Revegetation of Roadcut Slopes in Mesa Verde National Park, U.S.A.

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Abstract

The geology of Mesa Verde National Park (MVNP) poses unique problems to road construction and maintenance. Major geologic formations of the Park consist of an overlying resistant sandstone cap underlain by highly erodable shales. Once this sandstone cap is removed, the shales are easily eroded away, creating the notable mesas of the region. In many places, road construction has removed the sandstone layer and vegetation resulting in unaesthetic barren slopes that require continual maintenance and have proven difficult to revegetate. An experiment was conducted to evaluate the effectiveness of several cultural techniques combined with seeding and transplanting indigenous plants for revegetation of these roadcut slopes. Techniques evaluated were fertilization, mulching, soil pitting, and polyacrylamide amendments. Replicated test plots were established at three roadcut sites in MVNP to evaluate these techniques by measuring percent plant cover by species over a 4-year period. A combination of seeding grasses and transplanting forbs and shrubs appeared to be the optimal way to maintain species diversity and structure on the roadcuts while accomplishing the goal of revegetating these difficult sites. The perennial forb *Aster glaucodes* and the shrub *Artemisia ludoviciana* showed high survival when transplanted in the experimental roadcut sites. These species, as well as the perennial grass *Pascopyrum smithii*, also established well from seed. The addition of an organic fertilizer, in combination with mulch, proved to be the most effective method of improving vegetation cover for these and other transplanted species.

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Key words: Mancos shale, Menefee shale, mulch, organic fertilizer, polymer, seeding, transplants.

Introduction

In 1906, land was set aside to establish Mesa Verde National Park (MVNP) in southwest Colorado for the purpose of preserving a large concentration of prehistoric cliff dwellings and other ruins left by Native Americans that inhabited the area for about 1,200 years, until around 1300 A.D.

The need to build roads to the ruins posed problems early on. Heavy rains damaged dirt roads, especially on portions cut into the shale on precipitous slopes of the mesa. Landslides blocked the road or carried it away in certain areas. Roads had to be safe and passable in order to promote tourism in the park. The main construction of the present park road was completed in 1957 (Torres-Reyes 1970).

Although the roads have been improved greatly since MVNP was established, landslides are still a problem on portions of the road constructed on steep slopes. Roadcuts that expose Mancos and Menefee shales have been difficult to revegetate despite several attempts. Natural revegetation has not occurred on some roadcuts dominated by these shales, even after 40 years.

Natural outcrops of Mancos shale found in the arid and semi-arid regions of Colorado, New Mexico, Arizona, and Utah are typically devoid of vegetation (Potter et al. 1985). Mancos shale is a marine deposit from the Cretaceous Period and is found at lower elevations of MVNP (Griffitts 1990). Menefee shale formed later in the Cretaceous Period and was deposited in a continental freshwater sea. This formation is found at the higher elevations of the Park, above the Mancos shale (Griffitts 1990).

Being of marine origin, Mancos shale typically contains high concentrations of sodium (Na) and sulfate (SO_4) (Potter et al. 1985). Excess sodium can cause problems for revegetation, mainly through dispersion of soil particles, which prevents development of large soil pores and decreases water infiltration and percolation (Power et al. 1978). Clay soils with sodium may have increased surface sealing upon wetting, which then forms a crust when dry (Power et al. 1978). In years of high precipitation, anoxic conditions may develop in these substrates. These shale-derived soils contain smectite. The shrink-swell properties of smectite may cause additional water stress to colonizing plants.

MVNP averages 470 mm of precipitation annually with a mean annual temperature of 27°C (EarthInfo, Inc. 1998). These conditions make revegetation of these shale-derived soils even more challenging. Properties of the exposed sub-soils and the length and degree of slopes on the roadcuts also limit water conservation and water use efficiency by plants.

