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Increasing native diversity of cheatgrass-dominated rangeland through assisted succession

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Abstract

Increasing attention, resources and efforts are being focused on the conversion of weedy dominated rangelands back to perennial plant communities that resemble predisturbance communities in form, function and composition. A study was conducted in 1998 and replicated again in 1999 to determine whether native plants could be established through "assisted succession" - manipulating a cheatgrass-dominated area to perennial plant domination, then to native or near-native diversity. Cheatgrass dominated rangeland that had been successfully revegetated with crested wheatgrass (*Agropyron cristatum* [L.] Gaertner) was seeded with native species. Another area dominated by cheatgrass, but without crested wheatgrass, was also seeded. Four seedbed preparation methods were investigated: tilling, harrowing, application of a herbicide, and no treatment. Four different seeding methods were used in the 2 areas and 4 seedbed preparation techniques: drilling, broadcasting, a broadcast-cover method, and no seed. Seeding was done in February, and data were collected in mid-summer each year. Native grasses and shrubs emerged in greater numbers on treatments established on the crested wheatgrass matrix than on those established on the cheatgrass matrix. Perhaps in general, but especially in years with normal or below average precipitation, the assisted succession approach proved successful for restoration of native sagebrush-grassland steppe from cheatgrass range.

Resumen

Los pastizales dominados por malezas anuales, como el "Cheatgrass" (*Bromus tectorum* L.), cada vez mas están siendo convertidos a comunidades de plantas que se asemejan en forma, función y composición, a las existentes antes del disturbio. En 1998 se condujo un estudio, que se repitió en 1999, para determinar si las plantas nativas pudieran ser establecidas a través de "sucesión asistida", esto es, manipulando un área dominada por "Cheatgrass" para que dominen las plantas perennes y alcanzar una diversidad igual o cercana a la original. Un pastizal dominado por "Cheatgrass" que había sido revegetado exitosamente con "Crested wheatgrass" (*Agropyron cristatum* [L.] Gaertner) se sembró con especies nativas. Otra área dominada por "Cheatgrass"pero sin "Crested wheatgrass" también fue sembrada. Se investigaron cuatro métodos de preparación de la cama de siembra: Labranza, barbecho, aplicación de un herbicida y no tratamiento. En las dos áreas se usaron cuatro métodos de siembra: siembra en hilaras, semilla esparcida al voleo, un método de semilla dispersada al voleo y cubierta y sin semilla. La siembra se efectuó en Febrero y los datos se colectaron a mediados del verano de cada año. Los zacates nativos y los arbustos emergieron en mayor número en los tratamientos establecidos en el área con "Crested wheatgrass" que los establecidos en el área con solo "Cheatgrass". Quizás en general, pero especialmente en años con precipitación normal o abajo del promedio, la "sucesión asistida" probo ser exitosa en la restauración de la estepa de pastizal "Sagebrush".

Key Words: cheatgrass, crested wheatgrass, rangeland reseeding, restoration, sagebrush-steppe

Natural succession has been suggested as a model for restoration and management of disturbed plant communities (Luken 1990, Hironaka 1994, Jones 1997, 1998, Brown and Amacher 1999). In wildland restoration, 3 basic components of succession may be used to determine the suitability of land for intervention: site availability, species availability, and species performance (Rosenberg and Freedman 1984, Pickett et al. 1987, Luken 1990, Sheley et al. 1996). Each of these may be initiated, modified, or curtailed by restorationists with the aim of affecting the trajectory of succession.

The difficulty of seeding native species directly into areas dominated by cheatgrass (*Bromus tectorum* L.) and other exotic annuals is well documented (Campbell and Swain 1973, Pellant 1990, Allen 1995, Beckstead et al. 1995, Monsen and McArthur 1995). However, once perennial native species are reestablished in a system, exotic annual species often diminish (Nelson et al. 1970, Campbell and Swain 1973, Hironaka and Sindelar 1973, Monsen and McArthur 1995). Various strategies have been investigated to establish desirable plants in areas dominated by invasive annual species. One approach is to occupy the site with an aggressive perennial and then seed the desired native species. In this vein, Jones (1997) suggested seeding the native grass bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), and Roundy et al. (1997) suggested establishing exotic, perennial grasses on annual plant-dominated sites prior to seeding of native species. The objective of this study was to investigate the feasibility of using crested wheatgrass (*Agropyron cristatum* [L.] Gaertner) to move a site from annual-plant to perennial-plant domination, followed by niche opening and reinsertion of species native to the predisturbance plant community.

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Methods

Site description

The areas used in this study were on and adjacent to the U.S. Army Dugway Proving Ground (DPG), Tooele County, Utah. Due to an earlier fire, the study areas were without native vegetation. Some areas were within the boundaries of DPG (40° 15'35" N 112° 49' 20" W ; elevation = 1,600 m and 40° 12' 40" N 112° 47' 45" W; elevation = 1,446 m) and were dominated by a host of exotic annuals, primarily cheatgrass. The other areas were immediately adjacent to DPG on land administered by the U.S. Department of Interior Bureau of Land Management (BLM) (40° 18' 36"N 112° 51' 20"W ; elevation = 1,550m) and were seeded with crested wheatgrass after the last fire. The soils in all areas are Medburn coarse-loamy, mixed (calcareous), mesic, Xeric Torriorthents. Native vegetation at the sites is considered to be Wyoming big sagebrush (*Artemisia tridentata* Var. *wyomingensis* [Beetle & A. Young] Welsh), Indian ricegrass (*Stipa hymenoides* R. & S.), bottlebrush squirreltail, and bluebunch wheatgrass (*Elymus spicatus* [Pursh] Gould) (Trickler et al. 2000). The 36-year average precipitation for the general area is 174 mm, occurring mostly in winter and spring (NOAA 1999).

