J. Range Manage.
55: 217-221 May 2002

Establishment of silver sagebrush in the Northern Mixed Prairie

J.T. ROMO AND R.W. GRILZ

Authors are respectively Professor, Department of Plant Sciences, 51 Campus Drive, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5A8 and Habitat Professional, Ducks Unlimited Canada, 603 45th Street West, Saskatoon, SK S7L 5W5.

Abstract

Interest has been expressed in using silver sagebrush (*Artemisia cana* Pursh ssp. *cana*) in restoring the Northern Mixed Prairie in Saskatchewan. The objectives of this study were to determine the effects of seedbed manipulation treatments and autumn or spring sowing on establishment of silver sagebrush on sites previously seeded to native, perennial grasses. Seeds (achenes) were sown by broadcasting at 20 pure live seeds m^{-2}. Seedling emergence ranged from 5 to 6% of seeds sown. Most seedlings emerged in May and June; no seedlings emerged after July or in the second year after planting. Seventy-four to 84% of emerging seedlings survived the first growing season with 96 to 98% of these seedlings establishing. On upland sites, seedling emergence (1.1 seedlings m^{-2} SE ± 0.1) and establishment (0.9 seedlings m^{-2} SE ± 0.1) were similar between autumn and spring sowing and among seedbed manipulation treatments. On lowland sites, seedling emergence (1.4 seedlings m^{-2} SE+0.2) and establishment (0.8 seedlings m^{-2} SE ± 0.2) were similar between autumn and spring seeding. Density of seedlings establishing was greatest when the seedbed was tilled. Establishment of silver sagebrush appears primarily limited by low numbers of seedlings emerging, indicating very specific safe site requirements for this shrub. Drastic disturbance of the seedbed is not required to establish silver sagebrush in established stands of perennial grasses. Sowing silver sagebrush in late autumn when temperatures are consistently below 0°C or in early spring immediately after snowmelt is recommended.

Key Words: *Artemisia cana* ssp. *cana*, ecological restoration, seedling establishment, seedbed ecology

Resumen

Se ha expresado el interés de utilizar el "Silver sagebrush" (*Artemisia cana* Pursh ssp. *cana*) en restaurar la Pradera Mixta del Norte en Saskatchewan. Los objetivos de este estudio fueron determinar los efectos de tratamientos de manipulación de la cama de siembra y las siembras de otoño y primavera en el establecimiento de "Silver sagebrush" en sitios previamente sembrados con zacates perennes nativos. Las semillas (aquenios) fueron sembradas al voleo a razón de 20 Semillas Puras Viables m^{-2}. La emergencia de plántulas vario de 5 a 6% de las semillas sembradas. La mayoría de las plántulas emergieron en Mayo y Junio; no emergieron plántulas después de Julio ni en el segundo año después de la siembra. De 74 a 84% de las plántulas emergidas sobrevivieron la primer estación de crecimiento y un 96 a 98% de ellas se establecieron. En los sitios altos la emergencia de plántulas (1.1 plántulas m^{-2} ES ± 0.1) y el establecimiento (0.9 plántulas m^{-2} ES ± 0.1) fueron similares entre las siembras de otoño y primavera y entre los tratamientos de manipulación de la cama de siembra. En los sitios bajos la emergencia de plántulas (1.4 plántulas m^{-2} ES ± 0.2) y establecimiento (0.8 plántulas m^{-2} ES ± 0.2) fueron similares entre las siembras de otoño y primavera. La densidad de plántulas establecidas fue mayor cuando la cama de siembra fue labrada. El establecimiento de "Silver sagebrush"parce ser limitado principalmente por el bajo número de plántulas que emergen, indicando que este arbusto tiene requerimientos de sitio seguro muy específicos. En lugares donde se tienen establecidos zacates perennes no se requiere un disturbio drástico para establecer el "Silver sagebrush". Se recomienda sembrar el "Silver sagebrush"a fines de otoño, cuando las temperaturas están consistentemente bajo 0°C o a inicios de primavera, inmediatamente después de que la nieve se derrite.

