Establishing Native Plants on Abandoned Farmland at Rabbit Mountain Open Space, Boulder County, Colorado: Year 1

Principle Investigator: Cynthia S. Brown
Assistant Professor
Bioagricultural Sciences and Pest Management
1177 Campus Delivery
Colorado State University
Fort Collins, CO 80523-1177

Email: Cynthia.S.Brown@ColoState.edu
Phone: (970) 491 - 1949
FAX: (970) 491 – 2460

With: Jim Bromberg, Hilary Drucker, Meg Hollowed, Meredith Schon and John Shannon

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. This research (1) evaluated the abundance of native species planted in different proportions and compositions during the first year after seeding, (2) examined factors associated with success and failure of native plant establishment including weedy, non-native species, and soil nitrogen (N) and carbon (C) levels, and (3) established long term research plots for future research. Resident species had much greater cover than seeded species. Slender wheatgrass and western wheatgrass were the most abundant seeded grasses, while fourwing saltbush was the most abundant broadleaved species. Generally, the representation of seeded grasses and forbs reflected the proportion seeded. Cover of seeded species was not influenced by the cover of resident species, light availability, cover of litter, or cover of bare ground. The cover of resident and seeded species were related to the location in the study area indicated by block. This work provides critical baseline information that will guide the development of alternative native plant establishment and weed control methods. Furthermore, it will provide the opportunity for future long term research that will inform BCPOS and other land managers about which methods are most effective for restoration of native prairie communities and control of undesirable non-native species.

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). In the work proposed here, 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.

In this research project, we (1) quantified the abundance of native species planted in different proportions and compositions during the first year after seeding, (2) 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, and (3) established long-term research plots for future research.

We tested the following hypotheses: (1) Abundance of seeded grasses, herbaceous forbs and shrubs will reflect their proportions in the seed mixtures. Alternatively, the abundance of seeded 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 not present, (c) low N levels when weeds are present, and (d) reduced light availability. Alternatively, success of seeded species may be unrelated to these factors or show a different relationship than we expect.

METHODS

Study Site - The experimental plots are located in the Cemex Research Site shown in Figure 1.

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 is a complete randomized block design with four seed mixture treatments (Figure 2). Seeding rates and composition were determined by BCPOS ecologist Clair DeLeo and the mixtures were seeded February 1 - 3, 2006 by BCPOS personnel using a Truax FLX816 (10.5 ft wide with 16 rows, 8 inches apart) (Truax, Inc., New Hope, Minnesota). 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 are four blocks of 18 monoculture plots in addition to the mixture treatment plots. The monoculture plots are 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*) (two cultivars), Indian ricegrass (*Oryzopsis hymenoides*), little bluestem (*Schizachyrium scoparium*), and green needlegrass (*Stipa viridula*). The shrub species included in the mixes were prairie sage (*Artemisia lucoviciana*), 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 scarlet globemallow (*Sphaeralcea coccinea*). 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. Mix 2 included 75% grasses and 25% forbs and shrubs. Mix 3 included 66% grasses and 33% forbs and shrubs. Mix 4 included only grasses. The species compositions and seeding densities of seed mixtures are detailed in Appendix 2.

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 areas were located equidistant from each other and the two end sampling plots. This plot placement ensures that we sample 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).

Four 0.5 m^2 sampling subplots were located within each sampling plot, one at each corner of the plot (Figure 3). One corner of each subplot corresponded with the corner of the sampling plot, thus, were marked with rebar. These subplot locations will be 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 monocultures. Mammal scat, burrowing mammal activity and grazing were noted within sampling plots and subplots.

Soil N and C - 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 were pooled. Total soil C and N will be determined for each sample using the LECO CHN1000 (LECO Corporation, St. Joseph, MI, USA) by December, 2006 in the Natural Resources Ecology Laboratory facility at Colorado State University (CSU).

Light interception – The reduction of light availability at the soil surface by plant canopy was measured using a light ceptometer (AccuPar LP-80, Decagon Devices, Inc., Pullman, WA, USA) July 13 and 17, 2006. 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 plot level light interception.

