Published online May 13, 2005

Coexistence of Native and Introduced Perennial Grasses following Simultaneous Seeding

Blair L. Waldron,* Thomas A. Monaco, Kevin B. Jensen, R. Deane Harrison, Antonio J. Palazzo, and James D. Kulbeth

ABSTRACT

Revegetation of disturbed semiarid lands requires rapid stabilization of ecological process and soil resources. Introduced species have been widely adopted because the slow establishment of native species frequently results in poor ecosystem recovery and further site degradation. Little research has documented the managerial possibilities and species interactions associated with simultaneously establishing native and introduced grasses on semiarid lands. We conducted a 3-yr experiment at Fort Carson, CO, to evaluate if seven native perennial grasses would coexist with either Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], crested wheatgrass (*Agropyron* sp.), or Siberian wheatgrass [*A. fragile* (Roth) Candargy] after simultaneous seeding. Five grass mixes, each comprised of the seven natives and one introduced grass, and a standard military seed mix (mostly native grasses with a small introduced species component) were evaluated by comparing percentage ground cover of individual species. Predominance of crested and Siberian wheatgrass cover resulted in significantly lower native grass and weed abundance. In contrast, Russian wildrye and military treatments had lower introduced grass cover and high weed abundance, but much higher native grass cover. However, weed cover decreased to <5% in all treatments during the experiment. Western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve] was responsible for >80% of the native species cover in the military treatment for all 3 yr, whereas the Russian wildrye treatments had a more balanced mix of several native species. These results provide insights into managerial considerations for revegetation and weed control for frequently disturbed rangelands and suggest that some introduced grasses may coexist with native grasses.

Historical and recurrent grazing, fire, and other disturbances on semiarid western rangelands have resulted in widespread loss of native perennial grasses (Pickford, 1932; Whisenant, 1990) and replacement by invasive annual weeds (Billings, 1990). These disturbances complicate revegetation efforts because the structure and function of these damaged ecosystems do not resemble the predisturbance ecosystem under which the native species evolved (West, 1999).

In contrast to native species, introduced perennial grasses have generally had greater success when used to revegetate damaged ecosystems, stabilize hydrology, and preserve soil resources on western North American rangelands (Kilcher and Looman, 1983; Lawrence and Ratzlaff, 1989; Asay et al., 2001). Although introduced grasses have effectively stabilized thousands of hectares in the western USA and Canada, concerns have been raised about their effects on soil resources and structure (Elliott and White, 1987; Doormaar et al., 1995; Christian and Wilson, 1999) and the persistence of low biological diversity where they are planted (Wilson, 1989). Low diversity may be a result of depleted seedbanks of native species (Hassan and West, 1986; Humphrey and Schupp, 2001) or lower seed predation and greater seed carryover from year to year of introduced grasses compared with native grasses (Pyke, 1990). Not too surprisingly, secondary succession does not transition from dominance held by introduced perennial grasses or invasive annual grasses without an ample and mobile seed supply of native perennial species (Hironaka and Tisdale, 1963). However, Cox and Anderson (2004) described an "assisted succession" process in which rangelands infested with an invasive annual grass were restored to native sagebrush–grassland steppe species through the sequential process of establishing an introduced grass, disturbance, and finally seeding adapted native grasses, forbs, and shrubs.

Opportunities may exist to facilitate revegetation with native grasses by planting them at the same time with introduced grasses (Redente and DePuit, 1988). When planted together, the introduced grasses may act as an 'ecological bridge' by rapidly stabilizing soil resources and allowing the seeded native grasses to become a part of the functional ecosystem when environmental conditions are favorable. One aversion to this simple approach may stem from the assumption that the net effects of introduced grasses on native perennial grasses can only be negative and mediated by competition and/or inhibition. While competition among seedlings can be expected, introduced grasses may also have direct and indirect positive effects on native grass species. Rapid establishment by introduced grasses may ameliorate environmental stresses and directly assist germination and seedling establishment, the most vulnerable stages associated with revegetation in arid and semiarid regions (Pickett et al., 1987; Call and Roundy, 1991). Introduced grasses may also indirectly facilitate native grass establishment by suppressing invasive annual grasses (Stewart and Hull, 1949; Bookman and Mack, 1982) and their competitive influence on native grass species (Borman et al., 1991). This may be particularly important on rangelands that are frequently disturbed and replanted such as military training lands. The objective of this study was to determine the dynamics of coexistence between

