

Reestablishing Cold-Desert Grasslands: A Seeding Experiment in Canyonlands National Park, Utah

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Abstract—Eighteen different treatments were applied to an area seeded with the native grasses *Stipa comata* and *S. (Oryzopsis) hymenoides*. Plots received supplemental water up to annual rainfall levels. Treatments included 30% cover of native grass mulch (*Hilaria jamesii*); nitrogen and phosphorus fertilizer; cyanobacterial inoculant from an adjacent, undisturbed area; sugar (to stimulate microbial activity); no water; and various combinations of these treatments. Plots were evaluated one year later for number of grass seedlings established, number of grass seedlings eaten, and cover and biomass of the exotics *Salsola kali* and *S. iberica*. Different treatments resulted in strikingly different establishment rates of the seeded grasses, with any treatment using mulch having only 15 to 25% as many seedlings as the most successful treatment. Fertilized plots tended to have fewer seedlings as well. Sugar, by limiting nitrogen availability, was effective at reducing *Salsola* biomass and cover, as well as in encouraging perennial seedling establishment. *Salsola* cover had a small negative effect on total *Stipa* plants present. However, herbivory was significantly reduced for *Stipa* plants growing in *Salsola* canopies. Consequently, biomass was enhanced in plots with *Salsola*. In spite of precipitation during the growing season being below the 50-year average, plots without supplemental water did as well as those with supplemental water. As measured by overall native plant establishment, the most successful treatments were seed only (with and without supplemental water), the combination of sugar and spring-spread cyanobacteria, and native grass straw mixed in with fall-spread cyanobacterial inoculant.

Perennial bunch-grass communities have been heavily impacted in the western United States. Once widespread and free from annual exotics, these communities have been decimated by anthropogenic activities over the past two hundred years, especially livestock grazing (Gleason & Cronquist 1964; Sampson 1918; Smith 1899). In addition, most bunch-grass communities have been invaded by exotic annuals such as *Bromus tectorum* (cheatgrass) and *Salsola* sp. (tumbleweed). Resultant displacement of native species,

whether through competition or fire, now threatens remaining native communities (Billings 1990; McArthur et al. 1990).

Successful revegetation of these grasslands in semi-arid lands has been limited and, in spite of a great deal of money and effort (S. Monsen, personal communication), no successful restoration has been documented. Most of these failures are ascribed to competition from exotic annuals (Kay et al. 1981).

Nitrogen availability influences species composition in a number of disturbed ecosystems (Heil & Bruggink 1987; Parrish & Bazzaz 1982; McLendon & Redente 1992). Perennial species, generally having lower potential growth rates (Bazzaz 1979), are competitively favored in nitrogen-limited situations (Heil & Bruggink 1987; McGraw & Chapin 1989). Consequently, limitation of nitrogen availability in a system should favor later seral, perennial plants, while increased nitrogen availability should favor early seral annual species. Greater nitrogen immobilization can be achieved through increasing soil microbial biomass, since these decomposers compete with plants for nitrogen (Hunt et al. 1988; Lamb 1980). Stimulation of microbial biomass is done by the addition of a readily usable source of energy such as sucrose (sugar) (McLendon & Redente 1992) to the soils.

This study examines the efficacy of 18 different treatments (sugar, fertilizer, mulch and cyanobacterial inoculant, and no water) on 1) the establishment and survival of two seeded perennial bunch-grasses; 2) the cover and biomass of two exotic annual species, *Salsola iberica* and *S. kali* (Welsh 1994); and 3) the influence of the exotic annuals on the survival of the seeded native perennials.

Methods

The Needles district of Canyonlands National Park is located in southeastern Utah in the Colorado Plateau biogeographic province. Precipitation averages 23 cm yearly. Precipitation is spread fairly evenly throughout the year, although June is an extremely dry month, and October is very wet. Late summer and fall monsoons (August–October) provide 31% of yearly rainfall. This area is a cold desert, with an elevation of 1,370 m; annual high temperatures average 28 °C; annual low temperatures average –2 °C. The growing season is generally March to October. Undisturbed soils in this district are Begay fine sandy loams, with clay contents averaging 8 to 10% and silt 11 to 14%. Average NO₃-N content of soils in this area was 2.3 ppm; phosphorus was 5.9 ppm; pH ranged from 7.9 to 8.1.