Objectives

The U.S. National Park Service has adopted a policy of utilizing native plant species in restoration projects in an effort to maintain the genetic integrity of plants indigenous to each national park. The objective of this study was to test the effectiveness of common revegetation techniques on steep roadcut slopes with Mancos and Menefee shale parent material using various plant species indigenous to MVNP. Techniques that were evaluated were fertilization, mulching, soil pitting, and polyacrylamide amendment. The National Park Service has implemented similar studies on other roadside restoration projects in Grand Teton, Yellowstone, and Glacier National Parks, with funding from the Federal Highway Administration (Majerus 1996). Since the passage of the National Surface Transportation Act in 1982, the National Park Service has received funds from the Department of Transportation to repair and improve roads in the National Parks, including improvement of roadside aesthetics.

A related study (DeLeo 1999) was conducted to characterize plant and soil relationships on landslides located on Mancos shale in the backcountry and along old roadways in MVNP. This study resulted in recommendations for native species with a high restoration potential for disturbed slopes in MVNP (DeLeo 1999).

Materials and Methods

Study Site Description

Three roadcut sites were chosen for the evaluation of revegetation techniques. The sites are located along the MVNP entrance road. Two sites were located at mile marker 9.0 between the head of Moccasin Canyon and the head of School Section Canyon. In 1986, this section of the road, referred to as "B-cut," was moved to its present location just south of its original cut. The first study site at this location has a south aspect with a slope of approximately 40°. The second site is across the road from the first site and has a northwest aspect with a 34° slope. The sub-soil at these two sites are derived from Menefee shale and sandstone. Soil pH was determined to be 8.2 at site 1 and 8.0 at site two (soil chemistry was characterized in 1995 and results are presented in DeLeo 1999). The third study site (Fig. 1) was immediately adjacent to and east of the Montezuma Valley Overlook. The roadcut is large and incised by gullies from years of erosion. The slope is approximately 31° to 35° and south facing. This section of the road was constructed in 1957 (Torres-Reyes 1970) and has remained devoid of vegetation since then. The soil at this site is derived from Mancos shale and the pH was 7.9. Salt concentrations did not seem to be a hindrance to plant establishmend in this study (DeLeo 1999), although they have been reported

Figure 1. One of the three roadcut sites (site 3) within Mesa Verde National Park, Colorado where experimental plots were established. This section of the road was built in 1957 and the roadcut has remained devoid of vegetation since then. The parent material at this site is Mancos shale, which produces soils that are challenging to revegetate.

to be a hindrance to revegetating Mancos shale in other locations (Louderbough & Potter 1982).

Cultural Treatment Evaluation

In October of 1993, test plots were established at each of these three study sites. Test plots were arranged in a randomized complete block design with three replications. Five cultural treatments and a control were established to test the effects of selected amendments on plant establishment and survival.

All plots were seeded with a mixture of indigenous grasses, forbs, and shrubs with seed collected from within MVNP (Table 1). All plots also received containerized transplants of native grasses, forbs, and shrubs (Table 2). Seed originating from MVNP was used to produce these transplants at the USDA Upper Colorado Environmental Plant Center in Meeker, Colorado, with the exception of *Pascopyrum smithii* (western wheatgrass), which was grown from the commercial cultivar Arriba. Containerized seedlings were planted before the plots were seeded, with the exception of the excelsior mulch treatments, which were seeded first, followed by transplanting. The seed mixture was hand broadcast and lightly raked into the soil. After transplanting, each seedling was given approximately 2.7 L of water.

At each site, three blocks, each containing six 2.5- × 6.0-m plots (one plot for each treatment plus a control plot), were established. The treatments were: (1) Biosol®,[4] an organic fertilizer, (2) excelsior mulch, an erosion control blanket made of aspen (*Populus* sp.) shavings in plastic netting, (3) a combination of Biosol® and excelsior mulch, (4) polyacrylamide polymer (Western Polyacrylamide, Inc, Castle Rock, CO), a water-absorbing compound, (5) soil pitting and (6) control. Biosol® fertilizer and the polyacrylamide polymer were hand broadcast onto the plots and raked into the soil. Biosol® was applied at a rate of 2242 kg/ha. The polymer was applied at a rate of 146 kg/ha. These plots were then seeded and planted with containerized transplants as described above. Each transplant that was planted on plots with the polymer received an additional 30 g of polymer applied to the transplant hole. For the excelsior mulch treatment, the plots were seeded and then the excelsior blanket was secured in place with 30-cm long steel staples. The transplants were then planted through the excelsior blanket. The soil pitting treatment consisted of creating 15 small pits in each plot. These pits were approximately 30 cm wide and 15 cm deep. Transplants were planted on the down-slope edge of the pitted areas.