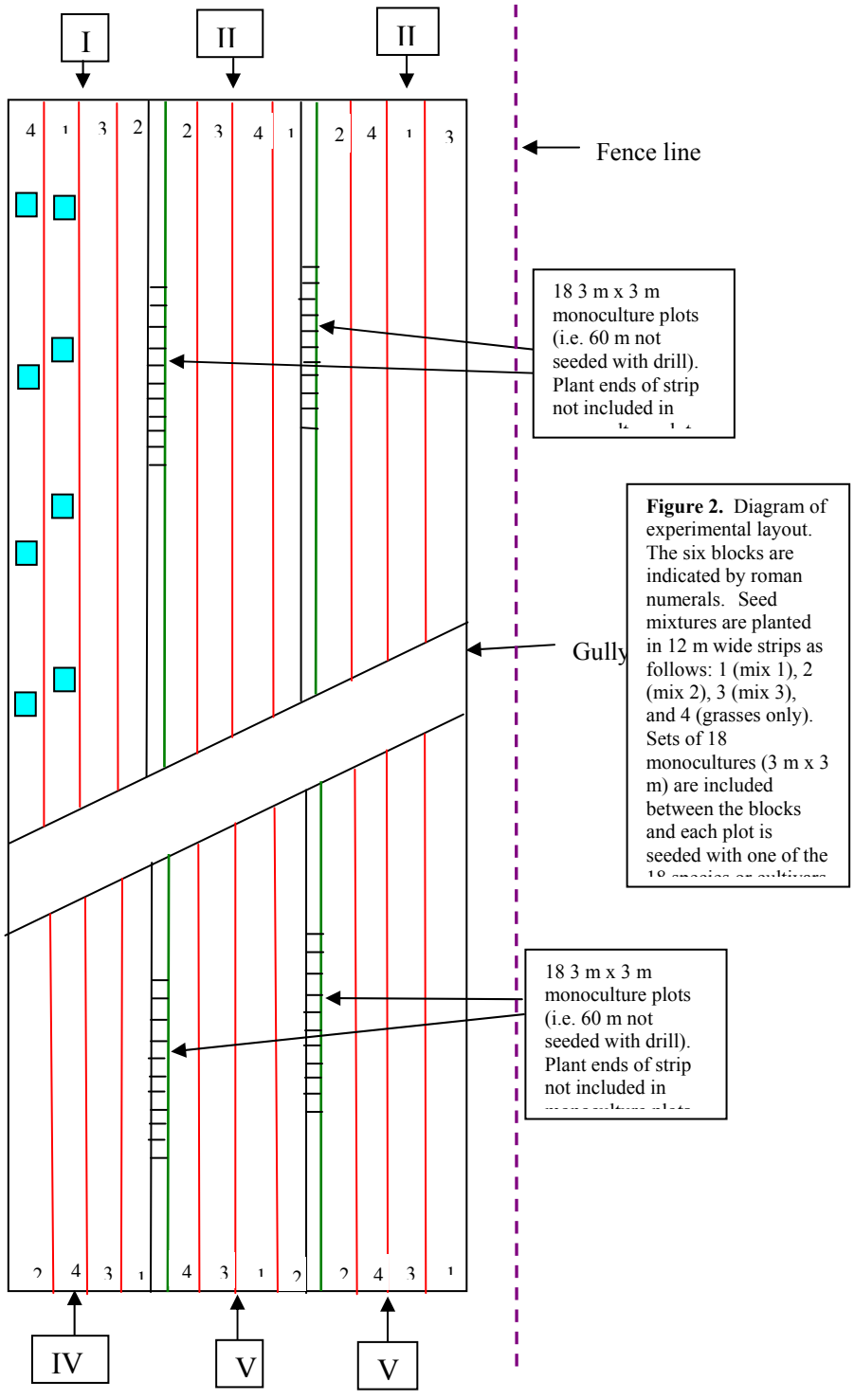

Figure 2. Diagram of experimental layout. The six blocks are indicated by roman numerals. Seed mixtures are planted in 12 m wide strips as follows: 1 (mix 1), 2 (mix 2), 3 (mix 3), and 4 (grasses only). Sets of 18 monocultures (3 m x 3 m) are included between the blocks and each plot is seeded with one of the

Figure 2. Experimental design and layout.

Statistical Analysis - Abundances of seeded and non-seeded plants, and percent carbon (C) and nitrogen (N) were analyzed using analysis of variance models (SAS version 9.1 and JMP version 5.0.5.1, SAS Institute, Inc., Cary, NC) that included block, seed mixture and their interaction. Results of analyses on raw data were similar to those of log transformed data, thus, results from the former are reported. Simple linear regression was used to evaluate the performance of seeded species with respect to abundance of species that were not seeded (resident species), cover of litter (log transformed) and bare ground, light interception (log transformed), and soil C and N. Student's t least significant differences or Tukey's least significant differences were employed for mean separations. Statistical significance was set at $\alpha = 0.05$.

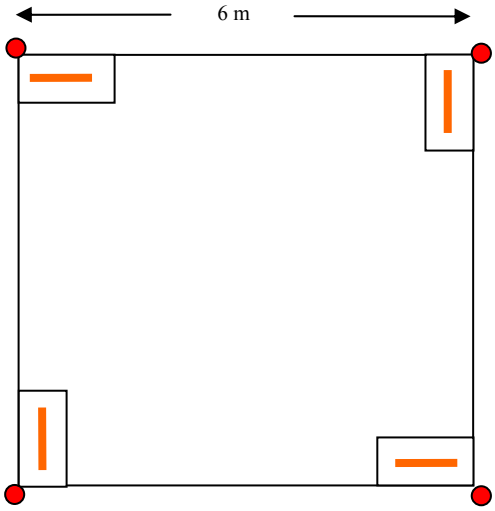

Figure 3. Sampling area layout. 0.5 m^2 subplots (0.5 x 1.0 m) were placed at the corners of the 6 m x 6 m plots. Soil samples were taken at the locations indicated by the red circles for total N and C measurements. Light interception was measured in the center of each 0.5 m^2 subplot, as indicated by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

RESULTS

Seeded Species

Species encountered during sampling and abbreviations for their names used throughout the following figures are listed in Table 1. The cover of seeded species (Figure 4) was highly correlated with density of seeded species (Figure 5) ($P < 0.0001$, $R^2 = 0.81$), thus, only analyses of cover are presented. Cover of seeded species was much lower than resident species (Figure 6), and there was no correlation between the abundance of seeded and resident species ($P = 0.59$,

$R^2 = 0.003$). There was a tendency for cover of seeded species to decrease with increasing litter (Figure 6), but this was not statistically significant ($P = 0.08$, $R^2 = 0.03$). There was no relationship between cover of seeded species and bare ground (Figure 6) ($P = 0.1$, $R^2 = 0.03$).