The experimental design was a split-block, with treatments randomized in strips across the replications. Three, 40-by 40-m replicate blocks were created each year for 2 years in a crested wheatgrass monoculture and in a cheatgrass-dominated annual community. Seedbed preparation treatments were randomly applied in 10-m strips across the blocks, and seeding method treatments were randomly applied perpendicular to the seedbed treatments. As a result, each 40-by 40-m replicate block contained 16, 10-by 10-m experimental units of different seedbed preparation and seeding method combinations.

Species seeded

A mixture of 8 species (3 shrubs and 5 grasses) native to the local area was seeded. Species and their seeding rates are shown in Table 1. Seeds were purchased from Granite Seed Co., Lehi, Utah.

Table 1. Native plant species and rate seeded in kg ha^{-1} pure live seed, Toole Co, Utah—1998 and 1999.

Species	Rate, Pure Live Seed
Wyoming big sagebrush (*Artemisia tridentata* var *wyomingensis*	(kg/ha)
[Beetle & A. Young] Welsh)	0.3
Four-wing saltbush (*Atriplex canescens* [Pursh] Nutt.)	2.5
Rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.)	0.2
Bluebunch wheatgrass (*Elymus spicatus* [Pursh] Gould)	1.7
Galleta (*Hilaria jamesii* [Torr.] Benth.)	1.2
Needle and thread grass (*Stipa comata* Trin.& Rupr.)	1.1
Sandberg bluegrass (*Poa secunda* Presl)	1.1
Squirreltail (*Elymus elymoides* [Raf.] Swezey)	1.1

Seedbed preparation

Seedbed preparation techniques included: tilling, harrowing, spraying a chemical herbicide, glyphosate (Roundup™ super concentrate weed and grass killer, *N*-[phosphonomethyl] glycine), and a control treatment of no seedbed preparation. Seedbeds were prepared in early February 1998 and 1999. Tilling with a 162-cm wide Rotovator completely removed all existing vegetation, mixed the soil to a depth of about 18 cm, and provided a smooth soil surface. Harrowing with a 200-cm wide field harrow resulted in a very rough soil surface, with moderate vegetation removal. Glyphosate applied as a broadcast spray at 1.26 kg a.i. ha^{-1} in a total volume of 358 liters ha^{-1} from a 1-m boom installed on the rear of a 4-wheel all-terrain vehicle resulted in little soil disturbance, and left dead vegetation as litter on the soil surface.

Seeding method

The seeding methods investigated included: drilling, broadcasting, broadcasting followed by covering the seeds, plus a control (no seed). Seed was sown in late afternoons in mid-March each year. Drilling was done in 1988 with a John Deere Flex Drill and in 1999 with a Truax FLXII-812 rangeland drill. Both drills were calibrated by raising the openers and manually turning the wheels. Openers on 40-cm centers were set to place the seed about 1 cm deep. As neither sagebrush nor rabbitbrush seed would pass reliably through the seed drills, they were broadcast instead of drilled into the appropriate experimental units. Broadcasting was done by hand, taking care to provide complete and even coverage of the experimental plots. The broadcast-cover method was accomplished by broadcasting all the seed as described above, then pulling a railroad tie across the plot with a tractor.

Data collection and analysis

Data were collected in July of each sampling year (1998, 1999, and 2000), using a 200-by 30-cm rectangular quadrat, randomly placed 12 times in each experimental unit. Within this quadrat, percent cover was visually estimated using cover classes for crested wheatgrass and cheatgrass. Species presence was noted, and for seeded species, the number of seedlings present within the quadrat was recorded. Emergence data were collected the summer after seeding, in July of 1998 and 1999. Establishment data were collected the following years. For data analysis and interpretation, the seeded species were placed into 3 groups: native grasses, Wyoming big sagebrush and rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.), and fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.). The Mixed Models analysis in SAS (SAS Institute 1996) was used to determine treatment effects and interactions. The analysis factors in the design were site (crested wheatgrass vs. cheatgrass), seedbed preparation technique (till, harrow, glyphosate, no treatment), seeding treatment (drill, broadcast, broadcast plus covering, no seed), and year of seeding (1998 vs. 1999). These factors and their interactions were considered fixed in the mixed models analysis. Factors considered random were replications and interactions of replications with other factors. Significant differences were accepted at the $\alpha = 0.05$ level.

Results

Precipitation

Precipitation was very different in the 2 seeding years of this study (Fig. 1). In 1998, February and March received above average precipitation, while April and May received only average or below average precipitation. In 1999, however, the opposite occurred: February and March precipitation was below average, while April, May, and June precipitation was above average.

