different.

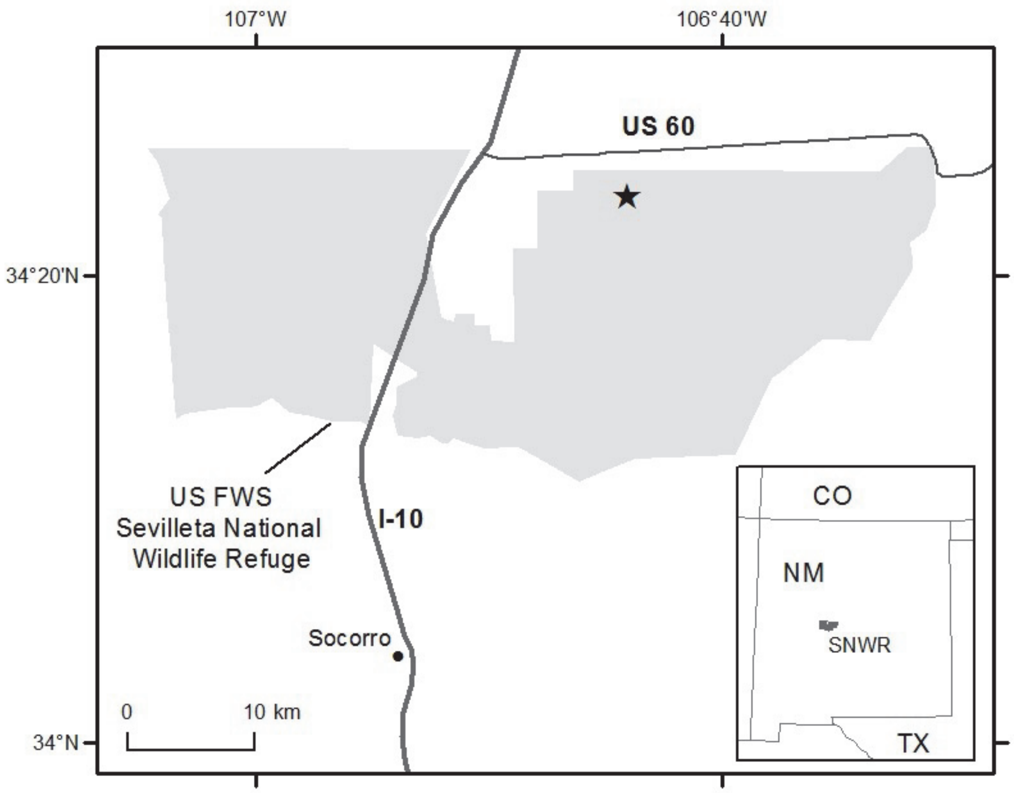
107°W
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fig1

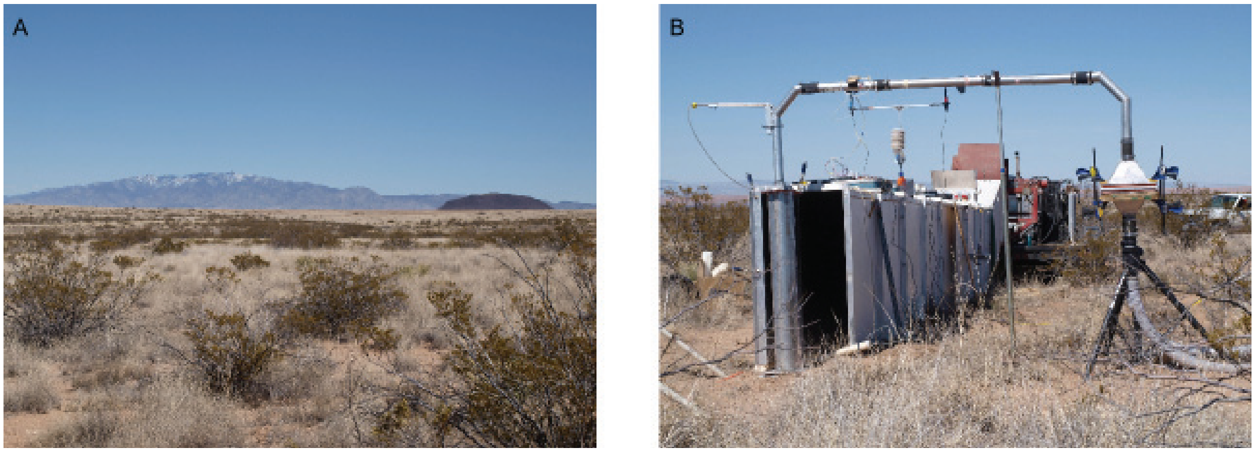
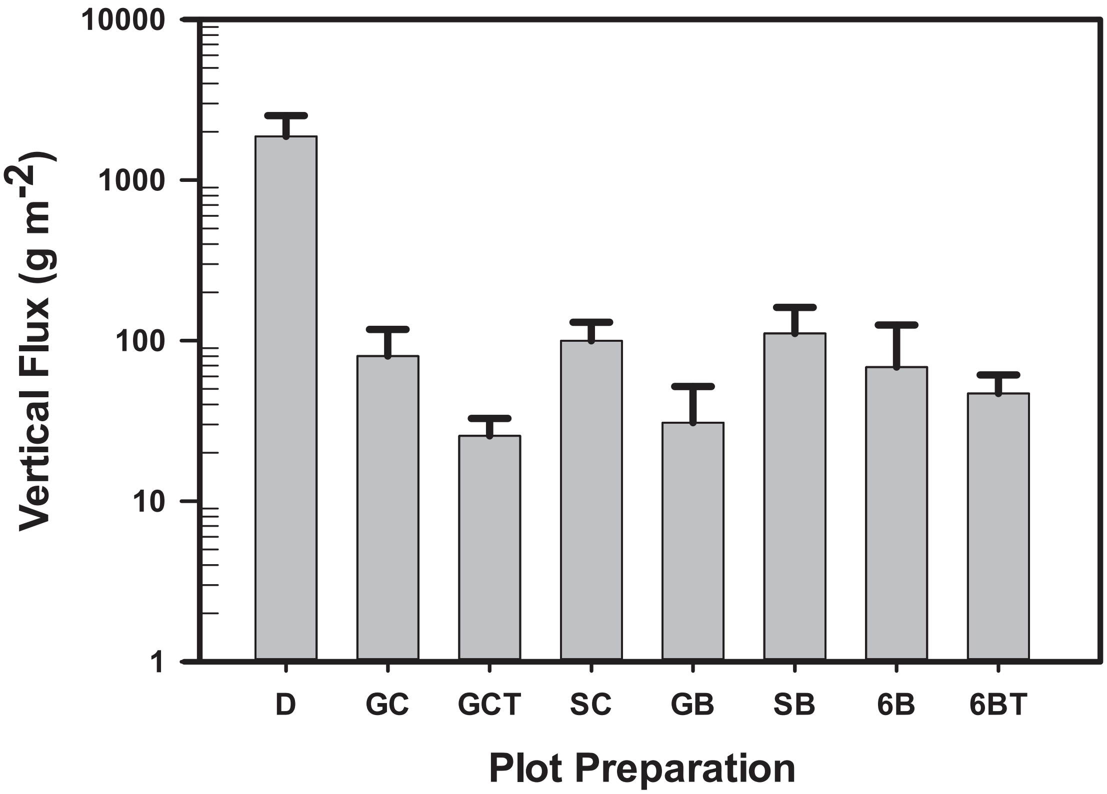


