Response of Vegetation, Soil Nitrogen, and Sediment Transport to a Prescribed Fire in Semiarid Grasslands

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Abstract—Shrubs and trees have invaded semiarid grasslands throughout much of the Southwestern United States. This invasion not only has decreased grass cover, but also increased runoff and erosion. In fact, sediment from rangelands constitutes the single largest source of nonpoint stream pollutants within the state of New Mexico. Fire, which was a natural factor that shaped and maintained the grasslands, is a management tool that may aid in restoring and maintaining grass cover. However, fire also poses the risk of increasing erosion and further degradation because protection afforded by vegetation is reduced immediately after the fire. Using a randomized block study design, this study measured vegetation cover, soil inorganic nitrogen (N) levels, and erosion amounts associated with the first application of prescribed fire on two semiarid grasslands. The potential for adverse effects from these fires was great because they were performed at the beginning of a drought period. After the first growing season following the fire, grass cover returned to pre-burn levels, and both soil N and erosion amounts were similar to the unburned areas. Thus, prescribed fire for reducing shrub and tree cover may pose minimal adverse risk even under drought conditions.

Fire shaped vegetative communities and played a role in ecosystem dynamics long before the influence of humans. Indeed, it is difficult to find a terrestrial ecosystem that has not been influenced by fire. In North America, lightning-ignited fires shaped prairies and forests (Biswell 1989; Cook 1995; Pyne 1982; Wright and Bailey 1982). Later, Native Americans used fire for hunting, food gathering, and maintaining open savanna-like landscapes, which provided protection against enemy attack (Biswell 1989; Mitchell 1978, Pyne 1982; Wright and Bailey 1982). In the Southwestern United States, widespread fires at 5- to 10-year intervals probably maintained semiarid grasslands (Collins and Wallace 1990; Cook 1995; Gottfried and others 1995; Wright 1980; Wright and Bailey 1982). Past research has demonstrated that shrubs and trees rapidly invade grasslands in the absence of fire (Briggs and Gibson 1992; Wright 1980).

In semiarid grasslands of the Southwest, shrub and tree invasions occurred following periods of extensive grazing and droughts beginning in the late 1800's and extending to the middle 1900's (Buffington and Herbel 1965). Even without grazing impacts, fire suppression in the mid 1900's created optimum conditions for shrub invasion (Brown 1982), which replaces soil-binding perennial grasses with shrubs such as mesquite (*Prosopis* sp.), juniper (*Juniperus* sp.), burroweed (*Isocoma tenuisecta* Greene), snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby), and four-wing saltbush (*Atriplex canescens* (Pursh) Nutt.). Burroweed and snakeweed, in particular, have replaced grasslands on millions of acres in the Southwest (Brown 1982). Concurrent with shrub invasion is an increase in runoff and sediment production from grasslands. In New Mexico, sediment contributions from rangelands (predominantly grasslands) constitute the second leading cause of stream impairment by nonpoint source pollutants (NMWQCC 1994).

Sediment represents a direct degradation of water resources, but it also represents the loss of productivity and soil nutrients. Erosion in the Southwest is episodic in nature, with most soil movement occurring after large, intense storms (Debano 1977). Erosion is initiated by raindrop impaction, which breaks down soil aggregates and suspends clays in surface waters (Brooks and others 1991). Vegetation cover, especially grass cover, reduces raindrop impaction, whereas bare soil promotes runoff and loss of sediment and nutrients. The increase in bare area associated with shrub invasion contributes to increased erosion and runoff from shrub-invaded grasslands (Weltz and Wood 1986). Thus, erosion rates may decline if the grass canopy can be increased and shrubs and bare soils decreased (Brooks and others 1991; Morgan and Rickson 1995).

Drought also is a factor that leads to increased runoff and erosion. Although counter-intuitive, Molles and others (1992) reported increased summer runoff with decreasing winter/spring precipitation in semiarid regions. Thus, periods of high runoff follow periods of winter/spring drought. Mechanisms proposed by Molles and others (1992) to explain this phenomenon include: (1) decreased vegetation and herbaceous cover during drought increases the area subject to raindrop impaction, which leads to increased runoff and sediment transport; (2) an increase in soil hydrophobicity (water-repellency) during drought increases runoff; and (3) the increase in bare soil (and associated solar/albedo relationships) may contribute to generation of

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higher-intensity summer thunderstorms following drought. Davenport and others (IN PRESS 1998) demonstrate how a slight decrease in vegetative cover, which represent areas of sediment removal, can connect areas of bare soil, which greatly increases the "connectiveness" of open spaces and greatly contributes to runoff. Increased runoff has greater energy to carry sediment and erode soils. Periods of soil erosion and arroyo-cutting follow periods of drought because of the strong effects that ground cover has on erosion rates (Wood and others 1987). Cutting of arroyos favors shrubs with deeper root systems that can reach deeper soil moisture.

Perhaps the most cost-effective way of shrub control is through the use of prescribed fire. Fire favors grass growth by killing shrubs (which reduces competition for shallow soil moisture by shrubs), increasing essential nutrients in ash deposition (which is released from litter and burned vegetation), and by increasing light at the soil surface and reducing litter that acts as mulch (Wright 1980). However, in shrub-invaded grasslands, the use of fire faces several potential problems. The lack of fuel continuity may not carry a fire across the landscape, except with high winds that usually exceed those allowed under current burn prescriptions. Also, with very dispersed fuels, cost per unit area increases and the area may require multiple applications of fire to significantly reduce shrub cover. The loss of shrub and grass canopy immediately after a fire increases the potential for soil erosion and nutrient loss. An area treated with prescribed fire remains more susceptible to runoff until the grass canopy can regain and exceed pre-burn coverage. The combination of an increase in available nutrients and reduced vegetation cover creates the possibility for loss of nutrient and soil resources (Baker 1990; Vitousek and Howarth 1991).

The effects of fire can range along a gradient from minimal to extreme, dependent upon the interaction of a variety of conditions. To evaluate the effects of fire in semiarid grasslands, we constructed conceptual models that identified potential patterns of response in a number of variables based upon fire intensity or time since burning. A major factor determining the magnitude of response is the fuel load and its continuity, which are factors that contribute to fire "intensity" (total energy released per unit area). If fuels are sparse and/or widely separated, then fires will not carry across the landscape and the effects would be minimal at the landscape scale, but important to small areas (individual plant scale). Sparse fuels with high fuel continuity may carry a fire across the landscape, which will increase its spatial coverage, but will still have low "intensity" (relatively low maximum temperature, short residence times, and shorter flame lengths). If fuels are high and relatively continuous, then both coverage and intensity will increase.

