Evaluation of Interseeding Seedbed Preparation and Sod Control Techniques

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Successful interseeding of alfalfa into grassland ecosystems requires the use of methods that prepare a suitable seedbed and effectively control the competition for soil water, nutrients, and sunlight from the established plant community. Both of these important conditions need to be produced mechanically by a set of toolbar plow shank tools that do not cause major destruction to the existing landscape. The interseeding seedbed preparation and sod control techniques trial evaluated variable furrow widths, variable widths of undercutting for sod control, the use of cultivator sweeps with the tip removed or left on to control competition from established sod, the effects of firming the seedbed with pack wheels or drag chains, and efforts to conserve soil moisture by covering the furrow with typical types of mulches. The objective of this study was to select a combination of toolbar plow shank tools that would prepare an adequate seedbed, control competition from the established sod effectively, and cause a minimum of landscape destruction.

Procedure

An interseeding seedbed preparation and sod control techniques furrow-width trial I was conducted from 1983 to 1988 on 0.60 acres located on the NE¼, NW¼, SW¼, sec. 23, T. 143 N., R. 96 W., at the Dickinson Research Extension Center Ranch Headquarters. The 33 X 50 foot plots were arranged in a randomized block design with three replications. The established plant community was mixed grass prairie. The soil was Vebar fine sandy loam. Travois alfalfa was used for all treatments. The seed was inoculated with rhizobium bacteria. The plots were interseeded 21 April 1983 at the seeding rate of 0.50 lbs PLS per row per acre. The unmodified toolbar interseeding machine constructed according to published plans (Chisholm et al. circa 1980) for the South Dakota State University pasture interseeder model 1979 was used with four plow shanks set at three-foot row spacings. The furrows were opened with 2-inch straight, 3-inch twisted, and 4-inch twisted chisel plow shovels (figures 1, 2, 3, 4, 5, and 6). A control plot with no interseeding treatment was included in each replication (Manske 1983).

An interseeding seedbed preparation and sod control techniques furrow-width trial II was conducted from 1985 to 1989 on 0.70 acres located on the SE¼, SW¼, SE¼, sec. 22, T. 143 N., R. 96 W., at the Dickinson Research Extension Center Ranch Headquarters. The 20 X 50 foot plots were arranged in a randomized block design with three replications. The established plant community was mixed grass prairie. The soil was Shambo loam. Anik, Kane, Rangelander, and Travois alfalfas were used for all treatments. The seed was inoculated with rhizobium bacteria. The plots were interseeded 11 April 1985 at the seeding rate of 0.50 lbs PLS per row per acre. The double toolbar interseeding machine developed by SDSU was modified by the addition of a third toolbar 30 inches behind the second toolbar. The modified toolbar interseeder was used with the plow shanks set at ten-foot row spacings. Seedbeds were prepared and the sod was controlled with various combinations of plow shank tools. Double straight coulters spaced 3 inches apart cut the sod ahead of 3-inch twisted chisel plow shovels that removed the sod from the furrow; the chisels were followed by cultivator sweeps set to undercut the sod at a depth of 1.5 to 2 inches below the soil surface. Furrows were opened with 2-inch straight, 3-inch twisted, 4-inch twisted, and 6-inch twisted chisel plow shovels without additional sod control from cultivator sweeps. The 3-inch chisel plow shovels were used with 6-, 12-, and 16-inch cultivator sweeps. A control plot of no interseeding treatments was included in each replication (Manske 1985).

An interseeding techniques cultivator sweep tip trial that evaluated the performance of the cultivator sweeps with the tip intact or with the tip removed was conducted from 1986 to 1989 on 0.28 acres located on the SE¼, SW¼, SE¼, sec. 22, T. 143 N., R. 96 W., at the Dickinson Research Extension Center Ranch Headquarters. The 20 X 100 foot plots were arranged in a randomized block design with three replications. The established plant community was mixed grass prairie. The soil was Shambo loam. Travois and Ladak alfalfas were used for all treatments. The seed was inoculated with rhizobium bacteria. The plots were interseeded 22 April 1986 at the seeding rate of 0.50 lbs PLS per row per acre. The modified interseeding machine with three toolbars was used with the plow shanks set at ten-foot row spacings. Double straight coulters spaced 3 inches apart, followed by a 3-inch twisted chisel plow shovel, followed by a 12-inch cultivator sweep with the tip intact or with the tip removed, were used to prepare the seedbed and control the sod. The cultivator sweep tip was cut in a reverse "V" shape that mirrored the angle of the sweep, with the widest part of the cut at three inches (Manske 1986).

