Influence of Crusting Soil Surfaces on Emergence and Establishment of Crested Wheatgrass, Squirreltail, Thurber Needlegrass, and Fourwing Saltbush

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Abstract

Crusting soil surfaces with vesicular pores occur in arid and semiarid regions of the world where herbaceous vegetation is sparse. Morphological properties of crusting surfaces can impair seedling emergence and plant establishment. This study evaluated site preparation and seeding methods and species useful for encouraging successful stand establishment in such soils. Plowing to prepare a seedbed reduced seedling emergence on some soils but increased plant establishment on all soils. More seedlings emerged and established on non-crusting coppice soil beneath shrubs than on crusting interspace soil between shrubs. Crested wheatgrass was the most successful species followed closely by squirreltail and distantly by Thurber needlegrass and fourwing saltbush. Fourwing saltbush seedlings became established and grew well in some treatments. Seedling emergence and establishment were highest with the deep-furrow seeding technique on the non-crusting coppice soil. The standard-drill technique gave the best stand on the site with the largest surface cover of bare, crusting interspace soil.

Soils with crusting surfaces occur in many arid and semiarid regions of the world. Various features of these soils in the western United States were described by Hugie and Passey (1964) and Schlatterer (1968). In the Great Basin these soils commonly are associated with northern-desert shrub and salt-desert shrub plant communities that have sparse herbaceous vegetation. In northern Nevada, such soils are found in the Humboldt Loess Belt, an 8-million-ha area of shallow, windblown silt and very fine sand deposition. These soils are on gently sloping fan piedmonts and nearly level alluvial flats. They include both typic and xerollic Durargids, Haplargids, Nadurargids, and Natrargids and have moderately fine and fine textured B2t horizons. These soils generally are crusted between shrubs (interspace soil) and are non-crusted beneath the shrubs (coppice soil) (Stuart et al. 1971, Blackburn 1975). The microtopographic positions, surface physiognomy, and morphological characteristics of the A horizon were presented by Eckert et al. in 1978. These surficial features are not mapped or measured even in detailed soil surveys, but must be determined on a site by site basis. The crusting interspace surfaces commonly are sandy loam, loam, or silt texture high in very fine sand or silt, with low organic matter content, are massive, and have vesicular pores. These factors contribute to the unfavorable behavior of this surface: unstable and slakes when saturated, dries to a crust that can reduce seedling emergence (Wood et al. 1978), and has a low water infiltration rate and high sediment production (Blackburn 1975).

Wood et al. (1978) stated that rangelands with these kinds of soils have higher potential productivity than their present fair to poor condition suggests. These authors postulated that the areas of crusting interspace soil increase with overgrazing, loss of herbaceous cover, and lowered range condition at the expense of non-crusting coppice surface soil. They also stated that revegetation of these problem soils through grazing management alone would be difficult, if not impossible, in a reasonable time and that artificial seeding methods are required to establish forage species. Therefore, we evaluated seedling emergence and plant establishment of various species seeded by different techniques on soils with crusting and non-crusting surfaces.

Methods

Four study sites in the big sagebrush vegetation type in north central Nevada were selected to represent a wide range of soils with a crusting A11 horizon (Table 1). Plots at Lower Coils Creek and Paradise Valley were seeded in the falls of 1974, 1975, 1976, and 1977. The Upper Coils Creek and Panther Canyon sites were seeded in all years except 1977.

Forty 6-m² plots were established within a 0.5-ha exclosure at each site. The first year (1974) 20 plots were plowed with a moldboard plow to remove competition and prepare a seedbed. Plowing mixed only about 10 to 15 cm of the A horizon. Brush was cleared manually with minimal soil disturbance on the remaining 20 plots. Because the plowed soil crusted and emergence was drastically lower than that in the unplowed soil for all seeding methods, the plowing treatment was discontinued after 1974. Four species, crested wheatgrass *(Agropyron desertorum)*, squirreltail *(Sitanion hystrix)*, Thurber needlegrass *(Stipa thurberiana)*, and fourwing saltbush *(Atriplex canescens)* were seeded in mid-October of each year. Total precipitation was measured at each study site for the period between planting and seedling evaluation in mid-May. Surface soil samples (A11 horizon) were collected at each seeding site and analyzed for particle size (Bouyoucos 1962), organic matter by a modified Walkley-Black method (Peech et al. 1947), and modulus of rupture (Reeve 1965).