Fire consumes above-ground vegetation, so vegetation cover will show an immediate decline following fire. However, nitrogen (N) mineralized during combustion of organic matter is expected to promote grass growth. Grass cover may return to or actually exceed undisturbed conditions due to reduction of litter, increased sunlight, and increased available nutrients. This would likely continue until the buildup of litter slows nutrient cycling or allows fire to progress through the system once more.

The immediate release of available N by fire is well documented in nearly all vegetation types, but there is little information on the effects of fire in semiarid grasslands on potentially mineralizable N, upon which future productivity relies. The overall goal of management with prescribed fire is to increase the rate of N turnover thereby favoring vegetation that responds quickly to fire, particularly grasses and forbs.

The objectives of this research were to determine the effects of prescribed fire in two semiarid grasslands on vegetation cover-type (bare, grass, or shrub), potentially mineralizable N (as a measure of site fertility) and soil erosion. Specific hypotheses included: (1) after an initial decline in vegetation cover, grasses should respond more rapidly than shrubs and achieve greater cover relative to shrubs; (2) N in ash should increase the amount of mineralizable N following the fire, but mineralizable N should return to that of control or unburned soils following regrowth of vegetation; and (3) high intensity precipitation should increase erosion following burning until the vegetation cover recovers, which would then lead to a decline in erosion. This article presents the 1-year results of the first in what is expected to be many prescribed fires directed at decreasing shrub invasion into semiarid grasslands in central New Mexico.

Methods

Site Description

The research is conducted at two study sites near Albuquerque, New Mexico. The West Mesa site is west of the City on Open Space property (fig. 1), and the Bernalillo Watershed is north of the City on Cibola National Forest property (fig. 1). The elevation of the West Mesa site is about 1820 m and the Bernalillo Watershed is about 1660 m. The West Mesa soil is a fine sandy loam and the Bernalillo Watershed soil is a clayey loam (CS White, unpublished data, 1996). The West Mesa grassland represents a Great Basin Desert Scrub/Desert Grassland ecotone, and the Bernalillo Watershed represents a Plains-Mesa Grassland/Desert Grassland ecotone (Brown 1982). Dominant perennial grasses on the Bernalillo Watershed were: black, blue, and sideoats grama (*Bouteloua eriopoda* (Torr.) Torr., *B. gracilis* (Willd. ex Kunth) Lag. ex Griffiths, *B. curtipendula* (Michx.) Torr.), respectively); purple threeawn (*Aristida purpurea* Nutt.); galleta (*Hilaria jamesii* (Torr.) Benth); and dropseed (*Sporobolus* sp.). Dominant perennial grasses on the West Mesa were: Indian ricegrass (*Oryzopsis hymenoides* (Roem & Schult.) Ricker): needle-and-thread grass (*Stipa comata* (Trin. & Rupr.)); purple threeawn; galleta; black grama; and dropseed. Annual precipitation for both sites averages about 20 to 25 cm; however, precipitation measured at the Albuquerque station of the U.S. Weather Bureau during the study period was considerably less than the monthly mean of the previous 40 years (fig. 2a). A precipitation deficit began during the beginning of 1995 and lasted through the first 5 months of 1996, after which slightly higher than normal precipitation occurred through the rest of 1996 (fig. 2b).

Both sites were removed from livestock grazing; the animals were removed in 1947 from the Bernalillo Watershed and in the early 1970's from the West Mesa. Despite the removal of grazing, each site had a substantial shrub component, particularly broom snakeweed. The Bernalillo