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Construction activities in summer and fall of 1991 resulted in a denuded 4.8-km long, 10-m wide strip through a *Stipa* (*Oryzopsis*) *hymenoides*-*S. comata* (Welsh 1994) perennial bunchgrass community. The strip was driven on repeatedly. The presence of buried water and electrical lines precluded ripping; instead, a tractor-pulled disc was used to break up the surface to a depth of 30 cm. The topsoil from the disturbed area was windrowed for 18 months before replacement. However, during replacement, the topsoil was mixed with subsoil. Resultant surface soils in the revegetated area still had a texture, pH and bulk density similar to adjacent undisturbed soils, but less soil structure, and therefore probably less water infiltration, than the adjacent area. Seed was collected on-site in summer, 1991 and spread in October, 1991. *S. hymenoides* seed was drilled to 40 mm (9 pounds/acre), while *S. comata* seed, with awns intact, was hand broadcast (9 pounds/acre).

A sprinkler system was installed along the corridor. Sprinkler heads were carefully placed to insure even water coverage over plots receiving supplemental water. Natural rainfall was monitored biweekly, and if less than the 50-year monthly average of rain was received, supplemental watering was done to reach that average. Rainfall was 22% below average over the March to November growing season. March through June had average or slightly above average rainfall, while July was down 31%, August was down 38%, September was down 46%, and October was down 43%. The sprinkler system was used 5 times for water supplements during these times.

The corridor was assessed for slope, soil depth, soil texture and adjacent vegetative communities. A homogenous portion was then designated for experimental treatments. A randomized block/plot design was used, with 18 treatments replicated in 7 blocks. Plots were 5 m by 10 m. Only the interior 3 m x 6 m area was used for sampling to avoid edge effects of neighboring treatments. Fertilizer treatments, applied in spring and fall, included nitrogen at 100 pounds/acre/yr and phosphorus at 50 pounds/acre/yr to increase fertility of the plots. Native grass straw was mixed into the soil before seeding to provide a slowly decomposing substrate for microbial populations (0.5 bale/plot). Sugar was applied to provide a readily available carbon source for microbial populations to stimulate their growth, thus reducing nitrogen availability to plants (636 pounds/acre/yr, applied every 2 months except December-January). Mulch, applied in the spring, consisted of a 50% cover of native grass straw to help conserve moisture in the plots. Cyanobacterial-lichen soil crusts were salvaged from a nearby area (by scalping the top 20 cm of soil) and spread 50 mm deep on the plots in order to inoculate the plots with nitrogen-fixing microorganisms. All treatments were applied in the fall, with the exception of mulch and spring crusts, which were applied in the early spring. Treatments are listed in Table 1.

Plots were sampled in fall, 1992. Five 1 m² quadrats were assessed in each plot. Data collected included numbers of established *Stipa*, evidence of herbivory on *Stipa*, and cover and biomass estimates of the exotic annuals *Salsola kali* and *S. iberica*. Soil bulk density in the plots was compared with an adjacent, undisturbed area. Data collected as percentages were arc-sine transformed before

Table 1—Treatments applied to experimental plots.

1. FC:	Fall-applied cyanobacteria
2. FC/S:	Fall cyanobacteria, sugar
3. FC/F:	Fall cyanobacteria, fertilizer
4. FC/M:	Fall cyanobacteria, mulch
5. FC/F/M:	Fall cyanobacteria, fertilizer, mulch
6. FC/S/M:	Fall cyanobacteria, sugar, mulch
7. FC/H:	Straw mixed in with fall cyanobacteria
8. S/M:	Sugar, mulch
9. F/M:	Fertilizer, mulch
10. M:	Mulch
11. SC:	Spring-applied cyanobacteria
12. SC/S:	Spring cyanobacteria, sugar
13. SC/F:	Spring cyanobacteria, fertilizer
14. SC/M:	Spring cyanobacteria, mulch
15. F:	Fertilizer
16. SD:	Seed
17. SD/NW:	Seed, no water
18. SC/S/NW:	Spring cyanobacteria, sugar, no water

analysis. Results were analyzed using ANOVA, Duncan's multiple range test and one-way regression analysis.