The kind of soil surface on each seeded row was described as either coppice or interspace before planting. Two kinds of simulated furrows were used. Both were made with a hoe. A standard-rangeland drill technique was used to seed the plowed treatment in 1974 and the unplowed treatments in all years. These furrows were 2 cm deep by 6 m long. A deep-furrow rangeland drill technique (McGinnies 1959) was also used in each year. These furrows were 12.5 cm deep by 6 m long. Seed was planted in four furrows of each

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This study was a cooperative investigation among U.S. Dep. Agr., Agr. Res. Serv., Bureau of Land Management, and Agr. Exp. Sta., Univ. of Nevada, Reno. Journal Series No. 483.

Plant nomenclature follows Plummer et al. (1977).

Manuscript received August 20, 1981.

Table 1. Description of study sites.

Site	Location	Precipitation (mid October-mid May) (cm)	Soil identification	Cover of morphological surface soil (%)	Shrub foliar cover; grass and forb basal cover types (%)
Lower Coils Creek	60 km northwest of Eureka in Eureka County	Long term average-18 mostly as snow.[1] 1974-75—18 1975-76—12 1976-77—11 1977-78—20	Fine, montmorillonitic, mesic, Abruptic Xerollic Durargids	Coppice-58 Interspace-42	Big sagebrush *(Artemisia tridentata)* 22.2 Low sagebrush *(Artemisia arbuscuie)* 1.4 Sandberg bluegrass *(Poa sandbergii)* 1.1 Squirreltail *(Sitanion hystrix)* 0.02
Upper Coils Creek	60 km northwest of Eureka in Eureka County	Long term average-18 mostly as snow. 1974-75—22 1975-76—14 1976-77—11	Fine, montmorillonitic, mesic, Xerollic Durargids	Coppice—50 Interspace—50	Big sagebrush 22.0 Low sagebrush 1.7 Yellowbrush *(Chrysothamnus vicidiflorus)* 0.2 Thurber needlegrass *(Stipa thurberiana)* 1.6 Sandberg bluegrass 1.6 Squirreltail 0.7
Panther Canyon	48 km south of Winnemucca, in Pershing County	Long term average-17 mostly as snow. 1974-75—24 1975-76—16 1976-77—12	Fine, montmorillonitic mesic, Xerollic Haplargids	Coppice—100 Interspace—0	Big sagebrush 19.3 Spiny hopsage *(Grayia spinosa)* 1.1 Sandberg bluegrass 6.7 Great Basin wildrye *(Elymus cinereus)* 0.7 Cheatgrass *(Bromus tectorum)* 4.4
Paradise Valley	65 km north of Winnemucca, in Humboldt County	Long term average-17, mostly as snow. 1974-75—17 1975-76—10 1977-78—25	Fine, loamy, mixed, mesic, Abruptic Xerollic Duragids	Coppice—35 Interspace—65	Big sagebrush 16.5 Gray horsebrush *(Tetramia canescens)* 0.2 Crested wheatgrass *(Agropyron desertorum)* 0.7 Squirreltail 0.5 Sandberg bluegrass 0.3 Cheatgrass 1.3 Tumble mustard *(Sisymbriam altissimum)* 0.5

[1]Long term averages were taken from the closest weather station with at least 30 years of records.

type at a rate of one seed per 1.3 cm of row and covered with 1.5 cm of soil. Seed was also broadcast and covered by simulated cow trampling. Within each 6-m^2 plot, nine randomly located hoofprint-sized microplots (11 cm^2) were used for each species. Five seeds were placed in each microplot. The planter simulated a hoofprint by placing his boot heel on the seeds and rotating the boot horizontally 90°. The object of this treatment was to disturb the surface soil but not to compact the soil. Seed was also broadcast with no simulated cow trampling on nine 30 cm^2 microplots of each species within each 6-m^2 plot. Twenty grass seeds or ten fourwing saltbush seeds were placed in each untrampled microplot. Each simulated seeding technique was replicated five times.

