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Impact of Foot Traffic from Military Training on Soil and Vegetation Properties[1]

CAPTAIN (USAF) RANDY C. A. WHITECOTTON[2,3]*
MARK B. DAVID[2]
ROBERT G. DARMODY[2]
DAVID L. PRICE[3]
[2]University of Illinois
Department of Natural Resources and Environmental Sciences
W-503 Turner Hall, 1102 S. Goodwin Av.
Urbana, Illinois 61801, USA
[3]US Army Engineering Research and Development Center
Construction Engineering Research Laboratory
Military Lands Division
PO Box 9005
Champaign, Illinois 61826, USA

ABSTRACT / The impact of military training activities (primarily foot traffic) on soils and vegetation was assessed at the United States Air Force Academy, Colorado, USA. In May–June 1998 after 2 years of intensive training use, mean bulk densities of the top 6 cm of soil in the high-use site (1.37 g/cm^3) and moderate-use site (1.30 g/cm^3) were significantly different from bulk density of the reference site (1.04 g/cm^3). Mean infiltration rates on the high use site (0.63 cm/min) and moderate use site (0.67 cm/min) were significantly different from the infiltration rate on the reference site (3.83 cm/min). Soil water holding capacities of the three sites were not significantly different. Descriptive comparisons of total aboveground biomass and litter indicated a 68% decrease in total aboveground biomass and a 91% decrease in litter when the high-use site was compared to the reference site. Using the Universal Soil Loss Equation, an estimated soil erosion rate for the reference plot (0.07 tons/ha/yr) was 30 times less than the erosion rate for the high use plot in the center of the basic cadet training encampment area (2 tons/ha/yr) and between 7 and 6 times less than the moderate use plot and the high use plot on the edge of the encampment area (0.5 and 0.4 tons/ha/yr, respectively). Therefore, training use appears to adversely affect bulk density, infiltration, total aboveground biomass, litter, and erosion. Without implementation of restoration practices, further site degradation is likely.

The mission of the United States Air Force is one of national defense. In order to accomplish this vital mission, the Air Force must produce qualified officers to lead the Air Force in protecting the nation. Due to the military nature of its mission, the United States Air Force Academy must conduct training exercises in natural areas to prepare its cadets for future war and peacetime contingency operations. In recent years the Department of Defense (DoD) has become more concerned with the natural resources entrusted to it on its 10.1 million hectares of land. Soils are a primary natural resource that can be disturbed by mechanical means, such as heavy equipment, livestock and animal trampling, and human recreational use. The DoD training areas are greatly impacted where tanks and other heavy equipment are used, but foot traffic can also disturb sites.

Past research on human foot traffic disturbance (trampling) of soils has focused primarily on recreational sites (e.g., campgrounds, trails, and picnic areas). Human foot traffic has been shown to increase bulk densities on recreational sites (Lutz 1945, Dotzenko and others 1967, Settergen and Cole 1970, Monti and Mackintosh 1979, Reed 1983, Trumbull and others 1994). Trumbull and others (1994) found that infiltration rates significantly decreased on recreational sites. Recreational use, which removed the litter layer and vegetative cover, caused compaction and subsequent erosion of the surface A horizon, and ultimately reduced water infiltration (Lutz 1945, Brown and others 1977). On wet sites, trampling also reduced pore space and the availability of moisture (Dawson and others 1978, Dunn and others 1980, Geohring and others 1992). LaPage (1962) concluded that compaction was most prevalent in the upper 15 cm of soil, and other researchers found that roots were nearly absent in these upper 15 cm of soil on recreational sites (Settergen and Cole 1970).

Young and Gilmore (1976) found that on Illinois

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*Author to whom correspondence should be addressed at: Air Force Institute of Technology, Civil Engineer and Services School, 2950 P Street, Bldg 643, Wright-Patterson Air Force Base, Ohio 45433-7765 USA.

campgrounds recreational use caused increases in soil pH, nitrogen (N), phosphorus (P), potassium, calcium, and sodium concentrations. They hypothesized that this was due to reduced leaching from soil compaction combined with nutrient additions in food and soap used at campsites (Young and Gilmore, 1976). LaPage (1967) reported ground cover loss on silt loam soils was accelerated by human kicking of loose gravel. Young (1978) determined from studies on Illinois campgrounds that the litter layer decreased by 71% and bare ground increased by 56% when compared to a control site. Trumbull and others (1994) reported that recreational sites lost 28–61 cm of soil due to erosion. Lack of vegetation and ground cover is typically the foremost factor contributing to soil erosion (Hofmann and Ries 1991).