Most Northern Mixed Prairie in Canada has been drastically disturbed since the arrival of European settlers in the late 1800s. In Saskatchewan, about 82% of native prairie has been cultivated for growing annual crops (Saskatchewan Agriculture and Food 1998). Ecological consequences of this conversion are a concern and, over the past decade, effort has been placed on restoring plant communities with native, perennial plants.

A common approach in restoration is to seed a simple mixture of native, perennial grasses to stabilize the site (Wark et al. 1995). Establishing perennial grasses enables restoration specialists to use herbicides to control unwanted early seral plants. Later, additional forb and grass species are sown to increase diversity. Interest has also been expressed in including silver sagebrush (*Artemisia cana* Pursh. ssp. *cana*) and other shrubs in restoration because of their importance in many aspects of the structure and functioning of ecosystems (Miller 1987, Allen 1988, Call and Roundy 1991, Pyke and Archer 1991).

Silver sagebrush is common throughout the Northern Great Plains and occupies early to late successional communities on a variety of soils (Beetle 1960). In the Northern Mixed Prairie of Canada, silver sagebrush is most abundant in the *Bouteloua-Stipa* faciation, and is less abundant in *Stipa-Bouteloua, Stipa-Bouteloua-Agropyron, Bouteloua-Agropyron*, and *Stipa-Agropyron* faciations (Coupland 1950, 1961). Even though silver

Thanks are extended to Dr. Y. Bai for useful comments on an earlier version of this manuscript.

Manuscript accepted 7 Sept. 01.

sagebrush is an important component of natural plant communities of the Northern Mixed Prairie, little research has been completed on establishing this shrub. The objective of this study was to determine effects of seedbed manipulation treatments and autumn or spring sowing on establishment of silver sagebrush on sites previously seeded to native, perennial grasses.

Materials and Methods

Seed Source

Silver sagebrush seeds (achenes) were collected in mid-October 1994 and 1995 near Outlook, Saskatchewan (51°29'N, 107°03'W, elevation 518 m). The collection site, a naturally revegetated roadcut, was dominated by silver sagebrush, western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve), and needle-and-thread (*Stipa comata* Trin. & Rupr.). Inflorescences were cut from plants, placed in large paper bags, and air-dried in a laboratory at room temperature for about 5 days. Inflorescences were rubbed by hand to remove seeds, and seeds were then cleaned with a Clipper desktop thresher. Cleaned seeds were stored in paper envelopes in darkness at 5°C until used.

Seeding trials

Three lowland and 2 upland sites were selected for seeding trials in 1994–95 and 1995–96 in south-central Saskatchewan. All sites are in the Mixedgrass Prairie Ecodistrict of the Grassland Ecoregion (Harris et al. 1983), and were within 85 km of the site where the seeds were collected. Two lowland sites, South Lucky Lake and North Lucky Lake, were located on the west edge of Luck Lake Heritage Marsh about 11 km north of Lucky Lake in the Beechy Hills ecological landscape (Padbury and Acton 1994). The third lowland site was 8 km south of Clavet in the Elstow Plain landscape. Lucky Lake sites are on a lacustrine plain and the Clavet site is on a fluvial plain (Acton 1977). Lucky Lake soils are Birsay fine-sandy loam whereas Clavet soils are loamy alluvium complexes (Ellis et al. 1968b). In 1995–96, new plots were located adjacent to those seeded in 1994–95. All sites had been cultivated and annual crops produced for several years before restoration was begun. A mixture of native, perennial grasses including western wheatgrass, northern wheatgrass (*Elymus lanceolatus* [Scribn. & Smith] Gould), slender wheatgrass (*Elymus trachycaulus* [Link] Gould ex Shinners), and green needlegrass (*Nassella viridula* [Trin.] Barkworth) was seeded in 1989.