Seedlings that emerged from coppice or interspace soil were counted in mid-May of each year. The number of grass seedlings was converted to percent emergence based on the number of seeds planted in rows or in the broadcast microplots. Since emergence of fourwing saltbush was very low, the stand was evaluated by distance between established plants rather than by percent emergence. In the fall of 1976, the frequency of established grass and shrub plants per 30 cm of row or for each microplot in the broadcast treatment was determined for all variables tested in 1974 and 1975. Frequency was not determined for the 1976 study, because the seeding failed, or for the 1977 study. A frequency of 100% indicates at least one established plant per 30 cm of seeded row or one plant for each microplot in broadcast treatments. A frequency of 50% indicates at least one established plant per 60 cm of row or one plant on at least half the microplots. Data were analyzed by an analysis of variance. Differences among means were evaluated with Duncan's multiple range test ($P<0.05$).

Seedling Emergence

Precipitation

Precipitation from October, 1974, through May, 1975, was average to above average at all locations (Table 1) with below average rainfall in June and July. Precipitation from October, 1975, through May, 1976, was below the long-term average; however, summer rainfall was much above average (particularly at Paradise Valley) and ranged from 9 to 14 cm. Precipitation during 1976-77 was much below average, resulted in a regional drought, and all seedings failed. This drought ended in 1977-78 with above average winter-spring precipitation and little summer rain. Overall seedling emergence followed the precipitation trend with higher emergence in 1974-75 (15.9%) and 1977-78 (14.3%) than in 1975-76 (7.0%). Soil moisture is the major limiting factor for seed germination and seedling emergence and establishment on semiarid rangelands in the Great Basin. Also, the risk of seeding failure increases particularly on problem surface soils because of the influence of hard surface crusts as indicated by modulus of rupture measurements (Table 2) and low infiltration rates (Blackburn 1975).

Site

In 1975, seedling emergence was greater at Paradise Valley and Upper Coils Creek than at the other two locations (Table 3). Emergence at all locations was higher in 1975 than in 1976, and at Paradise Valley and Lower Coils Creek emergence was highest in 1975 and 1978, respectively.

Table 2. Mean particle size distribution (%), organic matter content (%), and modulus of rupture (mbars) of AII horizon at each site.

Surface soil	Study site	Particle size: Sand	Silt	Clay	Organic matter	Modulus of rupture
Interspace	Lower Coils Creek	44	36	20	1.6	76
	Upper Coils Creek	29	49	22	2.1	61
	Panther Canyon	47	37	16	1.3	56
	Paradise Valley	42	46	12	0.6	84
Coppice	Lower Coils Creek	55	33	12	3.6	18
	Upper Coils Creek	36	48	16	5.8	0
	Panther Canyon	46	38	16	4.0	5
	Paradise Valley	42	44	14	3.5	0

Seedbed Preparation and Seeding Method

Plowing did not increase seedling emergence at any site and significantly reduced emergence from 17.9 to 13.7% at Upper Coils Creeks and from 12.3 to 5.7% at Paradise Valley, respectively. After plowing, coppice and interspace soils were not distinguishable since the plowed surface slaked into a crust over the entire treated area.

Seedling emergence in standard and deep furrows in 1975 was similar on three sites (Table 3). At Upper Coils Creek emergence was higher in deep than in standard furrows. This site has the greatest cover of perennial grasses (Table 1). Deep furrowing probably enhanced emergence by removing competing vegetation from the seeded row, while the standard-drill treatment placed seed directly into the competing vegetation. In the dry year of 1976-77, overall seedling emergence was greater in deep than in standard furrows. The difference between seeding methods was significant only at Upper Coils Creek but the trend at the other locations indicated a favorable response to deep furrows. Evans et al. (1970) showed that deep furrows improve the microclimate for seed germination. In the wet year of 1977-78 differences between seeding methods were not significant.

Generally, more seedlings emerged in the standard and deep furrow seeding treatments than in the broadcast treatments (data not shown). Emergence in spring of 1975 on the broadcast treatment with simulated trampling, however, was as successful, or more successful, at Upper Coils Creek (16.7%) and Panther Canyon (16.5%) than were the furrowed treatments, but many seedlings died by early summer. The broadcast treatment with simulated trampling was not effective in 1975 at Lower Coils Creek or Paradise Valley (<4%) because of the strong surface crust, or in 1976 or 1978 at any location. Emergence on the broadcast treatment without simulated trampling was very poor (<3%) in all years at all locations, and seedlings that did emerge died by early summer.

Table 3. Mean yearly emergence (%) for two seeding methods at four locations averaged over three grass species. Seeding failed in the drought year of 1976-77.