Vegetation on recreational sites can be impacted when roots are exposed by erosion (Cole 1982). Dunn and Carroll (1985) found recreational use decreased vegetation and litter by 56% and the species composition by 25% in comparison to the control site. Cole (1995a) reported that recreational sites with shrubs as the predominant vegetative type sustained more damage and took longer to recover than sites with forbs as the predominant vegetative type. Cole (1995b) found that with low trampling intensities (i.e., number of passes across a recreational site), heavy tramplers caused more vegetative loss than light tramplers did. Dawson and others (1978) found in their Iowa campground study that, following camping disturbance, native vegetation was replaced by trample-tolerant plants or by bare ground. Dunn and Carroll (1985) found that the centers of campsites were most denuded of vegetation and litter and that ground cover declined rapidly during the first year of recreational use. This rate of decline leveled off after a couple of years of use as more drought-resistant species invaded the site, which changed the community composition.

We hypothesize that training activities at the United States Air Force Academy Jack's Valley Training Area lead to soil and vegetative disturbances similar to the impacts caused by recreational use. Thus, these potential consequences were studied using methods predominantly employed in recreational use assessment. The objectives of this research were to determine the effects of foot traffic from training on vegetative, soil physical, and soil chemical properties and to use these measured soil and vegetative properties to assess the potential for soil erosion.

Materials and Methods

The research area was located in Jack's Valley Training Area (JVTA) at the United States Air Force Academy (USAFA). The USAFA covers 7500 ha, and JVTA includes about 12% of the total (900 ha). The elevation of Jack's Valley ranges from 2035 to 2200 m, and the elevation of the research area ranges from 2040 to 2050 m. The climate of the region is characterized by warm summers and cold winters (Larsen 1981). The annual average daily temperature is 9.4°C with an average daily minimum of −7.8°C in the winter and an average daily maximum of 27.8°C in the summer. The majority of precipitation occurs in thunderstorms during the warm period; annual average precipitation is 40 cm. Average annual snowfall ranges from 106 cm at lower elevations to 183 cm at higher elevations.

Three field sites were used: a reference site (low use intensity), a moderate-use site, and a heavy-use site (Figure 1). The impacts of the cadet training activities on the high- and moderate-use sites were compared to the impacts on the reference site (an undisturbed control site with similar slope, soils, aspect, and elevation was not available). The reference site was located north of the intermittent stream, outside of the main basic cadet training encampment area, whereas the other sites were within the encampment area. The sites were similar in terms of vegetation, soils, and slope. The aspects of the research sites differed, but due to the minimal grade of the slopes (<2%), the difference was not considered significant. Within each of the three sites, five plots (approximately 3 × 3 m) were randomly selected for soil sampling. Four additional plots (10 × 10 m) were selected for vegetation sampling, two in the high-use site, and one each in the moderate and reference sites.

The high-use site has been used intensively since 1996 for a 16-day period during July for basic cadet training encampment. This encampment supports 38 tents and approximately 450 cadets. In addition, during the rest of the year, but primarily during the summer months, the high-use site has been used for 10–12 overnight encampments and many associated field exercises. Cadets have camped, marched, undertaken physical training, and filled sandbags on this site as well. The moderate-use site was located downslope from and near the high-use site. Since 1996 the moderate-use site has been used mostly during July for the 16-day basic cadet training encampment period for physical training and some marching activities. The reference site's location across the intermittent stream minimized foot traffic (Figure 1). Deer frequently graze the area during periods of inactivity. Historically, the area was farmed in the early 1900s, but this practice was soon discontinued due to the erosivity of the soils. Following the failed attempts at farming, the area was used for grazing until the Academy was established in 1954. Jack's Valley