Upland sites were located in the Allan Hills and Coteau Hills ecological landscapes (Padbury and Acton 1994). They are hummocky, knob-and-kettle landscapes formed from glacial moraines; Weyburn loam soils predominate (Ellis et al. 1968a, 1968b). In 1994–95, the Allan Hills site was 27 km south of Allan and, in 1995–96, the site was 7 km further south. The Coteau Hills site was 24 km north and 41 km northwest of Lucky Lake in 1994–95 and 1995–96, respectively. Sites used for the 1994–95 trial were seeded in the spring of 1994 to the same mixture of native, perennial grasses seeded on lowland sites, and sites for the 1995–96 trial were seeded in the spring of 1995. These sites had been cultivated for annual crop production for many years before being seeded to perennial grasses.

Of the weather stations in Saskatchewan, Beechy is nearest the Lucky Lake and Coteau Hills sites, Watrous is closest to Allan Hills, and Saskatoon is nearest to Clavet. Annual temperatures within the area of study range from 1.9 to 4.7°C (Table 1). Average monthly temperatures

Table 1. Mean monthly temperatures and precipitation in 1994–1997, and normal temperatures and precipitation at Beechy, Watrous, and Saskatoon, Saskatchewan (Environment Canada 1998).

Station	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
		Temperature (°C)											
Beechy	1994	-18	-19	0.1	6	12	16	19	18	15	7	-3	-7
	1995	-12	-8	-3	2	11	17	18	17	12	5	-8	-14
	1996	-20	-9	-8	4	9	17	19	20	11	4	-10	-17
	1997	-17	-8	-6	3	11	17	19	19	15	6	-2	-3
	Normal	-14	-4	5	5	11	16	19	18	12	5	-5	-12
Watrous	1994	-21	-20	-1	5	11	16	18	17	14	6	-4	-12
	1995	-14	-13	-6	1	11	18	18	16	12	5	-9	-15
	1996	-22	-12	-11	2	8	16	18	19	11	3	-12	-19
	1997	-21	-11	-8	2	10	17	18	18	14	4	-4	-5
	Normal	-17	-13	-6	4	11	16	18	17	11	4	-6	-14
Saskatoon	1994	-21	-21	-3	5	11	15	18	17	14	6	-5	-14
	1995	-15	-13	-6	1	10	17	17	15	12	5	-10	-17
	1996	-25	-14	-11	3	8	16	18	18	10	2	-13	-20
	1997	-21	-11	-10	2	10	17	18	18	14	4	-4	-6
	Normal	-18	-14	-7	4	11	16	19	17	11	5	-6	-15
		Precipitation (mm)											
Beechy	1994	47	9	2	8	63	65	9	40	19	41	4	3
	1995	14	3	20	19	52	50	45	84	18	29	47	21
	1996	19	7	14	20	97	93	57	21	68	14	43	41
	1997	13	5	37	21	56	75	12	47	33	38	1	1
	Normal	16	11	16	20	46	67	62	39	30	17	14	16
Watrous	1994	26	12	11	10	61	112	49	81	12	30	14	18
	1995	21	16	52	57	30	73	29	153	3	60	13	14
	1996	6	15	11	31	55	94	64	24	59	27	22	31
	1997	28	4	16	31	65	106	18	64	98	31	1	2
	Normal	17	12	17	29	51	74	68	52	43	28	14	19
Saskatoon	1994	25	11	3	8	116	54	42	64	1	19	12	10
	1995	12	13	30	34	15	33	81	85	1	35	16	22
	1996	14	12	12	30	59	101	114	18	40	6	23	17
	1997	16	5	19	36	26	53	25	50	55	21	3	5
	Normal	16	13	16	20	44	63	58	37	32	17	14	17

are below freezing from November through March, with January the coldest month. Monthly temperatures are above freezing from April through October, peaking in July. Most precipitation is received during the growing season, with 78 to 81% of total annual precipitation received from April through October (Table 1).