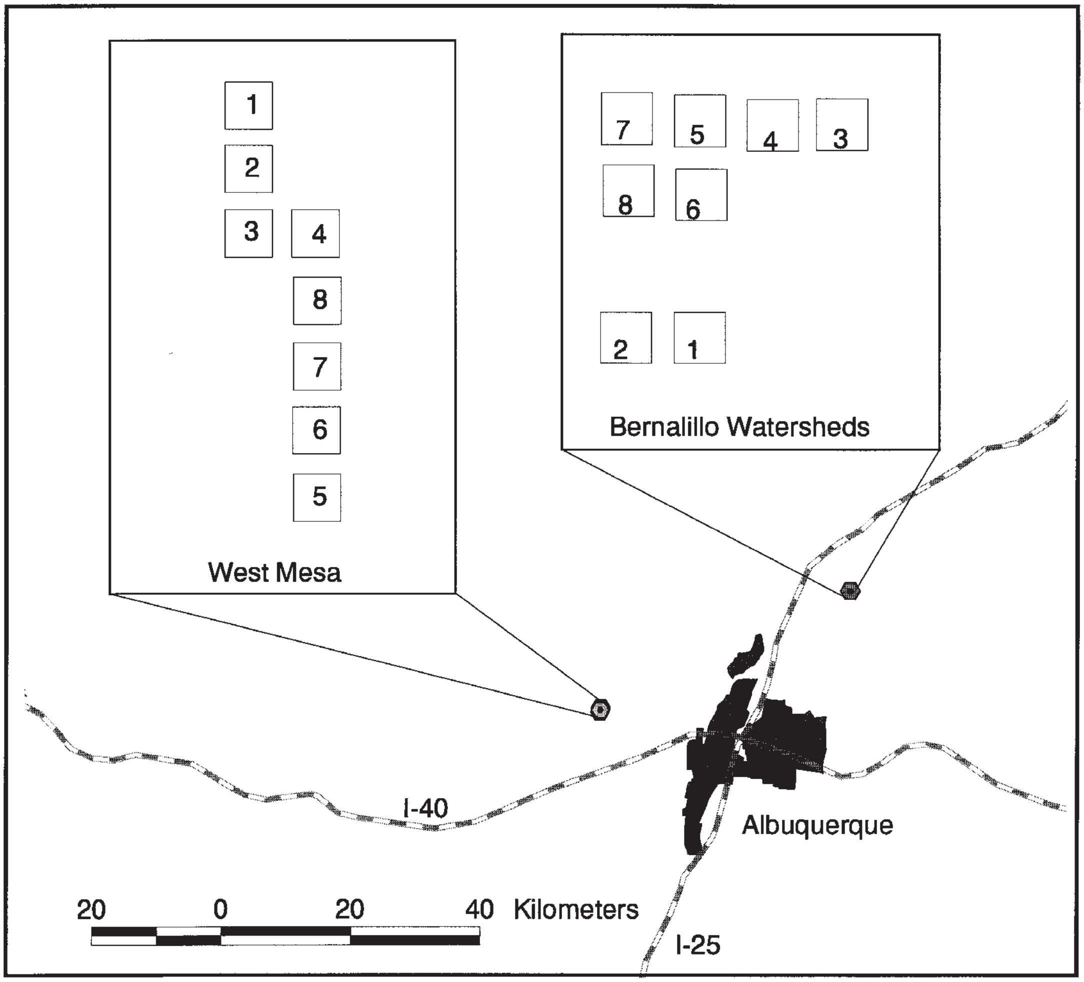

Figure 1—Map showing the general locations of the Bernalillo Watershed and West Mesa research sites located near Albuquerque, NM.

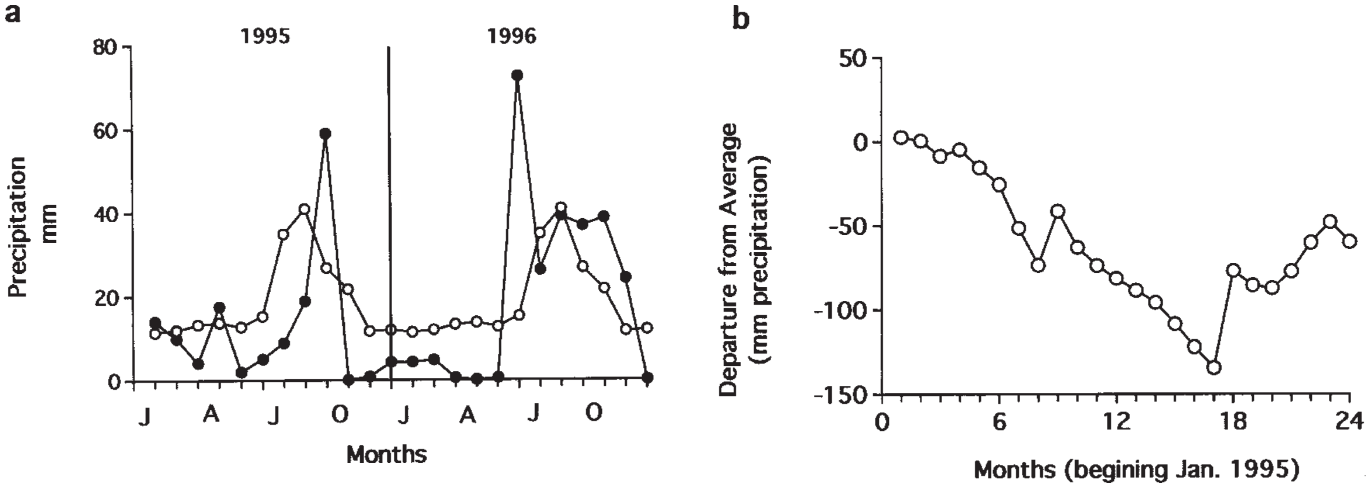

Figure 2—Monthly mean precipitation for the Abq weather station for the period since 1960 (open), and monthly precipitation (solid) during 1995 and 1996 (a), and cumulative departure curve from the long-term mean precipitation volumes beginning in 1995 through 1996 (b).

Watershed had extensive flood and erosion control features constructed by the Soil Conservation Service and the Forest Service in the 1950's, including steep-slope terraces, furrow plowing, pitting, check dams and grass seeding. These efforts followed severe flooding and erosion that blocked the main north-south highway with sediment in 1954, which occurred during a period of record-setting region-wide drought (Betancourt and others 1993).

Experimental Design

Each site includes eight plots; four control and four burned, which were arranged in a randomized block design. At the Bernalillo Watershed site, six plots (3 pairs of treatment and control) are located on one mesa, while the other two (1 treatment and 1 control) are located on a mesa to the south (fig. 1). On the West Mesa, plots were arranged in a near linear fashion below the ridge-line. At both sites, each plot is 1 ha (100 m on a side) with at least 30 m separating the plots on all sides. Soil and vegetation sampling took place within a 60 m by 60 m area within the 1 ha plot to protect against edge effects (fig. 3). Within each plot, three permanently marked 60-m lines were used for vegetation cover and density measurements. Soils were collected by cover-type (shrub, grass, or bare soil) along three adjacent 60-m lines. In the Bernalillo Watershed, each plot had two 3 x 10 m runoff-erosion collectors, while the West Mesa had only one collector per plot (to minimize potential disturbance to archeological resources).

Prescribed Fire

The Bernalillo Watershed was treated with prescribed fire November 15-16, 1995, with a total of about 168 ha burned. The experimental plots were contained within the burn area. The control plots were protected by fire retardant foam applied around their perimeters. Weather conditions were favorable for prescribed burning with warm temperatures for the season (about 55 °F), moderate relative humidity, and light winds. However, the fuels in the Bernalillo Watershed were discontinuous, which resulted in patchy coverage by the fire.

The West Mesa site was treated with prescribed fire February 14, 1996. At this site, only the treatment plots were burned. Again, weather conditions were favorable for prescribed burning with warm temperatures for the season, moderate relative humidity, and light but steady winds. Fuels were more continuous at this site and the grasses were of taller stature, which allowed for nearly complete burn coverage with only small patches that did not burn. The plots were blacklined on three sides, then lit across the top and the fire moved with the wind across the entire plot, leaving only a few patches unburned.

Measurements

Vegetation Community Structure—Aboveground cover of individual plant species, as well as non-vegetation ground cover by categories (bare soil, litter, gravel and rock), were measured using the Community Structure Analysis technique (Pase 1981, Wolters and others 1996). Each of the three 60-m vegetation transects within each plot were measured. These transects were measured before the prescribed fire, soon after the prescribed fire, and after the first growing season after the fire.

