Establishing Native Plants on Abandoned Farmland at Rabbit Mountain Open Space, Boulder County, Colorado: 2006 - 2008

Richard Lancaster[1] and Cynthia S. Brown[2]

[1]Graduate student
Email: richard.ecoypsych@gmail.com

[2]Assistant Professor, Principle Investigator
Email: Cynthia.S.Brown@ColoState.edu
Phone: (970) 491 - 1949
FAX: (970) 491 – 2460

Bioagricultural Sciences and Pest Management
1177 Campus Delivery
Colorado State University
Fort Collins, CO 80523-1177

January 28, 2009

SECTION 1 – ABSTRACT

This project addressed the priority research need to evaluate restoration techniques for former agricultural lands, particularly the establishment of diverse, stable native plant communities. We (1) evaluated the species richness and abundance of native species planted in different proportions and compositions during the first 3 years after seeding, (2) examined factors associated with success and failure of native plant establishment including weedy, non-native species, and first year soil nitrogen (N) and carbon (C) levels, (3) tested the effectiveness of broadleaf specific herbicides in controlling non-native forbs in established grasses and (4) assessed changes in species diversity over the three year period. Overall, cover of seeded species and litter increased, while cover of non-seeded species and bare ground decreased over the 3 years of the study. Slender wheatgrass, western wheatgrass and green needlegrass were the most abundant seeded grasses, while fourwing saltbush was the most abundant broadleaf species. In the first year, the density and cover of seeded forbs were greater in seed mixture treatments with higher proportions of forbs, but this pattern was due to fourwing saltbush and it weakened in subsequent years. Overall, seeded forb establishment was very poor. Species richness of seeded species did not differ among treatments. Non-seeded species, which were primarily non-native, had much greater cover than seeded species until the third year after seeding, when cover of seeded species was greater than cover of non-seeded species. Species richness of non-seeded species differed among treatments only in 2008 when it was lower in mixtures with higher proportions of grasses, the same plots treated with a mixture of broadleaf specific herbicides.

Soil percent N measured the first year was not related to seeded species cover in any year and was positively correlated with non-seeded cover in only the second year, which had higher precipitation than the other two years. This suggests that water was less limiting, thus it is

possible that N limited plant growth more than water. If this was the case, it is possible that weedy non-seeded species were best able to respond to greater N availability.

Cover of seeded and non-seeded species was negatively correlated with soil percent C in the first year. In the third year, cover of seeded species was positively correlated with this variable, which is associated with later successional soils in prairie ecosystems.

It appears that including forbs and shrubs in higher proportions does not increase their representation in the aboveground plant community. However forb and shrub establishment was too low in this study to draw meaningful conclusions about the effects of altered representation in seed mixtures. As the plant community developed, grasses gained dominance, which is a pattern that is consistent with other grassland restoration studies in which species richness and composition did not approximate remnant grassland sites.

INTRODUCTION

Colorado grasslands have been heavily impacted by agriculture. Re-establishing stable, productive and invasion resistant plant communities on lands that were once farmed is a huge challenge. It is possible to restore native, perennial vegetation to disturbed areas in arid regions (Bugg et al. 1997), but many questions remain about which approaches are most effective. The establishment of native shrubs from seed can prove to be especially difficult and the ideal proportion of grasses, forbs and shrubs to include in seed mixtures for optimal establishment of diverse plant communities is not well known. Previous work suggests that first establishing native perennial grasses to allow control of broadleaf weeds during establishment, then introducing forbs can be a successful approach to take, although grasses may need to be mowed or burned to facilitate forb establishment (Brown and Bugg 2001).

Abiotic factors such as soil N, moisture, and light availability strongly influence the development of plant communities. Higher levels of N favor establishment of ruderal species, which can out compete native perennial species and alter the path of secondary succession (McLendon and Redente 1992; Paschke, McLendon et al. 2000). This competitive advantage can reduce the success of seeded perennial species. More importantly the amount and timing of moisture availability can greatly influence the course of secondary succession. Differences in the amount of soil water available, rooting depths, and seasonal usage between native and invasive species can alter species composition (Brown et al. 2008). Understanding and manipulating these differences can help reach the desired goal of our restoration effort (Brown et al. 2008).

The amount of available light influences plant productivity and canopy structure as well as species composition. The amount of light that reaches the lower canopy of a plant community influences recruitment, growth and reproduction of the species growing there (Kotowski and van Diggelen 2004). The variation in light intensity causes changes in microclimate, leaf size, and phytomass (Flierovoet 1984). Grim and Jeffrey (1965) reported that among herbaceous plants that are commonly found in grasslands the initial height of seedlings and their survival was greater in experiments where they were grown at low light intensities (Grime and Jeffrey 1965), suggesting that high light environments were more stressful.

In this research project, we addressed the priority research need of Boulder County Parks and Open Space (BCPOS) to evaluate restoration techniques for former agricultural lands, particularly the establishment of diverse, stable native plant communities. We quantified the abundance of native species planted in different proportions and compositions during the first three years after seeding, evaluated factors associated with success and failure of native plant establishment including abundance and identity of non-native, weedy and invasive plants, soil nitrogen (N) and carbon (C), light availability, and vertebrate activity, evaluated the effectiveness of broadleaf specific herbicides in controlling non-native forbs in established grasses, and assessed changes in species diversity over the three year period.

We tested the following hypotheses: (1) Abundance of seeded herbaceous forbs and shrubs will be greater when they are included in higher proportions in seed mixtures. Alternatively, the abundance of seeded broadleaf species may differ from their proportional representation in the seed mixtures; (2) Success of seeded species will be positively associated with (a) low weed abundance, (b) high N levels when weeds are in low abundance, and (c) low N levels when weeds are in high abundance, and (d) reduced light intensity. Alternatively, success of seeded species may be unrelated to these factors or show a different relationship than we expect; (3) Broadleaf herbicides can be used on established seeded grasses to control non-native, non-seeded forb and shrub species. Alternatively, the use of broadleaf herbicides will have no effect on non-native forb and shrub species; and (4) Seeding treatments increase species diversity. Alternatively, the seeding treatments have no effect on species diversity of the site.

METHODS

Study Site

The experimental plots are located in the CEMEX Research Site shown in Figure 1.

The site was planted with milo or grain sorghum (*Sorghum bicolor*) the year prior to initiation of the experiment. This was done to catch snow to increase soil water levels and to ameliorate microclimatic conditions for seeded species. Seed for this study was planted directly into the standing milo.

Figure 1. The CEMEX Research Site is located south of the Rabbit Mountain Open Space parking area, and east of the county road. It is outlined in red.

Experimental Design

The experiment was a complete randomized block design with four seed mixture treatments (Figure 2). Seeding rates and composition were determined by BCPOS Plant Ecologist Claire DeLeo and the mixtures were seeded February 1 - 3, 2006 by BCPOS personnel using a Truax FLX816 seed drill (10.5 ft wide with 16 rows, 8 inches apart) (Truax, Inc., New Hope, Minnesota). The grass seed was planted in separate drill rows from the forbs and shrubs. This experiment was not designed to examine whether or not this separation of seed improved establishment of forbs and shrubs. Brown developed the experimental design and assisted with the first day of laying out the plots in January, 2006.

As shown in Figure 2, there were four blocks of 18 monoculture plots in addition to the mixture treatment plots. The monoculture plots were located in strips (10 ft wide, one drill width) between the mixture plots. Individual plots (10 ft x 10 ft) were seeded with a single species or cultivar that is included in the mixtures. Seed was broadcast at a rate of 50 PLS seeds/ft^2 and raked in by hand in February 2006. The species assignments to plots are detailed in Appendix 1.

Seed mixtures

The grasses included in each of the seed mixes were side oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), slender wheatgrass (*Elymus trachycaulus*), prairie junegrass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*; 1 cultivar, 1 native), Indian ricegrass (*Oryzopsis hymenoides*), little bluestem (*Schizachyrium scoparium*), and green needlegrass (*Stipa viridula*). The shrub species included in the mixes were prairie sage (*Artemisia ludoviciana*), fringed sage (*Artemisia frigida*), fourwing saltbush (*Atriplex canescens*), and rubber rabbitbrush (*Chrysothamnus nauseosus*). The herbaceous forb species included in the mixes were purple prairie clover (*Dalea purpurea*), blanketflower (*Gaillardia aristata*), yellow coneflower (*Ratibida columnifera*), and globemallow (*Sphaeralcea spp*). The proportions of grass species remained constant with respect to each other in all four mixtures. The forb and shrub species also were included in constant proportion with respect to each other. The total seeding densities are the same for all mixtures (i.e. approximately 50 kg pure live seed/ha). However, the relative proportion of grasses to forbs and shrubs varied among the mixtures. Mix 1 included half grasses and half forbs and shrubs (50:50) (hereafter 50% Broadleaf Species Mix). Mix 2 included 75% grasses and 25% forbs and shrubs (75:25) (hereafter 25% Broadleaf Species Mix). Mix 3 included 66% grasses and 33% forbs and shrubs (66:33) (hereafter 33% Broadleaf Species Mix). Mix 4 included only grasses (100) (hereafter 0% Broadleaf Species Mix). The species compositions and seeding densities of seed mixtures are detailed in Appendix 2.

Herbicide Treatments of 0% Broadleaf Species Mix in 2008

On June 16-20, 2008 an additional two 6 m x 6 m plots were established in the 0% Broadleaf Species Mix treatments in each of the six blocks (12 plots total). These new plots were located equidistant between two original sampling plots. On June 30, 2008 a mixture of broadleaf specific herbicides that included Tordon 22K (active ingredient) at 24 oz./acre, Escort XP (active ingredient) at 1 oz./acre, and Star Rain (active ingredient) at 0.67 oz./acre was applied to the 0% Broadleaf Species Mix treatments. This herbicide mix targeted field bindweed, Russian thistle, lambsquarters, and prickly lettuce. The newly established plots were excluded from this herbicide application to serve as controls. Sampling of these plots followed the same protocol used for plots established earlier, which is described below.

Sampling Methods

Seeded and non-seeded plant abundance - We established four sampling plots within each treatment plot. Each sampling plot was 6 m x 6 m and located in the center of the 12 m wide treatment plot (Figure 2). Corners of the sampling plots were marked with rebar wrapped in brightly colored flagging tape to facilitate relocation. The corners were marked with colored flags prior to field operations to avoid damaging equipment and shins. The sampling plots at either end of the treatment plots were at least 30 m from the treatment plot end. The remaining two sampling plots were located equidistant from each other and the two end sampling plots. This plot placement ensured that we sampled the variation present throughout the treatment plots. The sampling plots were georeferenced using a high precision GPS unit (Ag GPS 114, Trimble Navigation Limited, Sunnyvale, California). These data are available on request.

Four 0.5 m^2 sampling subplots were located within each sampling plot, one at each corner of the plot (Figure 3), and the mean of these was used in the statistical analysis. One corner of each subplot corresponded with the corner of the sampling plot, thus, were marked with rebar.

These subplot locations were re-sampled over time. One 0.5 m^2 sampling subplot was placed in the center of each monoculture plot. We counted the individual seedlings of seeded species and estimated the percent aerial cover of all species occurring in each 0.5 m^2 subplot. Presence of species within the 36 m^2 plots that did not occur within the 0.5 m^2 subplots was recorded in order to assess diversity at the larger scale. Correct identification of seedlings of seeded species was facilitated by examining seedlings grown in pots in the greenhouse at CSU and in the monoculture plots. Mammal scat, burrowing mammal activity and grazing were noted within sampling plots and subplots. Vegetation sampling was conducted July 19 through August 1, 2006, July 6 through July 23, 2007 for Blocks I - V, and August 12 and 13, 2007 for Block VI, and finally July 14 through July 28, 2008.

Soil N and C – July 7 and 8, 2006 and July 17 and 18, 2006 one soil sample 0 – 15 cm deep and 2 cm in diameter was collected at the four corners of each sampling plot, as indicated by the red circles in Figure 3, and the samples from each sampling plot were pooled. Total soil C and N were determined for each sample using the LECO CHN1000 (LECO Corporation, St. Joseph, MI, USA) in the Natural Resources Ecology Laboratory facility at Colorado State University (CSU).