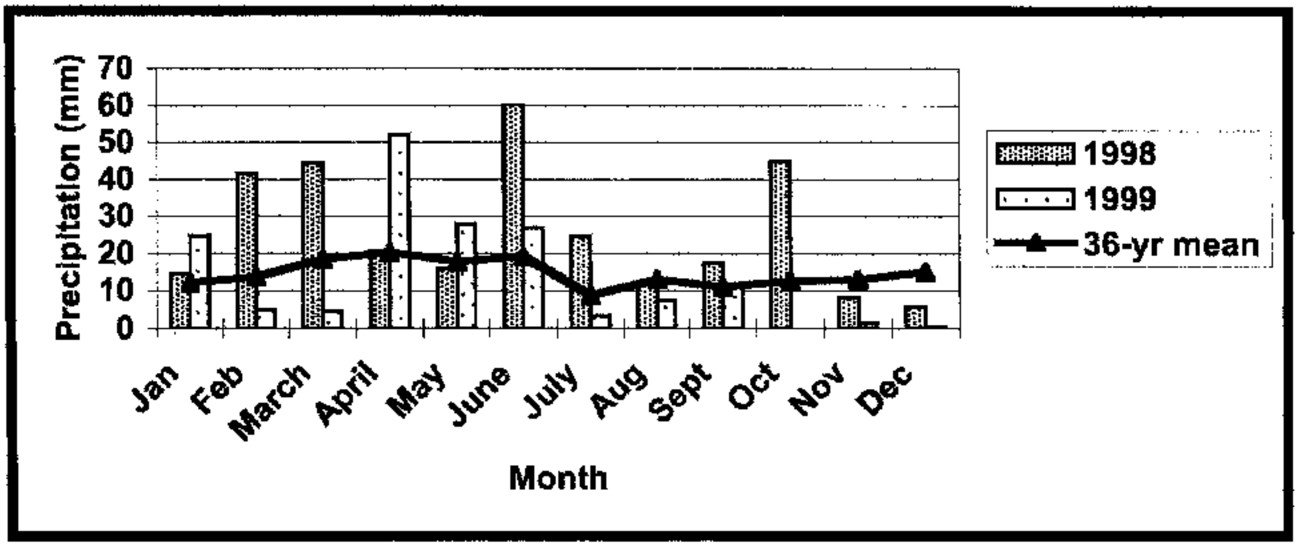

Fig. 1. Precipitation in 1998 and 1999 and 36-year average precipitation by month for Dugway Proving Grounds, Tooele Co., Utah.

Native grass emergence

When the emergence of native grass seedlings was compared across the 4 variables of year, site, seedbed preparation, and seeding treatment, two 3-way interactions occurred. A year by site by seeding method interaction (Fig. 2) indicated that the site effect was different in 1998 than in 1999, and that within each year, emergence did not respond to seeding methods in exactly the same way between sites. In 1998, seeding into crested wheatgrass resulted in significantly greater native grass seedling densities than did seeding into cheatgrass across all seeding techniques. In 1999, the grass emergence was similar within all seeding treatments independent of seeding technique.

The year by site by seedbed preparation interaction showed a similar response (data not shown). In 1998, all seedbed preparation treatments yielded nearly 100 percent more seedlings m^{-2} in crested wheatgrass than in cheatgrass. In 1999, however, the site effect was negligible. In both crested wheatgrass and cheatgrass, all treatments resulted in fewer than 4 seedlings m^{-2}.

Artemisia tridentata and *Chrysothamnus nauseosus* emergence

Sagebrush and rabbitbrush emergence also displayed two, 3-way interactions when year, site, seedbed preparation and seeding method were considered. In a site by seedbed preparation by seeding method interaction (Fig. 3), emergence was greater on the crested wheatgrass site than the cheatgrass site except in site preparation control plots. Seedling emergence varied by site preparation and seeding technique in crested wheatgrass, but neither had an effect in cheatgrass. In crested wheatgrass,

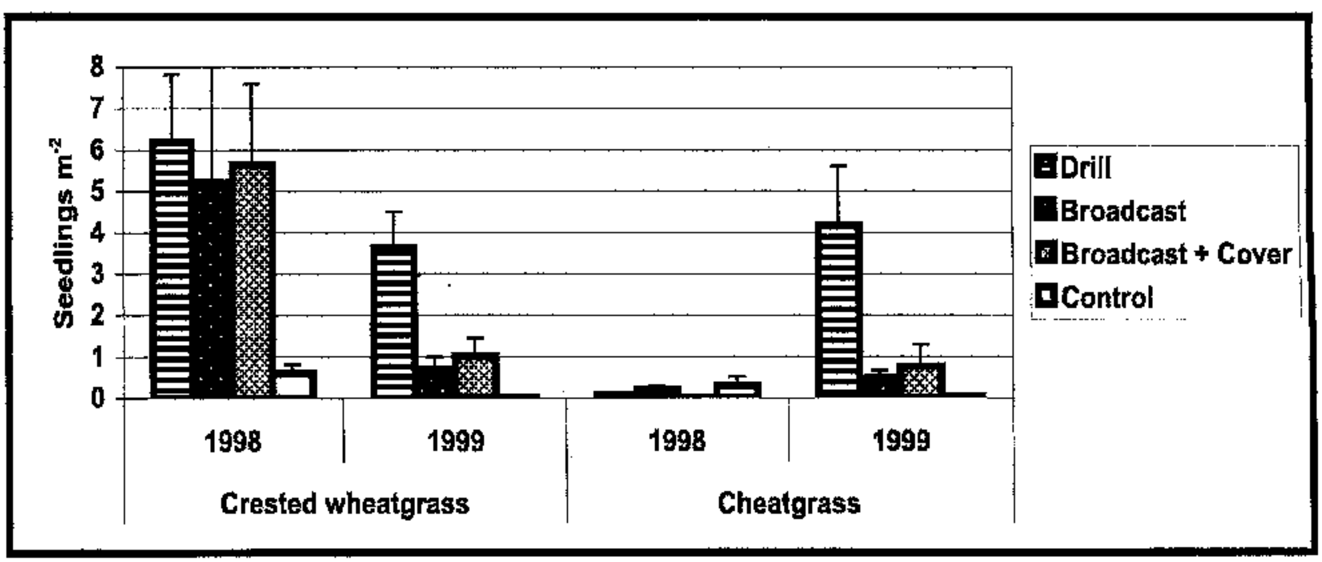

Fig. 2. Means and standard errors for native grass emergence at Dugway Proving Grounds, Tooele Co., Utah, as affected by year, site, and seeding method (P = 0.04). Data collected July 1998 and 1999.

