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A comparison of drills for direct seeding alfalfa into established grasslands

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Abstract

Information is presented on the suitability of various drills for direct seeding into permanent pastures and rangelands in Saskatchewan. Strips of sod 30 to 100-cm wide were killed during the growing season by glyphosate (*N*-[phosphonomethyl] glycine) in grazing lands at several sites in Saskatchewan. Six drills: 1 with a powered disk furrow opener, 2 with hoe openers, and 3 with rolling disk openers were used to seed measured amounts of alfalfa (*Medicago sativa* L.) seed in the killed strips in late fall of the same year or early the subsequent spring. Drill performance was assessed during the seeding operation, and emerged seedlings were counted early the following growing season. Seedling emergence ranged from near 0 to 48% of seed sown. Soil moisture conditions in early spring, which in turn were a function of winter precipitation, were a major limitation on seed germination. All of the furrow-opening mechanisms were capable of placing seed at a suitable depth for successful establishment in some situations. The best seedling emergence was obtained with drills having each opener suspended independently with sufficient weight to penetrate dead thatch and hard ground, and with mechanisms to control seeding depth and pack the soil around the seeds.

Key Words: ***Medicago sativa*, range, pasture, sod-seeding, drill openers**

More than 3 million hectares of land in Saskatchewan are used for livestock grazing. Nitrogen is the major limitation to greater production in the aspen parkland zone, and is the second limiting factor in drier areas (de Jong 1978). It is generally recognized that legumes in general, and alfalfa (*Medicago sativa* L.) in particular, can support *Rhizobium* bacteria which convert atmospheric nitrogen into a form suitable for plant use, and because of this, productivity is higher in pastures containing legumes. A recent report suggests that a legume content of 20% is optimum for pastures (Sheehy 1989).

The usual way to introduce or reintroduce a legume into a pasture is by cultivating, fallowing, and reseeding. This is costly, and in some areas not feasible because of rough topography, stoniness, or serious risk of erosion. Establishment of legumes by direct drilling into a pasture at the same time as a bipyridinium herbicide, usually paraquat (1,1′-dimethyl-4-4′-bipyridinium ion), is applied to suppress existing growth, has been successful in maritime climates where moisture is not limiting (Sprague 1960, Bartholomew et al. 1981, Vough and Decker 1983). In western Canada, legume establishment by direct seeding in forage fields has not been reliable when bipyridinium herbicides were applied at seeding time to suppress the resident vegetation (Bowes and Friesen 1967). The use of glyphosate (*N*-[phosphonomethyl] glycine) to kill the resident vegetation has allowed a better establishment of seeded forages (Waddington and Bowren 1976). A reliable establishment method to date was developed in northeastern Saskatchewan by Malik and Waddington (1990). Strips of resident forage were killed during the growing season, and legumes were seeded in the dead areas late enough in the fall for germination to be delayed until the following spring. A triple-disk range drill designed for experimental work in rough pastures (McLaughlin and Dyck 1986) was used.

Several other designs of furrow opener have been tried on established turf. Smith et al. (1973) designed a powered rotary cutting blade to break up the sod ahead of a double-disk opener. Baker (1976) reported that a winged hoe opener was superior to triple-disk or standard hoe openers in dead turf. Squires et al. (1979) and Decker et al. (1964) developed drills which removed a strip of turf ahead of the opener, which then seeded into the exposed soil. Except for the triple-disk range drill, the prototypes referred to above, and commercial machines produced from them, were designed in temperate areas, where moisture does not normally limit seedling establishment. Their efficacy has not been established in semiarid conditions.

Recently, drills designed to seed through trash on untilled grain fields have become available. Such conditions have similarities to forage fields, namely, a hard soil surface and undecayed plant material. The abilities of zero-till grain drills to sow forage seeds directly into turf has not been assessed.

The objective of this research was to compare the abilities of 3 commercial direct-seeding drills, 2 experimental zero-till drills and the triple-disk range drill, for seeding legumes into uncultivated dead turf in a semiarid area. Several sites encompassing a range of environmental conditions were used.