Results and Discussion

Average numbers of total *Stipa* plants observed in each treatment are shown in Figure 1. These numbers include all *Stipa* that survived the first growing season, regardless of their condition. Treatments fell into three groups. The four most successful treatments included seed only without water; native grass straw mixed in with fall-spread cyanobacterial inoculant; sugar plus spring-spread

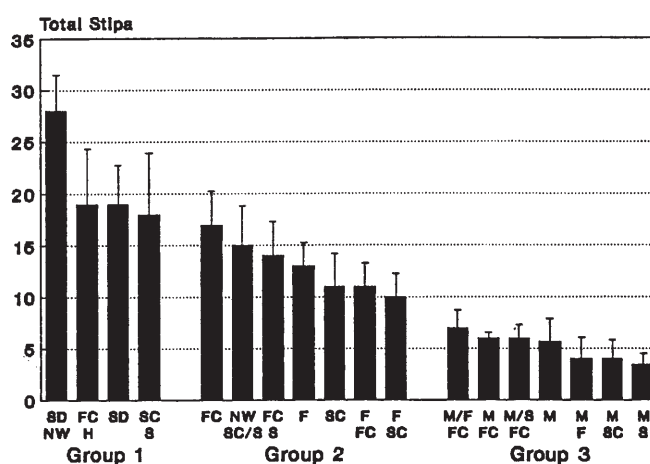


Figure 1—Total number of *Stipa* sp. present in each treatment, regardless of condition. FC = Fall applied cyanobacteria; SC = Spring applied cyanobacteria; F = Fertilizer; M = Mulch; S = Sugar; SD = Seed only; NW = No water; and H = Straw mixed in. Group 1 (a) was statistically different from Group 3 (b; $p < 0.01$); Group 2 was not different from 1 or 3.

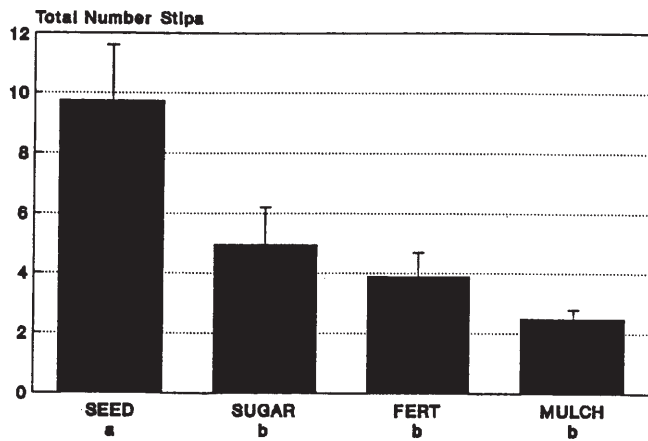


Figure 2—Total number of *Stipa* present, regardless of condition, lumped by common treatments. Statistical differences are denoted by different letters. Seed-only treatments had the fewest plants eaten when compared to the other treatments ($p < 0.01$). Other treatments were not statistically different among themselves.

cyanobacterial inoculant, and seed only with water. This first group had significantly higher numbers of *Stipa* than the third group, which consisted of all treatments with mulch. Fertilized treatments were found in the lower half of the treatments, with some averages statistically lower than the first group. Three noteworthy results can be seen from these data. First, mulch clearly had a detrimental effect on seedling survival for the first year in this experiment. Plots with mulch had fewer seedlings present when compared to the most successful plots, regardless of whether the mulch was applied alone or mixed with other treatments. Secondly, two of the four most successful treatments, measured by plant survival, were those plots that were seeded only, with no additional treatment. And thirdly, lack of additional watering did not adversely affect seedling survival during a growing season with below-average rainfall.