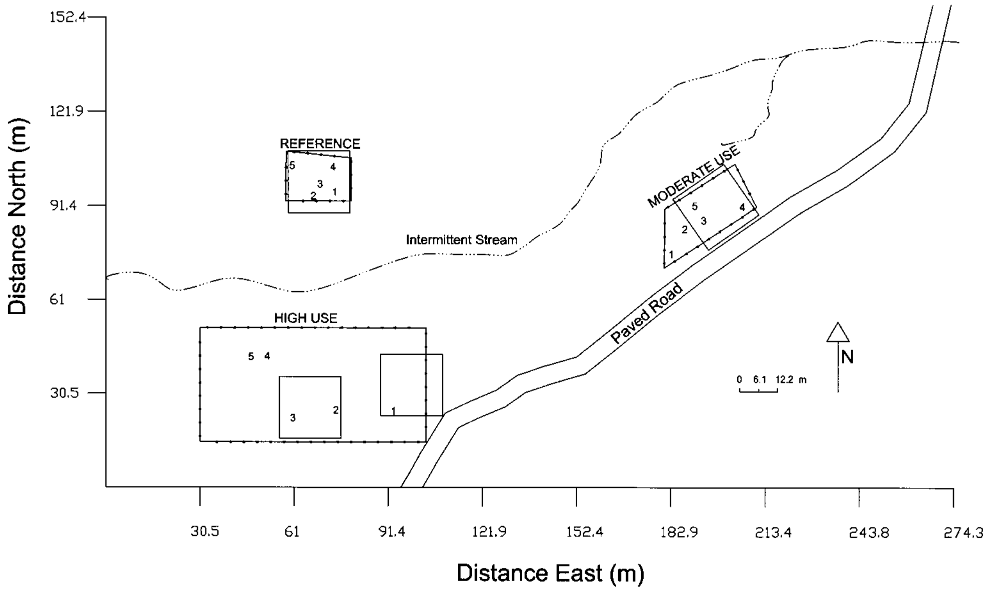

Figure 1. Map of the research area at Jack's Valley Training Area. The three study sites are labeled as reference, moderate-use, and high-use and are represented by a fence line. The five soil sampling plots within each site are numbered. The four vegetation sampling plots are represented by solid-line boxes.

Training Area includes seven primary plant communities: ponderosa pine woodland, ponderosa pine–Gambel oak woodland, Gambel oak shrubland, little bluestem–blue grama grassland, smooth brome grassland, early seral annuals/bare ground, and riparian edge along Monument Creek. The research area, although made up entirely of grassland communities, did not easily fit into these primary plant communities because the training disturbances had induced successional diversity. The reference site was a native grassland with community type *Stipa–Koeleria* species. The moderate-use site was early to mid-seral stage grassland/bare ground, with some *Stipa–Koeleria* species. The center of the high-use site was an early seral stage grassland/bare ground, with *Bromus* species. The edges of the high-use site were early to mid-seral stage grassland/bare ground, with *Stipa* species.

The soils in the research area were mapped as Pring sandy loam (a coarse loamy, mixed Aridic Haploboroll), although a few of the plots had a loamy sand surface texture, which would indicate the Tomah soil series (a coarse loamy, mixed Boralfic Argiboroll) (Larsen 1981). Pring and Tomah soils are part of the soil association commonly found on cold, semiarid foothills of the Rocky Mountains to include fans, terraces, ridges, and side slopes. The soils are primarily deep, nearly level to slightly sloping, well-drained soils that formed in material weathered from arkosic sedimentary rock.

Five soil cores were collected (in May 1998 before training) from each plot (75 cores total) and divided by depth (0–5, 5–10, and 10–20 cm) to determine texture and total C and N. Samples within a plot at a given depth were combined for analyses (45 composited samples). Bulk density (5 samples per plot, 75 total) and soil water holding capacity samples (2 samples per plot, 30 total) were collected from the 0-to-6-cm depth with a double-cylinder, hammer-driven core sampler (Blake and Hartge 1986). Bulk density samples were collected again shortly after the 16-day basic cadet training encampment (in August 1998). Infiltration rate was determined at six locations in each site. Soil preparation procedures for texture, total C, and total N analyses followed US EPA (1990).

Bulk densities were adjusted for coarse fragment content by assuming a particle density of 2.65 g/cm^3, and then calculating the bulk density as the mass of <2 mm soil divided by total core volume minus the volume of coarse fragments. Soil macropores were calculated as the air-filled pore space at 0.33 bars. Infiltration rate was determined with a 12-cm-diameter, 12-cm-high constant-depth infiltrometer (Bouwer 1986, USDA 1998). Two repetitions were conducted in the first plot of each site to standardize the techniques across the sites and to ensure leakage was not occurring; otherwise, one repetition of the experiment was conducted within each plot. Particle-size analysis was by hydrometer for clay and silt; sand was determined by sieving through a standard USDA sieve set (Gee and Bauder 1986). Soil water-holding capacity was measured using the pressure plate method at 0.10, 0.33, or 15.0 bars (Klute 1986). Total C and N concentrations in soil samples were determined using an elemental analyzer (US EPA 1990).