Materials and Methods

Experiments were started in each of the years 1985, 1986, and 1987. Soil characteristics are based on those of the Canada Soil Survey Committee, Subcommittee on Soil Classification (1978), and indicate approximate U.S. equivalents (USDA-SCS 1975). Seven experimental sites were selected in the Northern Great Plains in the province of Saskatchewan (Canada) (Fig. 1). Three of the sites were on Agriculture Canada Experimental Stations: at Swift Current in a Swinton silt loam, an Orthic Brown Chernozem (Aridic Haploboroll); at Scott on an Elstow loam, an Orthic Dark Brown Chernozem (Typic Boroll); and at Indian Head in an Indian Head clay, an Orthic Black Chernozem (Udic Boroll). Two sites were established in community pastures: at Webb in a Halton sandy loam, an Orthic Brown chernozem (Aridic Haploboroll); and at Pathlow in a Waitville loam, an Orthic Gray luvisoll (Typic Cryoboralf). The sixth site was at the Termuende Experimental Farm of the University of Saskatchewan at Lanigan on a Biggar sandy loam, an Orthic Dark Chernozem (Typic Boroll). The last

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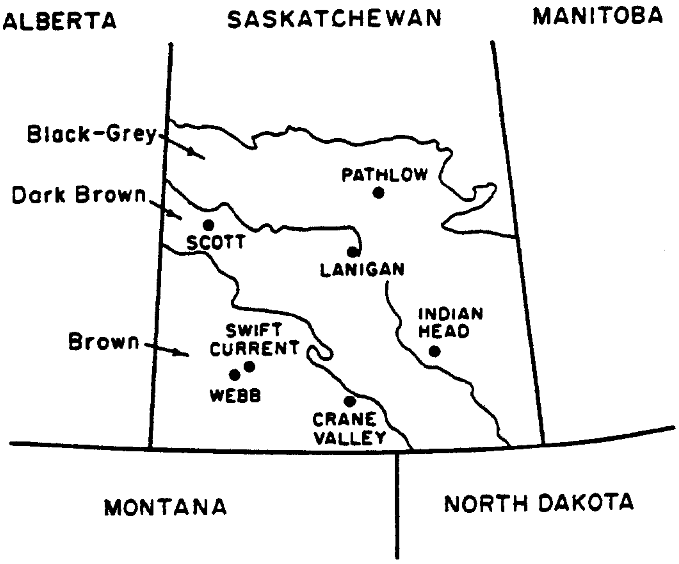

Fig. 1. Test sites in relation to soil zone for direct seeding of alfalfa into established forage in Saskatchewan.

site was located in a privately owned pasture near Crane Valley on a Haverhill clay loam, an Orthic Brown Chernozem (Aridic Haploboroll). Not all sites were used in each year (Table 1).

In 1985, strips of vegetation were killed by applying glyphosate at 2.2 kg a.e. ha^{-1} in 100 liters of water plus 0.5% v/v nonylphenoxypolyethoxy ethanol[1] surfactant. The width of the sprayed strips varied from site to site but was 100 cm at most sites in 1985 and 1986, 70 cm at the Lanigan site in 1985 and 1986, and 30 cm at all sites in 1987 and in all years at the Pathlow site. Standard 80 degree flat fan nozzles were mounted on a small tractor, 1 nozzle for the narrow width and 2 overlapping for the wider strips. One strip was sprayed at a time, and the distance between strips was 1.7 m. In 1986 and 1987 in addition to an application of glyphosate at 2.2 kg a.e. ha^{-1}, a second treatment consisting of a mixture of 1.1 kg a.e. ha^{-1} glyphosate plus 0.35 kg a.e. ha^{-1} of 2,4-D amine was applied in the same way. The length of the sprayed strips also varied from test to test, but was never less than 150 m. Time of herbicide application depended on location and weather (Table 1). Herbicides were always applied when the vegetation was physiologically active.

The several drills, their furrow opener designs, and the years when they were tested are described briefly in Table 2. The commercial drills had openers spaced at 15 cm, too close for direct seeding in much of western Canada. During use, seed was put through only 1 opener; the others were not removed, but were ignored unless they affected the operation of the test opener. Before the start of seeding in 1985, a new rotary blade was mounted on the test opener of the powered-disk drill to replace the original, which was badly worn. There was no major wear on the blade between years. Seeding was always as late in the fall as possible (Table 1). The triple-disk drill was rarely available at the same time as the other seeders, and the second seeding date when present is for that machine. In 1986, only the site at Indian Head was seeded with the triple disk drill before winter. The others were delayed until spring, 1987, and the Pathlow site was not seeded with this drill. Each drill was calibrated to seed approximately 100 seeds m^{-1} of row in 1985, and 200 seeds m^{-1} of row in 1986 and 1987. At each site, the true seeding rate was calculated after putting a known weight of seed in the drill, weighing the amount of seed remaining after seeding, and measuring the length of row seeded.