Forb and shrub transplants were started in containers in 1991 by the Upper Colorado Environmental Plant Center in Meeker, Colorado. As a result of being in containers for over 2 years, the quality of some of the transplants was poor. *Chrysothamnus nauseosus* (rubber rabbitbrush), *Atriplex canescens* (fourwing saltbush), and *Yucca baccata* (ba-

Table 1. Seed mixture for the experimental plots.

Scientific Name[a]	*Common Name*	*Seeding Rate (kg PLS[b]/ha)*	*Origin*	*Year*[c]
	Perennial grasses			
Pascopyrum smithii (Rydb.) A. Love	Western wheatgrass	3.4	commercial	1990
Elymus trachycaulus var. *trachycaulus* (Link) Gould ex Shinners	Slender wheatgrass	3.4	MVNP[d]	1991
Poa fendleriana (Steud.) Vasey	Mutton grass	3.4	PMC[e]	1993
	Perennial forbs			
Achillea millefolium L.	Yarrow	0.6	PMC	1992
Aster glaucodes Blake	Blue leaf aster	1.1	PMC	1992
Heterotheca villosa (Pursh) Shinners	Hairy goldenaster	1.1	PMC	1992
	Shrubs/trees			
Amelanchier utahensis Koehne	Utah serviceberry	2.1	MVNP	1990–1991
Artemisia ludoviciana Nutt.	Louisiana sage	1.5	PMC	1992
Cercocarpus montanus Raf.	True mountain mahogany	2.1	MVNP	1990–1991
Chrysothamnus nauseosus var. *nauseosus* (Pallas ex Pursh) Britt.	Rubber rabbitbrush	1.1	MVNP	1990–1992
Purshia tridentata (Pursh) DC.	Antelope bitterbrush	2.2	MVNP	1990–1991
Symphoricarpos oreophilus Gray	Snowberry	2.2	MVNP	1991
Quercus gambelii Nutt.	Gambel's oak	3.4	MVNP	1993

All seed originated from Mesa Verde National Park with the exception of *Pascopyrum smithii*. Seed listed as originating from the Plant Material Center in Meeker, Colorado was harvested from plants cultivated from seed collected at Mesa Verde National Park.
[a]Nomenclature follows that of USDA, NRCS (1997).
[b]PLS = pure live seed.
[c]Year = year seed was collected.
[d]MVNP = Mesa Verde National Park.
[e]PMC = Plant Material Center, Meeker, Colorado.

Table 2. Containerized transplants from the Upper Colorado Environmental Plant Center in Meeker, Colorado planted on the experimental plots.

Scientific Name	*Common Name*	*Total Transplants*
	Perennial grasses	
Elymus trachycaulus var. *trachycaulus* (Link) Gould ex Shinners	Slender wheatgrass	207
Leymus salinus var. *salinus* (M. E. Jones) A. Love	Salina wildrye	245
	Perennial forbs	
Aster glaucodes Blake	Blue leaf aster	86
Heterotheca villosa (Pursh) Shinners	Hairy goldenaster	72
Yucca baccata Torr.	Banana yucca	108
	Shrubs	
Artemisia ludoviciana Nutt.	Louisiana sage	86
Atriplex canescens (Pursh) Nutt.	Fourwing saltbush	46
Chrysothamnus nauseosus var. *nauseosus* (Pallas ex Pursh) Britt.	Rubber rabbitbrush	52

nana yucca) all had poor root development. The grass transplants, *Leymus salinus* (salina wildrye) and *Elymus trachycaulus* (slender wheatgrass), were started in the summer of 1993 and were of good quality at the time of planting.