fig2

Fig3



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1
Vertical Flux (g m-2)
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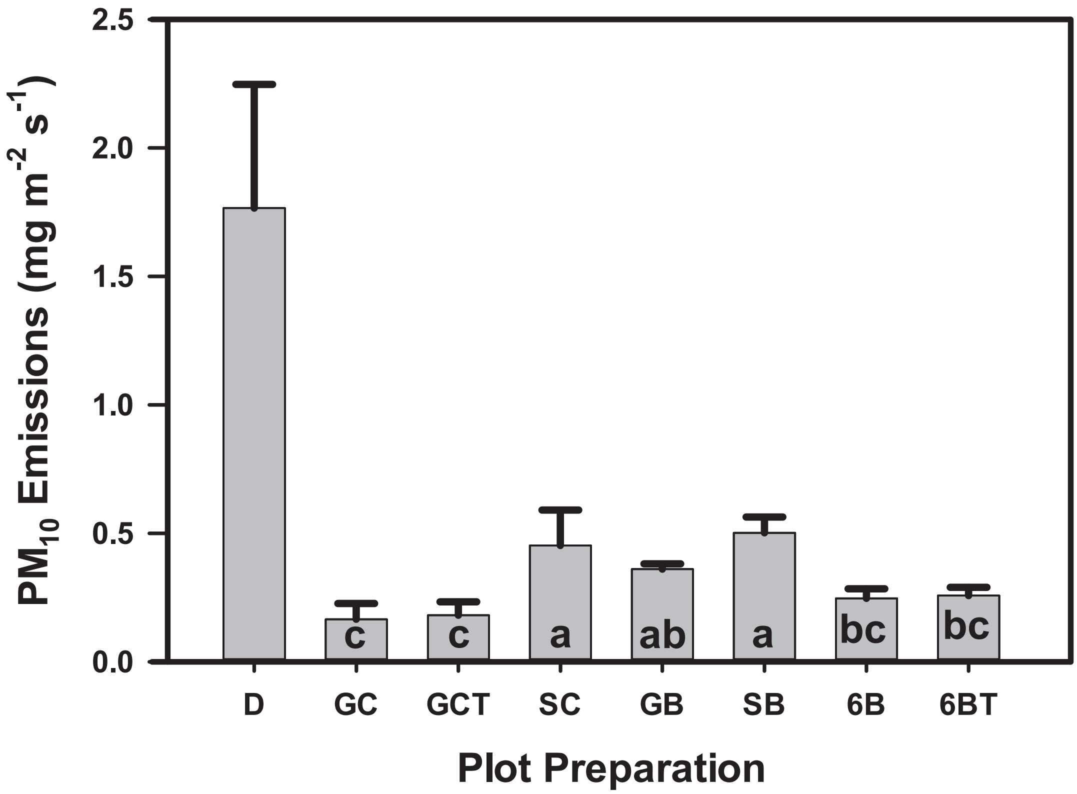
Plot Preparation

fig4



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PM10 Emissions (mg m-2 s-1)
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ab
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bc
bc
D
GC
GCT
SC
GB
SB
6B
6BT
Plot Preparation

fig5