Plant biomass and litter samples were collected using four 20- × 20-m plots to assess grassland communities and intensities of use: a high-use plot in the center of the basic cadet training encampment area, another high-use plot at the edge of the encampment area, a plot within the moderate-use site, and a plot within the reference site. Ten quadrats (each 0.5 m^2) were randomly placed within each plot. The vegetation was identified, clipped, composited by species, oven-dried at 50°C to achieve a constant weight, and then weighed to determine the species-specific biomass (grams per square meter) within each quadrat. Litter was also collected within each quadrat, oven-dried at 50°C, and weighed. Vegetative species and litter samples across each plot were composited.

The Universal Soil Loss Equation (USLE) was used to estimate rates of soil erosion occurring on the research area. USLE is defined as $A = R \times K \times L \times S \times C \times P$, where A is the gross erosion rate, R is the rainfall erosivity factor, K is soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the vegetation factor, and P is the conservation management factor (Wischmeier and Smith 1960). The USLE factors were determined for each plot based on the measured soil properties collected at the research area (e.g., K, L, and S) or obtained from US Department of Agriculture (USDA 1994) for local values (e.g., R, C, and P). A standardized plot size of 1 ha was used in computing the gross erosion rate, A.

One-way analysis of variance (ANOVA) with subsampling and Tukey's studentized range tests were conducted on the measured properties (SAS Institute 1990). Statistical significance for ANOVA and mean separation was determined using a P value of 0.05.

Results and Discussion

Bulk Density

During July of 1996, 1997, and 1998 the research area had been used for a 16-day basic cadet training encampment, with other less intensive training use occurring throughout the year. Bulk density samples were collected in May–June 1998 prior to the July 1998 basic cadet training encampment (preencampment samples) and in August 1998 following the July basic cadet training encampment (postencampment samples).

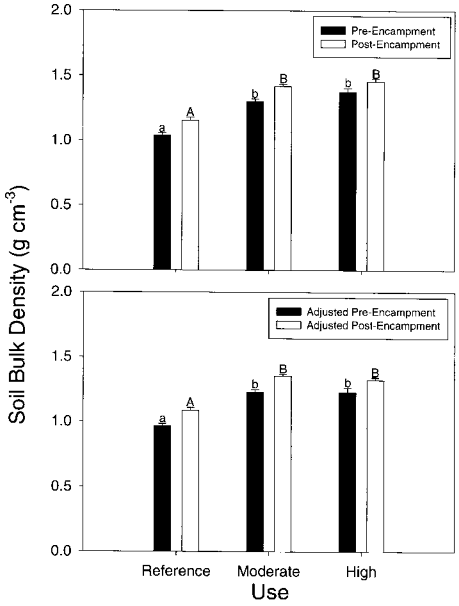

Figure 2. Pre- and postencampment mean soil bulk densities and adjusted soil bulk densities (with standard errors, $N = 25$, and adjusted for coarse fragments) based on intensity of use. Means with same letter and case style are not significantly different ($P > 0.05$).

The reference site had a mean bulk density of 1.04 g/cm^3, which was significantly lower than the mean bulk densities of the moderate-use site (1.30 g/cm^3) and the high-use site (1.37 g/cm^3) (Figure 2). The bulk densities of the high and moderate use sites were not significantly different. These results are similar to the findings of Monti and Mackintosh (1979) and Trumbull and others (1994) that camping increases soil bulk densities. Trumbull and others (1994) likewise found no significant differences between the bulk densities on their low-use and high-use campsites. Although the use categories are subjective, it is assumed that the application by Trumbull and others (1994) of the low-use definition is comparable to our moderate-use site and their control is similar to our reference site. The lack of significant difference in the soil bulk density between our moderate-use site and high-use site indicates that even a small amount of use can compact a training site.

Soil compaction tends to be greater towards the center of camping areas (Cole 1982). The highest bulk density we found (1.84 g/cm^3) was in plot 3 at the center of the high-use site. The lowest soil bulk density (0.90 g/cm^3) was found in plot 3 of the reference site. Differences of this magnitude have been reported for campsites (Dotzenko and others 1967, Monti and Mackintosh 1979).