Table 1. Species names and abbreviations. Resident 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
Scarlet globemallow		*Sphaeralcea coccinea*	SPHCOC
Green needlegrass	"Lodorm"	*Stipa viridula*	STIVIR
Resident Species			
prostrate pigweed		*Amaranthus blitoides*	AMABLI
redroot pigweed		*Amarathus retroflexus*	AMARET
prickly poppy		***Argemone polyanthemos***	**ARGPOL**
wild oat		*Avena fatua*	AVAFAT
field brome		*Bromus arvensis*	BROARV
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
poison hemlock		*Conium maculatum*	CONMAC
hare's ear mustard		*Conringia orientalis*	CONORI

field bindweed	*Convolvulus arvensis*	CONARV
hounds tongue	*Cynoglossum officinale*	CYNOFF
flixweed	*Descurainia sophia*	DEXSOP
toothed spurge	*Euphorbia dentata*	POIDEN
snow-on-the-mountain	***Euphorbia marginata***	**EUPMAR**
beeblossom	***Gaura L.***	**GAU**
annual sunflower	***Helianthus annuus***	**HELANN**
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
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
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
common mullein	*Verbascum thapsus*	VERTHA
prostrate vervain	***Verbena bracheata***	**VERBRA**
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.

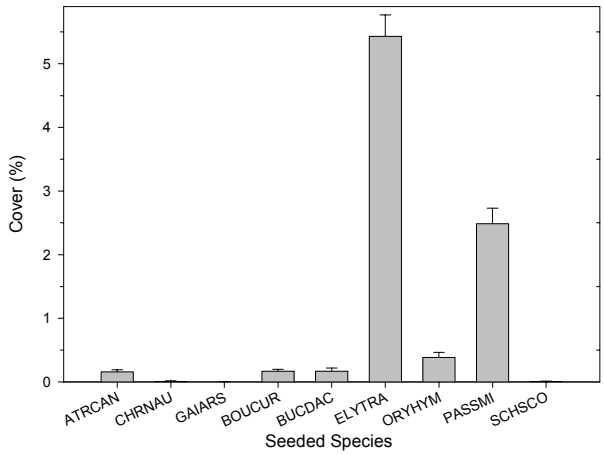

Figure 4. Mean cover of seeded species ± one standard error of the mean.

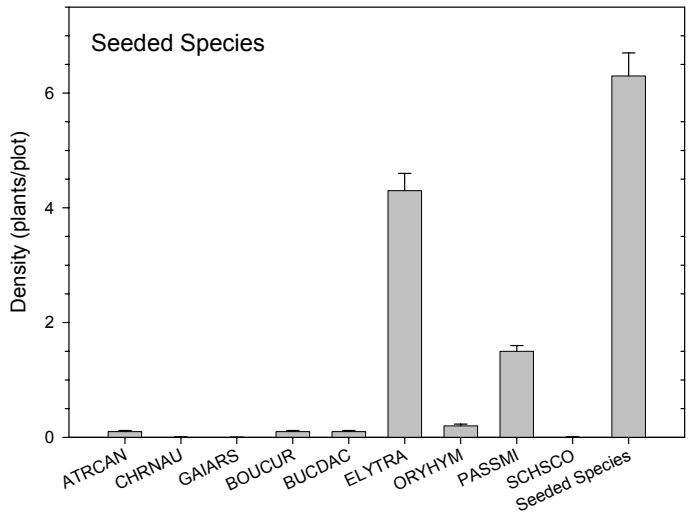

Figure 5. Mean density of seeded species ± one standard error of the mean.

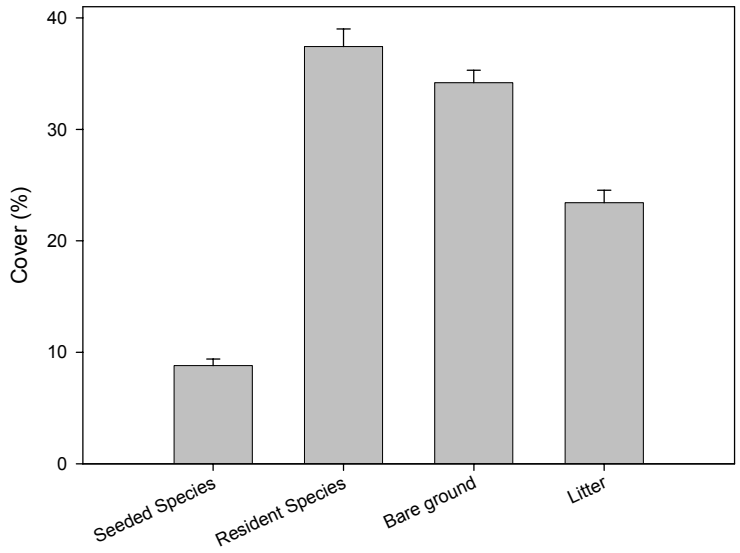

Figure 6. Mean cover of seeded species, resident species, litter and bare ground. (bars are mean ± one standard error of the mean).

Taken together, the cover of seeded species in each of the seeding mixture treatments depended on location in the field (significant Block x Seed mixture interaction, Table 2; Figure 6a). Seeded species in Mix 1 (50% grass) had higher cover than other seed mixtures in Block V, but had much lower cover than other mixtures in Blocks I, II, III and VI.

Table 2. ANOVA table for seeded species.