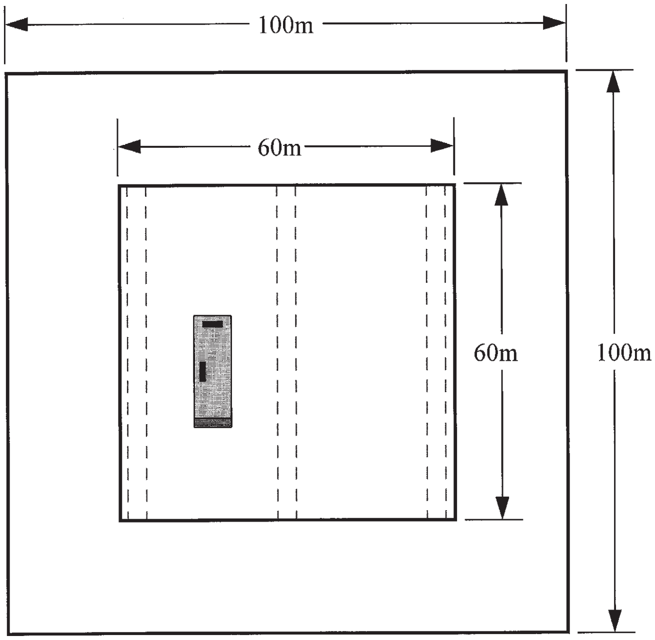

Figure 3—Design of experimental plots showing the interior 60 m by 60 m area actually sampled, the soil and vegetation transects (dashed lines) and the relative placement of the runoff collector (rectangular shaded area in plot). Erosion bridges were installed about 30 cm from the border of the runoff collector centered along the top and one side of the collector (darker shaded areas). Rain gutter with galvanized sheet metal lip that drained into a 20 l bucket was installed at the bottom of the collector.

Soil Measurements and Analyses—Soil samples were collected three times at both sites; before the prescribed fire, shortly after the prescribed fire, and after the first growing season after the fire. Surface soil samples were collected under three cover-types (shrub, grass, and bare soil) by taking 4-cm wide cores to a depth of 20 cm at two locations along three 60-m belt transects inside the sampling area. The six soil cores of each cover type from each plot were composited into a single sample. This sample design produced one composite sample from each plot for bare, grass, and shrub cover-types (sample-size of four for treatment and control).

Samples were transported on ice to the University of New Mexico, where they were sieved (2 mm), mixed, and stored at 5 °C for further analyses. After determining water-holding capacity (WHC)(White and McDonnell 1988), a portion of each sample was adjusted to 50 percent of determined WHC and up to 11 subsamples were apportioned into plastic cups. Each cup contained approximately 30 g dry-weight mineral soil. One subsample of each sample was immediately extracted with 100 ml 2 N KCl for NH_4^+-N and NO_3^--N analyses. The remainder of the cups were covered with plastic wrap, sealed with a rubber band, and incubated in the dark at 20 °C. The plastic wrap minimized water loss during incubation, yet exchange of CO_2 and O_2 was sufficient to keep the subsamples aerobic during incubation. Moisture content was monitored by mass loss and replenished as needed. At weekly intervals, one subsample of each sample was removed and extracted with KCl for 18-24 h. The clarified KCl was filtered through a Kimwipe® and analyzed for NH_4^+-N and NO_3^--N+NO_2^--N on a Technicon Auto-Analyzer (Technicon, Tarrytown, NY) as described in White (1986). Mineralizable N was equal to the maximal amount of inorganic N (sum of ammonium and nitrate) produced during incubation by each soil.

Water content of the composited sample was measured gravimetrically after 24-h desiccation at 105 °C. Soil texture was measured by the hydrometer method (Day 1965). These sampling and analysis methods allowed for the determination of soil characteristics by cover-type.

Sediment Yield—Runoff-sediment collectors were designed after those used by the Water Erosion Prediction Project (WEPP; USDA, 1196 Building SOIL, Purdue University, West Lafayette, Indiana 47907-1196). Size and placement of the collectors at the West Mesa site were negotiated with and approved by Albuquerque Open Space archaeologists to minimize soil disturbance and damage to articles of archeological value. Following site approval by the State Historic Preservation Office, one collector per plot was installed at the West Mesa site. Two collectors per site were installed at the Bernalillo Watershed. All collectors were constructed by installing galvanized flashing around the perimeter of the 3 m by 10 m runoff collection area after the fire treatment (fig. 3). Along the bottom 3-m side, a plastic raingutter with galvanized flashing was installed at ground level to collect runoff and sediment. At the end of the gutter, a hole was dug and a 20-l bucket was placed in the hole and attached to the end-cap on the gutter by a section of garden hose. Both sediment in the gutter and bucket were collected at periodic intervals. This experimental design resulted in four treatment and four control sediment samples for each collection at the West Mesa site, and eight treatment and control sediment samples at the Bernalillo Watershed (two collectors in four plots).

Soil Erosion Bridge—Change in soil microtopography within each runoff collector was monitored using two soil erosion bridges (one parallel to the top and one along the side of each collector; fig. 3) established within the collectors prior to the burn. A soil erosion bridge measures small-scale changes in soil microtopography (Shakesby 1993; Wilcox and others 1994). The purpose of the bridge is to accurately determine net soil gain or loss. Following a burn, contraction and expansion of vegetation could coincide with movement of soil from bare areas to vegetated areas. Movement of soil at this scale could result in a simple redistribution of soil with no net gain or loss. Similar to the pattern described by Watt (1947), the soil surface may rise as individual plants become established and mature (termed a building phase), and then degenerates upon plant mortality, but the area as whole could remain in equilibrium with simple redistribution of materials within the area. Soil bridges were utilized to measure changes in soil microtopography to provide an accurate measure of net soil movement.