The postencampment samples were also compared to determine if site usage during a third year of the 16-day basic cadet training encampment affected bulk densities (Figure 2). Although the same pattern was found in bulk densities due to treatment as was noted before encampment, differences were found between the preencampment and postencampment bulk densities. Preencampment bulk densities for each of the sites were significantly lower than postencampment bulk densities (using *t* tests). These results indicate that the 16-day basic cadet training encampment activities may have increased the bulk densities on all three sites, although seasonal variation may have also been important (i.e., desiccation or collapse of ice expansion from the previous winter). The reference site was subjected to a small amount of training use during the the third basic cadet training encampment, which might explain the increase in its bulk density.

To remove variation in soil bulk densities due to coarse fragment content, the coarse fragment content of each sample was subtracted and an adjusted bulk density was then calculated (Figure 2). The same patterns and significant differences in bulk density were found as in the unadjusted data which indicates that the differences we found were not due to differing coarse fragment contents.

Texture

Soil texture is closely related to bulk density and is an important indicator of a soil's susceptibility to compaction (Reed 1983). The texture of the surface soils in the plots at the high-use site was sandy loam (data not shown). Three of the five plots within the moderate-use site were sandy loams; the remaining two plots were loamy sands. For the reference site, three of the five plots were sandy loams, whereas the remaining two plots were loamy sands. Although there was some variation in the soil textures across the research area, analysis indicated no significant effects on bulk density.

The clay contents of the sites, which ranged from 4 to 10%, were compared to determine its effect on bulk density. The difference in clay contents among the different site usages was not significantly related to bulk density. The site usages were also compared by coarse fragment content, which ranged from 1.4% to 36.8% by volume, with a mean of 6.4%. The differences in coarse fragment contents among the different site usages were also not significant. The overall conclusion is that differences in coarse fragment content were not responsible for the bulk density differences we found.

Infiltration

Infiltration rates were related to site usage. At the reference site, the infiltration rate was 3.83 cm/min, significantly higher than the rates at the moderate-use site (0.67 cm/min) and the high-use site (0.63 cm/min). The infiltration rates of the high and moderate use sites were not significantly different from each other. Our results are similar to the findings of Lutz (1945), Trumbull and others (1994), and Monti and Mackintosh (1979); infiltration rates are significantly less on recreational sites. The mean infiltration rate at our reference site was 6 times greater than the moderate- and high-use sites. Although this difference was not as large as that measured by Monti and Mackintosh (1979), it matched what Lutz (1945) reported from his studies on sandy soils where infiltration rates on high use sites decreased by 6 times when compared to the control sites.

There were several possible reasons for the lower infiltration rate found on the high use site. First, as stated by Dunne and Leopold (1996), the decrease in vegetative cover due to land use changes caused large differences in infiltration on similar soil types. Second, Dawson and others (1978) found soil macropore space was 18% lower on campsites than the control site. We found a significant decrease in soil macropores between the reference versus both the medium- and high-use sites (57%, 46%, and 43% macropores in low-, medium-, and high-use sites, respectively). Another factor affecting infiltration rates may have been macrofaunal activity at our sites. Gopher activity on the reference site was high, as indicated by the large amount of gopher burrow midden material that was present throughout the entire reference site. No gopher midden was found on either the moderate- or high-use site. A feedback probably existed on the reference site where the lack of human recreational activity encouraged mammal activity, which in turn contributed to improved infiltration on this site. Reasons for this significant difference in mean infiltration rates included the greater surface vegetative and litter cover, the lower bulk density, the greater porosity, and the large number of gopher burrows on the reference site.

Soil Water-Holding Capacity

The intensity of use did not impact the soil water-holding capacity of the soils in the research area. There were no significant differences in mean soil water-holding capacities of the sites (Figure 3). In addition, the moisture retention curves were similar. Most water was drained out of the pores with relatively little pressure (0.33 bars, field capacity) being applied, as is typical in coarse-textured soils. Coarse-textured soils contain large numbers of macropores where gravitational forces easily drain the water. Little water remained in the pores as available water of the samples between 0.33

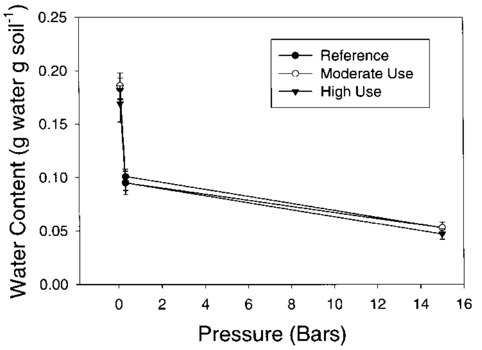

Figure 3. Moisture retention curves (with standard errors) for soils (0–6 cm) based on intensity of use ($N = 10$).

bars (field capacity) and 15 bars (permanent wilting point).