B.L. Waldron, T.A. Monaco, K.B. Jensen, R.D. Harrison, USDA-ARS, Forage and Range Research Lab, Logan, UT 84322-6300; A.J. Palazzo, ERDC, U.S. Army Cold Regions Research Lab., Hanover, NH 03755-1290; and J.D. Kulbeth, Fort Carson DECAM, Natural Resources Division, 5010 Tevis St., Bldg. 302, Fort Carson, CO 80913-1685. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA. Received 20 Oct. 2004. Integrated Weed Management. *Corresponding author (blair.waldron@usu.edu).

Published in Agron. J. 97:990–996 (2005).
doi:10.2134/agronj2004.0265

677 S. Segoe Rd., Madison, WI 53711 USA

native and introduced grasses and weeds following seeding of a military training area.

MATERIALS AND METHODS

Study Site

The experiment was conducted at the Fort Carson, Turkey Creek Recreation Area. This site is approximately 20 km south of Colorado Springs, CO (38°37′20″ N lat; 104°52′40″ W long), at 1920 m elevation. Soils at this site are a fine sandy loam (mixed, calcareous mesic Ustic Torriorhents). The 22-yr mean annual precipitation for Colorado Springs is 383 mm, with approximately 80% of this precipitation received from April to September. Figure 1 shows monthly mean precipitation for Fort Carson in 1999 to 2001 as well as the 22-yr mean. This site contains vegetation typical of the Great Plains steppe provinces (Bailey, 1995). Shrubs are rare, but one-seed juniper [*Juniperus monosperma* (Engelm.) Sarg.] has encroached into grasslands during the last century. Dominant grass species include western wheatgrass, blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steudel], and sideoats grama [*B. curtipendula* (Michx.) Torr.]. Subdominant grasses include green needlegrass [*Nassella viridula* (Trin.) Barkworth] and needle and thread grass (*Stipa comata* Trim & Rupr.). A fenced study site was tilled to a depth of 20 cm to initiate disturbance and reduce existing weeds in spring of 1997. Areas near the study site are regularly seeded with the military seed mix after disturbance by tracked vehicles during training exercises.

Experimental Design

We evaluated the ability of native and introduced perennial grasses to coexist and/or mutually exclude each other and weeds by individually seeding five different introduced grasses with a common native grass mix. These five seeding mixtures were also compared with a military seed mix. The six different seed mixes (treatments) were evaluated in a randomized complete block design with four replications. The five introduced grasses made up 26% of each mixture (kg PLS ha^{-1} basis), which also consisted of a common core-group of native grass species (Table 1). The core native species were believed to be well adapted to a major portion of the base and included the following: 'Barton' western wheatgrass (Alderson and Sharp, 1994), 'Pryor' slender wheatgrass (Majerus et al., 1991) [*Elymus trachycaulus* (Link) Gould ex Shinners], 'Critana' thickspike wheatgrass (Stroh et al., 1972) [*Elymus lanceolatus* (Scribn. & Sm.) Gould], 'Nezpar' Indian ricegrass (Alderson and Sharp, 1994) [*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth], 'Vaughan' sideoats grama (Alderson and Sharp, 1994), blue grama, and sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood].

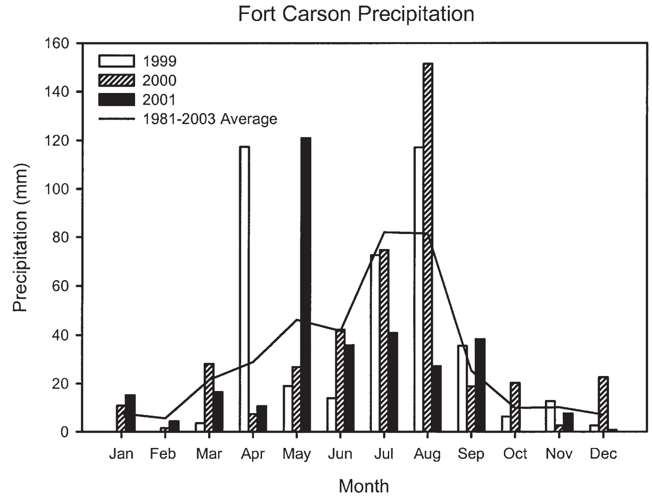

Fig. 1. Mean monthly precipitation for Fort Carson in 1999 to 2001 as well as the 22-yr mean.