Seedbed manipulation treatments were selected primarily for ease of application based on consultation with vegetation management specialists of Ducks Unlimited Canada. Manipulation treatments at the lowland sites included: 1) control—undisturbed sward; 2) mowing the sward to a 15-cm height; 3) haying—mowing+removal of phytomass; 4) haying followed by application of Glyphosate at 6.75 liters ha^{-1} in the autumn after grasses had grown new leaves, and; 5) haying followed by tillage of the soil to a 10–15 cm depth with a rotovator. Seedbed manipulation treatments on uplands consisted of the above except the haying treatment was not included and Glyphosate was applied after mowing. Plots were 5 by 5 m and seedbeds were manipulated in mid- to late September 1994 or 1995. Plots on the upland sites were located on upper slopes and knoll tops, positions where silver sagebrush stands are naturally located in this landscape.

Immediately after cleaning, 12 replicates of 50 silver sagebrush seeds were placed in Petri dishes containing 1 layer of #4 Whatman filter paper moistened with distilled water. Petri dishes were enclosed in clear plastic bags and incubated for 12 days at 10°C with 12-hours darkness and 12-hours light (220 μmol m^{-2} sec^{-1}), and germinated seeds counted. Total germination averaged 96% (SE±1.3) for 1994 seeds and 80% (SE±1.6) for 1995 seeds. Ten replicates of 100 pure live seeds (PLS) seeds were counted, weighed, and seeds g^{-1} calculated. Seeds for autumn and spring sowing were weighed and placed in paper envelopes to provide 20 PLS m^{-2} for each plot. During sowing, seeds were mixed with about 100 g of 'Redi-earth' potting mix and broadcast in plots on 4 November 1994, 21 April 1995, 5 November 1995, and 6–7 April 1996. Seeds sown in the spring were stored in darkness at 5°C over the winter. Autumn seeding was done just before snow began accumulating whereas seeds were sown about 10 days after snow had melted in the spring.

Four permanent 50- by 50-cm quadrats were placed 1 m apart along a transect through the center in each plot to monitor seedling emergence and establishment. Data from the 4 quadrats were pooled (1 m^2) in each replicate for statistical analysis. During the first growing season, newly emerged seedlings in quadrats were marked with colored, chicken leg bands every 2 weeks from 1 May to 30 June, in mid-July, and in late August. Seedling survival was also recorded at each counting period. In 1995–96, seedling emergence and survival were recorded in mid-May, June, July, and August 1996. Second-year seedling establishment was determined in late August of the second growing season after planting.

In June of the first growing season after seeding, cover of litter and bare ground was estimated in each replicate of each plot using point intercept (n = 100 points per treatment replicate) (Cook and Stubbendieck 1986). In mid-August of the first growing season, vegetation was clipped to ground level in one, 50- by 50-cm quadrat in each replicate of seedbed manipulations. Phytomass was sorted into perennial grasses, annual grasses, and forbs. Litter, dead phytomass on the soil surface, was also collected. Samples were dried at 80°C for 48 hours and weighed.

Seedbed manipulation treatments and season of sowing were factorially applied in a randomized-complete-block design (Snedecor and Cochran 1980) with 4 replicates per site at lowlands and 5 replicates on uplands. Sites were treated as random effects in analysis of variance. Treatment effects on phytomass, cover of litter, bare ground, seedling emergence, seedling survival, and seedling establishment from lowland and upland sites were analyzed separately because of differences in landscapes, history of management, and seedbed manipulation treatments. Means were compared with Tukey's HSD (Snedecor and Cochran 1980). Regression analysis (Snedecor and Cochran 1980) was used to relate seedling emergence and establishment. Statistical significance was presumed at $P \leq 0.05$ in all cases.

Table 2. Phytomass determined in August of the first growing season on upland and lowland sites in which seedbeds were manipulated.