Soil Total Carbon and Nitrogen

Both total C and total N concentrations generally decreased with depth in all samples. At the 0- to 5- and 5- to 10-cm depths, the mean total C concentration of the reference site (1.83 and 1.17 g/kg, respectively) was not significantly different from either the mean total C concentration of the moderate use site (1.80 and 1.0 g/kg, respectively) or the high use site (1.72 and 1.25 g/kg, respectively) (Figure 4). At the 10- to 20-cm depth, the mean total C concentration of the high use site (0.67 g/kg) was significantly different from the mean total C concentration of the reference site (0.93 g/kg). This difference between the mean total C concentrations of the high use and reference sites based on intensity of use, however, was not meaningful, as no pattern existed to explain the difference at this depth of 10–20 cm.

At all three depths, the mean total N concentration of the reference site (0.13, 0.09, and 0.07 g/kg, respectively) was not significantly different from either the mean total N concentration of the moderate-use site (0.14, 0.09, and 0.07 g/kg, respectively) or the high-use site (0.12, 0.1, and 0.05 g/kg, respectively). At the 0- to 5-cm depth, the C to N ratio of the reference site (16.6 mol/mol) was not significantly different from the C to N ratios of the moderate-use site (14.8 mol/mol) or the high-use site (16.4 mol/mol). At the 5- to 10- and 10- to 20-cm depths, the C to N ratio of the moderate-use site (12.7 and 12.4 mol/mol, respectively), however, was significantly different from the C to N ratio of the reference site (15.5 and 16.4 mol/mol, respectively) and the high use site (15.1 and 14.9 mol/mol, respectively). This difference between the C to N ratios based on intensity of use, however, was not meaningful, as no pattern existed to explain the difference. Therefore, the intensity of use did not affect C and N concentrations in these soils.

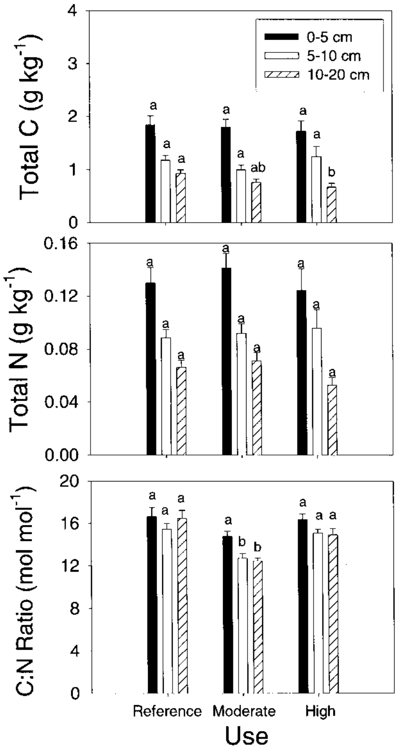

Figure 4. Mean total C concentration, total N concentration, and ratio of total C to total N concentration (with standard errors) for soils based on intensity of use. Means within a depth and with same letter are not significantly different ($P < 0.05$).

Plant Biomass and Litter

Aboveground biomass was 134, 81, 42, and 78 g/m^2 for low-, moderate-, and high-use center and high-use edge plots, respectively (Table 1). Corresponding mass amounts for litter were 104, 27, 10, and 26 g/m^2, respectively. A comparison between the reference plot and the high use plot in the center of the basic cadet training encampment area indicates a 68% decrease in total aboveground biomass and a 91% decrease in litter. A comparison between the reference plot and both the moderate-use plot and the high-use plot on the edge of the encampment area showed less of an effect: a 40% decrease in total aboveground biomass and a 75% decrease in litter. Possible reasons for this drastic denudation of vegetation and litter from the moderate- and high-use sites included mechanical trampling of vegetation by the cadets (Dunn 1984), the moderate impact from the lug-soled boots used by the cadets (Cole 1995b), and the kicking up of gravel damaging