The actual bridge is constructed from an aluminum bar (35 mm square), 1.5 m in length, with 31 holes machined and fitted with brass bushings at 5 cm intervals (fig. 4). The bridge is situated on two permanent rebar stakes, leveled

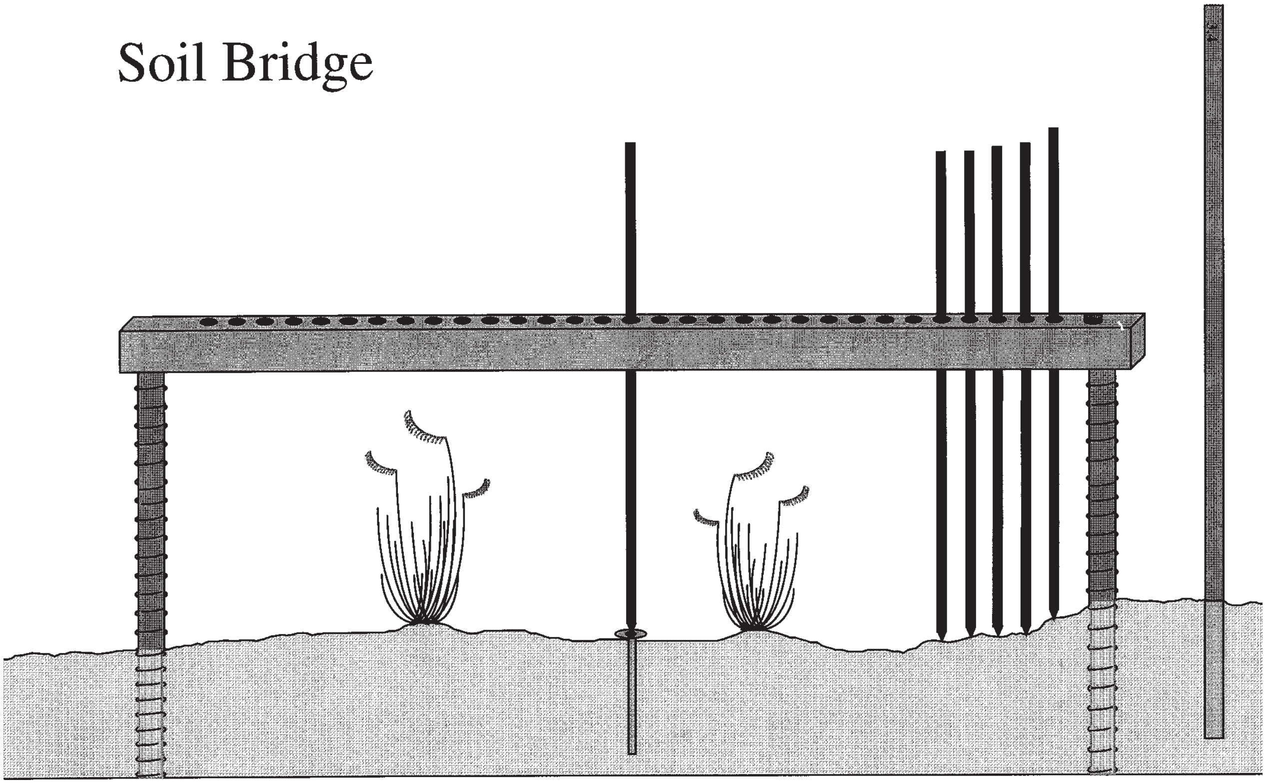

Figure 4—Schematic drawing of soil erosion bridge showing end rebar, center nail at soil surface, and 5 measuring pins.

with the help of a bubble level on the bridge, and secured with wood shims to prevent movement of the bridge. To increase the accuracy of this method, a spike with a dimple in the head is driven into the ground below the center pin. An aluminum pin is then inserted through the bridge and into the dimple in the head of the nail. The end rebar stakes and the center nail create a three point line, which increases the accuracy over what would normally be a two point line (Shakesby 1993; Wilcox and others 1994). Once the bridge is secured, pins are inserted through holes in the bridge to the soil surface and the portion of each pin extending above the bar is measured. The 30-point profile reflects the soil surface topography. When measured over time, these measurements document minor changes in soil surface dynamics and net gain or loss in soil resources. The soil erosion bridges were measured before the fire, immediately after the fire, in July 1996 after the summer rains began, and after the first growing season after the prescribed fire.

Statistical Analyses

Each site (Bernalillo and West Mesa) was analyzed separately. Effect of prescribed fire on soil potentially mineralizable N was analyzed using Analysis of Variance (ANOVA) procedures in SAS (SAS Institute Inc., Cary, NC). Soil bridge measurements and sediment transport were analyzed using repeated measures ANOVA procedures in SAS, which generated an analysis for the treatment, collection, and their interaction factors. Effect of the prescribed fire on vegetation cover was determined using the GLM repeated measures procedure on SPSS (v7.5, citation). Unless otherwise indicated, a significance level of $P \leq 0.05$ was used.

Results

Bernalillo Watershed

Vegetation Cover—Vegetation cover both before and after the prescribed fire was relatively sparse and patchy, which lead to high within-treatment variances for all collections. Cover of total vegetation, grass, and shrubs was the highest in the collection before the fire treatment (fig. 5), which was near the beginning of below-normal precipitation in the region (fig. 2). All cover-types declined on treatment and control plots in the second collection, after the prescribed fire. Total vegetation and grass cover increased in the third collection to near that of the first collection; however, shrub cover continued to decline in both the control and treatment plots. For total vegetation cover, grass cover, and shrub cover, treatment was not a significant factor, nor was the time x treatment interaction. The time factor was significant for the change in vegetation for both time intervals (change from collection 1 to 2 ($P = 0.001$), and from collection 2 to 3 ($P = 0.038$)).

Mineralizable N—Extractable inorganic N (sum of ammonium and nitrate) showed a general linear increase throughout the 70-d incubation period for soils from all cover-types (shrub, grass, and bare) from the Bernalillo Watershed and the West Mesa sites. Thus, the sum of ammonium and nitrate in the 70-d extraction equalled mineralizable N in most soils. In soils from the Bernalillo Watershed, mineralizable N is greatest in soils under shrub, slightly lower in soils under grass, and lowest in bare soils (fig. 6) for all collections. The fire treatment and the interaction of fire and collection were not significant factors ($P > 0.05$) on mineralizable N levels, but time of collection was highly significant ($P = 0.003$). The effect of collection is shown by both the treatment and control samples increasing after fire and then decreasing on the last collection (fig. 6).

Erosion—The amount of sediment transported from each collector was highly variable following the fire in both treatment and control plots (fig. 7). Although the means of

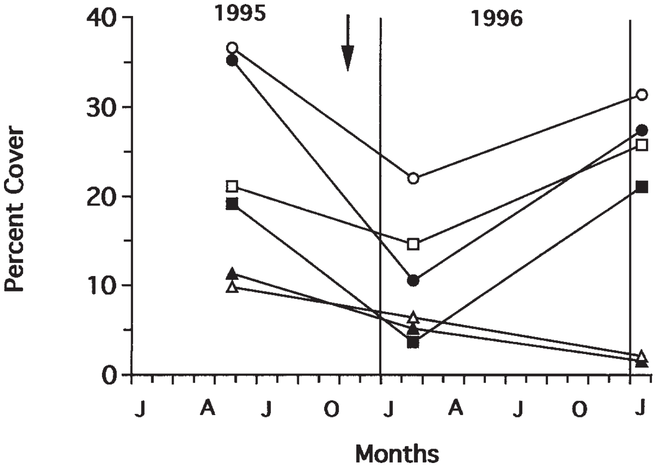

Figure 5—Changes in vegetation cover (circles, total cover; squares, grass cover; triangles, shrub cover) on the control (open symbols) and burned (filled symbols) plots at the Bernalillo Watershed. Arrow indicates when the prescribed burn occurred.