Factor	df	Seeded species		BOUCUR		BUCDAC		ELYTRA		ORYHYM		PASSMI	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	5.9	0.0001	4.4	0.001	3.2	0.01	2.85	0.02	1.37	0.24	5.63	0.0002
Seed Mixture	3	19.5	<0.0001	0.37	0.78	4.15	0.009	17.42	<0.0001	0.88	0.46	12.98	<0.0001
Block x Seed Mixture	15	4.4	<0.0001	1.60	0.10	1.76	0.06	3.41	0.0002	0.86	0.60	2.34	0.009

Six of the ten grass species planted were observed at least once in the plots and they comprised the majority of the seeded species cover (Figure 4). Cover of the most successful seeded grasses (slender wheatgrass and western wheatgrass) in each of the seed mixture treatments depended on location, although slender wheatgrass only marginally so (Table 2, Figure 7). In Mix 2 (75% grass) and Mix 4 (100% grass) they had lower cover when located in Blocks IV and V than when located in Blocks II and III. These species had very low cover in Mix 1 when located in Blocks I and II, which can be attributed to mechanical malfunction of the seeder that resulted lower seeding rates in Blocks I, II, 10 feet of Block III, and the seeded areas at the end of the monoculture strips between Blocks I and II, and II and III, but their cover in this mixture was similar in Blocks III, IV, V and VI. Cover of buffalo grass and sideoats grama were affected by location (Table 2, Figure 8a). Buffalo grass had greater cover in Block VI than other blocks. Sideoats grama had greater cover in Block II than other blocks. Cover of sideoats grama in Mix 4 (100% grass) was similar to Mix 3 (66% grass) and greater than Mixes 1 (50% grass) and 2 (75% grass) (Table 2, Figure 9). Indian ricegrass occurred in 40 plots but no relationship between location (i.e. Block) and seed mixture treatment could be detected (Table

2). Little bluestem was observed in only three plots, thus effects of location and seed mixture treatments are not biologically meaningful.

Two of the four shrub species and one of the four forb species were observed (Figure 4). Fourwing saltbush was present in 28 plots, while rubber rabbitbrush and blanketflower were present in only one plot each. No meaningful statistical analyses could be conducted on the latter two species. Cover of fourwing saltbush was greater in Blocks II and III than the other blocks. It did not occur in Mix 4 (100% grass), thus, its cover was greater in the three seed mixtures in which it was included.

Resident Species

Twenty nine resident species were found in the sampling plots (Table 1, Figure 10). Twelve of these species were native, but occurred in such small amounts that we were not able to statistically analyze their abundances. Four resident species had average cover greater than one percent and analyses will focus on them (Figure 10a). Kochia (Figure 10b) is not included in this group, although it dominated the vegetation in parts of the field. It was detected in 13 of the 96 plots and had average cover of nearly 25% in one plot and 13% in another, but the remainder had cover of no more than 2.25%, with the majority less than 1%. Cover of resident species differed among locations (Blocks), but not among seed mixture treatments (Table 3, Figure 8b). Block III had greater resident species cover than any other block. Resident cover in Block IV was lower than Block I and V, but not different from Blocks II and VI.

Table 3. ANOVA table for most abundant resident species.

Factor	df	CHESP1		CONARV		SALIBE		SOLTRI	
		F	*P*	F	*P*	F	*P*	F	*P*
Block	5	14.76	<0.0001	24.11	<0.0001	10.99	<0.0001	5.76	0.0002
Seed Mixture	3	1.34	0.27	2.37	0.08	1.41	0.25	1.43	0.24
Block x Seed Mixture	15	2.04	0.02	1.08	.039	0.39	0.98	0.91	0.56