Year of emergence and location	Seeding method: Standard furrow	Deep furrow	Location mean
1975 (Average ppt. year)			
Lower Coils Creek	11.4 ayz[1]	13.6 ayz	12.5 y
Paradise Valley	23.5 ax	17.6 ay	20.6 x
Upper Coils Creek	15.3 by	22.1 ax	18.7 x
Panther Canyon	9.5 az	10.1 az	9.8 y
Seeding method mean	14.9 a	15.9 a	
1976 (Low ppt. year)			
Lower Coils Creek	3.6 ax	6.4 ax	5.0 x
Paradise Valley	1.3 ax	5.8 ax	3.6 x
Upper Coils Creek	4.5 bx	9.7 ax	7.1 x
Panther Canyon	2.0 ax	6.0 ax	4.0 x
Seeding method mean	2.8 b	7.0 a	
1978 (High ppt. year)			
Lower Coils Creek	18.6 ax	16.7 ax	17.6 x
Paradise Valley	9.6 ay	11.9 ay	10.8 y
Seeding method mean	14.1 a	14.3 a	

[1] Emergence means between seeding methods within year and location followed by the same letter (a or b) or means among locations within year and seeding method followed the same letter (x, y, or z) are not significantly different at the 0.05 probability level as determined by Dunan's multiple range test.

Species

Emergence was similar each year for crested wheatgrass and squirreltail seedlings and the average emergence of both species was significantly greater than emergence of Thurber needlegrass (Table 4). More seedlings of crested wheatgrass, squirreltail, and Thurber needlegrass emerged in the moist years of 1974-75 and 1977-78 than in the dry year of 1975-76.

Emergence of fourwing saltbush was very low, 0.8%. However, when seeded at the rate of one seed/1.3 cm of row, this rate of emergence gave about 1 plant/m of row. The furrow treatments gave stands with distance between plants that varied from 0.9–8.4 m, 1.5–20.3 m, and 1.2–2.1 m in the springs of 1975, 1976, and 1978, respectively. The broadcast treatment with trampling failed at Lower Coils Creek and Paradise Valley, but produced stands with 34–121 m between plants at the other two locations. The broadcast treatment without trampling produced stands with 34 to 2280 m between plants at the Coils Creek sites, but planting failed at other locations.

Soil Surface

In the spring of 1975, emergence of each species was higher from the coppice soil than from the interspace soil (Table 4). This response was attributed to the degree of impedance to emerging seedlings by a soil crust. Wood et al. (1978) indicated that variations in crust strength were caused by differences in organic matter that affect aggregation of soil particles. The higher organic matter content of coppice soil (Table 2) resulted in a friable soil with no crust to impede seedling emergence. Emergence in 1976 and 1978 tended to be greater from coppice soil, but the difference was significant only for squirreltail in 1976. The 1976 data reflect a dry year when total germination was reduced and any soil effect was not fully expressed. Lack of a soil-surface effect in 1978 is probably the result of a wet year in which precipitation was sufficient to maintain a soil moisture tension low enough to reduce crusting of the interspace soil. Wood et al. (1978) found similar results in a greenhouse study when interspace soil was kept wet.

Plant Establishment

Precipitation

The long-term impact of a seeding treatment on a species is expressed by the abundance and distribution of established plants of that species. These parameters were evaluated by frequency of occurrence per 30 cm of seeded row. The average frequency of established plants in 1976 was greater from the 1974-75 seeding (51%) than from the 1975-76 seeding (30%) and was no doubt a response to higher emergence and survival in the average precipita-

Table 4. Mean emergence (%) for three grasses seeded in 3 years on two soil surfaces averaged over four locations in 1975 and 1976 and two locations in 1978. Seeding failed in the drought year of 1976-77.

Year of emergence and soil surface	Crested wheatgrass	Squirreltail	Thruber needlegrass	Soil mean
1975 (Average ppt. year)				
Coppice	29.0 ax[1]	25.2 ax	9.6 bx	21.3 x
Interspace	14.1 ay	11.5 ay	2.8 by	9.5 y
Species mean	21.1 a	18.4 a	6.0 b	
1976 (Low ppt. year)				
Coppice	9.1 ax	8.3 ax	1.0 bx	6.1 x
Interspace	6.1 ax	4.4 ay	0.6 bx	3.7 x
Species mean	7.6 a	6.4 a	0.8 b	
1978 (High ppt. year)				
Coppice	21.2 ax	18.4 ax	7.4 bx	15.5 x
Interspace	15.6 ax	16.2 ax	6.2 bx	12.7 x
Species mean	18.4 a	17.3 a	6.8 b	

[1]Emergence means among species within year and soil followed by the same letter (a or b) or means between soil surfaces and within year and species followed by the same letter (x or y) are not significantly different at the 0.05 probability level as determined by Duncan's multiple range test.

tion year of 1974-75 than in the below-average precipitation year of 1975-76.