In 1985 and 1986, seed harvested in 1984 from the 'Rangelander' alfalfa breeder seed plot at Swift Current Research Station was used. In 1987, newly harvested seed of an experimental line of alfalfa (ssp. *falcata*) was used. Seed was not scarified, so a proportion could probably be classified 'hard'.

In 1985, all experiments were completely randomized designs

[1]Agsurf, Interprovincial Cooperatives Ltd., Saskatoon, Sask.

Table 2. Manufacturer, descriptions of furrow opener designs, and the years when they were used.

Manufacturer	Design of furrow opener	Trial years
1. Agriculture Canada triple-disk range drill	Fluted rolling coulter followed by double-disk opener, all very heavy (McLaughlin and Dyck 1986)	1985–86 1986–87 1987–88
2. John Deere Powertill	Rotary disk driven from tractor power takeoff (Smith et al. 1973)	1985–86 1986–87 1987–88
3. Agriculture Canada Double-disk press drill	Vertical rolling coulter with offset disk opener (Lawrence and Dyck 1990)	1986–87 1987–88
4. Agriculture Canada Zero-Till hoe drill	High clearance, narrow hoe opener	1985–86
5. Moore Unidrill	Single offset disk opener	1985–86
6. Connor-Shea Pasture drill	Rolling coulter followed by a narrow winged hoe opener (Baker 1976)	1987–88

Table 1. Dates of herbicide application and seeding at the sites used for direct seeding of alfalfa into forage over the period 1985–88.

	Time of herbicide application			Time of seeding[1]		
Site	1985	1986	1987	1985	1986	1987
Ag. Canada, Swift Current	11 June	—	28 July	21 Oct. 1 Nov.	—	— —
PFRA Pasture, Webb	11 June	—	—	22 Oct. 4 Nov.	—	—
Private Pasture, Crane Valley	—	—	7 Aug.	—	—	3 Nov.
Ag. Canada, Scott	—	16 June	—	—	24 Oct. 22 Apr. 87	—
U. of S. Exp. Farm, Lanigan	13 June	17 June	29 July	17 Oct. 30 Oct.	22 Oct. 23 Apr. 87	20 Oct. 29 Oct.
Ag. Canada, Indian Head	—	13 Aug.	28 Aug.	—	21 Oct. 29 Oct.	26 Oct.
Community Pasture, Pathlow	9 Sept.	10 Sept.	17 Sept.	18 Oct. 29 Oct.	24 Oct.	20 Oct. 30 Oct.

[1]Where present, a second seeding date always refers to seeding by the triple-disk range drill.

Table 3. Precipitation and heat units (degree days above or below 5.5° C) during winter and growing season at several experimental sites in Saskatchewan between 1985–1988.

Year	Swift Current + Webb (Swift Current)	Crane Valley (Ormiston)	Scott	Lanigan (Nokomis)	Indian Head	Pathlow (Melfort)
	Experimental site[1]					
Winter precipitation 1 Oct.–28 Feb. (mm)						
1985–86	72	59	70	44	94	70
1986–87	59	42	55	38	70	73
1987–88	41	31	47	64	56	97
Growing-season precipitation 1 Mar.–31 Jul. (mm)						
1986	217	188	255	274	335	216
1987	167	208	289	207	246	173
1988	155	181	165	97	234	111
Winter degree-days below 5.5° C, 1 Oct.–28 Feb.						
1985–86	1902	2047	2369	2376	2251	2506
1986–87	1280	1377	1830	1825	1678	1977
1987–88	1553	1658	2229	2228	1912	2225
Growing-season degree-days above 5.5° C, 1. Mar.–31 Jul.						
1986	1006	1106	859	974	1036	933
1987	1186	1258	1044	1130	1208	1091
1988	1314	1376	1130	1268	1269	1197

[1]The name in parentheses is the location of the nearest meteorological site to the experimental site where the locations differ.

with 4 machines, each seeding 2 adjacent rows per plot (3 rows at the Pathlow site). In 1986 and 1987, seeders (3 in 1986, 4 in 1987) were randomized within herbicide treatments, and seeded 2 rows per plot in 1986, and 1 row per plot in 1987. The year after seeding, each row was divided into 4 (3 at the Pathlow site). Emerged seedlings were counted over a 3-m distance chosen at random within each section of each row, resulting in 8 subsamples per plot for 1985 and 1986 experiments (9 at the Pathlow site in 1985) and 4 subsamples per plot for 1987 experiments. An attempt was made to select a time when initial germination was complete but no losses due to drought or pests had occurred. It was assumed that the drills would have their strongest influence on seedling populations early in the growing season. Most counts were made in June but some were made in May. In 1988, some counts were delayed until July because soil moisture was very low in early spring, and germination was delayed.