The introduced grass species were selected because of their ability to establish and persist in harsh, disturbed environments and their capacity to compete with weeds. These introduced grasses were 'Bozoisky-select' (Asay et al., 1985) and 'Tetra-1' (Jensen et al., 1998) Russian wildrye, 'RoadCrest' [*Agropyron cristatum* (Fisch. Ex Link) Schultes] (Asay et al., 1999) and 'CD-II' (Asay et al., 1997) crested wheatgrass [*Agropyron desertorum* (Fisch. Ex Link) Schultes], and 'Vavilov' (Asay et al., 1995) Siberian wheatgrass (Table 1).

The military seed mixture treatment included 'Barton' western wheatgrass, 'Vaughan' sideoats grama, 'Nordan' crested wheatgrass, 'Ladak' alfalfa (*Medicago sativa* L. × *M. falcata* L.), alkali sacaton [*Sporobolus airoides* (Torr.) Torr.], and sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray] (Table 1). Although the composition of the native grasses in the military mix was different from that in the introduced native mix, we

Table 1. Species and their respective seeding rate (PLS, pure live seed) and percentage of mix for the military and introduced-native grass mixes. Introduced-native grass mixes included one of the following five introduced grasses: 'Bozoisky' Russian wildrye, Tetra-1 Russian wildrye, 'RoadCrest' crested wheatgrass, 'CD-II' crested wheatgrass, or 'Vavilov' Siberian wheatgrass.

Treatment	Species	PLS	% of mix (kg PLS basis)	% of mix (no. PLS basis)
		kg ha^{-1}	%	
Military mix	'Barton' western wheatgrass	8.9	51	20.7
	'Vaughan' sideoats grama	4.9	28	19.8
	alkali sacaton	0.4	3	14.9
	sand dropseed	0.3	2	33.6
	'Nordan' crested wheatgrass	2.0	12	7.4
	'Ladak' alfalfa	0.8	4	3.6
	total	17.4	100	100
Introduced-native mixes	introduced grass	4.5	26	19.5†
	'Barton' western wheatgrass	4.5	26	11.9
	'Pryor' slender wheatgrass	2.2	14	8.4
	'Critana' thickspike wheatgrass	2.2	13	8.1
	'Nezpar' indian ricegrass	1.1	6	3.7
	'Vaughan' sideoats grama	1.1	6	5.0
	blue grama	1.1	6	21.8
	sand lovegrass	0.6	3	21.6
	total	17.4	100	100

† Average of the five introduced grasses. Seed test wt. ranges from 77 180 to 90 800 seeds kg^{-1}.

Table 2. Weed species encountered and included in the "weed cover" category during the 3-yr experiment of plant cover at Fort Carson, CO.

Common name	Scientific name
Japanese brome	*Bromus japonicus* Thunb. Ex Murr.
Downy brome	*Bromus tectorum* L.
Wild oat	*Avena fatua* L.
Witchgrass	*Panicum capillare* L.
Prickly lettuce	*Lactuca serriola* L.
Russian thistle	*Salsola iberica* Sennen
Scarlet pimpernel	*Anagallis arvensis* L.
Field bindweed	*Convolvulus arvensis* L.
Sunflower	*Helianthus annuus* L.
Lambs quarter	*Chenopodium album* L.
Pepperweed	*Alyssum alyssoides* L.
Birdsrape mustard	*Brassica rapa* L.
Purple aster	*Machaeranthera canescens* (Pursh) Gray

included it in the experiment because the military mix was frequently used to revegetate lands in Fort Carson. Treatments were dormant seeded at a rate of 17.4 kg PLS ha^{-1} on 5 Nov. 1997 with a tractor and a John Deere Flexiplanter (Moline, IL) equipped with depth bands to maintain a planting depth of 1.25 cm. Plots consisted of six seeded-rows (~1.75 by 30 m).

Data Collection and Analyses

Ground cover of native and introduced grasses and weeds were measured by placing a 0.5 m^2 frame in six random locations within each plot and visually estimating cover percentage. Ground cover served as an estimate of soil stabilization, a process critical to range management on military training lands that are frequently disturbed (e.g., vs. forage yields, etc.).