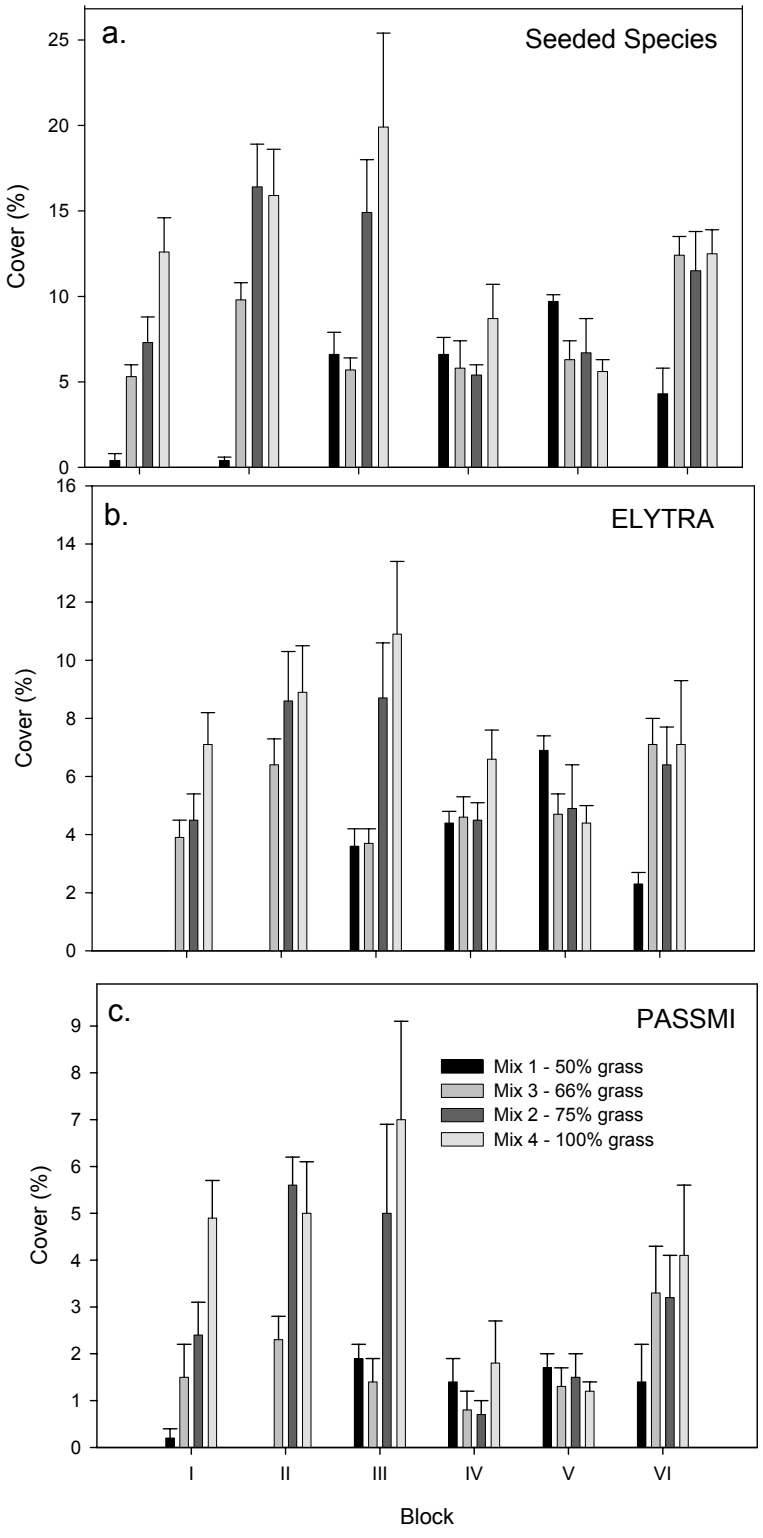

Figure 7. Cover of seeded species with significant Block x Seed mixture interaction in ANOVA.

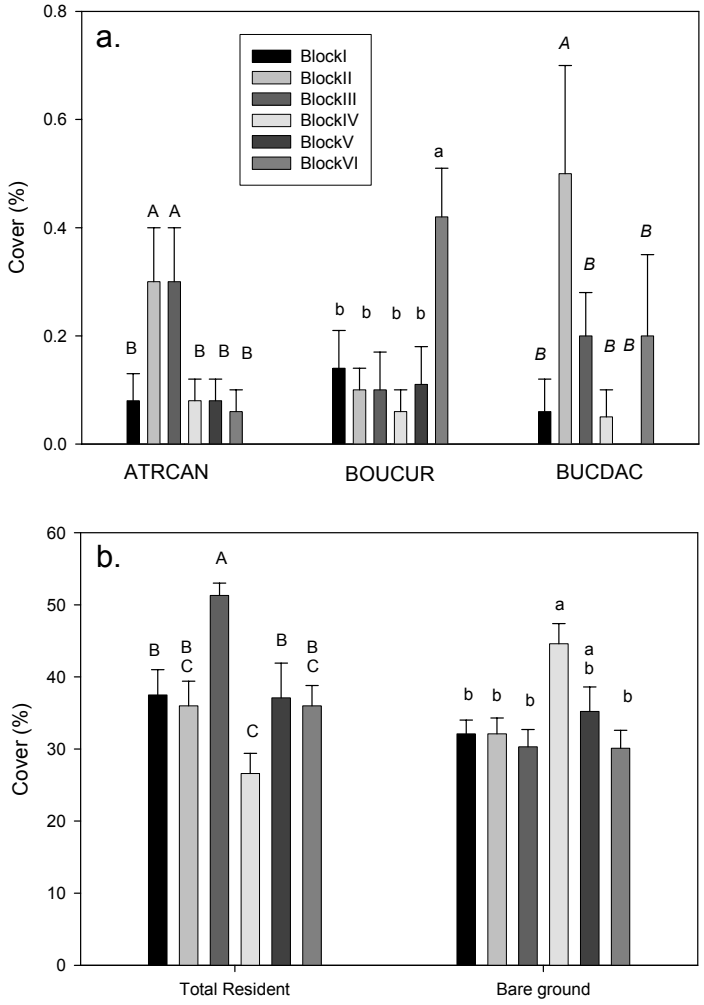

Figure 8. Cover of (a) seeded species and (b) resident species and abiotic factors with significant Block effects in ANOVA. Means with different letters are significantly different at $\alpha = 0.05$.

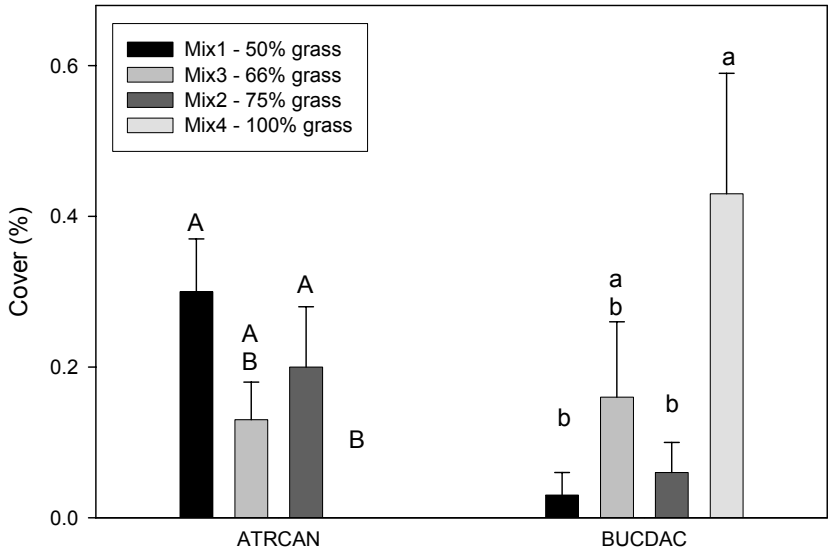

Figure 9. Cover of seeded species with significant Seeding mixture effects in ANOVA. Means with different letters are significantly different at $\alpha = 0.05$.