Light penetration –Penetration of photosynthetically active radiation to the soil surface was measured using a light ceptometer (AccuPar LP-80, Decagon Devices, Inc., Pullman, WA, USA) July 13 and 17, 2006, July 11 through 15, 2007 and finally July 14 through July 28, 2008. One measurement was made in the middle of each 0.5 m^2 subplot, as indicated in Figure 3, and the mean of the four measurements was used as sampling plot level light interception.

Species diversity – Changes in species diversity were calculated using both Simpson's index:

$$\sum p_i$$

and the Shannon diversity index:

$$-\sum(p_i*\ln(p_i))$$

where p_i is the proportion cover for the i^{th} species. In addition to these indices, species richness was computed in each sampling plot for the following response variables: seeded species, non-seeded species, native and non-native non-seeded species, and native and non-native grasses, forbs and shrubs. The results of analyses of Simpson and Shannon indices did not differ from analyses of species richness. Thus, we present only species richness results.

Climate – Precipitation data were acquired from the High Plains Regional Climate Center (http://www.hprcc.unl.edu/). Two different stations were considered, Flatiron Reservoir (Station No. 052934) and Waterdale (Station No. 058839). The Flatiron Reservoir station is at a similar elevation as the CEMEX site, 1678 m (5504 ft) and 1682 m (5520 ft), respectively. However, it was missing several days of data for each year and is closer to the foothills. The Waterdale station is at an altitude of 1594 m (5230 ft) and is located due north of the CEMEX site. This station not only had fewer missing data but also had 30 year averages for comparison. For these reasons we report the precipitation data from the Waterdale station.

Statistical Analysis

Cover and density of seeded plants, cover of non-seeded plants, cover of litter and bare ground, all of which were measured in each of three years, and soil percent carbon (C) and nitrogen (N), which were measured only in the first year, were analyzed using mixed analysis of variance models (SAS version 9.1 and JMP version 5.0.5.1, SAS Institute, Inc., Cary, NC) that included block as a random effect, seed mixture as a fixed effect and their interaction as a random effect. The three years were analyzed separately to look for year to year trends as well as differences among mixtures. Simple linear regression was used to evaluate the performance of seeded species with respect to abundance of species that were not seeded (non-seeded species), cover of litter and bare ground, light interception, and soil percent C and N in the first year of the study (SAS version 9.1 and JMP version 5.0.5.1, SAS Institute, Inc., Cary, NC). Student's t or Tukey's least significant differences were employed for mean separations. The effect of the herbicide application was analyzed using a t-test (SAS version 9.1 and JMP version 5.0.5.1, SAS Institute, Inc., Cary, NC). Statistical significance was set at $\alpha = 0.05$.

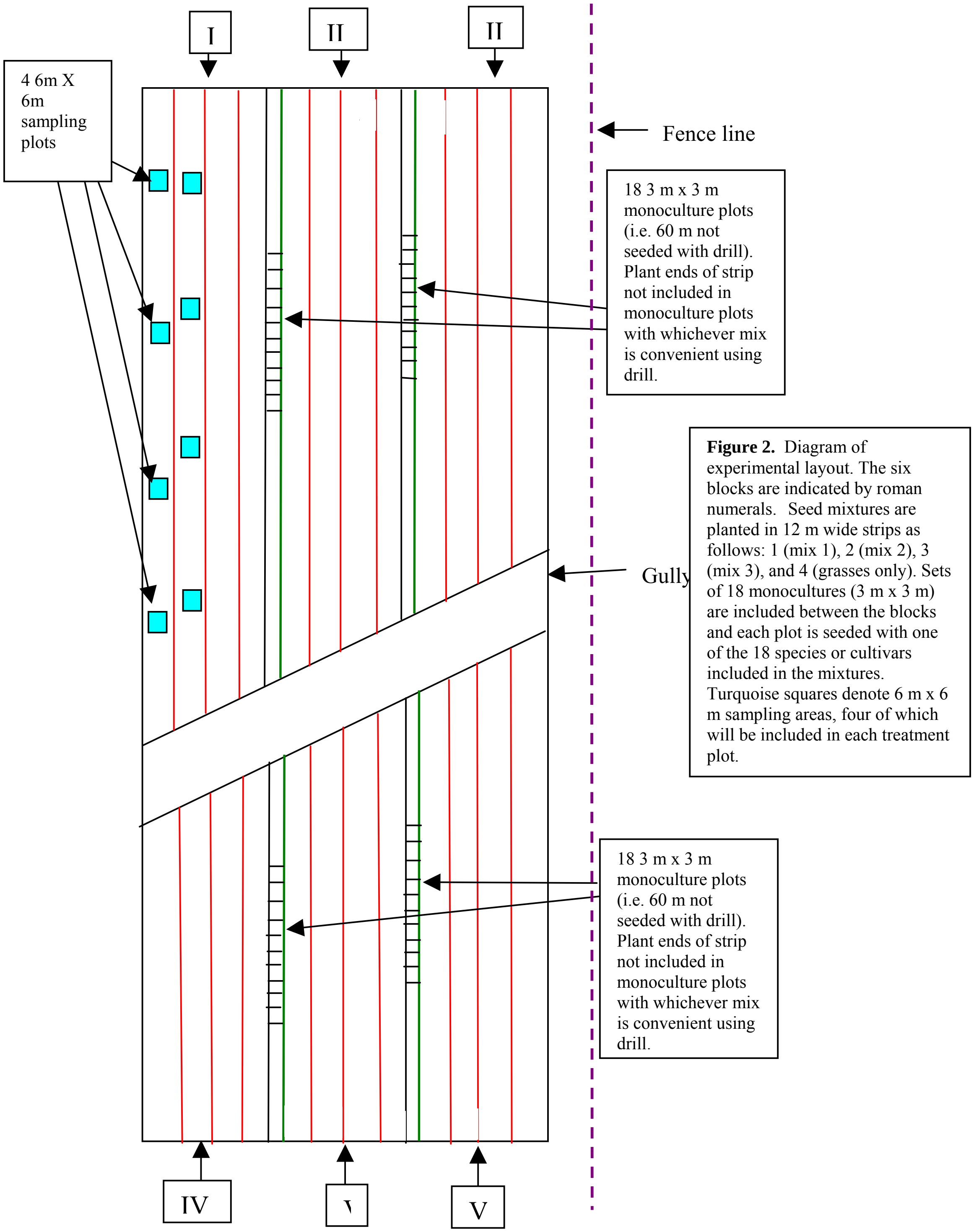

Figure 2. Experimental design and layout.

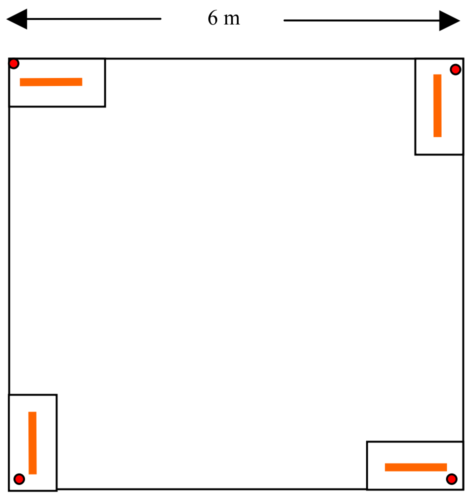

Figure 3. Sampling area layout. 0.5 m^2 subplots (0.5 x 1.0 m) were placed at the corners of the 6 m x 6 m sampling plots in which percent cover by species was estimated. Soil samples were taken at the locations indicated by the red circles for total N and C measurements. Light interception was measured in the center of each 0.5 m^2 subplot, as indicated by the orange bar. Identities of all plant species present within the 36 m^2 area of each sampling plot were recorded.

RESULTS

Seeded Species

Species encountered during sampling and abbreviations for their names used throughout the following figures are listed in Table 1. There was no correlation between the cover of seeded and non-seeded species in 2006 (P = 0.52, R^2 = 0.004), but they were negatively correlated in 2007 (P < 0.0001, R^2 = 0.26), and in 2008 (P < 0.0001, R^2 = 0.23). Cover of seeded species was lower than non-seeded species for 2006 and 2007 but was higher than non-seeded species in 2008 (Figure 4).

There was no relationship between cover of seeded species and litter in 2006 or 2007 and a negative correlation in 2008 (P = 0.0001, R^2 = 0.16). There was a negative association between cover of seeded species and bare ground in 2006 (P = 0.0379, R^2 = 0.05), but a positive relationship in 2007 (P = 0.0016, R^2 = 0.11) and 2008 (P = 0.0016, R^2 = 0.11). Over time, the total cover of seeded species increased, the cover of bare ground decreased and the amount of litter increased (Figure 4).

Table 1. Species names and abbreviations. Non-seeded species in bold are native to Colorado.

Common name	Variety	Scientific Name	Code
Seeded Species			
Fringed sage		*Artemisia frigida*	ARTFRI
Prairie sage		*Artemisia ludoviciana*	ARTLUD
Fourwing saltbush		*Atriplex canescens*	ATRCAN
Sideoats grama	"Vaughn"	*Bouteloua curtipendula*	BOUCUR
Blue grama	Native	*Bouteloua gracilis*	BOUGRA
Buffalograss	"Texoka"	*Buchloe dactyloides*	BUCDAC
Rubber rabbitbrush		*Chrysothamnus nauseosus*	CHRNAU
Purple prairie clover, Kanab		*Dalea purpurea*	DALPUR
Slender wheatgrass	"San Luis"	*Elymus trachycaulus*	ELYTRA
Blanketflower		*Gaillardia aristata*	GAIARS
Junegrass	Native	*Koeleria macrantha*	KOEMAC
Indian ricegrass	"Rimrock"	*Oryzopsis hymenoides*	ORYHYM
Western wheatgrass	"Arriba"	*Pascopyrum smithii*	PASSMA
Western wheatgrass	“Native”	*Pascopyrum smithii*	PASSMN
Yellow coneflower		*Ratibida columnifera*	RATCOL
Little bluestem	"Camper"	*Schizachyrium scoparium*	SCHSCO
Globemallow		*Sphaeralcea spp*	SPHSP
Green needlegrass	"Lodorm"	*Stipa viridula*	STIVIR
Non-seeded Species			
		Alysum spp.	ALYSP
prostrate pigweed		*Amaranthus blitoides*	AMABLI
redroot pigweed		*Amarathus retroflexus*	AMARET
prickly poppy		***Argemone polyanthemos***	**ARGPOL**
wild oat		*Avena fatua*	AVAFAT
		Agropyron cristatum	AGRCRI
field brome		*Bromus arvensis*	BROARV
		Bromus inermis	BROINE
cheatgrass		*Bromus tectorum*	BROTEC
littlepod false flax		*Camelina microcarpa*	CAMMIC
musk thistle		*Carduus nutans*	CARNUT
prostrate or spotted spurge		*Chamaesyce maculata*	CHAMAC
creeping spurge		*Chamaesyce serpens*	CHASER
common lambsquarters		*Chenopodium album*	CHEALB
		Chenopodium berlandieri	CHEBER
		Chenopodium sp1	CHESP1
Canada thistle		*Cirsium arvense*	CIRARV
field bindweed		*Convolvulus arvensis*	CONARV
poison hemlock		*Conium maculatum*	CONMAC
hare's ear mustard		*Conringia orientalis*	CONORI

hounds tongue	*Cynoglossum officinale*	CYNOFF
flixweed	*Descurainia sophia*	DESSOP
toothed spurge	*Euphorbia dentata*	EUPDEN
snow-on-the-mountain	***Euphorbia marginata***	**EUPMAR**
beeblossom	***Gaura L.***	**GAU**
annual sunflower	***Helianthus annuus***	**HELANN**
		HESNEO
		HETVIL
foxtail barley	*Hordeum jubatum*	HORJUB
kochia	*Kochia scoparia*	KOCSCO
prickly lettuce	*Lactuca serriola*	LACSER
western sticktight	***Lappula occidentalis***	**LAPOCC**
pineappleweed	*Matricaria matricarioides*	MATMAT
alfalfa	*Medicago sativa*	MEDSAT
	Nutalia nuda	NUTNUD
witchgrass	*Panicium capillare*	PANCAP
Virginia ground cherry	*Physalis virginiana*	PHYVIR
devils shoe string	*Polygonum arenastrum*	POLARE
	Polygonum aviculare	POLAVI
wild buckwheat	*Polygonum convolvulus*	POLCON
	Polygonum ramosissimum	POLRAM
slimflower scurf pea	***Psoralidium tenuiflorum***	**PSOTEN**
wild rose	***Rosa* sp.***	**ROSMUL**
Russian thistle	*Salsola iberica*	SALIBE
lanceleaf sage	***Salvia reflexa***	**SALREF**
butterweed, golden ragwort	*Senecio sp.1*	SENSP1
tumble mustard	*Sisymbrium altissimum*	SISALT
buffalobur	*Solanum rostratum*	SOLROS
cut-leaved nightshade	*Solanum triflorum*	SOLTRI
spiny sowthistle	*Sonchus asper*	SONASP
sand drop seed	***Sporobolus cryptandrus***	**SPOCRI**
white heath aster	***Symphyotrichum ericoides***	**SYMERI**
salsify sp	*Tragopogon sp1*	TRASP1
salsify sp	*Tragopogon sp2*	TRASP2
cow cockle	*Vaccaria pyramidata*	VACPYR
prostrate vervain	***Verbena bracheata***	**VERBRA**
common mullein	*Verbascum thapsus*	VERTHA
crownbeard, crow pen daisy	***Ximenesia encelioides***	**XIMENC**
Unknowns		
common ground cherry		
unk sp1		
unk sp2		
unk sp3		