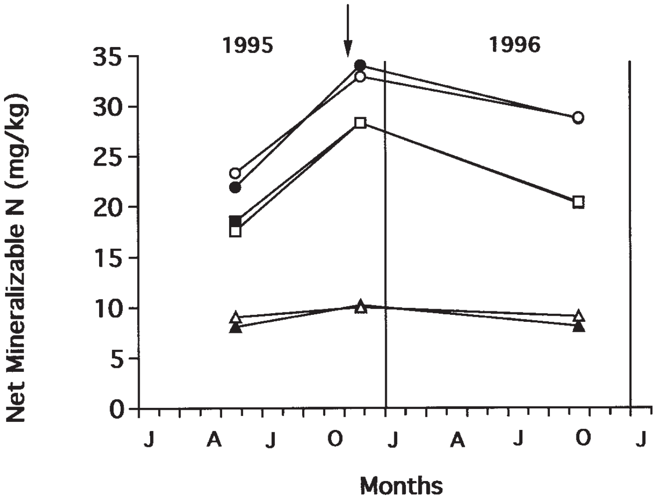

Figure 6—Changes in mineralizable N content of soils beneath different vegetation cover-types (circles, shrub; squares, grass; triangles, bare soil) on the control (open symbols) and burned (filled symbols) plots at the Bernalillo Watershed. Arrow indicates when the prescribed burn occurred.

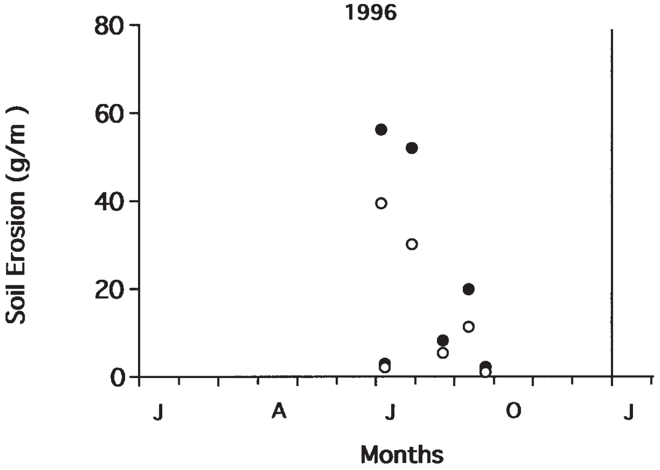

Figure 7—Amount of soil trapped in the gutters at the bottom of the runoff collectors in the control (open circles) and burned (filled circles) plots for six different collections during 1996 at the Bernalillo Watershed. The first runoff events occurred in late June and early July, 1996.

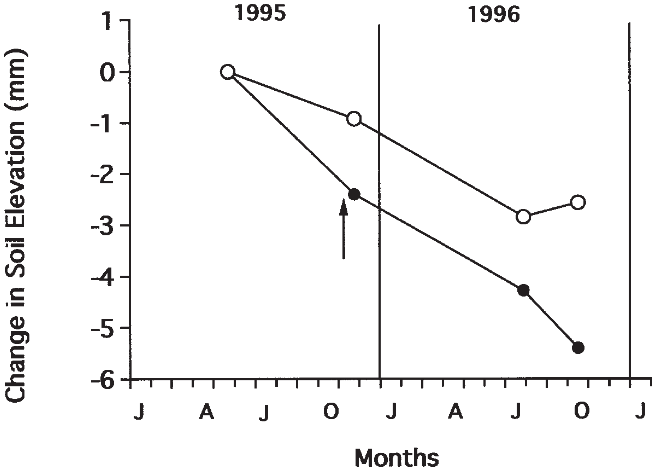

Figure 8—Net change in the soil surface measured below the erosion bridges within the control (circles) and burned (filled circles) plots at the Bernalillo Watershed. Arrow indicates when the prescribed burn occurred.

the treatment plots were consistently higher than the means of the controls, there was no significant effect of the treatment factor (P = 0.102) on sediment transport, which in part was due to the high within-treatment variance. Collection was a highly significant factor (P < 0.001), while the treatment x collection interaction factor was near significant (P = 0.052). In general, the relative difference between the treatment and controls diminished during the course of the first year, which would be consistent with a relatively greater increase in cover on burned plots in response to the precipitation from June 1996 through the end of the year with a corresponding increase in site stability following plot establishment.

Soil Erosion Bridges—The repeated measures ANOVA identified that treatment, collection, and their interaction were all significant factors (P = 0.038, P = 0.001, and P = 0.045; respectively) for the change in soil microtopography in the Bernalillo Watershed. Both treatment and control soils show a decline in soil surface (representing net erosion) during the course of the study, except for the control plots which showed no change or a net gain for the last collection (fig. 8). The rate of loss appears greater in the treatment than in the control plots.

West Mesa

Vegetation Cover—Vegetation cover was relatively uniform across the plots and the grasses were taller than at the Bernalillo Watershed, which led to much more uniform coverage by the prescribed fire treatment. Initially, total cover, grass cover, and shrub cover were similar between the treatment and control plots (fig. 9); however, all three cover types were significantly reduced following the prescribed fire while cover by these types on the control plots was unchanged. Following the first growing season after the fire, grass cover on the burned plots increased 19.5 percent (from 0.7 percent cover to 20.2 percent), while grass cover on the control plots increased by 4.7 percent (from 21.1 to 25.8 percent, which was not a significant increase). Shrub cover was significantly reduced on the burned plots after the fire and did not increase by the third collection. Shrub cover in the control plots was not significantly different after the fire, but declined between the second and third collection. For total vegetation cover, grass cover, and shrub cover, treatment and the time x treatment interaction factors were significant (P < 0.05).