Plots were evaluated on 25 Aug. 1999, 18 July 2000, and 13 Aug. 2001. Sampling frames were placed in different locations each year. Cover percentages were partitioned by species; however, cover for native and introduced grasses and weed species were pooled within their respective categories for analyses. The most frequent weed species are shown in Table 2.

Cover data were analyzed across and within years using the MIXED procedure (SAS Inst., 1998). For the across year analysis, the best covariance structure between years was determined and used with the MIXED repeated option (SAS Inst., 1998). Treatment differences within years, and year-to-year differences within treatments are reported when treatment × year interactions were significant. Mean comparisons were made among treatments using Fisher Protected LSD tests at the $P = 0.05$ level of probability.

RESULTS

Total Cover

Total plant cover was relatively stable across all 3 yr with no treatment × year interaction. Few significant differences for total plant cover (mean of 1999–2001) were observed between treatments (Table 3). The crested

Table 3. Mean total plant cover of six seeding treatments for 3 yr (1999–2001) at the Turkey Creek Recreation Area, Fort Carson, CO. Means within a column followed by different letters are significantly different ($P < 0.05$).

Treatment	Total plant cover
	%
Bozoisky	29.8 a
Tetra-1	29.5 a
Military	27.9 a
RoadCrest	26.9 ab
Vavilov	26.3 ab
CD-II	23.7 b

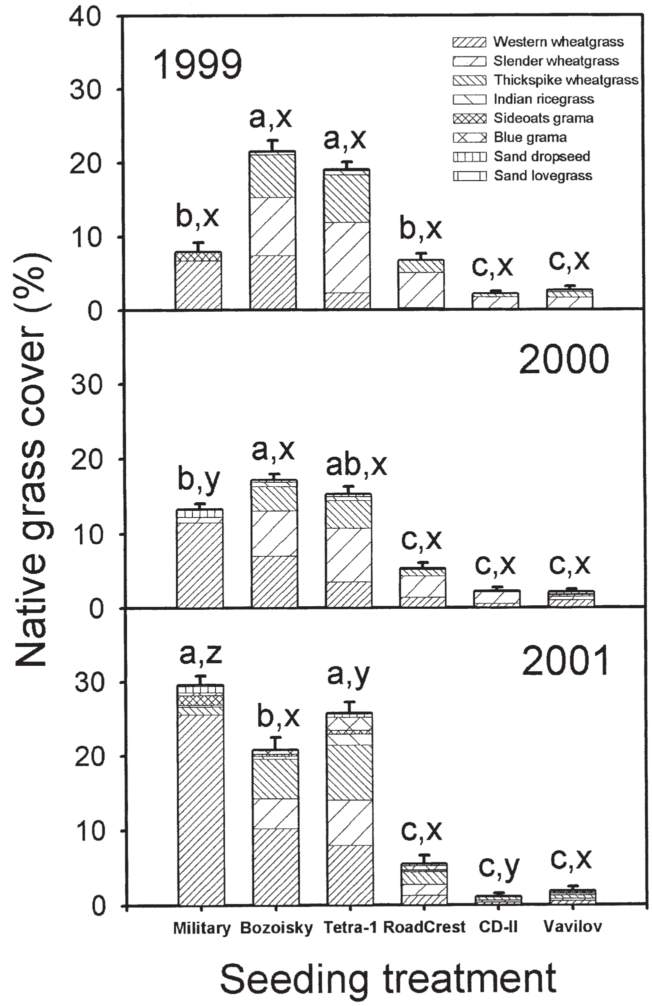

Fig. 2. Percentage cover of native grasses for 3 consecutive years at Turkey Creek Recreation Area, Fort Carson, CO, after seeding with six treatments. Error bars indicate ±1 SE of the treatment means (within year) for native grass cover. Means within a year followed by different a, b, and c lowercase letters, and means within a treatment (across years) followed by different x, y, and z lowercase letters are statistically different ($P < 0.05$).

wheatgrass (CD-II) treatment had the lowest total plant cover. In contrast, the highest total plant cover was found in the Russian wildrye treatments (Tetra-1 and Bozoisky).