Monitoring of Experimental Plots

Vegetation sampling on the experimental plots was completed in the latter half of June of each year from 1994 through 1997. The individual transplants were monitored for survival. Vegetation on all treatments was sampled for cover at the species level (Bonham 1989). Cover was estimated with the use of a 20- × 50-cm quadrat (0.10 m^2). Ten randomly placed quadrats were sampled for each plot. Results of vegetation measures for 1995 and 1996 are reported by DeLeo (1999). Here, we report on results from the first (1994) and last (1997) years of the vegetation monitoring.

Results

Plant Cover

After four growing seasons, the combination (Biosol® plus Excelsior mulch) treatment showed significantly higher percent plant cover than the control at sites 1 and 3 (Table 3). At site 1, the Biosol® treatment also had significantly higher plant cover than the control. These significant effects of the Biosol® and combination treatments were evident in 1994, largely due to a relative abundance of annual forbs in these amended plots (Table 3). However, the Biosol® and combination treatments at sites 1 and 3 appeared to benefit perennial grasses after 4 years (Table 3). At site 2, which has a northwest aspect, none of the treatments significantly increased total plant cover after 4 years, as they did at sites 1 and 3, which have south aspects (Table 3). Cover was greatest overall at the more mesic and gently sloping (~34°) site 2 (Table 3).

Transplant Survival

Survival of the transplants showed the same general response to treatments (Table 4) as did plant cover. Transplant survival was highest overall at the more mesic site 2, relative to sites 1 and 3. After 4 years, the transplants in the Biosol® plus excelsior treatment had the greatest survival rate at all sites (Table 4).

Some of the indigenous transplant species exhibited high survival rates on the experimental plots, particularly in the Biosol® + excelsior treatment. *Aster glaucodes* (blue leaf aster), *Artemisia ludoviciana* (Louisiana sage), and *E. trachycaulus* had consistently high survival in the three sites where they were transplanted (Table 4). *A. glaucodes* and *A. ludoviciana* are two species that spread rhizomatously once established at a site. *A. glaucodes* was observed as one of the first species to colonize disturbances on Mancos and Menefee shale in MVNP (DeLeo 1999). It may initially establish by seed and then spread vegetatively. *E. trachycaulus* is a bunchgrass that is also prevalent on Mancos shale disturbances on the North and East Rims in MVNP (DeLeo 1999).

Two other species, *L. salinus* and *C. nauseosus* exhibited high survival rates at sites 1 and 2 (Table 4). *L. salinus* was observed thriving on the eroded but stable Mancos shale hills near the Park entrance. However, the growth of *L. salinus* appeared to be slow on the experimental plots, which may be lacking specific physical and biological factors necessary for the development of later successional species.

Discussion

Treatment Effects

It was expected that the pitting treatment would improve vegetation establishment by providing plant microsites and conserving soil moisture. However, the ef-

Table 3. Mean percent plant cover at all sites for 1994 and 1997.