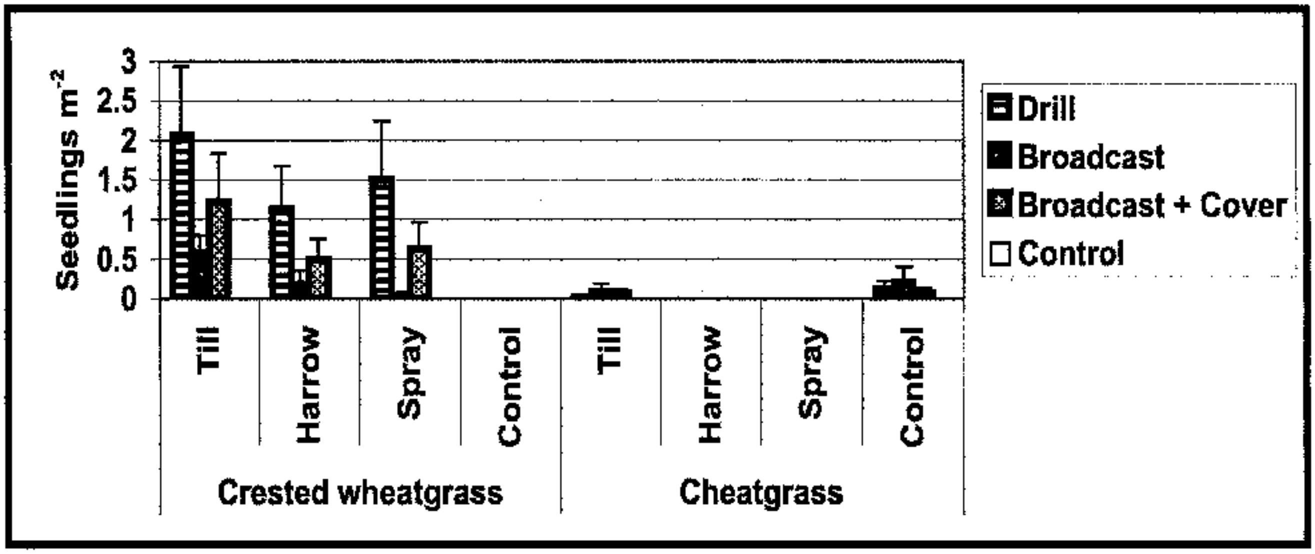

Fig. 3. Means and standard errors for *Artemisia tridentata* and *Chrysothamnus nauseosus* emergence at Dugway Proving Grounds, Tooele Co., Utah, as affected by seeding method, site, and seedbed preparation (P = 0.04). Data collected July 1998 and 1999.

tilling the seedbed provided the greatest density of seedlings across all seeding techniques. However, even a lower density of emergence - 0.6 plants m^{-2} with herbicide application followed by broadcast and cover - would be an acceptable density if these shrubs established. Drill seeding in crested wheatgrass resulted in at least 50% more emergence than any other seeding technique. Broadcast and cover in crested wheatgrass resulted in at least 46% more sagebrush and rabbitbrush seedlings than simply broadcasting alone.

An interaction of year by site by seeding method (not shown) exhibited a site effect in 1998 and none in 1999. In 1998, the cheatgrass site showed little or no emergence across all seeding types. The crested wheatgrass site, however, had densities of up to 2 seedlings m^{-2}. In 1999, no seeding method resulted in more than 0.2 seedlings m^{-2} in either crested wheatgrass or cheatgrass.

Atriplex canescens emergence

Analysis of the fourwing saltbush data revealed a 2-way and a 3-way interaction. The 3-way interaction was of site, seedbed preparation, and seeding method (Fig. 4). Seedling emergence was much greater on the crested wheatgrass site, especially within the tilling treatment, relative to the cheatgrass site. In the crested wheatgrass, combinations that included the till treatment provided at least 73% more seedlings m^{-2} than combinations that included other seedbed preparation techniques. In addition, the drill-seeding method provided greater than 30% more seedlings m^{-2} than other seeding method combinations. In the cheatgrass site, all combinations of seeding method and seedbed preparation produced less than 0.4 seedlings m^{-2}. The 2-way interaction (not shown) was year by seedbed prepara-