Common treatments were combined into four categories: seed-only, sugar, fertilizer, and mulch (cyanobacterial inoculant was excluded, as it crossed most treatments). When averages for these categories were compared, the seed-only treatment had a statistically greater number of seedlings present than the rest of the treatments (Fig. 2). The other three categories (sugar, fertilizer and mulch) were not statistically different from each other. These categories did show the same trends as in the uncombined data: seed-only had the greatest establishment, followed by sugar, fertilizer and then mulch.

Herbivory by rabbits and mice was intense during the first year of this experiment. Plants counted as “eaten” were those that had been chewed to less than 5 cm in height. Plants that were completely removed were not counted. “Uneaten” were plants that showed either no herbivory, or herbivory was slight. Figure 3 presents the number of plants eaten as a percentage of total plants in the plots. Due to high variability, there was no statistical difference among treatments, although herbivory ranged from 27% to 69% of the plants present. Average numbers of total uneaten *Stipa* plants are presented in Figure 4.

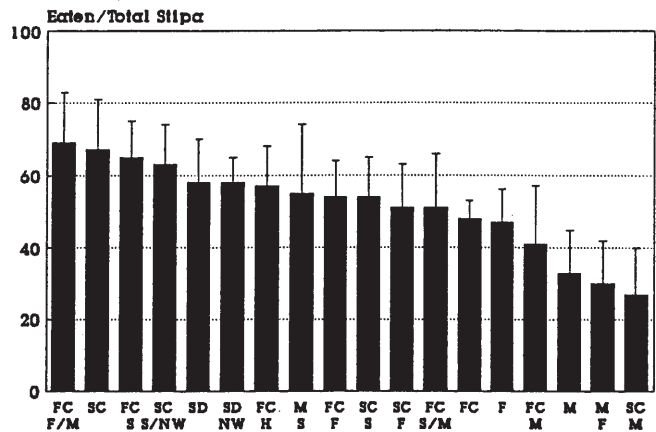


Figure 3—The ratio of eaten to total *Stipa* sp. in each treatment. FC = Fall applied cyanobacteria; SC = Spring applied cyanobacteria; F = Fertilizer; M = Mulch; S = Sugar; SD = Seed-only; NW = No water; and H = Straw mixed in. Due to high variability, no differences were statistically significant.

This figure is similar to the one showing total *Stipa* density. Indeed, there is a significant correlation between the total number of plants in the plot, and the number of plants eaten ($r = 0.85$; $p < 0.01$). Consequently, those plots with the greatest number of established plants were also those with the greatest amount of herbivory. Fertilized plots, with higher levels of available nitrogen and phosphorus, might have been expected to have more palatable plants, and consequently suffer higher herbivory rates. Concomitantly, sugared plots, with less available nitrogen, might be expected to show the reverse. However, this was not the case, as there was no difference between combined fertilized, sugared or mulched treatments (Fig. 5). Fertilized

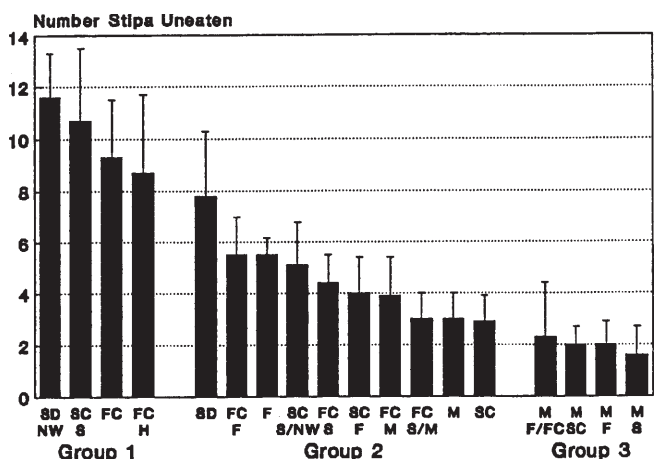


Figure 4—Total *Stipa* sp. uneaten in each treatment. FC = Fall applied cyanobacteria; SC = Spring applied cyanobacteria; F = Fertilizer; M = Mulch; S = Sugar; SD = Seed-only; NW = No water; and H = Straw mixed in. Group 1 (a) was statistically different from Group 3 (b; $p < 0.01$); Group 2 was not different from 1 or 3.