For each subsample, seedling emergence was calculated as percent of drilled-in seeds. The arcsine transformation was applied to data before analyses of variance. Mean separations were accomplished with Duncan's multiple range test on the transformed means. For experiments started in 1985, the within-plot mean square was used as the error term. For experiments started in 1986 and 1987, the within-plot mean square was used to test the herbicide × drill interaction for significance. Where the interaction term was found nonsignificant, it was combined with the within-plot sum of squares to form the error term with which main effects were tested. The means were transformed back to percentages for presentation.

Results

Growing conditions varied enormously among sites and years (Table 3). From 1985 to 1988 there was a trend to less winter and growing-season precipitation. Also, temperatures during the growing season increased over the same period. Soil moisture at seeding depth appeared good early in spring 1986, and also early in 1987, although a mild winter in 1986–87 allowed more evaporation than usual, and there was little soil moisture at depth. The winter of 1987–88 had more normal temperatures but the low precipitation following the dry year of 1987 resulted in extremely dry soil in the spring of 1988 at all sites.

Table 4. Comparison of the influence of glyphosate alone and when mixed with 2,4-D on seedling emergence following direct seeding.

Experimental site	1986 Experiments: Glyphosate (2.2 kg/ha)	1986 Experiments: Glyphosate + 2,4-D (1.1 + 0.35 kg/ha)	1987 Experiments: Glyphosate (2.2 kg/ha)	1987 Experiments: Glyphosate + 2,4-D (1.1 + 0.35 kg/ha)
	(%)			
PFRA Pasture Webb	16*[1]	9	—	—
Private Pasture Crane Valley	—	—	3	3
Ag. Canada Scott	11	9	—	—
U of S Exp. Fm. Lanigan	10	9	3*	0
Ag. Canada Indian Head	29	25	2	2
Community Pasture Pathlow	3	3	2	1

[1]Seedling establishment significantly ($P<0.05$) better after using glyphosate at 2.2 kg/ha to control resident vegetation than after using glyphosate + 2,4-D.

Table 5. Comparison of seedling emergence in spring 1986 as percent of seeds sown in late fall 1985.

Type of Drill	Experimental site			
	Ag. Canada Swift Current	PFRA Pasture Webb	Univ. of Sask. Ex. Farm, Lanigan	Community Pasture, Pathlow
	(%)			
Triple-disk drill	11a[1]	3	1ab[1]	48a[1]
Zero-Till hoe drill	1b	5	0bc	6c
Powered-disk drill	1b	6	2a	8bc
Single offset disk drill	1b	5	0c	14b

[1]Values in the same column followed by a different letter are significantly different ($P<0.05$) according to a protected Duncan's multiple range test conducted on the transformed data.

Overall, the mixture of glyphosate and 2,4-D controlled the resident vegetation less well than did the glyphosate alone. There was a significant herbicide effect on seedling emergence ($P<0.05$) in 2 experiments; at Webb in 1986, and at Lanigan in 1987. In both cases, seedling establishment was better with glyphosate alone (Table 4). There were no significant interaction effects between drill and herbicide.

In 1986, an abundance of seedlings was produced only at the Pathlow site and only where the triple-disk drill had been used (Table 5). The triple-disk drill performed significantly better than the other drills at Swift Current and at Pathlow, and was equal in performance to the powered-disk drill at Lanigan. The hoedrill was equal in performance to the triple-disk drill but inferior to the powered-disk drill. There were no differences in drill performance at Webb pasture.

In 1987, a uniform seedling stand developed from all drills at Indian Head although the triple-disk drill performed significantly better than the other drills (Table 6). Elsewhere, except at the Pathlow site, good through not uniform seedling stands developed, with no significant differences among drills. At the Pathlow site, the powered-disk drill was superior to the double-disk press drill, but seedling populations were low.

Emergence was very low at all sites in 1988. At the Pathlow site, the triple-disk drill and the winged-hoe drill were equal in performance, and both were superior to the other 2 drills (Table 7). At Crane Valley, the triple-disk drill and the powered-drill were similar in performance, and the triple-disk and the double-disk press drill were similar in performance, but the powered-disk was superior to the press drill. There were no significant differences between the drills at the other sites.