		*1994 Treatment**						*1997 Treatment*					
	Site	*C*	*B*	*EM*	*B+EM*	*Pit*	*Pol*	*C*	*B*	*EM*	*B+EM*	*Pit*	*Pol*
Annual forbs	1	0.63[a]	5.37[b]	0.37[a]	5.37[b]	1.60[a]	0.33[a]	0.07[a]	0.40[a]	0.07[a]	0.00[a]	0.00[a]	0.13[a]
	2	0.53[a]	14.57[b]	0.03[a]	9.60[b]	0.43[a]	0.23[a]	0.13[a]	1.80[a]	0.53[a]	0.00[a]	0.00[a]	0.13[a]
	3	0.20[a]	6.17[b]	0.00[a]	0.93[a]	0.00[a]	0.00[a]	0.00[a]	0.20[a]	0.13[a]	1.93[a]	0.00[a]	0.87[a]
Biennial forbs	1	0.50[a]	0.00[a]	0.50[a]	0.33[a]	0.07[a]	1.13[a]	0.07[a]	0.07[a]	0.13[a]	0.13[a]	0.07[a]	0.53[a]
	2	3.27[a]	0.93[a]	1.37[a]	0.87[a]	2.27[a]	0.90[a]	0.93[a]	0.60[a]	1.00[a]	1.07[a]	0.27[a]	0.27[a]
	3	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.47[a]	0.00[a]	0.00[a]
Perennial grasses	1	1.50[a]	3.90[a]	1.40[a]	10.30[b]	1.57[a]	3.03[a]	3.33[ab]	7.07[ab]	1.53[a]	8.07[b]	2.73[ab]	6.13[ab]
	2	2.37[ab]	6.00[a]	1.77[b]	2.50[ab]	2.33[ab]	3.23[ab]	3.53[a]	6.80[a]	2.00[a]	5.53[a]	2.53[a]	2.07[a]
	3	0.37[a]	0.77[a]	0.00[a]	6.57[b]	0.27[a]	0.03[a]	0.00[a]	0.87[a]	0.33[a]	6.07[b]	0.20[a]	0.47[a]
Perennial forbs	1	0.07[a]	0.33[a]	0.90[ab]	2.40[b]	0.07[a]	0.00[a]	4.73[a]	8.87[a]	4.40[a]	10.00[a]	3.87[a]	2.27[a]
	2	2.40[a]	2.77[a]	1.30[a]	2.27[a]	2.53[a]	0.83[a]	3.87[a]	7.33[a]	6.93[a]	12.07[a]	10.80[a]	6.73[a]
	3	3.33[a]	0.17[a]	0.47[a]	0.53[a]	3.50[a]	0.00[a]	1.20[a]	0.33[a]	0.60[a]	0.67[a]	0.60[a]	0.07[a]
Shrubs	1	0.00[a]	1.50[a]	0.43[a]	1.27[a]	0.43[a]	0.07[a]	0.07[a]	6.40[a]	4.20[a]	8.93[a]	2.13[a]	2.20[a]
	2	0.03[a]	0.17[a]	0.07[a]	0.23[a]	0.10[a]	0.23[a]	2.00[a]	4.60[a]	1.87[a]	2.67[a]	4.27[a]	3.00[a]
	3	0.17[a]	1.77[a]	0.13[a]	1.37[a]	0.00[a]	0.03[a]	0.27[a]	1.93[a]	0.20[a]	2.33[a]	0.20[a]	0.33[a]
Total plant cover	1	2.70[a]	11.10[b]	3.60[a]	19.67[c]	3.73[a]	4.57[a]	8.27[a]	22.80[bc]	10.33[ab]	27.13[c]	8.80[a]	11.27[ab]
	2	8.60[ab]	24.43[c]	4.53[a]	15.47[b]	7.67[ab]	5.43[a]	10.47[a]	21.13[a]	12.33[a]	21.33[a]	17.87[a]	12.20[a]
	3	4.07[ab]	8.87[a]	0.60[b]	9.40[a]	3.77[ab]	0.07[b]	1.47[a]	3.33[a]	1.27[a]	11.47[b]	1.00[a]	1.73[a]

Means for lifeform groups within a row ($n = 15$) followed by the same letter are not significantly different using a Tukey's Studentized Range (HSD) test at $\alpha = 0.05$. Seeded and planted species are indicated by bold font. Means comparisons were conducted for lifeform groups only.
*Treatment codes: C = control; B = Biosol®; EM = excelsior mulch; B+EM = Biosol® + excelsior mulch; Pit = soil pitting; Pol = polymer.

fect of this treatment could not be sufficiently evaluated because the majority of pits at site 1, and all of the pits at site 3, were filled as a result of slope instability. Only at site 2 did the pits remain intact, but pitting did not improve vegetation cover, nor transplant survival at this site.