***** Probably *Rosa woodsii*, not *R. multiflora*, which is exotic.

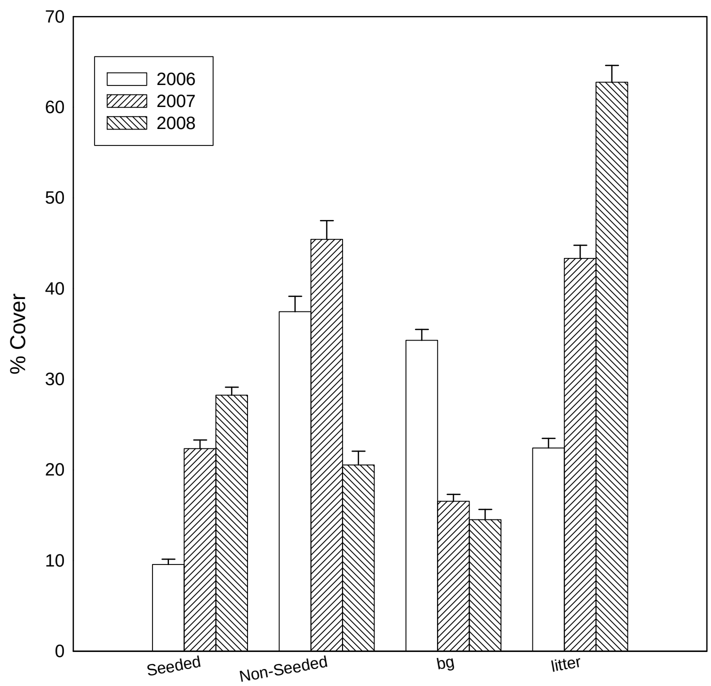

Figure 4. Mean cover of seeded species, non-seeded species, bare ground and litter for 2006, 2007, and 2008 (± one standard error of the mean).

The increase over time of seeded species cover was due primarily to increased cover of slender wheatgrass in 2007 and green needlegrass in 2008 (Figure 5). Densities (Table 2, Figure 6a, b, c) and cover (Table 3, Figure 7a, b, c) of western wheatgrass were roughly proportional its representation in the seed mixtures in 2006, but these differences diminished over time. Density of slender wheatgrass was proportional to its representation in the seed mixtures throughout the study (Table 2, Figure 6d), but its cover did not differ among seed mixture treatments in any year (Table 3, Figure 7d). Its density decreased over time (Figure 6d and 7d). Despite differences in density among seed mixture treatments (Table 2, Figure 6d), the cover of slender wheatgrass did not differ among mixes in any year (Table 3, Figure 7d).

The only seeded forb or shrub species that differed in density or cover among treatments were fourwing saltbush (Figure 6e and 7e) and scarlet globemallow (Figure 6f and 7f). Fourwing saltbush density was highest in 50% Broadleaf Species Mix in the first and second years, but was absent in 2008 (Figure 6e). The cover of fourwing saltbush increased between 2006 and 2007 with the highest cover in the 50% Broadleaf Species Mix. Globemallow was present in 2007 and 2008 but there was a significant difference in cover among seed mixture treatments only in 2007 (Table 3, Figure 7f). In that year, its cover was higher in 50% Broadleaf Species Mix than 0% Broadleaf Species Mix and 33% Broadleaf Species Mix. Its density among seed mixture treatments did not differ either year it was detected (Table 2, Figure 6f).

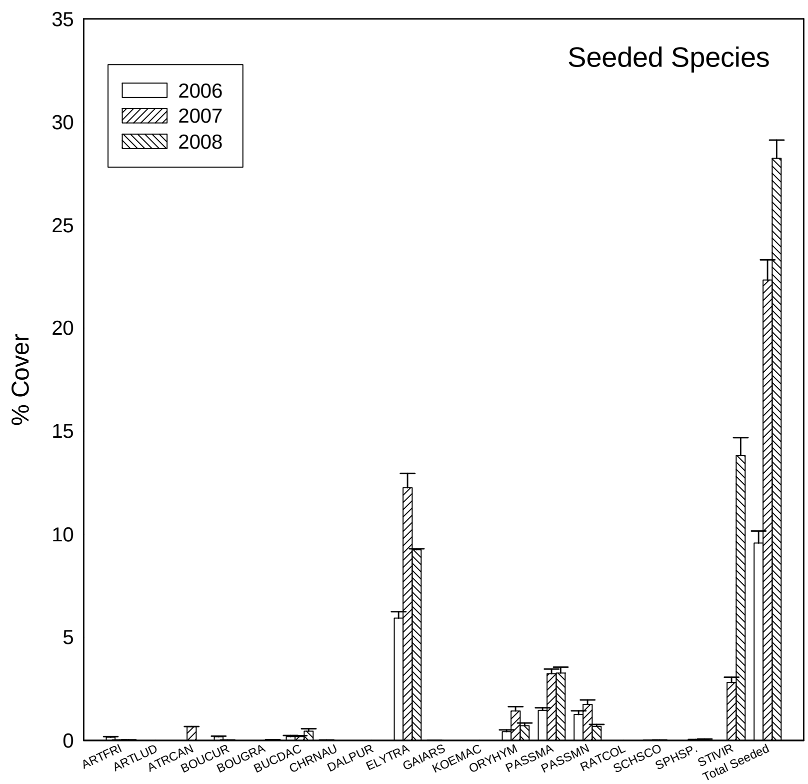

Figure 5. Mean cover of individual seeded species: fringed sage (*Artemisia frigida*, ARTFRI), prairie sage (*Artemisia ludoviciana*, ARTLUD), fourwing saltbush (*Atriplex canescens,* ATRCAN), sideoats grama (*Bouteloua curtipendula*, BOUCUR), blue grama (*Bouteloua gracilis,* BOUGRA), buffalograss (*Buchloe dactyloides*, BUCDAC), rubber rabbitbrush (*Chrysothamnus nauseosus*, CHRNAU), purple prairie clover (*Dalea purpurea*, DALPUR), slender wheatgrass (*Elymus trachycaulus*, ELYTRA), blanketflower (*Gaillardia aristata*, GAIARS), junegrass (*Koeleria macrantha*, KOEMAC), Indian ricegrass (*Oryzopsis hymenoides*, ORYHYM), western wheatgrass "Arriba" (*Pascopyrum smithii*, PASSMA), western wheatgrass "Native" (*Pascopyrum smithii*, PASSMN), yellow coneflower (*Ratibida columnifera*, RATCOL), little bluestem (*Schizachyrium scoparium*, SCHSCO), globemallow (*Sphaeralcea spp*, SPHSP), green needlegrass (*Stipa viridula*, STIVIR) and total cover of seeded species for 2006, 2007, and 2008 (± one standard error of the mean). Means with different letters are significantly different at $\alpha = 0.05$.

Table 2. ANOVA of density of seeded species fourwing saltbush (*Atriplex canescens,* ATRCAN), slender wheatgrass (*Elymus trachycaulus*, ELYTRA), western wheatgrass "Arriba" (*Pascopyrum smithii*, PASSMA), western wheatgrass "Native" (*Pascopyrum smithii*, PASSMN), globemallow (*Sphaeralcea spp*, SPHSP) for 2006, 2007, and 2008. *Note*: Data for the two varieties of western wheatgrass were combined in 2006 because we were not able to reliably distinguish them from one another. Dashes indicate a species was not detected in that year.

2006:

Factor	df_{num}	df_{den}	Total Density		ATRCAN		ELYTRA		PASSMI		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	3.51	0.051	8.91	0.0017	3.81	0.04	4.21	0.03	------	------

2007:

Factor	df_{num}	df_{den}	Total Density		ATRCAN		ELYTRA		PASSMA		PASSMN		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	0.74	0.54	5.13	0.014	3.98	0.03	0.81	0.51	0.96	0.44	2.7	0.09

2008:

Factor	df_{num}	df_{den}	Total Density		ATRCAN		ELYTRA		PASSMA		PASSMN		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	1.59	0.24	------	------	3.86	0.03	0.14	0.93	0.43	0.73	3.21	0.06

Table 3. ANOVA of cover of the seeded species fourwing saltbush (*Atriplex canescens,* ATRCAN), slender wheatgrass (*Elymus trachycaulus*, ELYTRA), western wheatgrass "Arriba" (*Pascopyrum smithii*, PASSMA), western wheatgrass "Native" (*Pascopyrum smithii*, PASSMN), globemallow (*Sphaeralcea spp*, SPHSP) for 2006, 2007, and 2008. *Note*: Data for the two varieties of western wheatgrass were combined in 2006 because we were not able to reliably distinguish them from one another. Dashes indicate a species was not detected in that year.

2006:

Factor	df_{num}	df_{den}	Seeded species		ATRCAN		ELYTRA		PASSMI		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	2.75	0.08	5.00	0.02	2.85	0.08	4.05	0.03	------	------

2007:

Factor	df_{num}	df_{den}	Seeded species		ATRCAN		ELYTRA		PASSMA		PASSMN		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	0.17	0.91	4.12	0.03	0.96	0.44	0.28	0.84	1.69	0.22	3.53	0.04

2008:

Factor	df_{num}	df_{den}	Seeded species		ATRCAN		ELYTRA		PASSMA		PASSMN		SPHSP	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	1.02	0.41	----	----	2.86	0.07	0.73	0.55	1.65	0.23	1.68	0.22