The cover of *Chenopodium* sp. in different seed mixture treatments depended on location (i.e. Block) (Table 3, Figure 11). The cover of this species in Block III was greater than in any other block and it was concentrated on the east side of the block. Cover of field bindweed was greater in Block I and III than any other blocks and greater in Block II than Blocks IV, V and VI (Table 3, Figure 12). The cover of Russian thistle was greater in Blocks V and VI than any other blocks and was similar in Blocks II and IV. Blocks I and III had Russian thistle cover similar to Block II, but less than Block IV (Table 3, Figure 12). Cover of cut-leaved nightshade increased progressively from Block I to Block VI (Table 3, Figure 12).

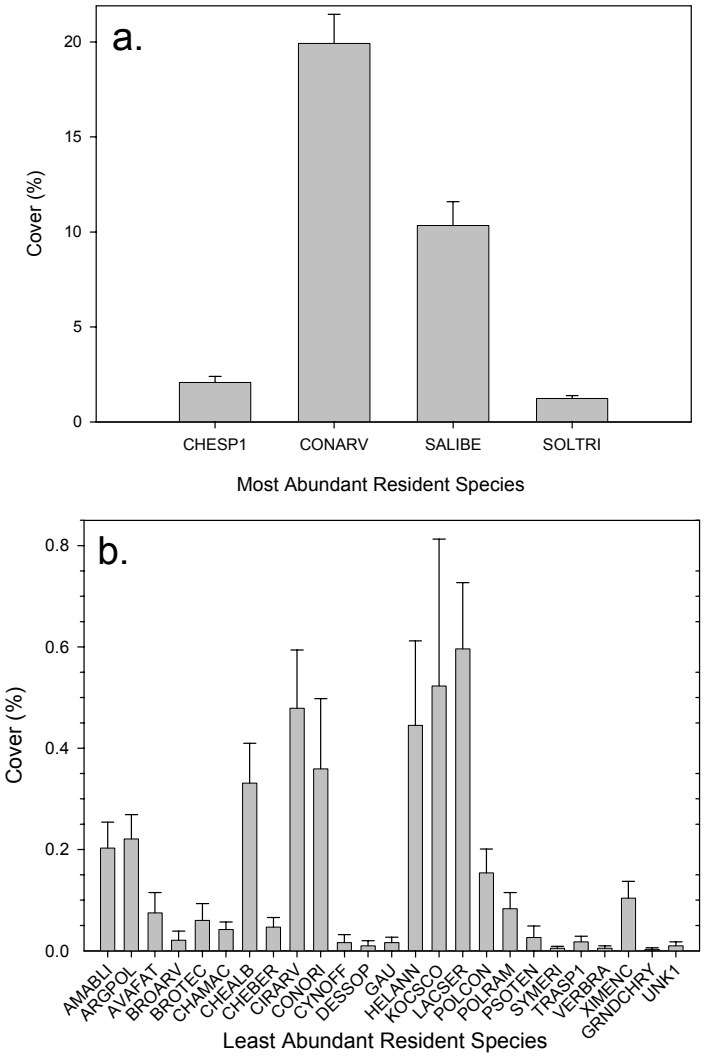

Figure 10. Mean cover of (a) most abundant and (b) least abundant resident species ± one standard error of the mean.

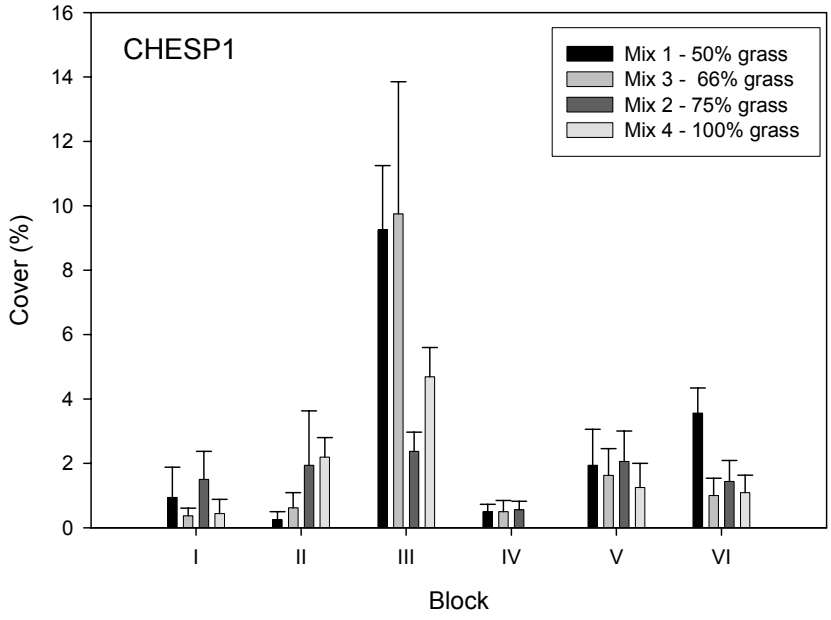

Figure 11. Cover of *Chenopodium* sp. by block and seed mixture (bars are mean ± one standard error of the mean). Means with different letters are significantly different at $\alpha = 0.05$.