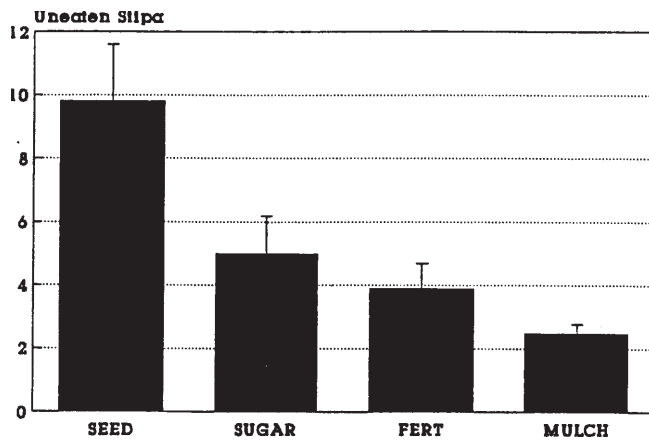


Figure 5—Total *Stipa* uneaten, with common treatments lumped. Seed-only treatments had the fewest plants eaten when compared to the other treatments ($p < 0.01$). Other treatments were not statistically different among themselves.

treatments showed an herbivory average of 50%, while sugared plots averaged 57%. Seed-only had significantly less herbivory than the other treatments.

Herbivory on *Stipa* was most often explained by the placement of the grass relative to *Salsola* canopies. Numbers of grasses growing outside the canopy of a *Salsola* were highly correlated with numbers of plants eaten ($r = 0.82$; $p < 0.01$); plants under *Salsola* were eaten 47% less often than those in the open. Numbers of grasses inside the canopy of the tumbleweed showed no correlation with herbivory events ($r = 0.22$; $p > 0.05$). However, there was also a high and significant correlation between total number of *Stipa* present and the number growing in the open ($r = 0.91$; $p < 0.01$).

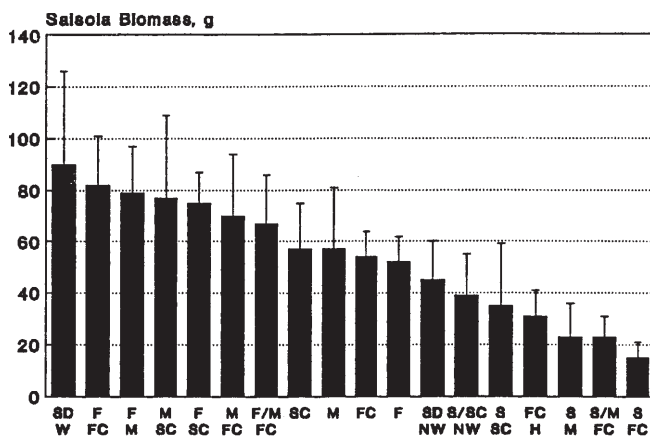


Figure 6—Total *Salsola* biomass in each treatment. FC = Fall applied cyanobacteria; SC = Spring applied cyanobacteria; F = Fertilizer; M = Mulch; S = Sugar; SD = Seed-only; NW = No water; and H = Straw mixed in. No differences were statistically significant, probably due to the high variability.

This may indicate seeded grasses were better able to establish outside *Salsola* canopies.

The two species of *Salsola*, *S. iberica* and *S. kali*, were combined for biomass and cover estimates. Average *Salsola* biomass ranged from 15 to 90 grams per plot in the different treatments, with 5 of the 6 lowest biomasses found in the sugared treatments (Fig. 6). However, the tremendous amount of variability among plots resulted in no statistical differences between treatments. When common treatments were lumped for *Salsola* biomass (Fig. 7), sugared plots had significantly less biomass than other treatment categories. Fertilized plots had 3 times the tumbleweed biomass of sugared plots, while the watered plots had 5 times the biomass of sugared plots. Fertilized, seed-only and mulch treatments were not different from each other.

Cover estimates for *Salsola* are presented in Figure 8. Although average cover values ranged from 23 to 42%, no statistical differences were seen. This may have been due to the high variability found. Some trends were apparent, however. Fertilized treatments were all at the high end of the cover estimates, while seed-only and sugared plots showed a tendency towards reduced *Salsola* cover. Combining treatment categories (Fig. 9) showed fertilized treatments with significantly greater cover than sugar or seed-only treatments. Mulched treatments were not statistically different from any other treatments.