Native Species Cover

Analysis of native species cover resulted in significant treatment and treatment × year effects. Cover of native grasses generally decreased with increasing cover of introduced grasses ($r = -0.77$, $P = 0.0001$). Bozoisky and Tetra-1 treatments resulted in significantly greater native grass cover (Fig. 2), and significantly lower introduced grass cover (Fig. 3) than the RoadCrest, CD-II, and Vavilov treatments in all years. Native grass cover increased between 1999 and 2001 in the military and Tetra-1 treatments. This was most pronounced in the military treatment, where native grass cover tripled from 1999 to 2001 (Fig. 2). By 2001, native grass cover comprised 90, 67, and 79% of total cover in the military,

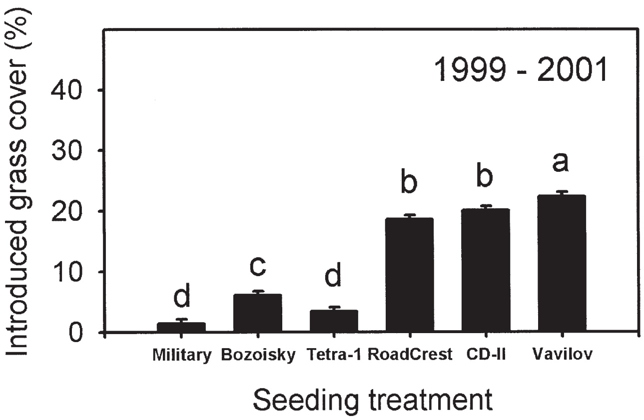

Fig. 3. Average (1999–2001) percentage cover of introduced grasses at Turkey Creek Recreation Area, Fort Carson, CO, after seeding with six treatments. Error bars indicate ±1 SE of the treatment means for introduced grass cover. Means followed by different lowercase letters are statistically different ($P < 0.05$).

Bozoisky, and Tetra-1 treatments, respectively. In contrast, cover of native grasses in the RoadCrest, CD-II, and Vavilov treatments changed very little between 1999 and 2001, and comprised 19, 4, and 6% of the total cover in 2001, respectively.

In addition to total native species cover, treatments also differed in native species composition (Fig. 2). Western wheatgrass was responsible for >80% of the native species cover in the military treatment in all 3 yr. Western wheatgrass never comprised >49% of the native species cover, and slender and thickspike wheatgrasses were major components in the Russian wildrye treatments (Fig. 2). Interestingly, western wheatgrass was not initially present in the crested and Siberian wheatgrass treatments, but was found in 2000 and 2001 (Fig. 2). The increases in native species cover during the experiment appear to be primarily a function of large increases in western wheatgrass. Native species richness was greatest in the third year of the experiment.

Introduced Species Cover

Cover of introduced grasses changed very little for the six treatments between 1999 and 2001 with no treatment × year effects present. Similar to native species cover, introduced grass cover for the six treatments produced two distinct groups—a low cover group (military and Russian wildrye treatments) and a high cover group (Siberian and crested wheatgrass treatments) (Fig. 3). Small significant differences were present within each group with Vavilov resulting in the highest introduced cover and the Military and Tetra-1 treatments having the lowest introduced cover. On average, introduced grass cover for the high and low group made up 87 and 17%, respectively, of the total plant cover of plots in 2001.

Weed Cover

In 1999, large significant weed cover differences were evident among the seeding treatments. Two treatments (military and Tetra-1), characterized as having low in-