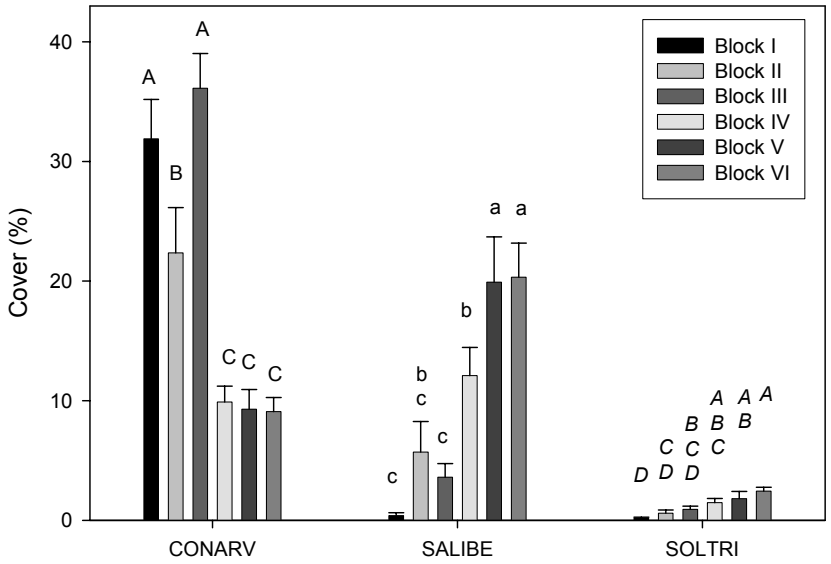

Figure 12. Cover of abundant resident species by block. Bars are mean ± one standard error of the mean. Means with different letters are significantly different at $\alpha = 0.05$.

Abiotic factors

We detected no effects of location (i.e. Block) and seed mixture treatment on cover of litter and light interception by the plant canopy (Table 4). Bare ground in Block IV was similar to Block V, but higher than Blocks I, II, III, and VI (Table 4, Figure 8b).

We detected no differences in percent nitrogen (N) among blocks or seed mixes (Table 5). Percent carbon (C) differed among blocks (Table 4, Figure 13).

Table 4. ANOVA for abiotic factors.

Factor	df	Light Interception		Litter		Bare ground		Soil % C		Soil % N	
		F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Block	5	1.0	0.4	2.2	0.1	4.4	0.002	45.10	<0.0001	1.27	0.29
Seed Mixture	3	2.0	0.1	2.0	0.13	0.2	0.9	0.69	0.56	1.12	0.35
Block x Seed Mixture	15	0.7	0.7	1.4	0.2	0.6	0.8	0.22	1.0	0.45	0.97

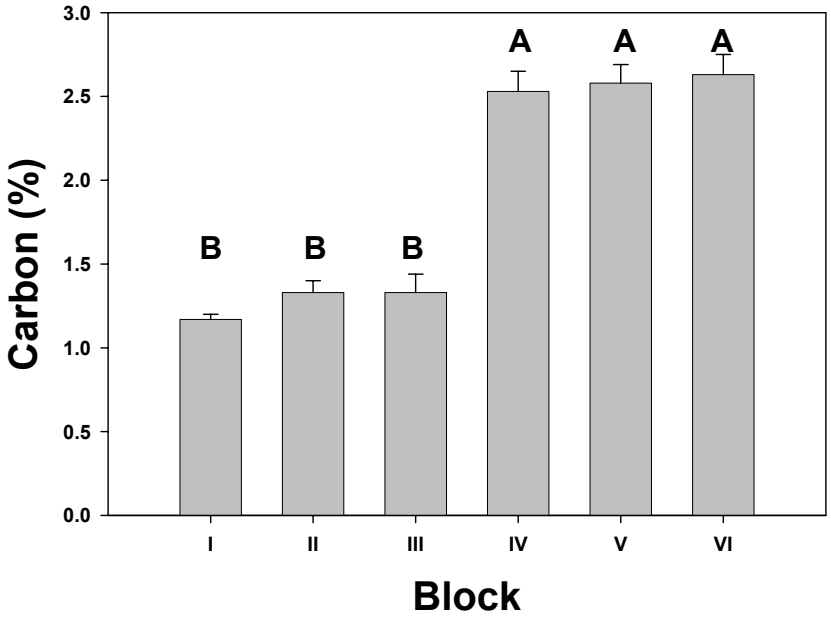

Figure 13. Soil percent carbon in experimental blocks. Means with different letters are significantly different at $\alpha = 0.05$.

Percent C was correlated with cover of resident species, but percent N was not and neither percent C nor percent N were correlated with cover of seeded species (Table 5, Figure 14).

Table 5. Statistics for simple linear regression of seeded and resident species cover on percent C and N.