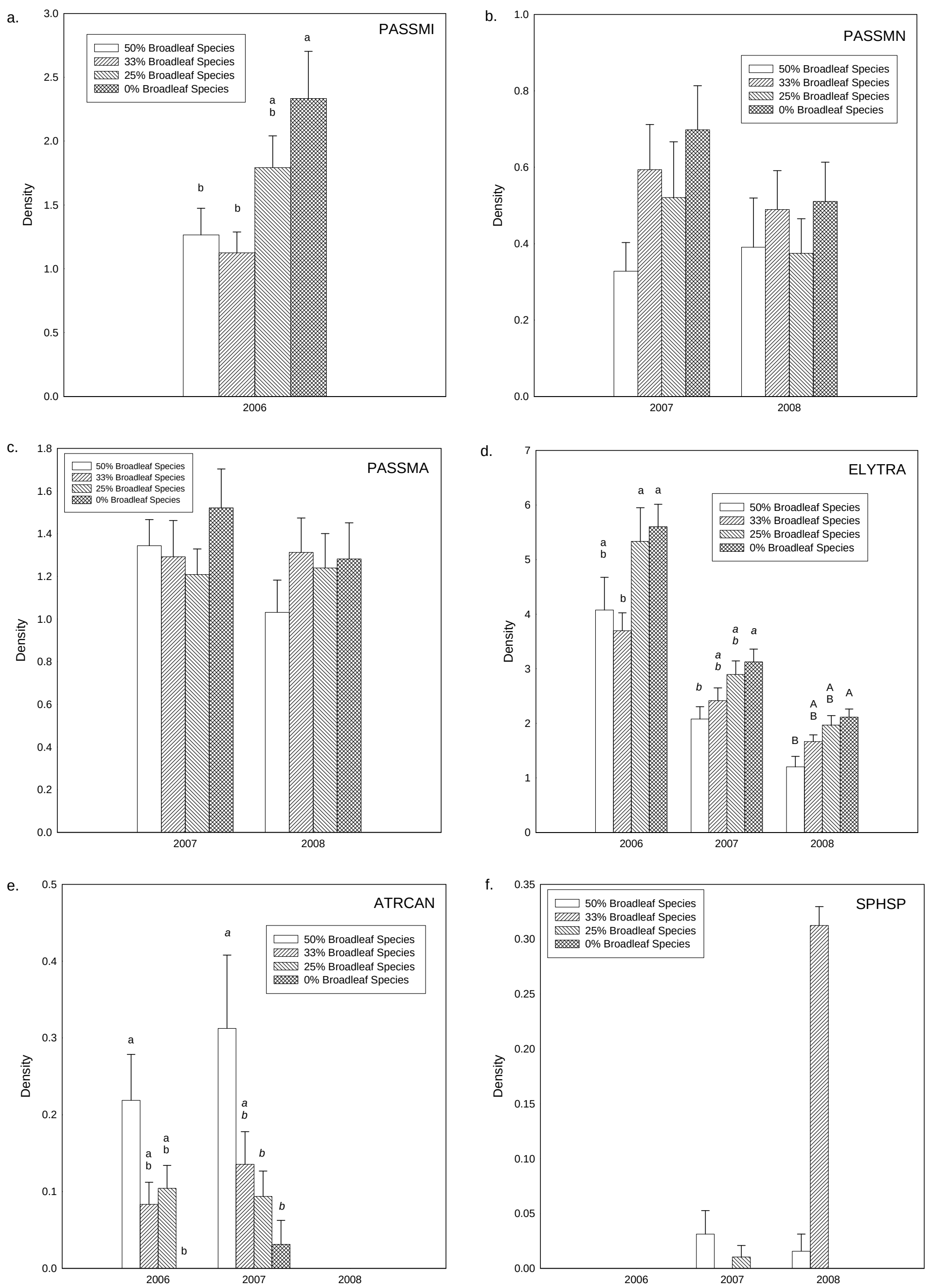

Figure 6. Mean density of seeded species with differences among seed mixtures in at least one of the three years of the study, 2006, 2007, and 2008 (± one standard error of the mean): (a) western wheatgrass (*Pascopyrum smithii*, PASSMI), (b) western wheatgrass “Native” (*Pascopyrum smithii*, PASSMN), (c) western wheatgrass “Arriba” (*Pascopyrum smithii*, PASSMA), (d) slender wheatgrass (*Elymus trachycaulus*, ELYTRA), (e) fourwing saltbush (*Atriplex canescens*, ATRCAN), and (f) globemallow (*Sphaeralcea spp*, SPHSP). Means with different letters are significantly different at α = 0.05. *Note*: Data for the two varieties of western wheatgrass were combined in 2006 because we were not able to reliably distinguish them from one another.

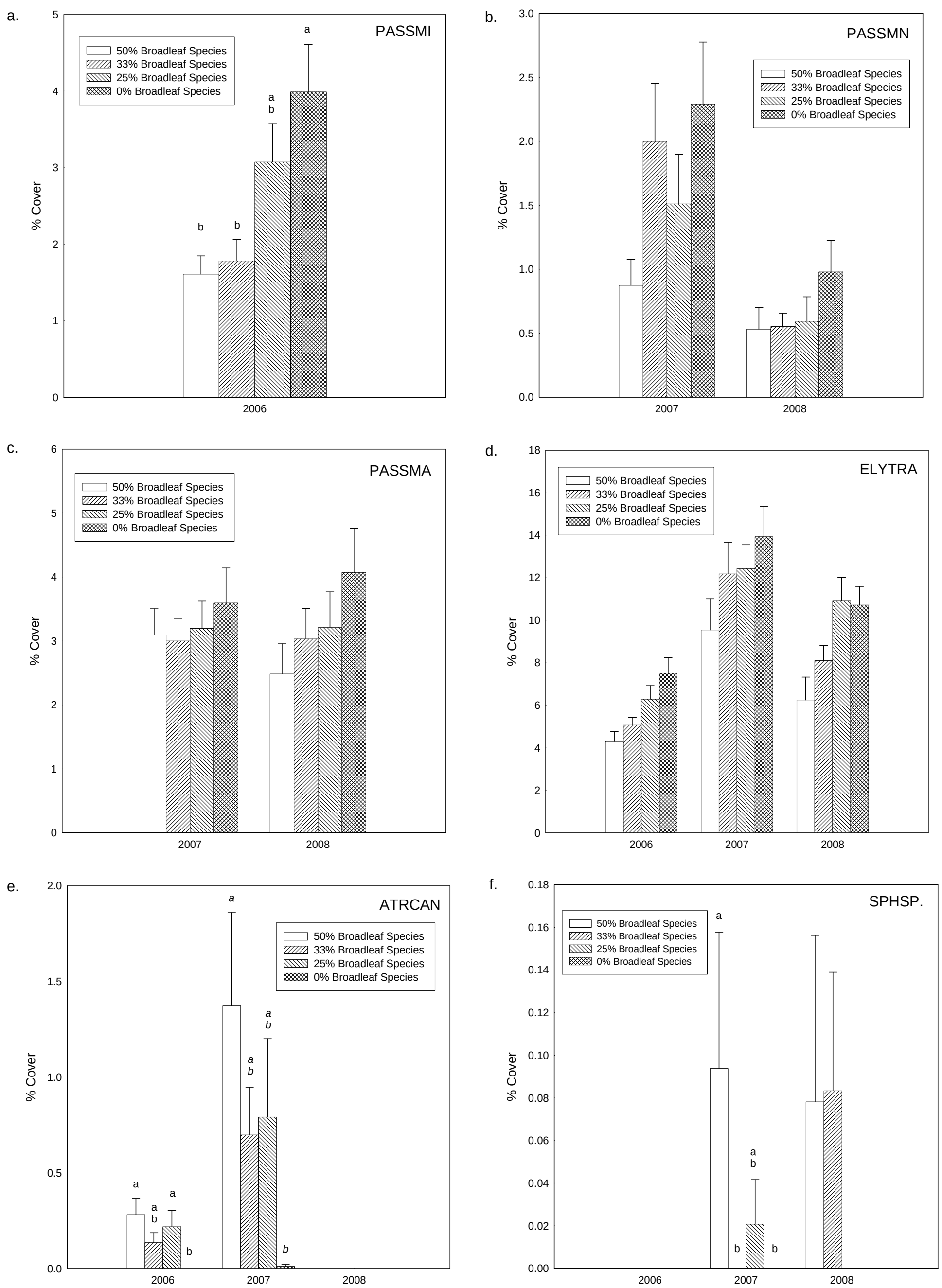

Figure 7. Mean cover of seeded species with differences among seed mixtures in at least one of the three years of the study, 2006, 2007, and 2008 (± one standard error of the mean): (a) western wheatgrass (*Pascopyrum smithii*, PASSMI), (b) western wheatgrass "Native" (*Pascopyrum smithii*, PASSMN), (c) western wheatgrass "Arriba" (*Pascopyrum smithii*, PASSMA), (d) slender wheatgrass (*Elymus trachycaulus*, ELYTRA), (e) fourwing saltbush (*Atriplex canescens*, ATRCAN), and (f) globemallow (*Sphaeralcea spp*, SPHSP). Means with different letters are significantly different at $\alpha = 0.05$. *Note*: Data for the two varieties of western wheatgrass were combined in 2006 because we were not able to reliably distinguish them from one another.

Non-Seeded Species

For the most abundant non-seeded species, annual grasses field brome (*Bromus arvensis*, BROARV) and cheatgrass (downy brome, *Bromus tectorum*, BROTEC) increased over time (Figure 8a and 9e, f). Cover of the most abundant non-seeded forbs generally did not change until 2008 (Figure 8a and 9b, c, d). There was a decrease in cover of field bindweed (*Convolvulus arvensi*, CONARV), kochia (*Kochia scoparia*, KOCSCO), prickly lettuce (*Lactuca serriola*, LACSER), and Russian thistle (*Salsola iberica*, SALIBE) (Figure 8a) that year. Cover of the least abundant non-seeded species was variable during the three years of the study (Figure 8b). The mean cover of these species was less than 1% in all years (Figure 8b).

Cover of non-seeded species was greatest in 50% Broadleaf Species Mix and lowest in 0% Broadleaf Species mix in 2006 and 2008 (Table 4, Figure 9b). Cover of cheatgrass was lowest in 0% Broadleaf Species Mix and highest in the 33% Broadleaf Species Mix in all three years (Table 4, Figure 9e). In 2008 field brome cover was lower in 25% Broadleaf Species Mix and 0% Broadleaf Species Mix than in the 33% Broadleaf Species Mix and the 50% Broadleaf Species Mix (Table 4, Figure 9f). Russian thistle cover differed among seed mixture treatments only in 2006 when its cover was greater in 50% Broadleaf Species Mix than the 33% Broadleaf Species Mix and the 25% Broadleaf Species Mix (Table 4, Figure 9b). Kochia had lower cover in the 0% Broadleaf Species Mix than the 50% Broadleaf Species Mix and 33% Broadleaf Species Mix in 2008, but we detected no differences among treatments in 2006 and 2007 (Table 4, Figure 9c). Cover of field bindweed was lower in the 0% Broadleaf Species Mix than the 25% Broadleaf Species Mix in 2008, but we detected no differences among seed mixture treatments in 2006 and 2007 (Table 4, Figure 9d).

The cover of non-seeded species was negatively correlated with bare ground in 2006 ($P <$ 0.0001, $R^2 = 0.44$), 2007 ($P < 0.0001$, $R^2 = 0.37$), and 2008 ($P = 0.0141$, $R^2 = 0.07$). The relationship between non-seeded species cover and litter was negative in 2006 ($P < 0.0001$, $R^2 =$ 0.29), and positive in both 2007 ($P = 0.0017$, $R^2 = 0.11$) and 2008 ($P = 0.0455$, $R^2 = 0.04$).

Table 4. ANOVA of cover of non-seeded species cheatgrass (*Bromus tectorum*, BROTEC), field brome (*Bromus arvensis*, BROARV), field bindweed (*Convolvulus arvensi*, CONARV), kochia (*Kochia scoparia*, KOCSCO),), prickly lettuce (*Lactuca serriola*, LACSER) and Russian thistle (*Salsola iberica*, SALIBE) for 2006, 2007, and 2008.

2006:

Factor	df_{num}	df_{den}	Non-Seeded Species		BROTEC		BROARV		CONARV		KOCSCO		SALIBE	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	3.65	0.04	3.26	0.06	1.64	0.23	2.32	0.12	0.51	0.68	5.2	0.01

2007:

Factor	df_{num}	df_{den}	Non-Seeded Species		BROTEC		BROARV		CONARV		KOCSCO		SALIBE	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	3.18	0.06	3.54	0.04	1.59	0.23	0.43	0.74	0.69	0.58	2.43	0.11

2008:

Factor	df_{num}	df_{den}	Non-Seeded Species		BROTEC		BROARV		CONARV		KOCSCO		SALIBE	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	6.88	0.005	4.52	0.02	4.21	0.03	4.29	0.03	23.18	<0.0001	0.99	0.42