Regression analysis was used to determine whether *Salsola* biomass or cover affected either total numbers of *Stipa* present in a plot, or the percentage of *Stipa* eaten in a plot. *Salsola* biomass showed no significant effect on the total *Stipa* in a plot ($r = -0.18$), although removal of one data point resulted in $r = -0.33$, which was statistically significant. There was no effect of *Salsola* biomass on the percentage *Stipa* eaten ($r = -0.23$). *Salsola* cover did not have a significant effect on the percentage eaten ($r = -0.24$), but did have some effect on the total *Stipa* present in the plot ($r = -0.37$; $p < 0.05$), though the “ r ” value was small.

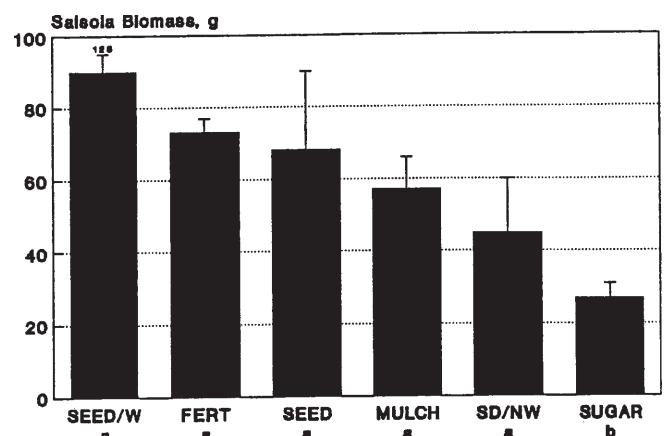


Figure 7—*Salsola* biomass, lumped by common treatments. Statistical differences are denoted by different letters. Sugar treatments had significantly less *Salsola* biomass when compared to the other treatments ($p < 0.01$). Other treatments were not statistically distinguishable.

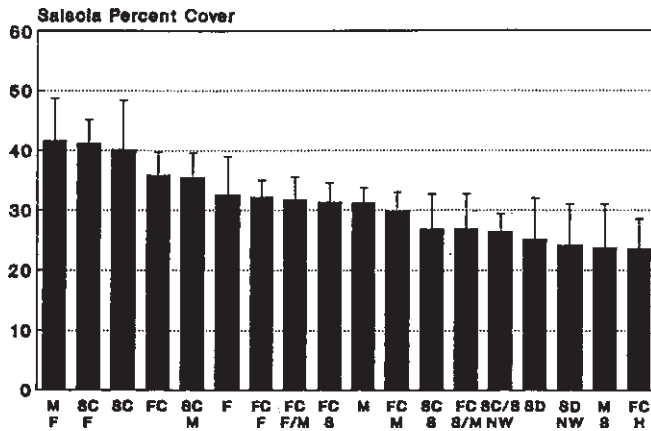


Figure 8— *Salsola* cover in each treatment. FC = Fall applied cyanobacteria; SC = Spring applied cyanobacteria; F = Fertilizer; M = Mulch; S = Sugar; SD = Seed-only; NW = No water; and H = Straw mixed in. No differences were statistically significant, probably because of high variability in the samples.

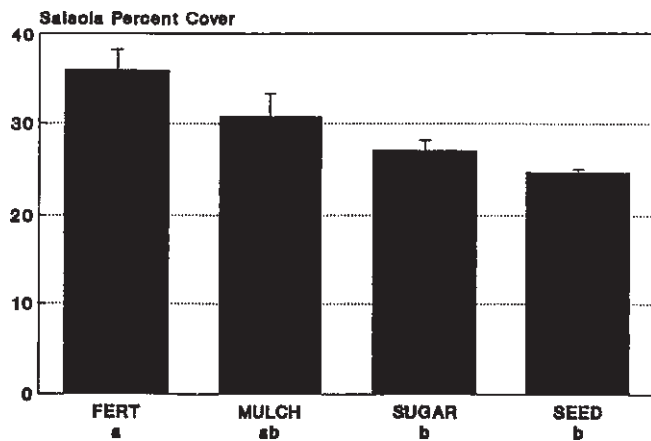


Figure 9— *Salsola* cover, lumped by common treatments. Statistical differences are denoted by different letters. Fertilized treatments showed greater cover than sugar or seed-only treatments ($p < 0.03$). Mulched treatments were not statistically different from any other treatment.