Table 1. Total aboveground biomass and litter results

Species	Dry mass (g/m^2)	% Relative biomass
Low-use plot		
Stipa comata	47.4	35.3
Artemisia frigida	35.74	26.7
Sporobolus asper	14.3	10.7
Carex rossii	10.1	7.5
Bouteloua gracilis	8.6	6.4
Eriogonum annuum	2.8	2.1
Bromus tectorum	2.1	1.5
Verbascum thapsus	1.9	1.4
Tradescantia occidentalis	1.9	1.4
Sitanion hystrix	1.7	1.3
Poa pratensis	1.7	1.3
Linaria dalmatica	1.3	1.0
Koeleria macrantha	1.1	0.8
Bromus japonicus	1.1	0.8
Senecio fendleri	0.6	0.5
Dalea purpurea	0.4	0.3
Gaura coccinea	0.4	0.3
Cryptantha sp.	0.3	0.2
Agropyron smithii	0.3	0.2
Conyza canadensis	0.3	0.2
Sporobolus cryptandrus	0.3	0.1
Total aboveground biomass	134.1	
Biomass—grasses	78.5	
Biomass—forbs/sedges	55.6	
Litter	103.8	
Moderate-use plot		
Koeleria macranths	35.2	43.7
Stipa comata	19.6	24.3
Carex rossii	5.6	6.9
Bouteloua gracillis	4.2	5.2
Sporobolus asper	3.5	4.3
Agropyron smithii	3.4	4.2
Rosa woodsii	1.5	1.9
Thelosperma megapotamicum	1.2	1.5
Heterotheca villosa	1.1	1.4
Artemisia frigida	0.9	1.2
Oenothera albicaulis	0.9	1.1
Dalea purpurea	0.7	0.9
Linaria dalmatica	0.6	0.7
Lesquerella montana	0.5	0.6
Tradescantia occidentalis	0.4	0.5
Tragopogon dubius	0.4	0.5
Lithospermum incisum	0.4	0.5
Liatris punctata	0.4	0.5
Plantago patagonica	0.1	0.1
Total aboveground biomass	80.7	
Biomass—grasses	65.9	
Biomass—forbs/sedges	13.3	
Biomass—shrubs	1.5	
Litter	27.2	
High-use plot, center of encampment		
Bromus tectorum	13.6	32.1
Erodium cicutarium	6.8	16.1
Poa pratensis	6.7	15.8
Sitanion hystrix	4.9	11.6
Sporobolus cryptandrus	3.1	7.4
Carex rossii	1.1	2.6
Plantago patagonica	1.0	2.4
Dalea purpurea	0.9	2.1
Cryptantha virgata	0.9	2.0
Bouteloua gracillis	0.8	1.9
Koeleria macrantha	0.7	1.7
Conyza canadensis	0.6	1.3
Linaria dalmatica	0.4	1.0
Agropyron smithii	0.3	0.7
Vulpia octoflora	0.2	0.5
Taraxacum officinale	0.1	0.3
Antennaria parvifolia	0.1	0.3
Linum sp.	0.1	0.1
Total aboveground biomass	42.4	
Biomass—grasses	30.4	
Biomass—forbs/sedges	12.0	
Litter	9.7	
High-use plot, edge of encampment		
Stipa comata	17.9	22.9
Sporobolus asper	10.5	13.4
Linaria dalmatica	8.6	11.0
Poa pratensis	8.4	10.8
Carex rossii	7.3	9.3
Bromus tectorum	4.7	6.0
Koeleria macrantha	3.8	4.8
Bouteloua gracillis	3.3	4.2
Artemisia frigida	2.7	3.4
Andropogon gerardii	2.3	3.0
Heterotheca villosa	2.2	2.8
Dalea purpurea	1.5	2.0
Vulpia octoflora	1.2	1.5
Verbena bracteata	1.1	1.4
Plantago patagonica	0.9	1.1
Lithospermum incisum	0.6	0.7
Erodium cicutarium	0.3	0.4
Sporobolus cryptandrus	0.3	0.3
Verbascum thapsus	0.2	0.3
Taraxacum officinale	0.2	0.3
Castilleja linearifolia	0.1	0.2
Arenaria fendleri	0.1	0.1
Unknown 7	0.1	0.1
Eriogonum annuum	0.1	0.1
Cryptantha virgata	0.1	0.1
Total aboveground biomass	78.4	
Biomass—grasses	52.4	
Biomass—forbs/sedges	26.0	
Litter	26.2	

the vegetation (especially on the high-use plots in the center of the basic cadet training encampment area, H2 and H3, where coarse fragment content was high) (Dunn 1984).