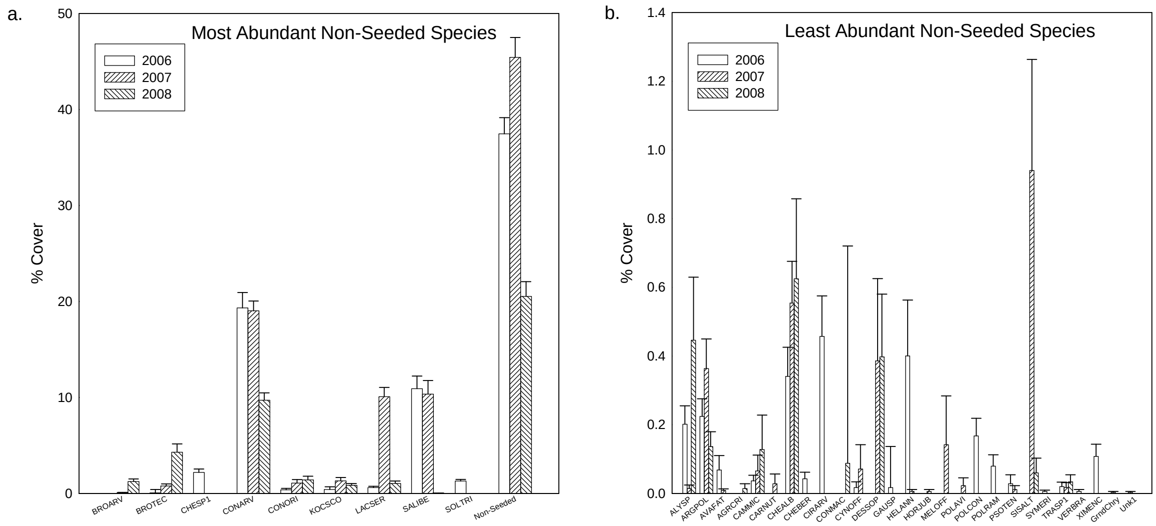

Figure 8. Mean cover of (a) most abundant non-seeded species: field brome (*Bromus arvensis*, BROARV), cheatgrass (*Bromus tectorum*, BROTEC), lambsquarter (*Chenopodium spp*, CHESP), field bindweed (*Convulvulus arvensis*, CONARV), hare's ear mustard (*Conringia oreientalis*, CONORI), kochia (*Kochia scoparia*, KOCSCO), prickly lettuce (*Lactuca serriola*, LACSER), Russian thistle (*Salsola iberica*, SALIBE), cut-leaved nightshade (*Solanum triflorum*, SOLTRI) and (b) least abundant non-seeded species: madwort (*Alyssum spp*, ALYSP), prickly poppy (*Argemone polyanthemos*, ARGPOL), wild oat (*Avena fatua*, AVEFAT), crested wheatgrass (*Agropyron cristatum*, AGRCRI), littlepod false flax (*Camelina microcarpa*, CAMMIC), musk thistle (*Carduus nutans*, CARNUT), common lambsquarter (*Chenopodium alba*, CHEALB), pitseed goosefoot (*Chenopodium berlandieri*, CHEBER), Canada thistle (*Cirsium arvense*, CIRARV), poison hemlock (*Conium maculatum*, CONMAC), hound's tongue (*Cynoglossum officinale*, CYNOFF), flixweed (*Descurainia sophia*, DESSOP), beeblossom (*Guara L.*, GUAR), annual sunflower (*Helianthus annuus*, HELANN), foxtail barley (*Hordeum jubatum*, HORJUB), yellow sweetclover (*Melilotus officianlales*, MELOFF), prostrate knotweed (*Polygonum aviculare*, POLAVI), wild buckwheat (*Polygonum convulvus*, POLCON), bushy knotweed (*Polygonum ramosissimum*, POLRAM), slimflower scurf pea (*Psoralidium tenuiflorum*, PSOTEN), tumble mustard (*Sisymbrium altissimum*, SISALT), white heath aster (*Symphyotrichum ericoides*, SYMERI), salsify (*Tragopogon spp*, TRASP), prostrate vervain (*Verbena bracheata*, VERBRA), crow pen daisy (*Ximenesia enceliodes*, XIMENC), common ground cherry, and unknown spp1 for 2006, 2007, and 2008 (± one standard error of the mean).

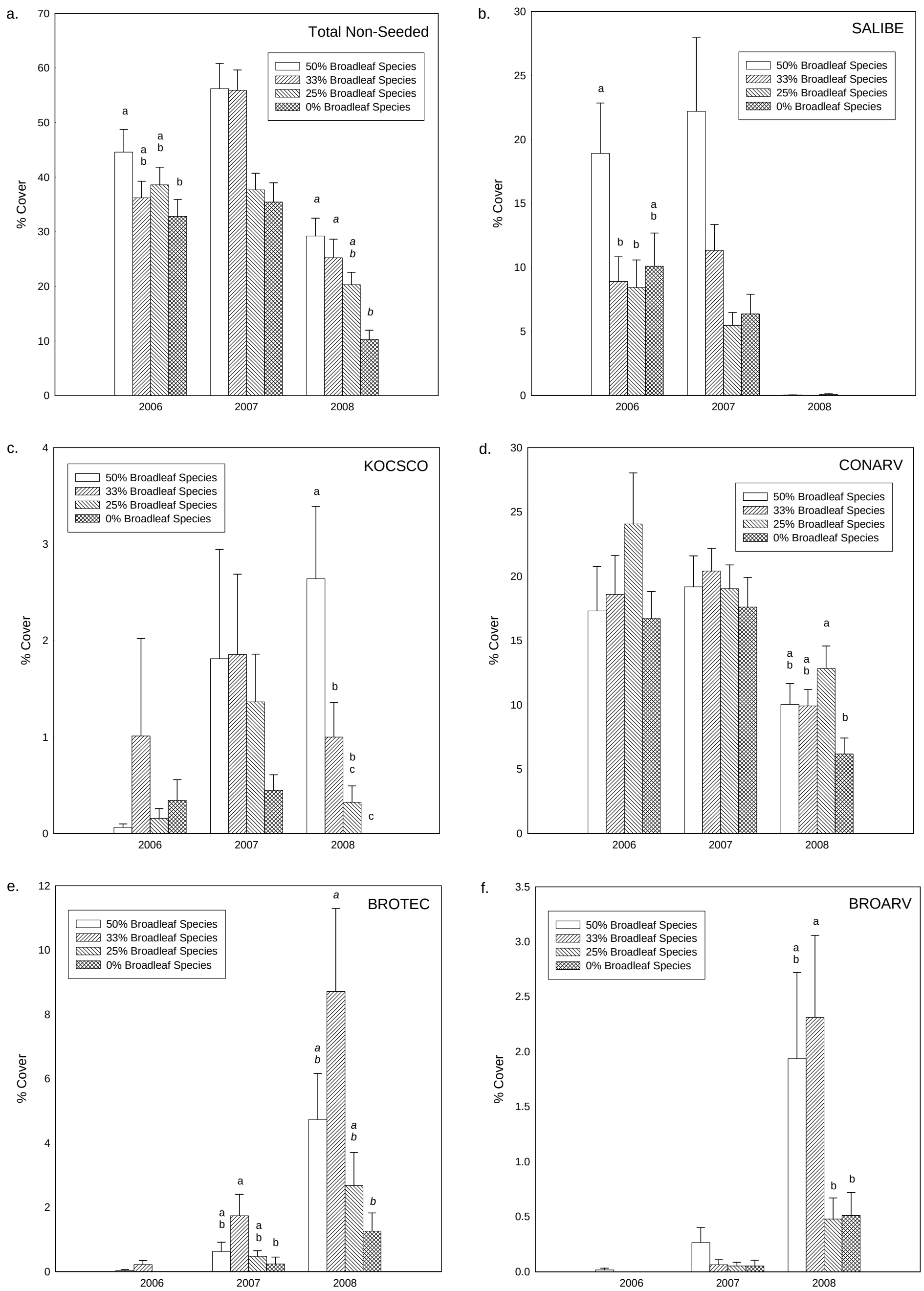

Figure 9. Mean cover of (a) total non-seeded species, (b) Russian thistle (*Salsola iberica*, SALIBE), (c) kochia (*Kochia scoparia*, KOCSCO), (d) field bindweed (*Convolvulus arvensis*, CONARV), (e) cheatgrass (*Bromus tectorum*, BROTEC) and (f) field brome (*Bromus arvensis*, BROARV) with significant mix differences in 2006, 2007, and 2008 (± one standard error of the mean). Means with different letters are significantly different at $\alpha = 0.05$.

Species Richness

Species richness of seeded species did not differ among seeding treatments in any year of the study (Table 5), although seeded shrubs had lower species richness than the other seed mixtures in 2007 (Figure 10). In 2008, non-seeded, non-native species richness was lower in the 0% Broadleaf Species Mix than the 50% Broadleaf Species Mix (Table 5, Figure 11a). In 2008, non-seeded, non-native grass richness was lower in 0% Broadleaf Species Mix than 33% Broadleaf Species Mix with other mixtures intermediate (Figure 11b). In 2008, non-seeded, non-native forb richness was inversely proportional to representation of grasses in the seed mixture (Figure 11c). In particular, 50% the Broadleaf Species Mix had higher non-seeded, non-native forb richness than 0% Broadleaf Species Mix, and the other two mixtures had intermediate richness.

Table 5. ANOVA of richness of seeded species, non-seeded native species, non-seeded non-native species, non-seeded non-native grass species and non-seeded non-native forb species for 2006, 2007, and 2008. *Note*: There were no non-seeded non-native shrub species detected in any of the three years.

2006:

Factor	df_{num}	df_{den}	Seeded species		Non-Seeded Native Species		Non-Seeded Non-Native Species		Non-Seeded Non-Native Grass		Non-Seeded Non-Native Forbs	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	1.5	0.26	1.09	0.40	0.46	0.71	1.65	0.23	0.43	0.73

2007:

Factor	df_{num}	df_{den}	Seeded species		Non-Seeded Native Species		Non-Seeded Non-Native Species		Non-Seeded Non-Native Grass		Non-Seeded Non-Native Forbs	
			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	2.99	0.07	3.35	0.054	2.48	0.11	0.61	0.62	2.63	0.09

2008:

Factor	df_{num}	df_{den}	Seeded species	Non-Seeded Native Species	Non-Seeded Non-Native Species	Non-Seeded Non-Native Grass	Non-Seeded Non-Native Forbs

			F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Seed Mixture	3	15	0.63	0.60	0.32	0.81	3.93	0.03	3.51	0.05	4.44	0.02

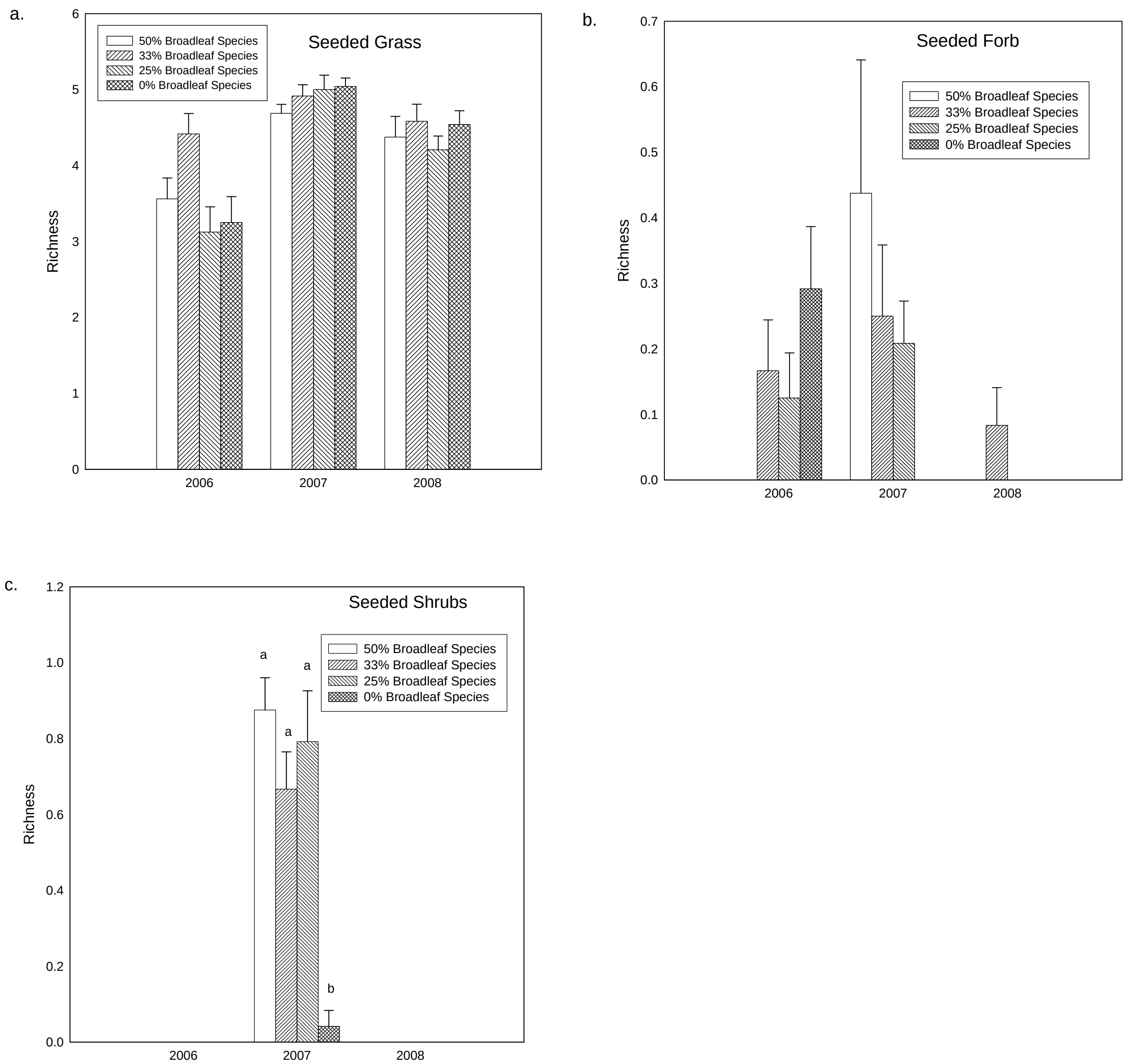

Figure 10. Mean richness of (a) seeded grass species (b) seeded forb species and (c) seeded shrub species for 2006, 2007, and 2008 (± one standard error of the mean). Means with different letters are significantly different at $\alpha = 0.05$. *Note:* No seeded shrubs were detected in 2006 or 2008.