Seedbed Preparation and Seeding Method

Seedling emergence did not increase, and in some cases decreased on the plowed treatment. However, plant establishment was significantly increased by plowing from 30 to 46% (Table 5). Establishment was highest on the plowed treatment at Panther Canyon (55%) and at the Coils Creek sites, both 53% frequency. Establishment was poorest on the plowed treatment at Paradise Valley (24%), due to disturbance of the A11 horizon and development of a massive crust, and on the unplowed treatment at Panther Canyon (16%), due to a dense stand of cheatgrass *(Bromus tectorum).* The combinations of location, plowing, and species that resulted in the best establishment were: crested wheatgrass on plowed soil at both Coils Creek sites (90% frequency), crested wheatgrass on plowed soil at Panther Canyon (84%), and squirreltail on plowed soil at Panther Canyon (81%).

Specific reasons for the positive effect of plowing on establishment and growth of seeded species were not determined. Other than the obvious reduction in competitive vegetation, plowing could also improve soil tilth by incorporating surface organic matter, increase aeration and porosity, and modify the environment by creating a very rough microtopography that would catch drifting snow, pond water, and increase the quantity of water percolating into the soil.

Average frequency in 1976 from the 1974-75 seeding was similar in standard (36%) and in deep furrows (40%) (Table 5). On unplowed soil, however, establishment was enhanced by deep furrows (34%) compared with standard furrows (26%) and each grass species responded favorably to the deep furrow treatment. In plowed soil, average frequency of established plants was the same in both kinds of furrows; however, frequency of crested wheatgrass was significantly greater in standard furrows.

Stand frequency of crested wheatgrass and squirreltail on the broadcast seeding with simulated trampling on plowed soil ranged from 22 to 82% (data not shown). Without trampling, frequencies were similar, but the highest value was 62%. Good seed coverage was obtained in plowed soil by the simulated trampling procedure. Even without trampling, enough "safe sites" (Harper et al. 1965) were available. The rough microtopography, together with some seed coverage by blowing soil, moderated the seedbed environment and permited germination, emergence, and establishment. Stands of Thurber needlegrass and fourwing saltbush were very poor or failures.

Some establishment (17 to 44%) was obtained from broadcast seeding and simulated trampling on the unplowed treatment at Lower Soils Creek. Most of these plants were on the coppice soil where some microrelief occurred. On interspace soil, even with simulated trampling, seed coverage was not adequate for germination, emergence, and establishment because seed was planted directly into the surface crust. Establishment was very low (2 to 4%) on sites with competitive herbaceous vegetation. Establishment at Paradise Valley was very low (16%) because the interspace soil makes up most of the surface cover and most microplots were on this soil.

Table 5. Mean frequency (%) per 30 cm of row of established grass and shrub plants in 1976 seeded by two methods on plowed and unplowed soil in 1974.

	Plowing treatment					
	Unplowed			Plowed		
	Seeding method					
Species	Standard furrow	Deep furrow	Species mean	Standard furrow	Deep furrow	Species mean
Crested wheatgrass	45 d[1]	56 c	51 w	84 a	73 b	78 u
Squirreltail	31 e	46 d	39 x	65 b	69 b	67 v
Thurber needlegrass	18 g	27 ef	23 y	17 g	24 e-g	20 y
Fourwing saltbush	7 h	7 h	7 z	19 gh	20 gh	20 y
Plowing mean			30			46

[1]Establishment means for seeding

[1]Establishment means for seeding methods followed by the same letter (a-h), and for species followed by the same letter (u-z) are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Table 6. Mean frequency (%) per 30 cm of row of established grass and shrub plants in 1976 on the unplowed soil at Lower Coils Creek for seedling emergence in spring 1975 (average ppt. year) or spring of 1976 (dry year).