Aspect also appeared to play a role in vegetation establishment. The north-facing slope (site 2) had the greatest percent cover compared with the other sites. Total amount of solar radiation may also have made a difference in vegetation establishment. On the southwest-facing slope (site 1) there was greater percent cover and transplant survival than at the south-facing site 3, which likely received more solar radiation. The southwest-facing site 1 was also shaded in the morning hours from a hillside to the southeast.

The apparent lack of nutrients in the roadcut substrate (DeLeo 1999) appeared to be a hindrance to plant establishment on all sites. The treatments that improved plant cover and transplant survival the most were those that included the Biosol® fertilizer (Tables 3 & 4). *Salsola kali* ssp. *tragus* (*L.*) *Celak* (Russian thistle), an annual forb, comprised a large percentage of the plant cover during the first year of the study on nearly all fertilized plots. This proliferation of annuals, which were not part of the seed mixture or transplants, was short-lived and was no longer apparent by 1995. A proliferation of annual species is often observed after initial fertilizer applications (DePuit & Coenenberg 1979; McLendon & Redente 1991; Brown et al. 1992; Gardiner 1993). *S. kali*, in particular, is dependent on high nitrogen availability and will not persist once available nitrogen is removed from the soil (Redente et al. 1992). Although competition from annual weeds can hinder the establishment of natives (Van Epps & McKell 1983), some exotic annual plant cover has been found to facilitate establishment of perennial native species on extremely harsh sites (Allen & Allen 1988; Brown et al. 1992).

The combination of Biosol® and excelsior mulch was the most successful treatment overall. The combination treatment had the highest percentage of plant cover for all sites in 1997 and generally resulted in the best transplant survival. Farmer et al. (1974) observed greater grass yield for both native and introduced species on plots with fertilizer and mulch combined when compared with either treatment alone.

The polymer treatment was unsuccessful in significantly improving plant establishment at any site. The water-absorbing capability of the cross-linked polyacrylamide may have been compromised by the high calcium and magnesium salt concentrations in the roadcut substrates (DeLeo 1999). The presence of salts in solution have been found to reduce the hydration of polymer gels, especially solutions containing salts of the divalent cations Ca^{2+} and Mg^{2+} (Bowman et al. 1990; Johnson 1984). The granules of the cross-linked polyacrylamide may also absorb water away from germinating seeds (Woodhouse & Johnson 1991), thus explaining why the evenly spread solution form of polyacrylamide has improved crop seedling emergence in some studies

Table 4. Percent survival of transplants as measured in 1997, 4 years after the test plots were established.

		Treatment*					
Species	*Site*	*C*	*B*	*EM*	*B+EM*	*Pit*	*Pol*
Artemisia ludoviciana	1	33	100	67	100	100	100
	2	100	67	67	100	100	100
	3	39	92	42	58	58	25
Aster glaucodes	1	83	100	100	100	50	83
	2	100	83	83	100	100	100
	3	33	0	33	33	33	33
Heterotheca villosa	1	33	0	0	33	0	0
	2	33	33	67	100	67	100
	3	67	0	0	33	33	33
Yucca baccata	1	0	67*	17	0	17	0
	2	17	0	33	0	0	17
	3	0	33	33	0	0	33
Leymus salinus	1	25	33	17	42	17	33
	2	50	42	58	58	83	83
	3	8	72	8	33	25	8
Elymus trachycaulus	1	33	55	33	89	22	0
	2	53	78	67	89	67	78
	3	8	63*	17	63*	15	13
Atriplex canescens	1	0	33	33	0	0	67
	2	0	0	0	33	33	0
	3	0	0	0	0	0	0
Chrysothamnus nauseosus	1	67	100	67	67	67	67
	2	67	100	33	100	100	100
	3	n.p.†	n.p.	n.p.	n.p.	n.p.	n.p.

Means followed by an asterisk are significantly different from the corresponding control mean using a Tukey's Studentized Range (HSD) test at $\alpha = 0.05$.
*Treatment codes: C = control; B = Biosol®; EM = excelsior mulch; B+EM = Biosol® + excelsior mulch; Pit = soil pitting; Pol = polymer.
†none planted.