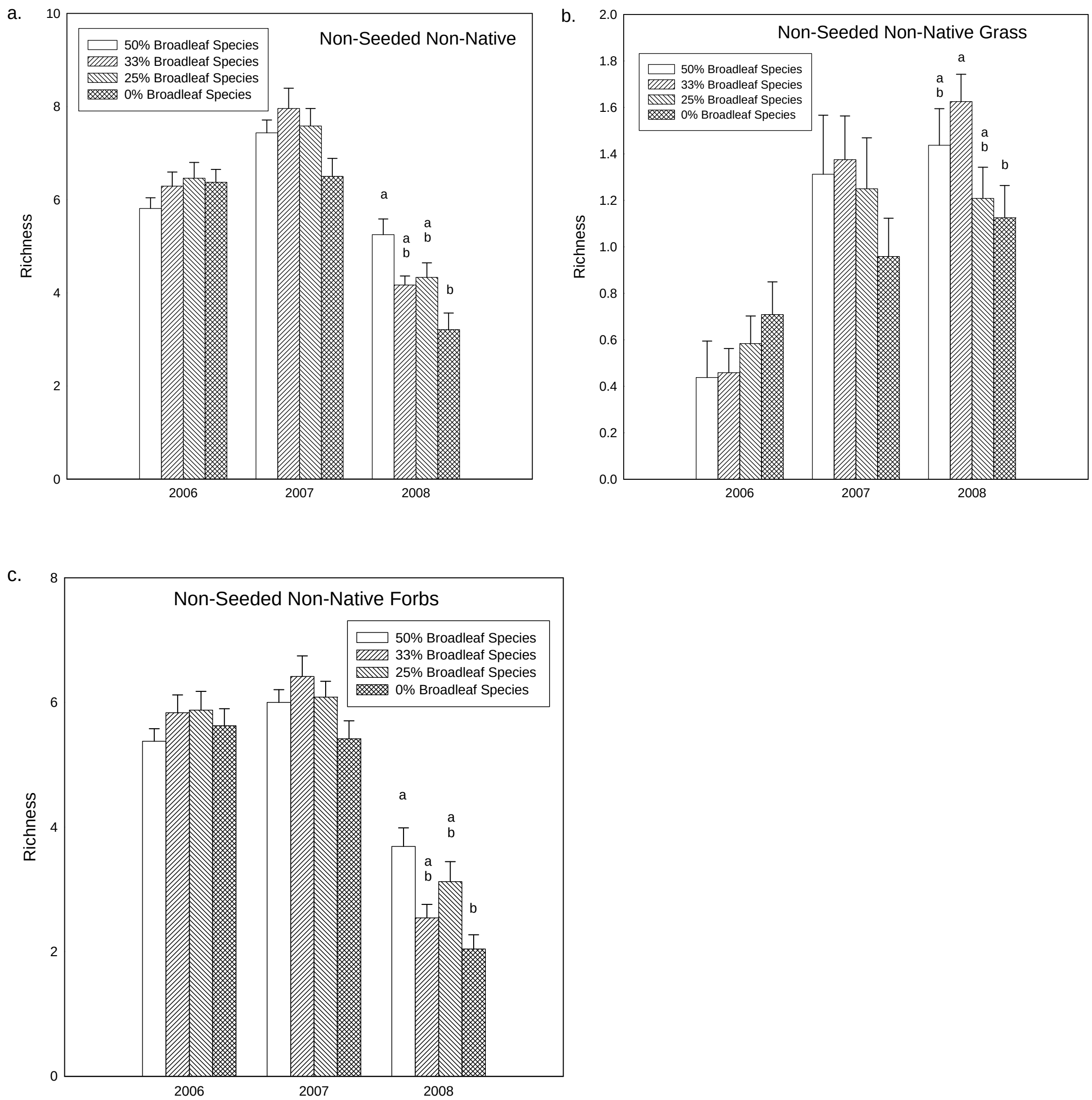

Figure11. Mean richness of (a) non-seeded non-native species (b) non-seeded non-native grass species and (c) non-seeded non-native forbs species for 2006, 2007, and 2008 (± one standard error of the mean). Means with different letters are significantly different at α = 0.05. *Note*: There were no non-seeded non-native shrub species detected in any of the three years.

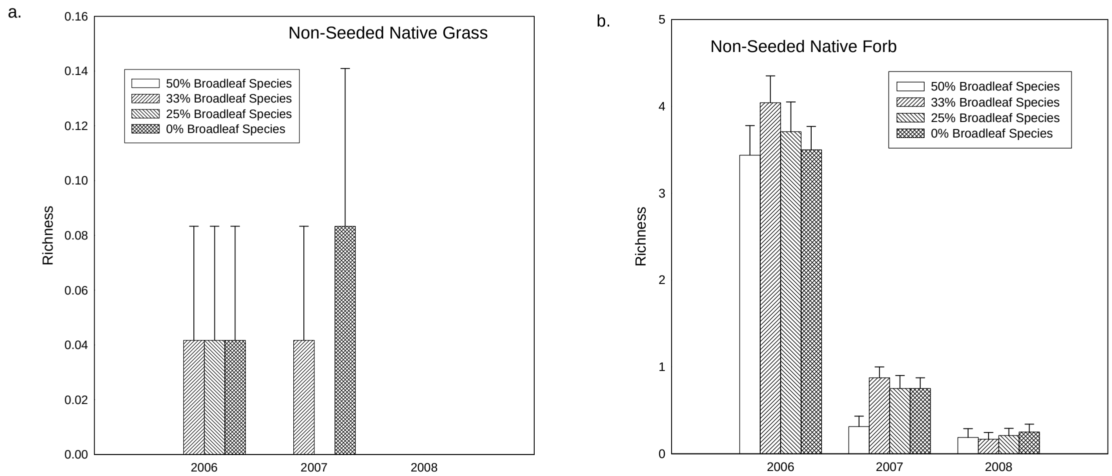

Figure 12. Mean richness of (a) non-seeded native grass species (b) non-seeded native forb species for 2006, 2007, and 2008 (± one standard error of the mean). Means with different letters are significantly different at $\alpha = 0.05$. *Note*: There were no non-seeded native shrub species detected in any of the three years.

Herbicide Treatment

We were not able to detect an effect of the application of a broadleaf specific herbicide mixture on the cover of non-seeded species (t = 1.62, df = 34, P = 0.11) or the individual targeted species (field bindweed: t = 1.29, df = 34, P = 0.21; Russian thistle: not detected; lambsquarters: not detected; prickly lettuce: t = -0.65, df = 34, P = 0.52) by comparing the cover of these species in sprayed and unsprayed plots in the 0% Broadleaf Species Mix (Figure 13).

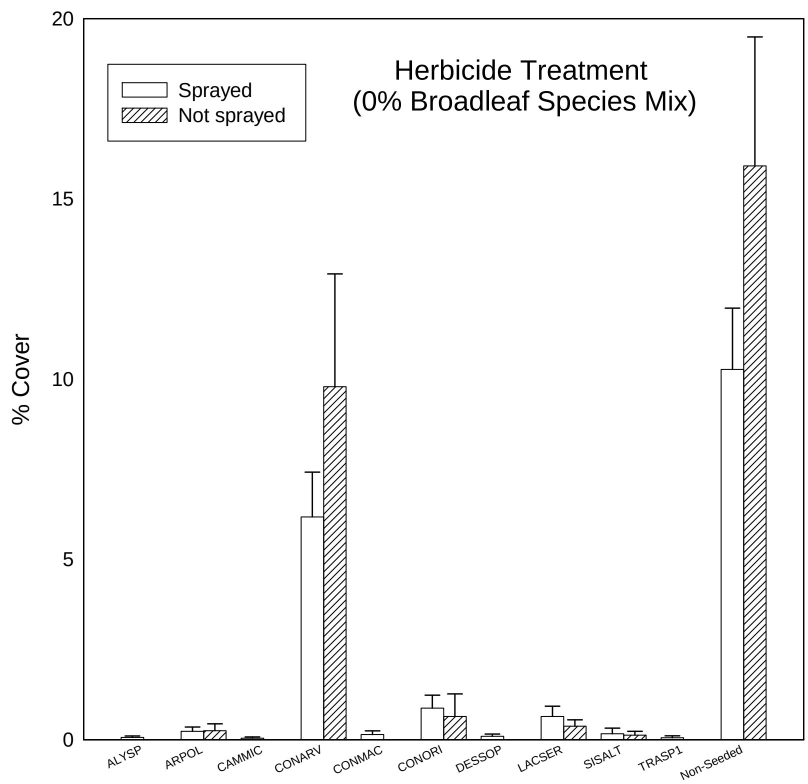

Figure 13. Mean cover of non-seeded broadleaf species detected in 0% Broadleaf Species Mix after herbicide application: madwort (*Alyssum spp*, ALYSP), prickly poppy (*Argemone polyanthemos*, ARGPOL), littlepod false flax (*Camelina microcarpa*, CAMMIC), field bindweed (*Convolvulus arvensis*, CONARV), poison hemlock (*Conium maculatum*, CONMAC), hare's ear mustard (*Conringia oreientalis*, CONORI), flixweed (*Descurainia sophia*, DESSOP), prickly lettuce (*Lactuca serriola*, LACSER), tumble mustard (*Sisymbrium altissimum*, SISALT), salsify (*Tragopogon spp*, TRASP) and total non-seeded.

Cimate

Spring precipitation at Waterdale was below the 30 year average for all three years of the study with the first year of plant establishment being the driest of all (Figure 14). August was much wetter in 2007 and 2008 than the 30-year average, while in 2006 only marginally more precipitation than the 30-year average fell that month. October of 2006 and 2007 received higher precipitation than the 30-year average, as did December of 2006 and 2007.