Sites	Seedbed Manipulation Treatment	Plant Group: Perennial Grasses	Annual Grasses	Forbs	Total	Litter
		($g\ m^{-2}$)				
Uplands	Control	125a[1]	0.9a	24a	149a	8a
	Mowing	147a	4a	14a	164a	2a
	Glyphosate	27b	17a	16a	59b	21a
	Tillage	46b	19a	19a	85b	1a
	SE	22	4	5	17	4
Lowlands	Control	197a	0.1a	8a	206a	271a
	Mowing	169a	0.7a	13a	183a	182a
	Haying	200a	0.1a	7a	207a	88b
	Glyphosate	73b	6.0b	66b	144a	81b
	Tillage	94b	7.5b	36b	137a	22c
	SE	28	2	11	13	29

[1] Means followed by the same letter within a site and plant group are not significantly different ($P > 0.05$) using Tukey's HSD.

Table 3. Seedling emergence and establishment (mean ± SE) of silver sagebrush each month from autumn or spring sowing averaged over sites, years, and seedbed manipulation treatments for upland and lowland sites.

Site	Time of sowing	Month of Emergence: May	Jun.	Jul.
		Emergence (% of total seedlings)		
Upland	Autumn	36 ± 10	38 ± 6	27 ± 6
	Spring	35 ± 9	58 ± 8	5 ± 3
Lowland	Autumn	64 ± 5	33 ± 5	3 ± 1
	Spring	64 ± 8	15 ± 5	20 ± 6
		Establishment (% of seedlings emerging each month)		
Upland	Autumn	46 ± 10	84 ± 6	100 ± 0
	Spring	68 ± 3	90 ± 6	100 ± 0
Lowland	Autumn	51 ± 6	96 ± 2	100 ± 0
	Spring	89 ± 5	100 ± 0	92 ± 8

Results

Upland Sites

Application of Glyphosate and the tillage treatment reduced total phytomass and that of perennial grasses on upland sites, but mass of annual grasses, forbs, and litter was similar among seedbed manipulation treatments (Table 2). Cover of litter (33%, SE ± 2.9, P = 0.317) and bare ground (63%, SE ± 3.7, P = 0.307) was similar among seedbed manipulation treatments.

Averaged across season of sowing and seedbed manipulation treatments, seedling emergence was 5.3% (SE ± 0.7) of seeds sown. Most seedlings emerged in May and June (Table 3); no seedlings of silver sagebrush emerged after July or in the second year after planting. A trend of increasing establishment with emergence occurring at a later date was also apparent (Table 3).

Eighty-four percent of emerging seedlings survived the first growing season (Surviving seedlings m^{-2} = 0.01+0.84 X Emerged seedlings m^{-2}, R^2 = 0.89, P < 0.001). Seedlings established in the second growing season were correlated with emergence (Established seedlings m^{-2} = 0.01+ 0.82 X Emerged seedlings m^{-2}, R^2 = 0.89, P < 0.001), indicating 82% survival of emerging seedlings. Of seedlings that survived the first year, 96% survived through August of the second growing season (Established seedlings m^{-2} = 0.01+0.96 X Seedlings surviving m^{-2}, R^2 = 0.96, P < 0.001). Emergence (1.1 seedlings m^{-2}, SE ± 0.1), survival (0.9 seedlings m^{-2}, SE ± 0.1), and establishment (0.9 seedlings m^{-2}, SE ± 0.1) were similar between autumn and spring sowing and among seedbed manipulation treatments.

Lowland Sites

On lowland sites, Glyphosate and tillage reduced phytomass of perennial grasses, but that of annual grasses and forbs increased with the same treatments (Table 2). Haying, Glyphosate, and tillage reduced litter mass because plant material was removed from plots in all 3 treatments (Table 2). However, litter cover was greatest with mowing and applying Glyphosate, intermediate in control, haying, or mowing, and least with tillage (Table 4). Tillage created nearly 5-fold more bare ground than the remaining manipulation treatments (Table 4).