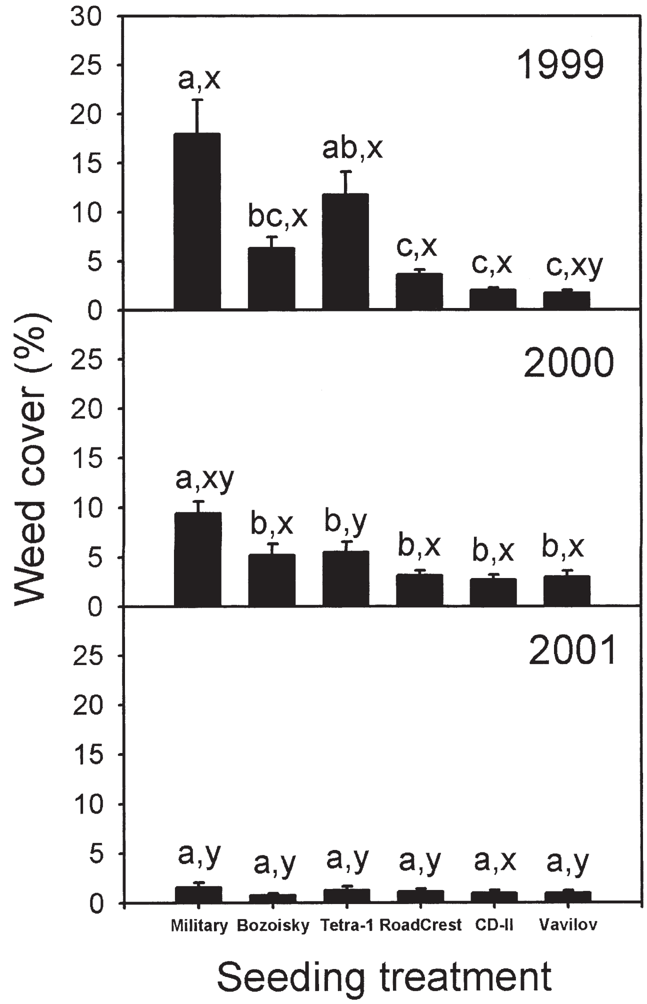

Fig. 4. Percentage weed cover for 3 consecutive years at Turkey Creek Recreation Area, Fort Carson, CO, after seeding with six treatments. Error bars indicate ±1 SE of the treatment means (within year) for weed cover. Weeds used in this cover category are listed in Table 2. Means within a year followed by different a, b, and c lowercase letters, and means within a treatment (across years) followed by different x, y, and z lowercase letters are statistically different ($P < 0.05$).

troduced grass cover and high native grass cover, had significantly greater weed cover in 1999 than the crested and Siberian wheatgrass treatments (Fig. 4). In 1999, weed cover in the military treatment comprised 67% of total cover as compared with 20% for Bozoisky, and an average of 9% in the wheatgrass treatments. The military treatment continued to have nearly twofold greater weed cover than all other treatments in 2000. High introduced grass cover was associated with lower weed cover ($r = -0.53$, $P = 0.0001$), whereas native grass cover was not correlated with weed cover ($r = 0.12$, $P = 0.312$). However, cover of weeds tended to decline between 1999 and 2001 for most treatments, and by 2001 all treatments had comparably low weed cover (Fig. 4).

DISCUSSION

Our experiment demonstrated that the crested and Siberian wheatgrass treatments resulted in significantly higher introduced grass, but lower weed cover and native grass cover during the 3-yr experiment than the Russian wildrye and military treatments. On the contrary, the Russian wildrye and military treatments produced low introduced grass cover and moderate to high initial weed cover. In addition, the narrow range in total plant cover among treatments suggests plant productivity on this rangeland site has an upper limit, and plant production was partitioned differently among introduced grass, native grass, and weed cover for these treatments.

Species Interactions

Rapid establishment of crested and Siberian wheatgrass cultivars is associated with high germination and emergence when seeds are placed at various depths (Asay et al., 1995, 1997, 1999), a situation that occurs when seeding grasses with rangeland drills. These introduced grasses also have been greatly improved through genetic selection for drought tolerance and cold temperature growth (Johnson and Asay, 1978, 1993). Crested wheatgrass has been shown to have greater capacity than native bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Löve] to capture soil N from pulse events associated with spring and summer rain events (Jackson and Caldwell, 1989; Bilbrough and Caldwell, 1997). Crested wheatgrass roots also grow earlier in the season and at lower temperatures than bluebunch wheatgrass roots (Eissenstat and Caldwell, 1988a, 1988b; Aguirre and Johnson, 1991), and seedlings are known to compete strongly with cheatgrass for water (Buman et al., 1988). These specific traits enable introduced grasses to quickly establish and also grow in late winter and early spring, when annual weeds commonly proliferate in disturbed areas. It is possible that these mechanisms may have assisted the crested and Siberian wheatgrass treatments to better interfere with the growth and development of weed species, as indicated by the low weed cover in these respective treatments.