Conclusions

This seeding experiment calls into question several assumptions often made by restoration ecologists. First, mulch is generally assumed to be beneficial, especially in arid and semi-arid regions. In this study, straw mulch applications reduced the survival of seedlings compared to non-mulched treatments. Similar results have been reported from a project near Grand Junction, CO (J. Lance, personal communication). This may be a result of using dry straw. Both species of *Stipa* generally grow in loose, sandy soils. Since water percolates easily through these soils, long-lasting soil moisture in the upper horizons

would not naturally occur unless the entire soil profile was charged with water. Straw, on the other hand, may hold water in the upper soil layer regardless of water levels in lower soil profiles. This may “fool” seeds into germinating at an inappropriate time and/or concentrating their roots in surface soils, instead of deploying these roots in deep soils.

In addition, rainfall patterns in this area may make straw mulch a liability for seedlings. Storms in the spring often produce small, short bursts of rainfall, and straw mulch may absorb the entire rainfall event, preventing much moisture from reaching the soil. Since temperatures are high, this surface moisture could evaporate before ever becoming available to plant roots.

A second commonly held belief is that establishment of native plants takes place in semi-arid lands only during years when rainfall is well above average. This study demonstrates that this is not always true. Plant establishment in the non-watered plots was as successful as in any other treatment during a growing season of below-average rainfall. The fact that spring had average or slightly above-average rainfall may have been more important than an overall below-average growing season. Other factors may be equally important as rainfall to the success of seedling survival, including soil conditions, herbivory, and mechanisms that increase water availability such as reduced air temperatures or plant microclimates.

The presence of exotic annuals in a perennial-dominated community is generally assumed to be a liability, especially where water resources are limiting (Hunter 1990; Mack 1981). The ability of annual seedlings to outcompete perennial seedlings has been demonstrated repeatedly (Bartolome & Gemmill 1981; Hull and Miller 1977; Kay et al. 1981; Young et al. 1972). Annual plants are generally at a competitive advantage in relatively high water and high nutrient situations (Romney et al. 1978). These factors are often not taken into account in revegetation efforts, as evidenced by the many projects that use fertilizers and water. The effects of water and nutrients on annual plants can be seen clearly in this study. Increasing levels of water, even only to imitate average annual rainfall, favored the establishment and growth of the exotic annual *Salsola*. Comparing the seed-only, no water treatments with the seed-only with water treatments, we can see that the biomass of this plant increased by over 70%. Low nutrient availability, induced by sugar applications that stimulated microbial biomass production, significantly reduced *Salsola* biomass and cover. Consequently, limiting water and nutrient availability should be considered in areas where annual exotics are a problem.

Exotic annuals may not always be a problem, and may actually aid in revegetation efforts. As demonstrated by this study, *Salsola* biomass and cover had no, or little, effect on *Stipa* survival or percentage eaten, though more *Stipa* plants were found outside than within *Salsola* canopies. However, growth under a *Salsola* canopy clearly protected the native grasses from herbivory. During data collection for this study, non-quantified observations were made that *Stipa* plants growing in the canopy of *Salsola* plants were much larger than plants growing in the open, often having 5 to 6 blades and being 20 to 30 cm tall, compared to plants with 1 to 5 blades that were 5 to 20 cm tall in the

open. It is not known whether such severe herbivory will significantly affect long-term survival of these plants, though it seems likely. When biomass, not just number of established plants of desired species is considered, the protection offered by a *Salsola* canopy may outweigh the negative effect that increasing *Salsola* cover has on the desired perennial species in years of average rainfall. It is not known whether the negative impacts of these annual species would be greater in years of more limited water. *Salsola* populations did quite well in a recent 5-year drought in this area, and may compete effectively with perennial grass species when water is scarce.