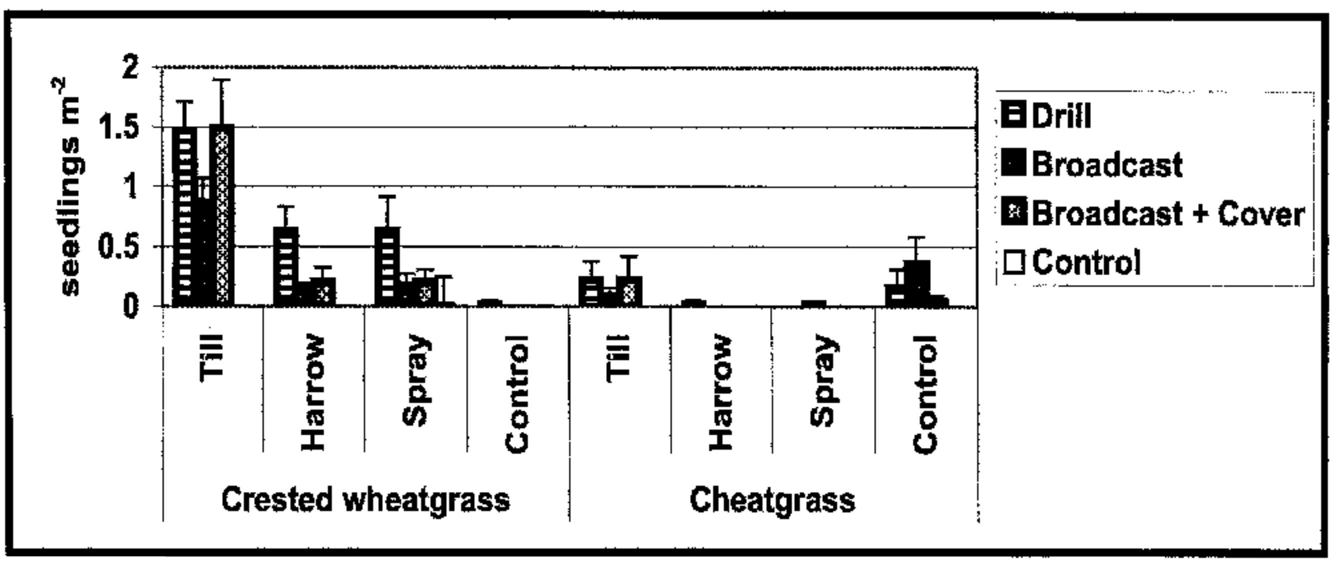

Fig. 4. Means and standard errors for *Atriplex canescens* emergence at Dugway Proving Grounds, Tooele Co., Utah, as affected by seeding method, site, and seedbed preparation (P = 0.01). Data collected July 1998 and 1999.

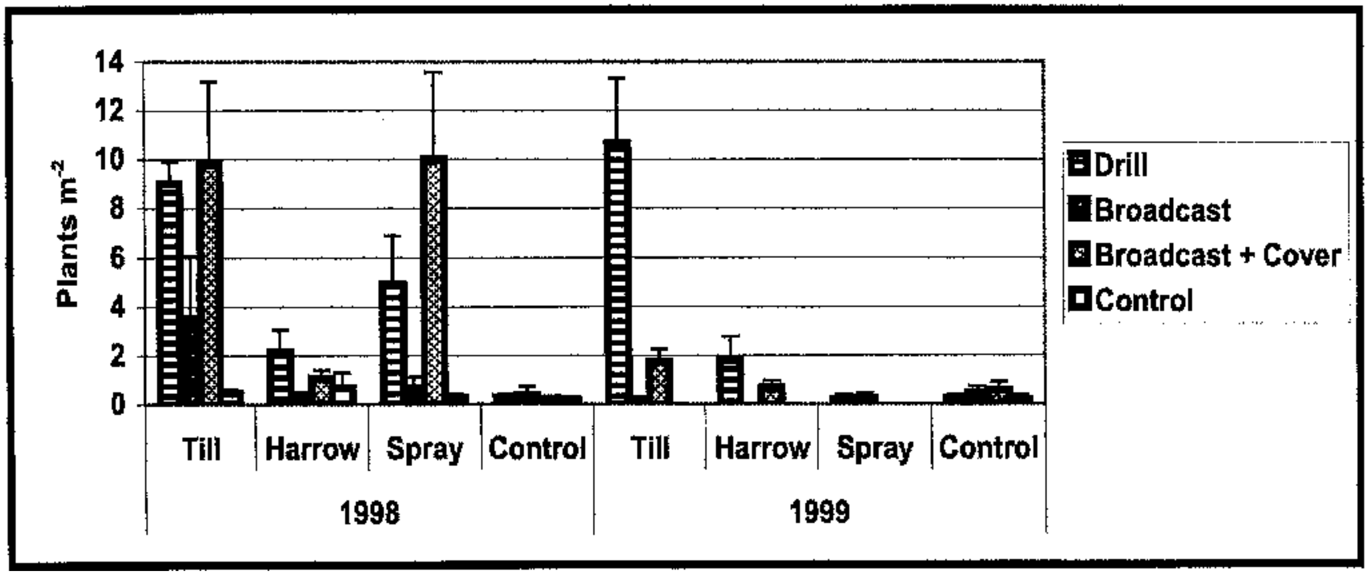

Fig. 5. Means and standard errors for native grass establishment in crested wheatgrass at Dugway Proving Grounds, Tooele Co., Utah, as affected by seeding method, year, and seedbed preparation ($P = 0.02$). Data collected July 1998 and 1999.

tion technique. In 1998, tilling provided 69% more emerged seedlings m^{-2} than harrowing and 34% more than glyphosate application. In 1999, tilling yielded greater than 80% more seedlings m^{-2} than either harrowing or spraying.

Establishment of native grass seedlings

Each plot was reexamined in July of the second growing season to investigate the establishment of seeded species. The establishment of native grasses displayed a 4-way interaction (site by year by seedbed preparation by seeding method) in this analysis. The interaction associated with site was simply no response (survival of previous year's emerged seedlings) in cheatgrass across all treatment combinations and levels vs. a varied response in crested wheatgrass. In crested wheatgrass (Fig. 5), establishment was generally much greater from the 1998 planting than that of 1999. The exception to that was a similar response in both years to the till and drill and harrow and drill combinations, which produced similar results for both years. Establishment from 1998 drill or broadcast and cover seeding methods was relatively similar across all land preparation techniques. However, establishment from 1999 was significantly stronger with drilling.