	Soil surface			
	Coppice		Interspace	
	Year of Emergence			
Species	1975	1976	1975	1976
Crested wheatgrass	75 a[1]	77 a	62 ab	47 c
Squirreltail	73 a	67 ab	50 bc	33 d
Thurber needlegrass	63 ab	6 e	27 d	0 e
Fourwing saltbush	31 d	5 e	24 d	6 e
Soil mean	60	38	41	22

[1]Establishment means followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Species

The average frequency of established plants showed a significant difference among species: crested wheatgrass-65%, squirreltail-53%, Thurber needlegrass-22%, and fourwing saltbush-13%. This same relation generally was true for both plowed and unplowed treatments (Table 5). All species except Thurber needlegrass had a much higher frequency in plowed soil than in unplowed soil.

Soil Surface

The average frequency of established plants in 1976 from plantings made in 1974 and 1975, respectively, was significantly greater in unplowed coppice soil (60 and 38%) than in unplowed interspace soil (41 and 22%) (Table 6). The difference in establishment between surface soils was attributed to the friable structure and non-crusting surface of the coppice soil that allowed more seedlings to emerge. After emergence, higher water infiltration rate and more favorable soil moisture relations and nitrogen fertility (West and Klemmedson 1978) enhanced establishment of emerged seedlings. The most significant interaction between the kind of soil surface and seeding method was found at Paradise Valley in the spring of 1975. The deep-furrow seeding method resulted in significantly lower frequency of established crested wheatgrass and squirreltail plants (9 and 11%, respectively) compared to the standard-furrow seeding method (34 and 29%). The massive AIIv surface horizon at this site was disturbed and powdered by deep furrowing. When saturated, the soil along the berms of the furrows became unstable, and flowed together. Seed and seedlings were buried too deeply to emerge, and the micro-climate effect of deep furrows was also lost.

Conclusions

Descriptive criteria for selecting a successful site in the big sagebrush/grass type include the density and size of big sagebrush. These characteristics are related to soil depth, soil moisture relations, and soil fertility and indicate site quality for seedling establishment and stand productivity. In areas of crusting soil surfaces the same shrub criteria can be related to suitable microsites for seedling emergence and establishment. For example, a dense stand of large shrubs each with a coppice about the size of the canopy would indicate a site with a large proportion of the land surface covered by soil with texture, structure, and moisture holding characteristics favorable for seedling emergence and establishment. Conversely, a site with a sparse shrub cover would indicate a poor site for seeding because most of the land surface would be covered with a soil with characteristics unfavorable for seedling emergence and establishment.

Plowing was a good method of seedbed preparation based on the year and sites studied and generally improved establishment on sites with an understory of competitive herbaceous species. The advantages of plowing for plant establishment outweighed the disadvantages for seedling emergence. Even on the site with strong crust development, plowing did not reduce establishment compared to the unplowed condition. Although plowing was an effective method of seedbed preparation, the high energy requirement might be a negative factor in benefit/cost analysis. Brush control that did not include plowing resulted in excellent stands of seedlings and established plants on sites without an understory of competitive herbaceous species. Plant establishment, however, was much lower on unplowed soil at sites with an herbaceous understory.

Seedling emergence and plant establishment were generally better in deep furrows than in standard furrows. This difference was more pronounced in years with average and below-average precipitation than in wet years. Deep furrows drastically reduced seedling emergence and establishment on the site with a well-developed AIIv horizon. On such sites, standard furrows should be used to reduce soil disturbance. Broadcast seeding, either with or without trampling, was a very inefficient and generally unsuccessful method of seeding these sites. Results from broadcast seeding may also be extrapolated to predict the probability of plant establishment under grazing management where competitive vegetation is present.

Crested wheatgrass and squirreltail had good seedling emergence and plant establishment. Performance of squirreltail suggests the opportunity to include this native species in seeding mixtures if seed is available. Emergence and establishment were much less for Thurber needlegrass than for the other two grasses. However, in years of above average precipitation and by seeding in deep furrows, establishment of this species could result in about one plant in each 0.5 to 1.2 m of row. This species should be considered for inclusion in seeding mixtures if good seeding techniques are used and seed is available. Emergence and establishment of fourwing saltbush were good on some treatments and at some locations, but generally this species performed poorly by common standards. However, even with low frequency of established plants, distance between plants in the resultant stands of shrubs was <2 meters for the best treatments on the best sites, from 26 to 55 meters for the less successful treatments, and from 142 to 573 meters for the least successful treatments that did not result in complete failure. Fourwing saltbush should also be considered for use in seeding mixtures for sites where it is adapted and where good site preparation and seeding techniques are used.

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