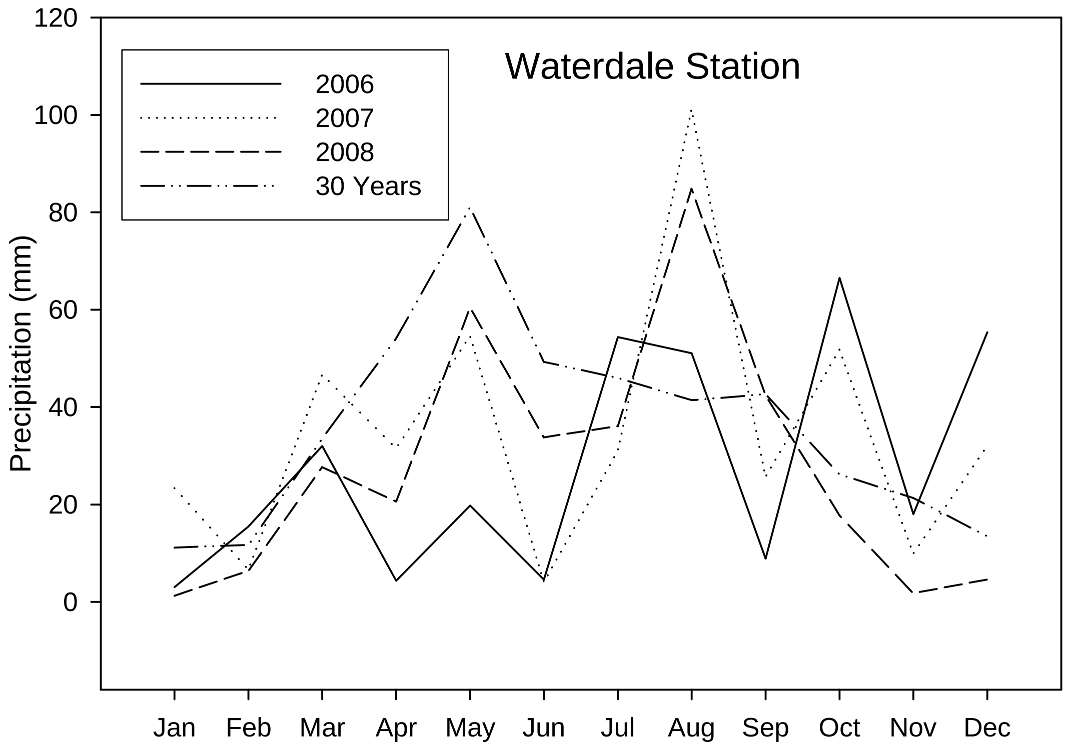

Figure 14. Mean monthly precipitation for 2006, 2007, and 2008 as well as the 30 year averages.

Abiotic factors

The cover of seeded species in 2006, 2007, or 2008 was not related to 2006 soil percent N. Cover of seeded species was negatively correlated to 2006 soil percent C in 2006 ($P = 0.02$, $R^2 = 0.05$), and positively related in 2008 ($P = 0.0008$, $R^2 = 0.12$), but was not related in 2007. There was no relationship between light penetration and seeded species cover in 2006 and 2007, but a negative relationship in 2008 ($P = 0.0004$, $R^2 = 0.13$). Cover of non-seeded species in 2007 was positively related to 2006 soil percent N ($P = 0.007$, $R^2 = 0.08$). Cover of non-seeded species in 2006 was negatively correlated to 2006 soil percent C ($P = 0.01$, $R^2 = 0.07$), but unrelated to this variable in 2007 and 2008. Light penetration was negatively correlated to non-seeded species cover in 2006 ($P = 0.02$, $R^2 = 0.05$) and positively related in 2008 ($P = 0.04$, $R^2 = 0.05$). There was no relationship between light penetration and non-seeded cover in 2007.

Animal activity

No burrowing mammal activity was observed in sampling plots or subplots in 2006, 2007, or 2008. Elk scat was observed in two sampling plots in 2006 and both rabbit and deer scat has been found in multiple plots in 2007 and 2008. Grazing was noted on wild oat in one plot and western wheatgrass in another in 2006. Grazing of flower heads was also noted on the abundant prickly lettuce in this year. In 2008, the remains of two dead deer were found, one on the north side and one on the south near the gully. In 2007 and 2008 a red tail hawk (*Buteo jamaicensis*) was seen circling the study site and the nearby prairie dog (*Cynomys* spp.) colony located to the south. Possible coyote tracks were found in 2008 and a coyote was witnessed on the prairie dog colony south of the study site.

DISCUSSION OF RESULTS

Our results indicate that the cover of seeded species increased from 2006 to 2008. Our hypothesis that the abundance of seeded grasses, herbaceous forbs and shrubs would reflect their proportions was not supported since we only had two seeded broadleaf species establish and then disappear over time as grasses become more dominant. Seeding proportion and density effects were observed in the first year after seeding for prairie plantings on agricultural lands in the Central Valley of California, but these differences were not apparent in subsequent years (Brown 1998). This same pattern has been noted in previous studies (Sluis 2002; Jongepierova et al. 2004).

We hypothesized that success of seeded species would be positively associated with low weed abundance. In the first year, there was no indication that non-seeded vegetation reduced the performance of seeded species. However, in 2007 and 2008, there was a strong negative correlation between seeded and non-seeded species cover. Since the cover of bare ground was negatively associated with cover of non-seeded species and positively correlated with cover of seeded species in 2007 and 2008, this suggests that more non-seeded species created less open space and a more competitive environment for the seeded species.

We hypothesized that success of seeded species would be improved with greater soil N levels in the absence of weeds, and would be reduced with greater soil N levels in the presence of weeds. However, we detected no relationship between percent soil N, measured at the beginning of the study, and cover of seeded species throughout the study. The same was true of non-seeded species cover except in 2007 when there was a strong positive relationship. This may have been due to increased precipitation in 2007, which could shift the resource most limiting to plant growth from water to N, resulting in greater plant growth with greater N availability (Brown et al. 2008). It is not surprising that only non-seeded species responded to N in 2007. Early successional species rapidly convert available N into biomass, whereas the slower growth rates of perennial species limit their ability to respond rapidly (Claassen and Marler 1998).

In 2006, soil percent C was negatively associated with cover of both seeded and non-seeded species. This was not true in 2007 when neither was affected by percent soil C. In 2008, seeded species cover increased with levels of soil C. Since soil C was measured only at the beginning of the study, we cannot be certain that soil C levels did not change over time, but the length of our study was short compared to the amount of time it takes for soil C to change significantly. Soil C changes on the order of decades, rather than years. For example, soil C is slow to increase in mid-western old field succession and takes decades to recover after tillage is halted (Knops and Tilman 2000) with later successional soil having higher soil C due to increased deposition and decomposition of plant material over time (Zak et al. 1990). Despite this, our results suggest that native species performed better over the course of the study in soils with higher soil C levels.

We hypothesized that light would serve more as a stressor of the seeded species than as a limiting resource. Our results in supported this hypothesis only in 2008, which is the time that plants should have been least sensitive to high light because they were well established. Light appeared to act as a stressor for non-seeded species in 2006 (i.e. there was a negative association between light and cover of non-seeded species), but as a limiting resource in 2008 (i.e. there was a positive association between light and cover of non-seeded species). Since seeded species were negatively associated with light penetration (i.e. greater cover of seeded species was correlated with lower light penetration) in 2008, it is possible that the seeded species were suppressing the non-seeded species through light competition by the end of the study, but not vice versa.

The poor performance of the seeded forb and shrub species may have been due a number of factors. It is possible that the forbs were planted too deeply by the seeder for optimal establishment. This is supported by the relatively better performance of the larger seeded broadleaf species (fourwing saltbush and scarlet globemallow) compared to smaller seeded species such as fringed sage, which is usually very easy to grow (Brown, personal communication, 2009).

Poor forb and shrub establishment may also have been due to the variation in precipitation between years. The relatively good establishment of fourwing saltbush in the first two years is not surprising given its vigorous nature. Its disappearance in 2008 might be the result of less winter precipitation in 2007-2008 and competition with seeded grass species that may have been able to take advantage of higher precipitation early in the growing season of 2008 (Redente et al. 1984). The disappearance of fourwing saltbush may also be explained by poor adaptation to the conditions at the study site (Brown et al. 2008), however this was not evaluated in this study.

The dominance of the western wheatgrass varieties as well as slender wheatgrass is probably due to these species not having special germination requirements like green needlegrass and Indian ricegrass (Fulbright et al. 1983; Fulbright et al. 1984; Redente et al. 1984). There is evidence that dry summer conditions can result in higher proportions of forbs and deep rooting species in grassland communities (Morecroft et al. 2004) which may or may not persist after resumption of more normal precipitation depending on their pre-drought density (Tilman and El Haddi 1990).

Finally, we also tested the hypothesis that broadleaf specific herbicides can be used effectively in established grasses to control non-native forbs. The herbicide treatment applied to 0% Broadleaf Species mix did not reduce the cover of the targeted species when sprayed plots were compared to unsprayed plots. However, we detected decreased cover of the target species in the sprayed plots in 0% Broadleaf Species mix compared to unsprayed plots in the other seed mixture treatments only in 2008, the year the herbicides were applied. It is likely that we were unable to detect a difference between sprayed and unsprayed plots because of low replication relative to the amount of variation in the cover values. Overall, the combination of native perennial grasses and broadleaf specific herbicides resulted in the lowest cover of non-seeded species, especially kochia and field bindweed, which were targeted by the herbicide mixture.

Overall, we have documented the initial stages of secondary succession in this abandoned farm field. The increase in cover of seeded species, which we expect to see in rarely disturbed native prairies, and litter, and decrease in cover of non-seeded species, which are early-successional species, and bare ground typifies patterns observed in other prairie systems (Camill et al. 2004; Ruprecht 2006; Foster et al. 2007) .

Management implications

This study provides no evidence that increasing proportional representation of forb and shrub species in seed mixtures can lead to greater establishment three years after seeding. Grasses are likely to dominate despite initial representation of forbs and shrubs and the competitive advantage of perennial grasses over forb and shrub species has been documented (Redente et al. 1984).

There was no evidence that separation of forbs and shrubs from grasses in the seeder seed boxes promoted the establishment of broadleaf species since survival was so low, but the study was not designed to evaluate this approach.

Success in maintaining forbs and shrubs in restored grasslands may require alternative establishment techniques such as establishing small areas of forbs and shrubs that can be managed more intensively than the surrounding expansive areas in which grasses dominate. We suggest a staged revegetation approach that includes introducing forbs and shrubs in small areas after native grass establishment. This approach enables the use of broadleaf-specific herbicides until the forbs are introduced as suggested by our study and others (Brown and Bugg 2001). Based on the competitive effects of established native perennial cool-season grasses suggested by our study and elsewhere (Redente et al. 1984), this will best be accomplished by transplanting seedlings of forbs and shrubs into small patches in which competition from grasses is reduced by removing aboveground biomass using fire, tillage, mowing or herbicides. The number and size of patches may be set based on the resources and labor available to maintain them. New patches may be established in subsequent years as resources and labor are available. Once established, the patches of forbs and shrubs will serve as seed sources to colonize the parts of the site suited to their growth. It may also be fruitful to plant forbs into these patches as seedling transplants instead of seed. Although labor intensive, it may be more efficient than trying to establish desired broadleaf species throughout a site.

CONCLUSION

The establishment of seeded grasses on this site has been very successful, but the forbs and shrubs failed. Since survival of seeded broadleaf species was so low, we cannot draw strong conclusions about the effect of their differential representation in seed mixtures. Given past BCPOS experience, different approaches to establishing forbs and shrubs are clearly necessary. It is important to plant seed from accessions that are adapted to the site conditions and to minimize competition from non-seeded species, and the most competitive seeded species, in particular the grasses. As concluded by Sluis 2002, we have much to learn about how species are maintained in remnant grasslands before we will be able to successfully recreate their species richness and composition.

ACKNOWLEDGEMENTS

We thank Jim Bromberg, Hilary Drucker, Meg Hollowed, Meredith Schon, John Shannon, and Kyle Mcaddy for their assistance with data collection, data entry, and report preparation.

LITERATURE CITED

Brown, C. S. 1998. Restoration of California Central Valley grasslands: applied and theoretical approaches to understanding interactions among prairie species. Dissertation. University of California, Davis, California, USA.

Brown, C. S., and R. L. Bugg. 2001. Effects of established perennial grasses on introduction of native forbs in California. Restoration Ecology 9:38-48.

Brown, C. S., Val. J. Anderson, V. P. Claassen, M. E. Stannard, L. M. Wilson, S. Y. Atkinson, J. E. Bromberg, T. A. Grant III, and M. D. Munis. 2008. Restoration Ecology and Invasive Plants in the Semiarid West. Invasive Plant Science and Management 1:000-000.

Bugg, R. L., C. S. Brown, and J. H. Anderson. 1997. Restoring native perennial grasses to rural roadsides of the Sacramento Valley of California: establishment and evaluation. Restoration Ecology 5: 214-225.

Claassen, V., and M. Marler. 1998. Annual and perennial grass growth on nitrogen-depleted decomposed granite. Restoration Ecology 6:175-180.

Camill, P., M. J. McKone, et al. 2004. Community- and ecosystem-level changes in a species-rich tallgrass prairie restoration. Ecological Applications 14: 1680-1694.

Fliervoet, L.M. & Werger, M.J.A. 1984. Canopy structure and microclimate of two wet grassland communities. New Phytologist 96: 115-130.

Foster, B. L., C. A. Murphy, et al. 2007. Restoration of prairie community structure and ecosystem function in an abandoned hayfield: A sowing experiment. Restoration Ecology 15: 652-661.