Establishment of *Artemisia tridentata* and *Chrysothamnus nauseosus*

The establishment of sagebrush and rabbitbrush also displayed a 4-way interaction of site by year by seedbed preparation by seeding method. Again, the interaction associated with site was simply no response (survival of previous year's emerged seedlings) in any treatment combinations or levels in cheatgrass. In crested wheatgrass (Fig. 6), establishment of

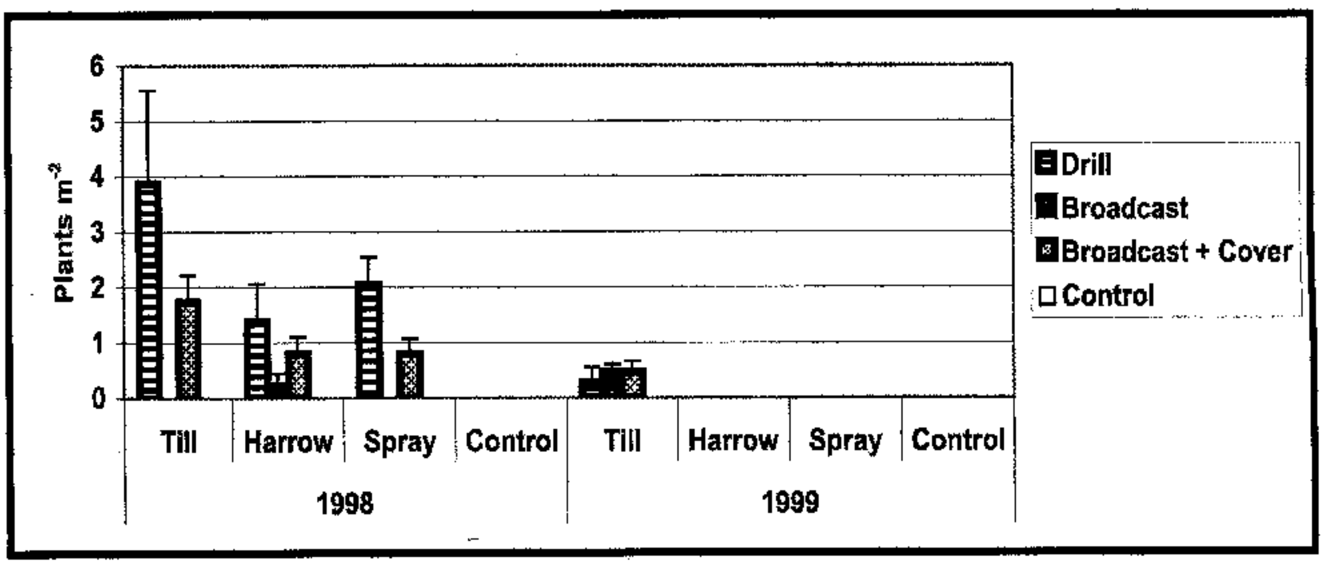

Fig. 6. Means and standard errors for *Artemisia tridentata* and *Chrysothamnus nauseosus* establishment in crested wheatgrass at Dugway Proving Grounds, Tooele Co., Utah, as affected by seeding method, year, and seedbed preparation ($P < 0.01$). Data collected July 1998 and 1999.

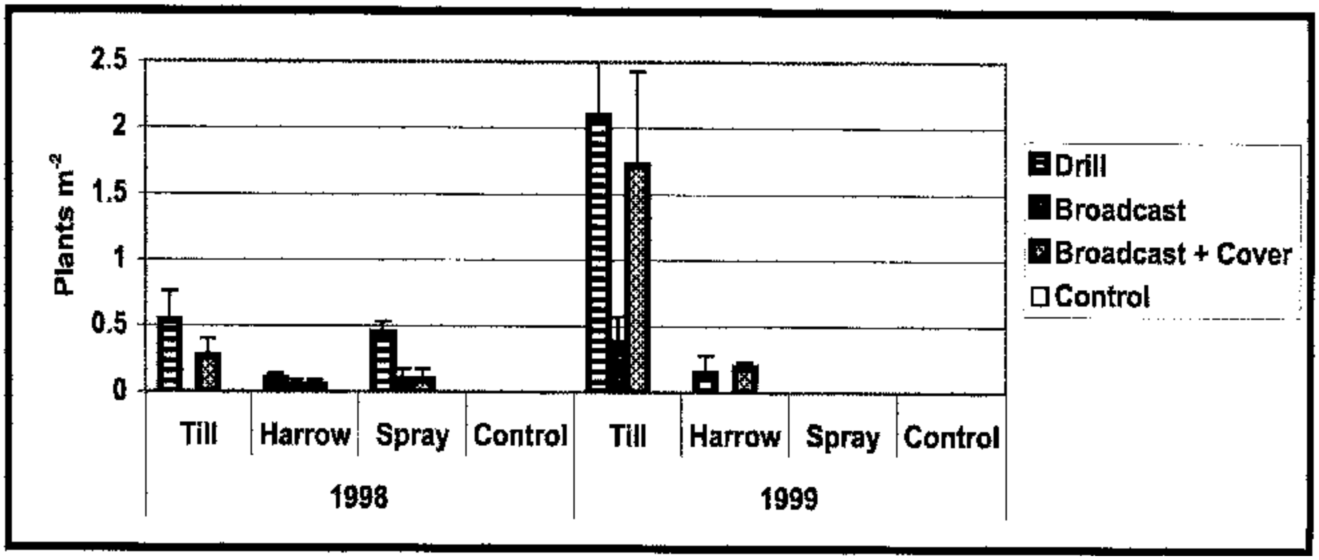

Fig. 7. Means and standard errors for *Atriplex canescens* establishment in crested wheatgrass at Dugway Proving Grounds, Tooele Co., Utah, as affected by seeding method, year, and seedbed preparation (P < 0.01). Data collected July 1998 and 1999.

these shrubs occurred in several treatment combinations within areas seeded in 1998 and to a very small degree in 1999 with treatments associated with tilling. Establishment patterns from the 1998 treatment combinations mimicked those of emergence for these species.