Mineralizable N—Mineralizable N was highest in soils under shrub, intermediate under grass, and lowest in bare

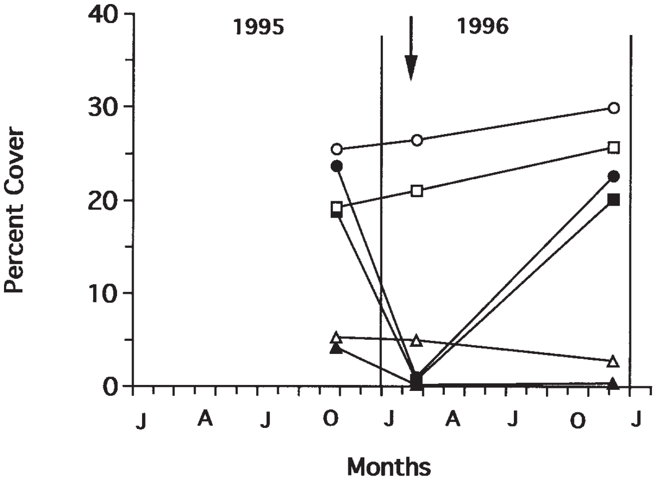

Figure 9—Changes in vegetation cover (circles, total cover; squares, grass cover; triangles, shrub cover) on the control (open symbols) and burned (filled symbols) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

soils (fig. 10). The repeated measures ANOVA identified collection to be the only significant factor (P < 0.001) for mineralizable N in soils of the West Mesa. Mineralizable N increased in all soil-types following the prescribed fire in both treatment and control plots, except for the soils under grass in the control plots. All soils showed a particularly sharp decline in mineralizable N following the summer growth in both the control and burned plots.

Erosion—Treatment, collection, and their interaction were not significant factors for soil erosion at the West Mesa site. Variance was very high in all collections in both the treatment and control plots. The high variance and small sample size (four plots per treatment) resulted in no significant differences between treatment and control plots (fig. 11), but the means of the treatment plots were higher than the mean of the control plots in all collections.

Soil Erosion Bridges—The treatment plots showed a net rise in the soil surface immediately after the prescribed burn, but the soil surface degraded to below the initial level in both subsequent collections (fig. 12). The control plots showed no significant change during the study period. The only significant difference between the treatment and control plots occurred in the immediate post-treatment collection.

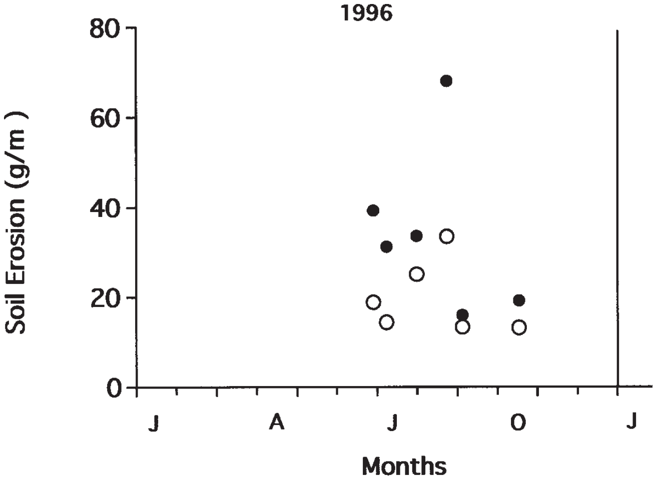

Figure 11—Amount of soil trapped in the gutters at the bottom of the runoff collectors in the control (open circles) and burned (filled circles) plots for six different collections during 1996 at the West Mesa. The first runoff events occurred in late June and early July, 1996.

Discussion

To say that the weather conditions before and after the prescribed fires were less than optimal would be an understatement. As with most management activities, an extensive planning and budget process preceded the actual prescribed fires. The original study plan targeted a late September-October prescribed fire at both sites, a period when the days are still warm with breezes, but not high winds, and maximum fine fuel in response to summer rains. Instead, the drought that started at the beginning of 1995 continued through the summer, providing little new growth. In September the rains exceeded the long-term average (fig. 2b), which forced a delay until November for the Bernalillo Watershed and February for the West Mesa. Optimally, ash produced by the fire would have leached into the soil with the light rains expected at that time of year. However, precipitation continued below normal through the winter and winds blew ash off the burned plots, which was evident from the ash trapped by vegetation in the unburned plots. In the Bernalillo Watershed, this was particularly important because the control plots were "islands" within the

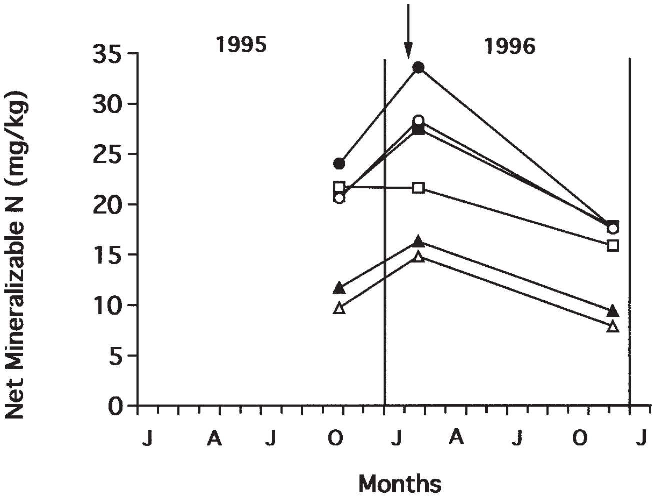

Figure 10—Changes in mineralizable N content of soils beneath different vegetation cover-types (circles, shrub; squares, grass; triangles, bare soil) on the control (open symbols) and burned (filled symbols) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