These results reinforced the findings of Monti and Mackintosh (1979) and Dunn and others (1980) that recreational activity reduces vegetation and the litter

Table 2. Potential erosion estimates using universal soil loss equation by intensity of use[a]

Site and plot	Soil erodibility factor (*K*)	Slope-steepness factor (*S*)	Topographic factor (LS)	Vegetation factor (C)	Erosion rate (A) (tons/ha/yr)
Reference	0.15	2	0.34	0.008	0.007
Moderate use	0.15	1	0.22	0.08	0.5
High use-edge	0.14	1	0.22	0.08	0.4
High use-center	0.14	1	0.22	0.38	2.0

[a] For all United States Air Force Academy plots the rainfall erosivity factor (*R*) was 80, the slope-length factor (*L*) was 250, and the conservation management factor (*P*) was 1.

layer. Dunn and Carroll (1985) found recreational use decreased vegetation and litter by 56%. They also found that the center of campsites was more denuded than the rest of the camping area. Research on Illinois campsites found litter layers decreased by 71% (Young 1978).

Wagar (1964) found that grasses were more tolerant than broad-leaved species to recreational trampling. Yorks and others (1997) reported that following recreation, forbs suffered immediate loss, and shrubs and trees decreased in long-term diversity. A comparison of the forb biomass between the reference plot (56 g/m^2 forbs) and the high use plot-center (12 g/m^2) of the encampment area showed a 78% decrease. A comparison of the forb biomass between the reference plot and the moderate-use plot (13 g/m^2 forbs) showed a 76% decrease. As suggested by the research of Dawson and others (1978) and Dunn and others (1980), the training activities induced disturbance, which led to the early seral annuals/bare ground communities found on the training sites. It appeared the basic cadet training activities drastically denuded the vegetative cover and litter layer and reduced the life form diversity.

Potential Soil Erosion

Because erosion rates were not measured directly, the USLE was used to estimate potential soil erosion rates (*A*). USLE estimates of a potential erosion rate for the reference plot (0.07 tons ha/yr) was 30 times less than the erosion rate for the high-use plot in the center of the basic cadet training encampment area (2 tons/ha/yr) (Table 2). The potential erosion rate estimate for the reference plot was between 6 and 7 times less than the rates for the moderate- and the high-use plots on the edge of the encampment area (0.5 and 0.4 tons/ha/yr, respectively). Training activities appeared to have drastically increased the potential for soil erosion on the high and moderate use sites, primarily due to the vegetation factor (C). As more soil and litter are lost from the research area, vegetation cover is diminished, resulting in even more soil erosion. Soil erosion from the grassland sites in JVTA could degrade the plant and animal habitat and diminish the water quality and aquatic habitat of Monument Creek. Therefore, some restoration efforts should be undertaken.

Management and Restoration

Use of the research area for basic cadet training encampment is essential to the mission of the United States Air Force Academy. Continued use of the research area for basic cadet training encampment and other uses, however, may further degrade the soils and vegetation to such an extent that soil erosion will result. Past research indicates several management and restoration practices, if properly implemented, that may minimize the impacts of the training use. These practices include, but are not limited to:

1. Significantly reducing or eliminating the other training uses.
2. Restricting training to roads, trails, and previously established areas. Past research, although not completely in agreement, seems to indicate that concentrating use to a few sites, when properly managed, is preferred over spreading out training use.
3. Implement comprehensive education and awareness programs.
4. Revegetation with resistant grasses should occur several meters outside of basic cadet training encampment area center. In the center, apply mulch to reduce soil erosion. Temporary fencing or planting of shrubs will reduce spread of trampling.
5. In compacted areas outside of the center of the basic cadet training encampment area, aerating the soil will help alleviate compaction, improve infiltration, decrease runoff, and thereby facilitate revegetation efforts.

Conclusion

In keeping with this environmental mission, this research has several implications for the United States Air Force Academy's use of Jack's Valley Training Area. Three years of intensive use has caused significant impacts, which include increased bulk densities and compaction, decreased infiltration, and decreased plant biomass and litter. Continued use will likely cause increased soil erosion, which could diminish plant growth, damage animal and aquatic habitats, decrease water quality, and interfere with training activities. Therefore, management and restoration practices should be implemented to minimize the impacts of this training use.

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