Overall, seedling emergence was rarely uniform. Sections of a row where seedlings were abundant alternated with sections bereft of seedlings. There was no evidence of differences among drills in this respect.

Table 7. Comparison of seedling emergence in spring 1988 of seeds sown in late fall 1987.

Type of Drill	Experimental site			
	Univ. of Sask. Ex. Farm, Lanigan	Ag. Can. Indian Head	Private Pasture Crane Valley	Community Pasture Pathow
	(%)			
Triple-disk drill	1	2	3ab[1]	3a[1]
Double-disk press drill	1	3	2bc	1b
Powered-disk drill	1	2	6a	1b
Winged hoe drill	1	4	1c	2a

[1]Values in the same column followed by a different letter are significantly different ($P<0.05$) according to a protected Duncan's multiple range test conducted on the transformed data.

Discussion

The relationship between seeding rate in the field and population of established plants is not close, because of the great variability of stresses which cause seedling deaths during establishment. In western Canada, an alfalfa plant every 15 cm in each row is effectively a solid stand. At the seeding rates used in this study, establishment of between 3 and 7% will produce an excellent stand. These numbers should perhaps be doubled to allow for the inevitable losses between early season plant numbers and the numbers of plants surviving by the end of the establishment year. On this basis, many of the seedings were unsatisfactory. At the Pathlow site, all drills used in fall 1985 produced adequate stands initially, although the triple-disk drill was clearly superior. At the Swift Current site the triple-disk drill was the only one which produced a satisfactory stand after seeding in 1985 (Table 5). Seedings made in fall 1986 or spring 1987 were successful for all drills at most sites (Table 6). Spring 1988 was so dry that establishment was inadequate at all sites (Table 7).

The drills used can be placed in 3 groups based on opener type: those with a disk-type furrow opener, either single, double, or triple; those with a hoe-type opener, with or without a coulter ahead of the hoe; and those with a powered-disk furrow opener. All 3 types have been shown to place seed at depths suitable for successful establishment of forages (Baker 1976, Smith et al. 1973). However, their tests were conducted in maritime climates and with experimental seeding equipment usually of 1 opener. In the present experiments, commercial drills based on their designs were used, which gives a more practical test of the equipment.

The triple-disk drill was considered the control drill and was used in each of the years and at all sites but 1. Overall, it was equal to or better than the other drills used. Its superiority is undoubtedly due to its weight which guarantees good penetration of any soil, its independent depth control on each opener, and its packer wheel with a U-shaped cross-section which closes the furrow by pressure

Table 6. Comparison of seedling emergence in spring 1987 of seeds sown in late fall 1986 (glyphosate and glyphosate + 2,4-D).

Type of drill	Experimental site				
	PFRA Pasture Webb	Univ. of Sask. Ex. Farm Lanigan	Ag. Can. Indian Head	Ag. Can. Scott	Community Pasture Pathlow
	(%)				
Triple-disk drill	12	12[2]	38a[1]	11[2]	—
Double-disk press drill	16	10	26b	10	2b[1]
Powered-disk drill	10	6	19c	9	4a

[1]Values in the same column followed by a different letter are significantly different ($P<0.05$) according to a protected Duncan's multiple range test conducted on the transformed data.
[2]Seeded in April 1987.

mostly from the sides. The furrow opener of the double-disk press drill drill combines the rolling coulter of the triple-disk drill into one of the disks of the opener. The mechanism worked well, but because the drill was designed for cultivated land, it lacked sufficient weight to cut to the set depth in dry undisturbed soil and in thick thatch. When compared to the triple-disk drill, the single offset disk drill did not perform as well (Table 5). The seed metering mechanism seemed unable to meter alfalfa seeds adequately, plugging at low settings and seeding too densely at higher settings. This problem was not encountered with grass-alfalfa mixtures (McCartney, personal communication).

The 2 drills with hoe openers had major differences (Table 2). The zero-till hoe drill was designed for seeding annual cereals in cereal stubble. Depth of seeding was set by a caster wheel at the front of the machine and packer wheels at the back. The hoes ran too deep or were out of the ground for about half the seeded distance because of undulating microrelief. When the hoes ran at the right depth, a section of dead sod was turned out of the furrow made by a hoe, and the alfalfa was placed in the furrow. Coverage was good. On the winged-hoe drill, depth of penetration was controlled by land wheels at each end of the support frame; consequently, depth of penetration varied more in the middle of the machine than at the ends. Baker (1976) used wheels to control the depth of penetration of each hoe. The winged-hoe drill was used for seeding only in the fall of 1987. The following spring was very dry, and none of the drills produced satisfactory seedling counts. Performance of the winged-hoe drill was equal to that of the triple-disk drill at 4 of 5 sites, but the hoe design was not superior to other openers as found by Baker (1976).