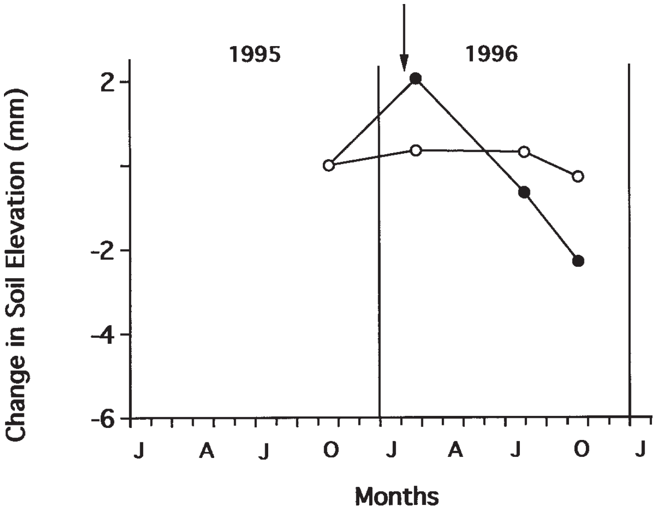

Figure 12—Net change in the soil surface measured below the erosion bridges within the control (circles) and burned (filled circles) plots at the West Mesa. Arrow indicates when the prescribed burn occurred.

treated area and could receive ash from all sides. In contrast, the treatment plots were "islands" within the sea of unburned grasslands at the West Mesa site, so potential ash contribution was less than at the Bernalillo Watershed. Rains finally came in June of 1996, but they were high intensity thundershowers that generated runoff and soil erosion, even on the control plots where vegetation was not consumed by fire. Thus, the full benefit of nutrients in the ash was not expressed at the treatment plots, and the control plots benefitted from ash blown from the treatment plots.

For the collection after the fire, vegetation cover in the control plots was less than before the fire, which in part could have been caused by the persistent drought conditions preceding the prescribed fire. However, trespass animals on the site consumed an unknown amount of vegetation and could be the cause of the observed decline. Perhaps the best evidence of the drought was the persistent decline of shrub cover throughout the first year of study. The decline may indicate that shrubs are more susceptible to winter/spring drought, which is the period when soil moisture at greater depth is usually replenished. At both sites, grass cover in both treatment and control plots increased in the final collection while the shrubs showed no change or a decline. Thus, the desired change in greater cover by grass relative to shrubs occurred on both sites, but the change cannot be attributed to fire alone because of the continued decline in shrubs in the control plots at both sites.

Contribution of ash to the control plots may account for the lack of an expected treatment effect in the soils of the burned plots for mineralizable N. However, mineralizable N also increased in the soils beneath shrubs and bare soils in the control plots on the West Mesa after the prescribed fire. This increase suggests that factors other than ash may contribute to the mineralizable N pool in the soils over the period between the pre- and post-burn soils. Possible explanations for the increase in mineralizable N could be the contribution of readily mineralizable N following mortality of microbial or root biomass during the drought period between the initial and post-fire soil collections.

The decline in mineralizable N content of soils in all plots at both sites between the second and third collection coincides with the increase in grass cover, which suggests that the available N pool may be sequestered in current growth. If precipitation remains above normal and available N is not replenished before the next growing season, then the decline in mineralizable N suggests that net primary production may be limited by available N supply during the next growing season.

The patterns of soil loss, although not statistically significant in most cases, were consistent with our expectations. Reduction in vegetation cover was expected to temporarily increase potential soil erosion, and the treatment plots at both sites had consistently higher (but not significantly different) soil loss than the control plots (fig. 7 and 11). As vegetation cover increased following the summer rains, erosion tended to decrease on both the treatment and control plots at both sites. It is possible that storm intensity also decreased over the summer, which could, in part, account for the apparent decline in erosion. This pattern of declining erosion as the summer runoff season advanced was also shown by Wilcox (1994) at another location in New Mexico, and Yair and others (1980) observed similar declines in sediment concentrations with repeated runoff events in arid regions of the northern Negev.

The soil bridges were installed on the sites before the prescribed fires and before the flashing was installed around the erosion collectors. The second bridge measurements reflect the combined effects of soil loss between the two collections, disturbance from installation of the flashing, soil compaction from footsteps by personnel during the prescribed fire, and trespass livestock at the Bernalillo Watershed. Between the second and third sampling period, both wind and water erosion could have contributed to the soil loss seen at both sites. Rain splash and water erosion probably were the major factors contributing to change between the third and fourth collection, as evident from the soil splashed onto the flashing between these collections (personal observation). If the trend in increasing vegetation cover continues, the soil surface is expected to stabilize, or perhaps even show a net increase if the vegetation traps enough particles and reduces compaction from rainsplash.

The soil bridges appear to over-estimate the rate of soil erosion as seen in the runoff plot as a whole. When the total mass lost during the study period from the erosion plots is evenly distributed over the entire plot, the control and treatment plots had an average loss of 0.09 mm and 0.14 mm, respectively, on the Bernalillo Watershed, and 0.12 mm and 0.2 mm, respectively, on the West Mesa. The soil bridges indicate greater loss (1.0 mm and more) from all plots, except the control plots on the West Mesa (fig. 8 and 12). Since the bridges were installed along the top and one side of the erosion plots, it is possible that soil loss from those positions is greater than from the plot as a whole.

Conclusions

Hypothesis 1: after an initial decline in vegetation cover, grasses should respond more rapidly than shrubs and achieve greater cover relative to shrubs. This occurred on both grasslands, but cannot be attributed to fire alone.

Hypothesis 2: N in ash should increase the amount of mineralizable N following the fire, but mineralizable N should return to that of control or unburned soils following regrowth of vegetation. This pattern did not occur, in that mineralizable N in both treatment and control soils rose after the fire and declined following the summer growing period.

Hypothesis 3: high intensity precipitation should increase erosion following burning until the vegetation cover recovers, which would then lead to a decline in erosion. Although not desired, this occurred at both grasslands with an apparent decline in erosion as the summer progressed. However, we can only assume the decline in erosion was due to increased vegetation cover because the contribution from other factors is unknown.

The results of this study are noteworthy for two reasons. First, the weather preceding and following the treatment with prescribed fire was very dry. This drought period lasted until early summer. The subsequent thunderstorms were frequent and heavy. Thus, it was expected that runoff and sediment yields and nutrient loss would be significantly greater from burn plots as compared to control plots. Surprisingly, this did not occur with regularity. Second, shrub cover was reduced and remained low relative to grass cover after the fire at the West Mesa site, but not different from the controls at the Bernalillo site. Research from other semiarid grasslands suggest that stimulation of grass growth occurs for up to four years following fires in these systems (Bock and Bock 1990;Pase and Granfelt 1977). Grass cover in the burn plots would have to continue to increase without an increase in shrubs for the management objective to be met following the first fire. It was anticipated that many fires may be required to obtain the desired objective. Future management will require continued treatment with fire to maintain the grassland in proper functioning condition.

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