Factor	Soil % Carbon			Soil % Nitrogen		
	Coefficient	*P*	R^2	Coefficient	*P*	R^2
Seeded species cover	-0.60	0.45	0.01	-99.90	0.07	0.03
Resident species cover	-5.4	0.01	0.07	-27.13	0.86	0.0003

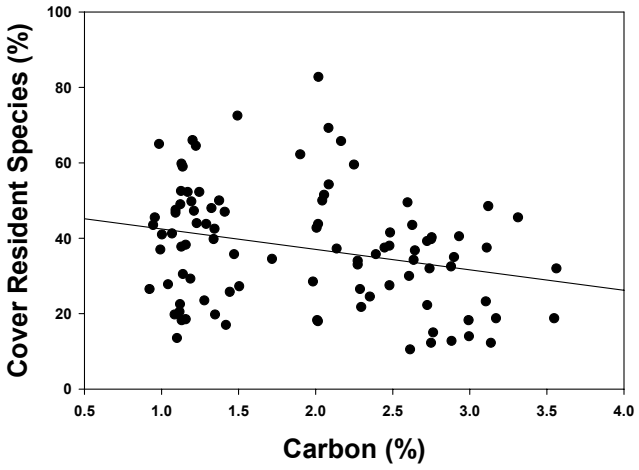

Figure 14. Simple linear regression of resident species cover on soil percent C.

Animal activity

No burrowing mammal activity was observed in sampling plots or subplots. Elk scat was observed in two sampling plots and rabbit scat in a single plot. Grazing was noted on wild oat in one plot and western wheatgrass in another.

DISCUSSION OF RESULTS

Performance of seeded species was not only related to their seeding density, but was greatly affected by where in the field they were planted. Which blocks resulted in greatest abundance of seeded species depended on the species. Overall, performance of seeded species was best in Blocks II and III, on the north half of the field and farther away from the bottom of the drainage. Resident species were also generally more abundant in this area. Soil N on this part of the field was not greater than the south half of the field and soil C was lower, thus, fertility does not appear to explain the observed differences.

We tested the hypothesis that abundance of seeded grasses, herbaceous forbs and shrubs would reflect their proportions in the seed mixtures, which our results generally supported. 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). Thus, it will be interesting to see whether the differences we observed this year will persist.

We hypothesized that success of seeded species would be positively associated with low weed abundance. Thus far, there is no indication that resident vegetation reduced the performance of seeded species. This may change over time and keeping non-native resident species in check will be an important part of the long term success of this prairie restoration project.

We detected no relationship between the abiotic factors measured and establishment of seeded species. Light availability was not related to seeded species performance in this first year of growth, but may become an important factor as seeded and resident species grow over time.

Although soil C levels were greater in blocks IV, V and VI, we detected no relationship between it and establishment of seeded species.

Interestingly, cover of resident species was negatively associated with soil C, which is counter-intuitive because C levels are usually associated with greater fertility. However, higher C levels may indicate lower N availability at our study site. We did not measure available N, but rather measured total N, which includes forms of N that are available to plants and those that are not. Thus, resident species may have had lower cover in areas with higher C levels due to lower N availability, which will require further investigation to determine. Finally, the differences among blocks in soil C may be a legacy effect of the cultivation history of the site and we will explore this possibility.

Management implications

Increasing proportional representation of species in seed mixtures can lead to greater establishment in the first year after seeding. Location in the field influenced success of seeded species and learning more about the features and history of the different areas will assist in making the best species selections. It appears that seeding diverse mixtures of species can maximize the likelihood that species adapted to the different microenvironments on a site will be present. This may lead to establishment of different species in different microsites, and good establishment overall.

The methods of seed bed preparation and seeding were quite effective under the climatic conditions of 2005- 06. It is still very early in the development of the seeded species to reach any final conclusions. Continued monitoring will be important in order to assess the long-term success of this restoration project.

We suggest testing multiple control methods for managing non-native species while the seeded species are becoming established including, but not limited to: (1) application of broadleaf specific herbicides to grass only plots, (2) testing the efficacy of carbohydrate starvation for Canada thistle and field bindweed management, (3) selective mowing to reduce kochia competition and seed production, and (4) release of biological control agents for the control of field bindweed. We also encourage BCPOS to utilize the CEMEX Study Site to its greatest benefit by continuing to facilitate long term research on native and non-native species and their interactions with each other and the environment.

CONCLUSION

The establishment of seeded species was quite good in the first year after seeding. Many of the species that were not apparent initially may become established in later years. This is especially likely for forb and shrub species, which are known to have long-lived seed and high levels of dormancy. For the future, the project will provide the opportunity for long term research testing establishment and management methods including, but not limited to: (1) staged revegetation and restoration approaches by introducing forbs after native grass establishment, enabling the use of broadleaf-specific herbicides until then (Brown and Bugg 2001), (2) comparison of efficacy of seeding vs. transplanting shrubs in sequential introduction, (3) testing methods of weed control and resource manipulation to facilitate the establishment of a diverse native plant community, and (4) studying ability of native plants to compete with weedy species and the impact that weedy species have on native species (Dukes 2001).

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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**	

Forbs & Shrubs

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 nauseosus*	400000	3	50	0.16	Ast
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 *Elymus trachycaulus* "San Luis"	159000	6.6	50	0.90	10.85	
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*	260000	8	50	0.67	8.04	

"Camper"						
Green Needlegrass *Stipa viridula* "Lodorm"	181000	6.6	50	0.79	9.53	
Total Grasses		**66.3**		**9.0**	**107.49**	Grain seed box
Forbs & Shrubs						
Prairie Sage *Artemisia ludoviciana*	4500000	3.3	50	0.0160	0.19	1 oz = 0.0625 Ast
Fringed Sage *Artemisia frigida*	4536000	3.3	50	0.0158	0.19	Ast
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	825000	15	50	0.40

Bouteloua gracilis 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**