The only other drill used in all years at all sites was the powered-disk drill. The new rotary blade cut a good slot in the soil but old, worn blades were observed to cut a very narrow slot. Seed is dropped immediately behind the blades, but some seed does not fall in the slot, even one made by a new blade. The soil cut by the blades is thrown behind in a spray, which inadequately covers seed when the blades are worn. Additionally, the light plastic packer wheels were totally inadequate to provide compaction. Given that seedling emergence using the powered-disk drill was equal to that using the triple-disk drill in 8 of 13 comparisons, it seems likely a better performance would have been obtained if the double disk openers used by Smith et al. (1973) had been used for seed placement behind the blades.

All the drills placed enough seed in a suitable position for satisfactory emergence some of the time, which indicates that all the styles of furrow opener can work adequately in the dry, hard soil conditions usually present in Saskatchewan in late fall. Best seedling emergence was obtained with drills sufficiently heavy to guarantee that the furrow opener mechanism could penetrate hard ground and with a mechanism on each opener to control seeding depth. In western Montana, Welty et al. (1983) identified a requirement for packing the soil over the seed. In the present studies, it was impossible to isolate the effects of packers from other features. However, because seeding took place in late fall, it is likely that natural processes over winter would contribute to good seed-soil contact by the time temperatures were high enough for germination the following spring.

Literature Cited

Baker, C.J. 1976. Experiments relating to techniques for direct drilling of seeds into untilled dead turf. J. Agr. Eng. Res. 21:133–144.

Bartholomew, P.W., D.L. Easson, and D.M.B. Chestnutt. 1981. A comparison of methods of establishing perennial and Italian ryegrasses. Grass and Forage Sci. 36:75–80.

Bowes, G.G., and G. Friesen. 1967. The use of paraquat to improve pastures in Manitoba. Weeds 15:241–243.

Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978. The Canadian system of soil classification. Can. Agr. Dep. Pub. 1646. Supply and Services Canada, Ottawa, Ont.

Decker, A.M., H.J. Retzer, and F.G. Swain. 1964. Improved soil openers for the establishment of small-seeded legumes in sod. Agron. J. 56:211–214.

de Jong, E. 1978. Water and forage crops. p. 1–23 *In:* Ed. J.D. McElgunn, Pasture Systems for the Cow-Calf. Agr. Can. Res. Sta., Swift Current, Sask.

Lawrence, T., and F.B. Dyck. 1990. A comparison of two furrow opener-depth control assemblies for seeding forage grasses. J. Range Manage. 43:82–83.

Malik, N., and J. Waddington. 1990. No-till pasture renovation after sward suppression by herbicides. Can. J. Plant Sci. 70:261–267.

McLaughlin, N.B., and F.B. Dyck. 1986. Directory of research equipment developed at the Swift Current Research Station. Agr. Can. Res. Br. Tech. Bull. 1986–9E.

Sheehy, J.E. 1989. How much dinitrogen fixation is required in grazed grassland? Ann. Bot. 64:159–161.

Smith, E.M., T.H. Taylor, J.H. Casada, and W.C. Templeton. 1973. Experimental grassland renovator. Agron. J. 65:506–508.

Sprague, M.A. 1960. Seedbed preparation and improvement of unplowable pastures using herbicides. Proc. 8th. Int. Grassl. Congr. 264–266.

Squires, N.R.W., R.J. Haggar, and J.G. Elliott. 1979. A one-pass seeder for introducing grasses, legumes, and fodder crops into swards. J. Agr. Eng. Res. 24:199–208.

USDA-SCS. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Agr. Handbk. 436. U.S. Gov. Print. Off., Washington, D.C.

Vough, L.R., and A.M. Decker. 1983. No-till pasture renovation. J. Soil and Water Conserv. 38:222–223.

Waddington, J., and K.E. Bowren. 1976. Pasture renovation by direct drilling after weed control and sward suppression by herbicides. Can. J. Plant Sci. 56:985–988.

Welty, L.E., P.F. Hensleigh, and V.R. Stewart. 1983. Methods for sod-seeding of small-seeded legumes and grasses. Montana Agr. Exp. Sta. Bull. 752. Bozeman, Mont.