The seeded native grasses increased in cover during the 3 yr to a greater extent when seeded with the Russian wildrye and military treatments compared with the crested and Siberian wheatgrass treatments. High native grass cover in the military treatment was expected because this treatment had double the amount of western wheatgrass and more than four times the amount of sideoats grama seed than the other five native-introduced mixes. In contrast, high native cover in the Russian wildrye treatments was likely a consequence of low initial establishment of Russian wildrye and less direct interference with native species growth. Less direct interference with native grasses is demonstrated by the fact that the warm-season grasses sideoats and blue grama were only present in the military and Russian wildrye treatments, respectively. Russian wildrye is slower to establish compared with crested and Siberian wheatgrasses (Asay and Johnson, 1983), but are known to be more drought-tolerant (Berdahl and Ries, 1997), particularly in late summer (Haferkamp et al., 1992). Thus, high drought tolerance may facilitate the ability of Russian wildryes to reduce weed productivity predominantly in mid- to late summer, whereas the crested and Siberian wheatgrasses appear to interfere with weed growth primarily in the early spring. The fact that both groups of introduced grasses had equally low weed cover in the second year of the experiment suggests that these introduced grasses had similar overall impacts on weed cover, but weed control by the Russian wildryes lagged behind the crested and Siberian wheatgrasses by 1 yr.

Managerial Considerations

Coexistence of native and introduced species was most successful with the Russian wildrye and the military treatments. Initial native species cover was poor and weed cover high in the military treatment, but by the third year, native species cover in this treatment exceeded all other species. This pattern of native species establishment in the military treatment was likely driven by a high proportion of western wheatgrass that was initially slow to establish, yet its rhizomatous growth form permitted it to spread and interfere with weeds and bunchgrasses (Samuel and Hart, 1992).

The initial low presence of introduced grasses and high initial abundance of weeds in the Russian wildrye and military treatments may have indirect effects on future community stability. Initial high weed cover, especially in the military treatment, provides an opportunity for weeds to produce considerably more seed than in the crested and Siberian wheatgrass treatments. Production of a larger weed seed bank in these treatments could result in greater weed proliferation compared with the treatments that controlled weeds in the first year of the experiment.

Crested and Siberian wheatgrasses maintained dominance in plots during the experiment, and unlike the Russian wildrye and military treatments, native grass cover was never above 6%. These results are consistent with previous reports demonstrating that the stability of crested wheatgrass plantings may be related to the longevity of the initial cohort of individuals (Looman and Heinrichs, 1973; Pyke, 1990). Native species appear to be least compatible with crested and Siberian wheatgrass at this site. Because native species cover predominantly consisted of western wheatgrass, it can be assumed that the low native species cover was largely a consequence of poor western wheatgrass performance relative to the introduced wheatgrasses. It is possible that western wheatgrass may increase with time in crested and Siberian wheatgrass plots, although it comprised only a small portion (~5%) of the plant cover after 3 yr. Greater drought tolerance and productivity in late-season (summer) of western wheatgrass compared with crested wheatgrass (Frank, 1994) may provide a mechanism for western wheatgrass to increase.

This study provides land managers with greater understanding of the dynamic interactions between native grasses and introduced grasses on semiarid rangelands. The use of crested and Siberian wheatgrass has positive aspects for land managers because they provide immediate weed control and community structure, which is known to significantly decrease the amount of water runoff in semiarid shrublands (Boeken and Orenstein, 2001). In contrast, Russian wildrye demonstrated that it may coexist with adapted native grass species and control weed growth almost as well as the crested and Siberian wheatgrasses, thus providing additional management opportunities. The military treatment, comprised of mostly native grass species, did finally reach a desirable community structure and weed control level 4 yr after planting, suggesting it is a poor option in frequently disturbed areas. Results may have differed at a drier site or over a longer time-frame, warranting additional research. However, these results are pertinent for semiarid environments similar to the one described, especially where frequent disturbance and reseeding negates extended evaluation.

ACKNOWLEDGMENTS

This research was funded by USDA-ARS and SERDP project CS-1103. The authors thank B.W. Davenport, R.L. Reed, W.H. Horton, and J. Lynn for technical assistance and Dr. C.A. Call and Dr. J.A. Young for insightful comments on an earlier draft of this manuscript.

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4. Demonstrate social responsibility in scientific and professional practice, by considering whom their scientific and professional activities benefit, and whom they neglect.
5. Provide honest and impartial advice on subjects about which they are informed and qualified.
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Approved by the ASA Board of Directors, 1 Nov. 1992