Though much was learned about ways to hasten revegetation of disturbed semi-arid grasslands in this study, levels of herbivory and other environmental stressors prevented any of the treatments from being judged successful in terms of overall plant establishment. This may be true even when factors controlling plant germination and establishment are better understood. Consequently, we should be careful not to overestimate our ability to revegetate these areas in a short time frame (10 years), and certainly should refrain from claiming that true restoration of these areas is possible until more supporting data are available.

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References

- Bartolome, J. W. and B. Gemmill. 1981. The ecological status of *Stipa pulchra* (Poaceae) in California. *Madrono* 28:172-184.
- Bazzaz, F. A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics* 10:351-371.
- Billings, W. D. 1990. *Bromus tectorum*, a biotic cause of ecosystem impoverishment in the Great Basin. G. M. Woodwell, editor. *The earth in transition: patterns and processes of biotic impoverishment*. Cambridge University Press, Cambridge, England.
- Gleason, H. A., and A. Cronquist. 1964. *The Natural Geography of Plants*. Columbia University Press, New York.
- Heil, G. W., and M. Bruggink. 1987. Competition for nutrients between *Calluna vulgaris* (L.) Hull and *Molina caerulea* (L.) Moench. *Oecologia* 73:105-107.
- Hull, J. C. and C. H. Muller. 1977. The potential for dominance by *Stipa pulchra* in a California grassland. *American Midland Naturalist* 97:147-175.
- Hunt, H. W., E. R. Ingham, D. C. Coleman, E. T. Elliott, and C. P. P. Read. 1988. Nitrogen limitation of production and decomposition in prairie, mountain meadow, and pine forest. *Ecology* 69:1009-1016.
- Hunter, R. 1990. Recent increases in *Bromus* populations on the Nevada Test Site. *Proceedings-symposium on cheatgrass invasion, shrub die-off and other aspects of shrub biology and management*. USDA Intermountain Research Station General Technical Report INT-276.
- Kay, B. L., R. M. Love, and R. D. Slayback. 1981. Revegetation with native grasses: a disappointing history. *Fremontia* 9:11-15.
- Lamb, D. 1980. Soil nitrogen mineralization in a secondary rainforest succession. *Oecologia* 47:257-263.
- Mack, R. N. 1981. The invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. *Agro-Ecosystems* 7:145-165.
- McArthur, E. D., E. M. Romney, S. D. Smith, and P. T. Tueller. 1990. *Proceedings-symposium on cheatgrass invasion, shrub die-off and other aspects of shrub biology and management*. USDA Intermountain Research Station General Technical Report INT-276. 351 p.
- McGraw, J. B. and F. S. Chapin III. 1989. Competitive ability and adaptation to fertile and infertile soils in two *Eriophorum* species. *Ecology* 70:736-749.
- McLendon, T. and E. F. Redente. 1992. Effects of nitrogen limitation on species replacement dynamics during early successional succession on a semiarid sagebrush site. *Oecologia* 91:312-317.
- Parrish, J. A. D. and F. A. Bazzaz. 1982. Responses of plants from three successional communities on a nutrient gradient. *Journal of Ecology* 70:233-248.
- Romney, E. M., A. Wallace, and R. B. Hunter. 1978. Plant response to nitrogen fertilization in the Northern Mojave Desert and its relationship to water manipulation. In: West, N. E. and J. Skujins, editors. *Nitrogen in desert ecosystems*. Dowden, Hutchinson, and Ross, Stroudsburg, PA.
- Sampson, A. W. and L. H. Weyl. 1918. Range preservation and its relation to erosion control on Western grazing lands. *USDA Bulletin* 675.
- Smith, J. G. 1899. Grazing problems in the Southwest and how to meet them. *USDA, Division of Agrostology Bulletin* 16. 47 p.
- Welsh, S. L. 1994. *A Utah Flora*. Great Basin Naturalist Memoirs. Brigham Young University, Provo, Utah.
- Young, J. A., R. A. Evans, and J. Major. 1972. Alien plants in the Great Basin. *Journal of Range Management* 25:194-201.