Fulbright, T. E., E. F. Redente, et al. 1983. Germination requirements of green needlegrass (Stipa-viridula Trin). Journal of Range Management 36: 390-394.

Fulbright, T. E., A. M. Wilson, et al. 1984. Effects of temporary dehydration on growth of green needlegrass (Stipa-viridula Trin) seedlings. Journal of Range Management 37: 462-464.

Grime, J.P. & Jeffrey, D.W. 1965. Seedling establishment in vertical gradients of sunlight. J. Ecol. 53: 621-642.

Jongepierova, I., J. W. Jongepier, et al. 2004. Restoring grassland on arable land: an example of a fast spontaneous succession without weed-dominated stages. Preslia 76: 361-369.

Knops, J.M.H. and D. Tilman 2000. Dynamics of soil nitrogen and carbon accumultaion for 61 years after agricultural abandonment. Ecology 81:88-98.

Kotowski, W. and R. van Diggelen (2004). Light as an environmental filter in fen vegetation. Journal of Vegetation Science 15: 583-594.

McLendon, T. and E. F. Redente 1992. Effects of nitrogen limitation on species replacement dynamics during early secondary succession on a semiarid sagebrush site. Oecologia 91: 312-317.

Morecroft, M. D., G. J. Masters, et al. 2004. Changing precipitation patterns alter plant community dynamics and succession in an ex-arable grassland. Functional Ecology 18: 648-655.

Paschke, M. W., T. McLendon, et al. 2000. Nitrogen availability and old-field succession in a shortgrass steppe. Ecosystems 3: 144-158.

Redente, E. F., T. B. Doerr, et al. 1984. Vegetation establishment and succession on disturbed soils in northwest colorado. Reclamation & Revegetation Research 3: 153-165.

Ruprecht, E. 2006. Successfully recovered grassland: A promising example from Romanian old-fields. Restoration Ecology 14: 473-480.

Sluis, W. J. 2002. Patterns of species richness and composition in re-created grassland. Restoration Ecology 10: 677-684.

Tilman, D. and A. El Haddi 1990. Drought and biodiversity in grasslands. Oecologia 89: 257-264.

Zak, D.R., D.F. Grigal, S.Gleeson, D. Tilman. 1990. Carbon and nitrogen cycling during old field succession constraints on plant and microbial biomass. Biogeochemistry 11:111-129.

Appendix 1. Monocultures

Rep 1 I-II N to S	Replicate b/wn blocks I-II Common name	Rep 2 II-III N to S	Replicate b/wn blocks II-III Common name	Rep 3 IV-V N to S	Replicate b/wn blocks IV-V Common name	Rep 4 V-VI N to S	Replicate b/wn blocks V-VI Common name
1	Blanketflower	1	Rabbitbrush (Rubber)	1	Buffalograss	1	Green Needlegrass
2	Indian Ricegrass	2	Little Bluestem	2	Purple prairie clover	2	Scarlet Globemallow
3	Fourwing saltbush	3	Western Wheatgrass "Arriba"	3	Slender Wheatgrass	3	Indian Ricegrass
4	Fringed Sage	4	Buffalograss	4	Yellow Coneflower	4	Side Oats Grama
5	Yellow Coneflower	5	Green Needlegrass	5	Prairie Sage	5	Purple prairie clover
6	Little Bluestem	6	Scarlet Globemallow	6	Blue Grama	6	Buffalograss
7	Buffalograss	7	Side Oats Grama	7	Scarlet Globemallow	7	Blue Grama
8	Purple prairie clover	8	Yellow Coneflower	8	Indian Ricegrass	8	Rabbitbrush (Rubber)
9	Junegrass	9	Indian Ricegrass	9	Blanketflower	9	Little Bluestem
10	Scarlet Globemallow	10	Fourwing saltbush	10	Western Wheatgrass "Native"	10	Fringed Sage
11	Side Oats Grama	11	Purple prairie clover	11	Side Oats Grama	11	Prairie Sage
12	Prairie Sage	12	Fringed Sage	12	Green Needlegrass	12	Slender Wheatgrass
13	Blue Grama	13	Slender Wheatgrass	13	Little Bluestem	13	Junegrass
14	Green Needlegrass	14	Blue Grama	14	Junegrass	14	Western Wheatgrass "Arriba"
15	Western Wheatgrass "Arriba"	15	Blanketflower	15	Western Wheatgrass "Arriba"	15	Western Wheatgrass "Native"
16	Western Wheatgrass "Native"	16	Junegrass	16	Fourwing saltbush	16	Yellow Coneflower
17	Rabbitbrush (Rubber)	17	Prairie Sage	17	Rabbitbrush (Rubber)	17	Fourwing saltbush
18	Slender Wheatgrass	18	Western Wheatgrass "Native"	18	Fringed Sage	18	Blanketflower

Appendix 2. Seed mixtures

Mix 1

Common Name *Species* "Variety"	Approx. Seeds/#	% of Mix	# PLS/ft2	PLS#/Acre	Comments
Side Oats Grama *Bouteloua curtipendula* "Vaughn"	191000	5.5	50	0.63	
Blue Grama *Bouteloua gracilis* Native	825000	7.5	50	0.20	
Buffalograss *Buchloe dactyloides* "Texoka"	56000	6	50	2.33	
Slender Wheatgrass *Elymus trachycaulus* "San Luis"	159000	5	50	0.68	
Junegrass *Koeleria macrantha* Native	2315400	5	50	0.05	
Western Wheatgrass *Pascopyrum smithii* "Arriba"	110000	2.5	50	0.50	
Western Wheatgrass *Pascopyrum smithii* Native	110000	2.5	50	0.50	

Indian Ricegrass *Oryzopsis hymenoides* "Rimrock"	141000	5	50	0.77	
Little Bluestem *Schizachyrium scoparium* "Camper"	260000	6	50	0.50	
Green Needlegrass *Stipa viridula* "Lodorm"	181000	5	50	0.60	
Total Grasses		**50**		**6.8**	
<u>Forbs & Shrubs</u>					
Prairie Sage *Artemisia ludoviciana*	4500000	5	50	0.0242	1 oz = 0.0625, Ast
Fringed Sage *Artemisia frigida*	4536000	5	50	0.0240	Ast
Fourwing saltbush *Atriplex canescens*	52000	5	50	2.09	Chn
Rabbitbrush (Rubber) *Chrysothamnus nauseosus*	400000	6	50	0.33	Ast
Purple prairie clover, Kanab *Dalea purpurea*	300000	9	50	0.65	Fab
Blanketflower *Gaillardia arstita*	199999	4.5	50	0.49	

Yellow Coneflower *Ratibida columnifera*	1230000	9	50	0.16	Ast
Scarlet Globemallow *Sphaeralcea coccinea*	500000	6.5	50	0.28	Mal
Total Forbs & Shrubs		**50**		**4.1**	

Mix 2

Common Name *Species* "Variety"	Approx. Seeds/#	% of Mix	# PLS/ft2	PLS#/Acre	Comments
Side Oats Grama *Bouteloua curtipendula* "Vaughn"	191000	8.25	50	0.94	
Blue Grama *Bouteloua gracilis* Native	825000	11.25	50	0.30	
Buffalograss *Buchloe dactyloides* "Texoka"	56000	9	50	3.50	
Slender Wheatgrass *Elymus trachycaulus* "San Luis"	159000	7.5	50	1.03	
Junegrass *Koeleria macrantha* Native	2315400	7.5	50	0.07	

Western Wheatgrass *Pascopyrum smithii* "Arriba"	110000	3.75	50	0.74	
Western Wheatgrass *Pascopyrum smithii* Native	110000	3.75	50	0.74	
Indian Ricegrass *Oryzopsis hymenoides* "Rimrock"	141000	7.5	50	1.16	
Little Bluestem *Schizachyrium scoparium* "Camper"	260000	9	50	0.75	
Green Needlegrass *Stipa viridula* "Lodorm"	181000	7.5	50	0.90	
Total Grasses		**75**		**10.1**	Grain seed box
<u>Forbs & Shrubs</u>					
Prairie Sage *Artemisia ludoviciana*	4500000	2.5	50	0.0121	1 oz = 0.0625 Ast
Fringed Sage *Artemisia frigida*	4536000	2.5	50	0.0120	Ast
Fourwing saltbush *Atriplex canescens*	52000	2.5	50	1.05	Chn
Rabbitbrush (Rubber) *Chrysothamnus*	400000	3	50	0.16	Ast

nauseosus						
Purple prairie clover *Dalea purpurea*	300000	4.5	50	0.33	Fab	
Blanketflower *Gaillardia arstita*	199999	2.25	50	0.25		
Yellow Coneflower *Ratibida columnifera*	1230000	4.5	50	0.08	Ast	
Scarlet Globemallow *Sphaeralcea coccinea*	500000	3.25	50	0.14	Mal	
Total Forbs & Shrubs		**25**		**2.0**	Fluffy seed box	

Mix 3

Common Name *Species* "Variety"	Approx. Seeds/#	% of Mix	# PLS/ft2	PLS#/Acre	12 Acres	Comments
Side Oats Grama *Bouteloua curtipendula* "Vaughn"	191000	8	50	0.91	10.95	
Blue Grama *Bouteloua gracilis* Native	825000	9.7	50	0.26	3.07	
Buffalograss *Buchloe dactyloides* "Texoka"	56000	8	50	3.11	37.34	
Slender Wheatgrass	159000	6.6	50	0.90	10.85	

Elymus trachycaulus "San Luis"						
Junegrass *Koeleria macrantha* Native	2315400	6.6	50	0.06	0.75	
Western Wheatgrass *Pascopyrum smithii* "Arriba"	110000	3.1	50	0.61	7.37	
Western Wheatgrass *Pascopyrum smithii* Native	110000	3.1	50	0.61	7.37	
Indian Ricegrass *Oryzopsis hymenoides* "Rimrock"	141000	6.6	50	1.02	12.23	
Little Bluestem *Schizachyrium scoparium* "Camper"	260000	8	50	0.67	8.04	
Green Needlegrass *Stipa viridula* "Lodorm"	181000	6.6	50	0.79	9.53	
Total Grasses		**66.3**		**9.0**	**107.49**	Grain seed box
<u>Forbs & Shrubs</u>						
Prairie Sage *Artemisia ludoviciana*	4500000	3.3	50	0.0160	0.19	1 oz = 0.0625 Ast
Fringed Sage	4536000	3.3	50	0.0158	0.19	Ast

Artemisia frigida						
Fourwing saltbush *Atriplex canescens*	52000	3.3	50	1.38	16.59	Chn
Rabbitbrush (Rubber) *Chrysothamnus nauseosus*	400000	4	50	0.22	2.61	Ast
Purple prairie clover, Kanab *Dalea purpurea*	300000	6	50	0.44	5.23	Fab
Blanketflower *Gaillardia arstita*	199999	3	50	0.33	3.92	Ast
Yellow Coneflower *Ratibida columnifera*	1230000	6	50	0.11	1.27	Ast
Scarlet Globemallow *Sphaeralcea coccinea*	500000	4.3	50	0.19	2.25	Mal
Total Forbs & Shrubs		**33.2**		**2.7**	**32.3**	

Mix 4

Common Name *Species* "Variety"	Approx. Seeds/#	% of Mix	# PLS/ft2	PLS#/Acre
Side Oats Grama *Bouteloua curtipendula* "Vaughn"	191000	10.5	50	1.20
Blue Grama *Bouteloua gracilis*	825000	15	50	0.40

Native				
Buffalograss *Buchloe dactyloides* "Texoka"	56000	12	50	4.67
Slender Wheatgrass *Elymus trachycaulus* "San Luis"	159000	10	50	1.37
Junegrass *Koeleria macrantha* Native	2315400	10	50	0.09
Western Wheatgrass *Pascopyrum smithii* "Arriba"	110000	5.25	50	1.04
Western Wheatgrass *Pascopyrum smithii* Native	110000	5.25	50	1.04
Indian Ricegrass *Oryzopsis hymenoides* "Rimrock"	141000	10	50	1.54
Little Bluestem *Schizachyrium scoparium* "Camper"	260000	12	50	1.01
Green Needlegrass *Stipa viridula* "Lodorm"	181000	10	50	1.20
Total Grasses		**100**		**13.6**