Seedling emergence decreased from May through July of the first growing season (Table 3) and averaged 6.4% (SE ± 0.8) of seeds sown. Establishment of later emerging seedlings was greater than earlier emerging ones (Table 3). On average, 74% of seedlings survived the first growing season (Surviving seedlings m^{-2} =0.001+0.74 X Emerged seedlings m^{-2}, R^2=0.81, P < 0.001) and 72% of emergent seedlings established (Established seedlings m^{-2}=0.01+0.72 X Emerged seedlings m^{-2}, R^2=0.79, P < 0.001). Of the seedlings that survived the first growing season, 98% established (Established seedlings m^{-2} =0.01+ 0.98 X Seedlings surviving m^{-2}, R^2=0.97, P < 0.001). Emergence (1.4 seedlings m^{-2}, SE ± 0.2), survival (1.0 seedlings m^{-2}, SE ± 0.1), and establishment (0.8 seedlings m^{-2}, SE ± 0.2) were similar between autumn and spring seeding. Emergence and survival during the first growing season varied among seedbed manipulations and were generally greatest in tillage and control (Table 5). Density of establishing seedlings was greatest when the seedbed was tilled.

Table 4. Cover of litter and bare ground determined in June of the first growing season on lowland sites in 5 seedbed manipulation treatments.

Cover Category	Seedbed Manipulation Treatment				
	Control	Mowing	Haying	Glyphosate	Tillage
	(%)				
Litter	69ab[1]	86b	66ab	88b	51a
Bare ground	17a	3a	8a	10a	47b

[1]Means followed by the same letter within a cover category are not significantly (P > 0.05) different using Tukey's HSD.

Discussion

As predicted from germination studies on silver sagebrush (Romo and Eddleman 1995, Romo and Young 2002), most seedlings emerged early in the growing season. This pulse in seedling emergence corresponds with the June peak in precipitation received in Northern Mixed Prairie (Table 1). Most seedlings of fringed sagebrush also emerge in May and June in the Northern Mixed Prairie (Bai and Romo 1996). Early emerging seedlings of silver sagebrush are more vigorous (Hou and Romo 1998a) and tolerant of freezing temperatures than later emerging ones (Hou and Romo 1998b). On the other hand, seedlings emerging too early in the spring may be killed by freezing temperatures or desiccation (Hou and Romo 1997, 1998b).

Emergence of shrubs with after ripening requirements (Booth and Schuman 1983, Haferkamp et al. 1990, Shaw et al. 1994) is greater from autumn than spring seeding because dormancy is broken by exposing seeds to cool, moist conditions. Silver sagebrush seeds are not dormant and emergence of seedlings was similar between autumn and spring sowing. Seedling populations were primarily limited by low emergence. Only 5 to 6% of the seeds sown produced seedlings. Less than 8% of seeds sown in southeastern Montana resulted in emergent seedlings (Eddleman 1980, Walton 1984). The fate of the remainder of the seeds sown in the present study is unknown, however, there are several explanations for limited seedling emergence.

First, seeds may have germinated, but seedlings did not emerge. Second, seeds were broadcast, thus some were likely buried at various soil depths. Emergence of silver sagebrush is greatest from about the 2- (Harvey 1981) to 5-mm depth (Walton 1984), and no seedlings emerge from depths greater than 25 mm (Walton 1984). Thirdly, if seedlings emerged, they may have perished before being counted in the spring or they may have emerged and died between seedling counts. Another possibility is that predators may have gathered or consumed seeds. The

Table 5. Effects of seedbed manipulation treatments on seedling emergence, survival, and establishment of silver sagebrush on lowland sites.