(Cook & Nelson 1986). Al-Rowaily and West (1994) tested the effects of cross-linked and non-cross-linked polyacrylamides on germination of *Agropyron cristatum* and transplant growth of *Artemisia tridentata* and did not find any benefits from the use of these two polymers.

Treatments that improve soil moisture availability were expected to increase vegetation establishment. However, pitting, the use of polymer, and mulching did not improve plant establishment when used alone, even where pits persisted. However, there appeared to be a synergistic effect when mulching was combined with fertilization (Table 3). It appears that improvements in soil fertility may be more important for revegetation success on Mesa Verde roadcuts than the use of treatments to improve soil moisture availability.

Plant Materials

Perennial, rhizomatous plants were the most successful species to establish on the exposed roadcut sites. These species included *A. ludoviciana*, *A. glaucodes*, and *P. smithii.* Other species that established well included *E. trachycaulus* from both seed and transplant, *C. nauseosus* transplants, and *Achillea millefolium* (yarrow) from seed. *L. salinus* transplants also persisted on the experimental plots but they appeared to grow slowly.

Perennial forbs and grasses may be the only plants that can persist on these harsh roadcut sites. The addition of organic matter and shading provided by colonizing annual plants (*S. kali* in this study) may facilitate the establishment of the seeded and planted perennial species. Possibly the greatest limit to the establishment of perennial woody species on these sites is the potential lack of soil microbes, especially plant symbionts. Most mid- to late-successional perennial plants in semi-arid ecosystems are facultatively or obligately dependent on mycorrhizae for survival (Allen 1989; Allen & Allen 1990). In addition, the shrub *Cercocarpus montanus* (true mountain mahogany), which colonizes disturbed sites within the park (DeLeo 1999), forms a symbiosis with dinitrogen-fixing soil actinomycetes in the genus *Frankia* (Paschke 1997). *Cercocarpus*-infective *Frankia* and mycorrhizal fungi may not occur on barren roadcut disturbances. The addition of inocula sources, such as native soil, should facilitate establishment of these species.

The species that showed the greatest establishment from seeding were *E. trachycaulus*, *P. smithii*, and *A. millefolium.* The greatest success observed in seeding disturbed areas has been with perennial grasses, and less success has been observed with forbs and shrubs (Hansen 1989). The seeding rate of forbs was low in the mixture compared with the grasses and shrubs (Table 1) and may have contributed to their poor establishment.

Shrub establishment was extremely low for all six of the species seeded. The only shrub that appeared to establish from seed was *Symphoricarpos oreophilus* (snowberry), and only on site 2. Recognized problems with the germination of shrub seeds include: high genetic diversity within the same species, seed dormancy, variation in seed size, and germination requirements different from the growth requirements of a mature shrub (Hansen 1989). Although mature shrubs may be very drought tolerant, germination and establishment are reduced under moisture stress in many of the species used in this study (Sabo et al. 1979). In addition, lack of microbial symbionts may have reduced shrub establishment from seed at these sites.

Conclusions

The two most effective treatments for revegetating roadcut slopes in MVNP were the Biosol® fertilizer in combination with excelsior mulch and Biosol® fertilizer alone. Transplants of *A. glaucodes*, *A. ludoviciana*, *E. trachycaulus*, and *C. nauseosus* appeared to be the best materials for revegetating roadcut slopes in MVNP. *E. trachycaulus* also established well from seed. *L. salinus* transplants also showed good potential for revegetation of these sites but may take longer to establish. If long-lived woody plants are desired on such roadcuts, other treatments may be necessary, such as the addition of soil biota and organic matter.

A combination of seeding grasses and transplanting with forbs and shrubs especially those with a rhizomatous growth form, may be the optimal way to maintain species diversity and structure on roadcuts of Mancos and Menefee shales while accomplishing the goal of revegetating these difficult sites.

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