Establishment of *Atriplex canescens*

Fourwing saltbush displayed a 4-way interaction of site by year by seedbed preparation by seeding method. Once again, the interaction associated with site was simply no response (survival of previous year's emerged seedlings) in any treatment combinations or levels in cheatgrass. In crested wheatgrass (Fig. 7) establishment from the 1998 seeding was moderate. The till-drill and spray-drill combinations were most effective, with the till-broadcast-cover treatment also providing some establishment. Establishment from the 1999 seeding was very successful in the till-drill and the till-broadcast-cover combinations with some establishment occurring in the harrow treatment combinations.

Cover of crested wheatgrass and cheatgrass

Cover classes of both crested wheatgrass and cheatgrass were recorded in July of 1998 and 1999 and analyzed to determine the effect of the seedbed preparation treatments on the annual and perennial monocultures. Analysis of crested wheatgrass cover data revealed a 2-way interaction of year by seedbed preparation treatment (Fig. 8). Glyphosate application effectively reduced crested wheatgrass cover in 1998, but did not reduce cover in 1999. Better growing conditions in February of 1998 compared to those in 1999 probably explain why glyphosate was effective in killing crested wheatgrass in 1998 but not in 1999. This finding helps explain the emergence and establishment data, which showed good emergence of most species

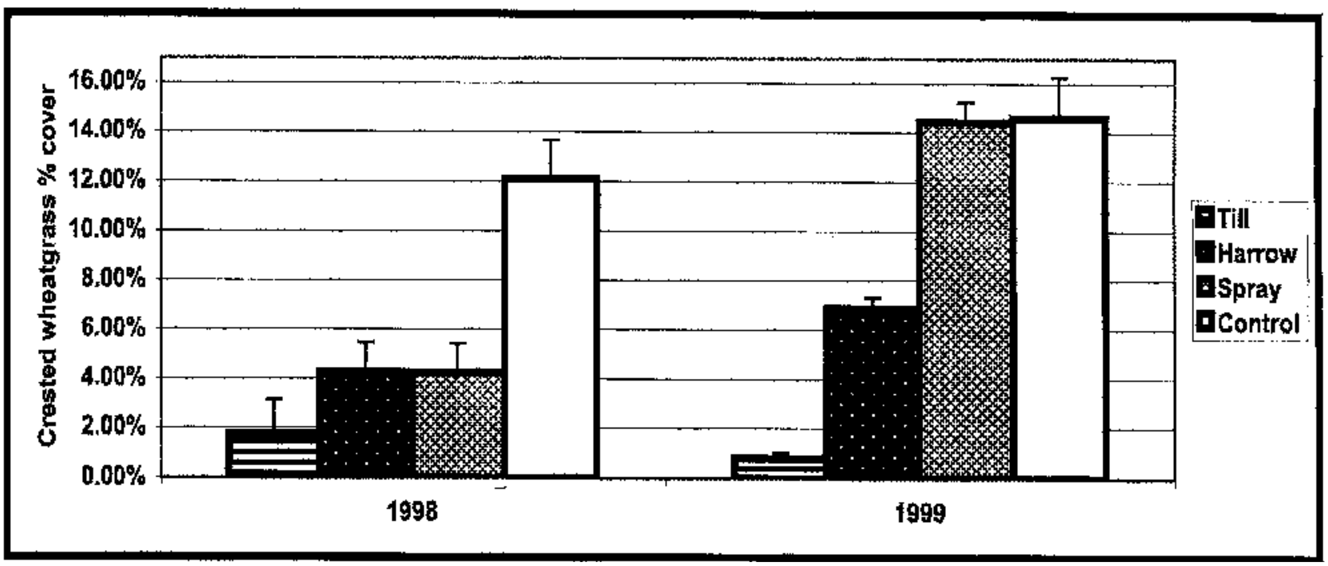

Fig. 8. Means and standard errors for crested wheatgrass cover after seedbed preparation at Dugway Proving Grounds, Tooele Co., Utah, as affected by year and seedbed preparation (P < 0.01). Data collected July 1998 and 1999.

when crested wheatgrass was sprayed in 1998, but low emergence with the same treatment in 1999. Cheatgrass cover (data not shown) was not affected significantly by any seedbed preparation treatments.

Discussion

This study illustrates a way in which the 3 basic components of succession (site availability, species availability, and species performance) may be manipulated to influence the outcome of succession. By using crested wheatgrass to "capture" a site from cheatgrass, niche availability and species performance for native seedlings may be enhanced, as evidenced by increased emergence and establishment in these areas. Seedbed perturbations can also increase niche availability and species performance. Species availability was increased by seeding desirable species. Different seeding methods resulted in various levels of success.

Difficulty in establishing native species in areas dominated by weedy annuals, including cheatgrass, is well documented (Pellant 1990, Allen 1995, Tausch et al. 1995). Cheatgrass inhibits the establishment of native species in 2 ways. First, because cheatgrass can germinate at low temperatures, it can germinate in autumn or spring, fully using winter and early spring moisture (Beckstead et al. 1995) and expanding root length and biomass faster than native species can at low temperatures (Harris 1967, Harris and Goebel 1976, Aguirre and Johnson 1991). In these conditions, cheatgrass may deplete soil water and competitively exclude native species. Second, cheatgrass-facilitated increases in fire frequency (Houston 1973, Whisenant 1990) may eliminate any native seedlings that do emerge. Because of the double jeopardy of competition and fire, it is extremely difficult to establish native species in cheatgrass-dominated areas.