Variable	Seedbed Manipulation Treatment				
	Control	Mowing	Haying	Haying + Glyphosate	Tillage
	(Seedlings m^{-2})				
Seedling Emergence	1.9ab[1]	0.6c	1.2bc	0.7c	2.3a
Seedling Survival[2]	1.3ab	0.4b	1.0ab	0.4b	1.9a
Seedling Establishment[3]	0.8b	0.3b	0.7b	0.4b	1.7a

[1]Means followed by the same letter are not significantly (P > 0.05) different using Tukey's HSD.
[2] Survival is the density of seedlings alive in August of the first growing season.
[3]Establishment is the density of seedlings alive in August of the second growing season.

importance of predation on seeds and seedlings of silver sagebrush is not known, but ants are a significant predator on seedlings of fringed sagebrush (Bai and Romo 1996). Some seeds may have entered secondary dormancy or lost viability as they were exposed to many wetting-drying cycles and wide fluctuations in temperatures in the field. However, no evidence exists that exposing seeds to environmental conditions encountered in the field causes secondary dormancy in silver sagebrush, but seeds of silver sagebrush loose viability rapidly when exposed to field environments (Romo and Young 2002). Low emergence of seedlings is interpreted to indicate that this shrub has very specific safe site requirements. Safe sites were apparently present in all seedbeds with most being created with tillage on lowland sites. Reduced competition caused by tillage or the increased amount of bare soil likely favored establishment of silver sagebrush. Competition from grasses also reduces establishment of Wyoming big sagebrush (Schuman et al. 1998), and establishment of fringed sagebrush is greater in disturbed than undisturbed swards (Bai and Romo 1996).

Identifying criteria for gauging success of establishing plants is key to selecting, evaluating, developing, and improving restoration practices. In naturally occurring silver sagebrush stands in Saskatchewan, shrub densities range from 0.3 to about 1.0 m^{-2} (Coupland 1950,1961, Romo unpub. data), and stem densities can reach 5 m^{-2} (Hulett et al. 1966, Lawrence and Romo 1994). If these densities are used as the ecologically-based standards for judging seeding success, establishment of silver sagebrush was successful in this study for densities fell within the range encountered in natural communities. In all seedings, plants produced seeds in the fourth year of growth (J.T. Romo pers. obser.) potentially leading to more plants establishing through natural regeneration.

Silver sagebrush appears to be a useful species for restoration in the Northern Mixed Prairie. Seeds can be easily collected from wildlands, seed processing is simple, and seeds are not dormant. Drastic disturbance of the seedbed is not required to establish this shrub in stands of perennial grasses, but greater densities can be expected on tilled sites or sites disturbed by burrowing animals. Sowing silver sagebrush in autumn after temperatures are consistently below 0°C or in spring immediately after snowmelt is recommended because seedling emergence, survival, and establishment were equivocal in autumn and spring seeding.

Literature Cited

Acton, D.F. 1977. Landscapes of southern Saskatchewan. Department of Energy, Mines and Resources, Ottawa, Ont.

Allen, M. F. 1988. Belowground structure: A key to reconstructing a productive arid ecosystem, p. 113–135. *In:* E.B. Allen (ed.), The reconstruction of disturbed arid lands-An ecological approach. Westview Press, Boulder, Colo.

Bai, Y. and J.T. Romo. 1996. Fringed sagebrush response to sward disturbances: Seedling dynamics and plant growth. J. Range Manage. 49:228–233.

Beetle, A.A. 1960. A study of sagebrush: The section *Tridentatae* of *Artemisia*. Wyoming Agr. Exp. Sta. Bull. 368. Laramie, Wyo.

Booth, D.T. and G.E. Schuman. 1983. Seedbed ecology of winterfat: Fruit versus threshed seeds. J. Range Manage. 36:387–390.

Call, C.A. and B.A. Roundy. 1991. Perspectives and processes in revegetation of arid and semi-arid rangelands. J. Range Manage. 44:543–549.

Cook, C.W. and J. Stubbendieck. 1986. Range research: Basic problems and techniques. Soc. Range Manage. Jostens Pub., Broomfield, Colo.

Coupland, R.T. 1950. Ecology of Mixed Prairie in Canada. Ecol. Monogr. 20:273–315.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. 49:135–167.