Site capture

Crested wheatgrass is established on more than 4 million ha of rangeland in western North America (Caldwell et al. 1981, Rogler and Lorenz 1983, Bakker et al. 1997). In the Great Basin it is relatively resistant to wildfire, aggressive in the seedling stage and has been shown to be effective at capturing sites from cheatgrass and other annual species (D'antonio and Vitousek 1992). It has persisted in stable monocultures for over 40 years (Trlica and Biondini 1990). In the Great Basin, capturing a site from cheatgrass domination through establishment of a perennial such as crested wheatgrass changes plant community structure and function. Fire frequency is reduced and resource allocation patterns shift to resemble those of a predisturbance community. Niches formed by perturbations in a crested wheatgrass monoculture may remain open and be effective for establishing native species, whereas niches formed in cheatgrass stands are often rapidly reinvaded. This approach of assisted succession shows promise in restoring native species to degraded areas of the shrub-steppe regions of the Great Basin.

Effects of precipitation and use of soil water

Differing precipitation patterns between the 2 years may help explain the difference in emergence of native species between the 2 sites. More seedlings emerged on the crested wheatgrass site in 1998 than in 1999, while more emerged in 1999 than 1998 on the cheatgrass site. In 1998, above-average precipitation in February and March may have facilitated germination and emergence of the native seedlings. After the period of above-average precipitation, average or below average precipitation in April and May accentuated competition for water in the cheatgrass areas.

Precipitation in February and March of 1999 was approximately 50% of average. This lack of precipitation could have severely reduced both germination and emergence of grasses. After this low-moisture period, 3 consecutive months with above-average precipitation provided a flush of moisture that may have ameliorated the competition for water in the cheatgrass area, allowing a greater percentage of germinated seedlings to emerge.

Although quite variable, greater emergence and establishment of native seedlings occurred on crested wheatgrass areas compared with areas dominated by cheatgrass and other annuals. By capturing the site with an aggressive perennial such as crested wheatgrass, the effects of environmental variations, such as the timing and amounts of precipitation, may be ameliorated or smoothed, so that native species have a greater chance of surviving to establishment.

Seedbed preparation and seeding method

Once the site is captured by crested wheatgrass, niche-opening disturbances must be used to open niches and allow establishment of native species. In this study, almost no seedlings emerged or established in experimental units without disruption of the monoculture, whether crested wheatgrass or cheatgrass. When a disruption, such as tilling, harrowing, or spraying of glyphosate, occurred, native species generally established in crested wheatgrass but not in cheatgrass. It was important that seedbed perturbations both remove existing vegetation and prepare an adequate seedbed for the seeded species. In this study, glyphosate was less effective in the second year likely as a result of unfavorable growing conditions during application, which did not allow full translocation of the herbicide.

Although recovery of crested wheatgrass cover must be expected, openings caused by disruptions persisted long enough for the native species to establish. Even the most severe disruptions were insufficient to allow a window of opportunity for establishment of native species in the annual-dominated areas.

Certain combinations of seedbed preparation techniques and seeding methods may be particularly effective in opening niches and allowing native seedlings to establish in crested wheatgrass. Tilling was especially effective, because it completely removed all existing plant competition and prepared a very uniform seedbed into which the seeds were placed. Application of an herbicide proved effective at reducing competition, as it has in previous studies (Nelson et al. 1970), an important find, given the scale and site characteristics where restoration is needed. Tilling may often be limited by terrain or area size; in that case glyphosate may be applied from the ground or from the air, which would be less costly than tillage, especially for large areas in need of restoration.

Seeding methods followed a similar pattern. Drilling is generally recognized as an effective way to seed rangelands (Nelson et al. 1970, Haferkamp et al. 1987, Winkel et al. 1991) and was most consistently successful in this study. Drilling, however, can be impractical over rough terrain and is limited by area. With this in mind, broadcasting may be as effective as drilling in certain conditions, especially when the seed is covered (Winkel et al. 1991, Roundy et al. 1993).

Recommendations

The long-term performance and persistence of seeded species, as well as the recovery of cheatgrass and crested wheatgrass populations, should be evaluated in the future. This study suggests a 2-step approach to restoring native diversity through using a model of "assisted succession," in sagebrush steppe areas currently dominated by cheatgrass. The first step is to convert a site from annual- to perennial-domination. Former sagebrush-steppe areas, now dominated by cheatgrass or other weedy annuals, experience a shift in fire frequency from 30–70 years to a frequency of every few years. Any native species that survive competitively in such areas are likely to be burned out within a few years. An overall effect of invasive annual species is to arrest secondary succession of these sites at an annual stage; succession does not continue to the long-lived, fire-intolerant native species. Crested wheatgrass or other aggressive perennial plants may be used to replace cheatgrass, thereby assisting succession to a perennial-dominated system. Many areas of the Great Basin have already been seeded to crested wheatgrass or other stable monocultures and are primed for the second step.

The second step in this process is to insert native species into the stable perennial matrix. Combinations of selected seedbed preparation techniques and seeding methods may be used to insert the native species into the stable matrix. Crested wheatgrass is not expected to be eliminated with such a strategy, but the diversity, structure and function of the resulting community will be more similar to those of the original, native community. In many cases, application of glyphosate may be as effective as more labor and cash-intensive tilling or harrowing. Broadcasting the seed, then covering it by dragging, was intermediate to drilling; and simple broadcasting may prove a worthy compromise in management applications.

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