Eddleman, L.E. 1980. Coal mine reclamation with native plants, p.80-90. *In:* Proc. 1980 Symposium on Watershed Manage. Boise, Ida.

Ellis, J.G., D.F. Acton, and H.C. Moss. 1968a. The soils of the Last Mountain Lake map area. Ext. Division, Univ. Saskatchewan, Saskatoon, Sask.

Ellis, J.G., D.F. Acton, and H.C. Moss. 1968b. The soils of the Rosetown map area. Ext. Division, Univ. Saskatchewan, Saskatoon, Sask.

Environment Canada. 1998. Climate data supplied by the Saskatoon, Saskatchewan office upon special request.

Haferkamp, M.R., D.C. Ganskopp, K.L. Marietta, and B.W. Knapp. 1990. Environmental influences on germination of utricles and seedling establishment of immigrant forage kochia. J. Range Manage. 43:518–522.

Harris, W. C., A. Kabzems, A.L. Kosowan, G.A. Padbury, and J.S. Rowe. 1983. Ecological regions of Saskatchewan. Saskatchewan Parks and Renewable Resources Tech. Bull. No. 10. Regina, Sask.

Harvey, S.J. 1981. Life history and reproductive strategies in Artemisia. M.S. Thesis, Montana State Univ., Bozeman, Mont.

Hou, J.Q. and J.T. Romo. 1997. Growth and freezing tolerance of winterfat seedlings. J. Range Manage. 50:165-169.

Hou, J.Q. and J.T. Romo. 1998a. Seed weight and germination time affect growth of two shrubs. J. Range Manage. 51:699–703.

Hou, J.Q. and J.T. Romo. 1998b. Cold-hardiness of silver sagebrush seedlings. J. Range Manage. 51:704–708.

Hulett, G.K., R.T. Coupland, and R.L. Dix. 1966. The vegetation of dune sand areas within the grassland region of Saskatchewan. Can. J. Bot. 44:1307–1331.

Lawrence, D.L. and J.T. Romo. 1994. Tree and shrub communities of wooded draws near the Matador Research Station in southern Saskatchewan. Can. Field Natur. 108:397–412.

Miller, R.M. 1987. Mycorrhizae and succession, p. 205–219. *In:* W.R. Jordan III., M.E.Gilpin, and J.D. Aber (eds.), Restoration ecology-A synthetic approach to ecological research. Cambridge Univ. Press, New York, N.Y.

Padbury, G.A. and D.F. Acton. 1994. Ecoregions of Saskatchewan. Minister of Supply and Services, Ottawa, Ont.

Pyke, D.A. and S. Archer. 1991. Plant-plant interactions affecting plant establishment and persistence on revegetated rangeland. J. Range Manage. 44: 550–557.

Romo, J.T. and L.E. Eddleman. 1995. Use of degree-days in multiple-temperature experiments. J. Range Manage. 48:410–416.

Romo, J.T. and J.A. Young. 2002. Temperature profiles and the effects of field environments on germination of silver sagebrush. Native Plants J. 3:5–13.

Saskatchewan Agriculture and Food. 1998. Agricultural statistics 1998. Saskatchewan Agr. and Food, Statistics Branch, Regina, Sask.

Schuman, G.E., D.T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51:223–230.

Shaw, N.L., M.R. Haferkamp, and E.G. Hurd. 1994. Germination and establishment of spiny hopsage in response to planting date and seedbed environment. J. Range Manage. 47:165–174.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical methods. Iowa State Univ. Press. Ames, Iowa.

Walton, T.P. 1984. Reproductive mechanisms of plains silver sagebrush *Artemisia cana cana* in southern Montana. M.S. Thesis, Montana State Univ., Bozeman, Mont.

Wark, D.B., W.R. Poole, R.G. Arnott, L.R. Moats, and L. Wetter. 1995. Revegetating with native grasses. Ducks Unlimited Canada, Stonewall, Man.