An interseeding techniques seedbed-firming trial that evaluated the performance of pack wheels (figure 11) and drag chains (figure 12) was conducted from 1986 to 1989 on 0.28 acres located on the SE¼, SW¼, SE¼, sec. 22, T. 143 N., R. 96 W., at the Dickinson Research Extension Center Ranch Headquarters. The 20 X 100 foot plots were arranged in a randomized block design with three replications. The established plant community was mixed grass prairie. The soil was Shambo loam. Travois and Ladak alfalfas were used for all treatments. The seed was inoculated with rhizobium bacteria. The plots were interseeded 22 April 1986 at the seeding rate of 0.50 lbs PLS per row per acre. The modified interseeding machine was used with the plow shanks set at ten-foot row spacings. The furrows were opened with double straight coulters spaced 3 inches apart, followed by a 3-inch twisted chisel plow shovel with a pack wheel or a drag chain behind the shank, followed by a 12-inch cultivator sweep (Manske 1986).

An interseeding techniques furrow-mulch trial (figures 13, 14, 15, 16, 17, and 18) that evaluated the performance of various types of mulches was conducted from 1988 to 1989 at the Dickinson Research Extension Center Ranch Headquarters. The plots were arranged in a randomized block design with three replications. The established plant community was mixed grass prairie. The soil was Shambo loam. Travois and Ladak alfalfas were used for all treatments. The seed was inoculated with rhizobium bacteria. The plots were interseeded 13 April 1988 at the seeding rate of 0.50 lbs PLS per row per acre. The modified interseeding machine was used with the plow shanks set at ten-foot row spacings. The furrows were opened with double straight coulters spaced 3 inches apart, followed by a 3-inch twisted chisel plow shovel, followed by a 12-inch cultivator sweep that had the point removed. Crested wheatgrass hay and oat straw were ground by a hay chopper and applied into the interseeded furrows of selected plots immediately after seeding. Strips of black plastic sheets were pinned to the ground to cover the selected furrows for a period of two weeks following seeding. A control interseeded treatment with no mulch added to the furrows was included in each replication (Manske 1988).

Alfalfa density was determined by counting plants per meter of row. Plant heights were determined by measuring from soil surface to top of plant. Alfalfa density and height data were collected monthly during June, July, and August.

Additional data were collected from the treatment plots of techniques trial I (Manske 1983). Aboveground herbage biomass production was sampled by the clipping method during the period with peak herbage (late July to early August). Six quarter-meter frames were clipped to ground level for each treatment. The clipped frames were placed central to the furrows, on the intact plant community, for each furrow-width treatment. Herbage was separated into biotype categories: short cool-season grasses, short warm-season grasses, mid cool-season grasses, mid warm-season grasses, sedges, and forbs. The samples were oven dried at 140°F. Quantitative species composition was determined by percent basal cover sampled with the ten-pin point frame method. The frames were placed across the furrows. Forb density was determined by identifying to species each plant rooted within 25 one-tenth-meter-square quadrats per plot (Manske 1987). Differences between means were analyzed by a standard paired-plot t-test (Mosteller and Rourke 1973).

Results and Discussion

Most of the growing seasons during the interseeding seedbed preparation and sod control techniques trial (1983-1989) received low-normal precipitation (table 1). The growing season of 1986 had four months with high rainfall, and the growing season was considered wet. One growing season, that of 1988, received less than 40% of normal rainfall and was considered to have severe drought conditions.

The alfalfa plant densities (table 2) on the furrow-width techniques trial I were low and ranged between 0.76 and 0.15 plants per meter of row after the first growing season. During each year of the study, there was no difference in interseeded alfalfa densities among the furrow-width trial I treatments with the furrows opened by 2-, 3-, and 4-inch chisel plow shovels. The alfalfa plant densities (table 3) on the furrow-width trial II treatments with the furrows opened by 2-, 3-, 4-, and 6-inch chisel plow shovels were generally low and ranged between 2.97 and 0.50 plants per meter of row. The 3-inch twisted chisel plow shovel was the narrowest tool that produced a suitable furrow and seedbed. The 4-inch and 6-inch twisted chisels were wider than the 3-inch chisel, but their use did not improve the density of established alfalfa plants. The furrows opened by three-inch chisel plow shovels followed by cultivator sweeps that undercut the sod had satisfactory plant densities that ranged between 6.87 and 0.87 plants per meter of row (table 3). During the first two years of the trial, alfalfa plant densities were not significantly different ($P<0.05$) among treatments with the three sizes of cultivator sweeps (table 3). During the following three years, alfalfa plant densities were significantly greater ($P<0.05$) on the 12-inch sweep treatments than on the 6-inch sweep treatments (table 3). Alfalfa plant densities on the 12-inch sweep and the 16-inch sweep treatments were not significantly different ($P<0.05$) during the first four years of the trial. During the fifth year of the trial, alfalfa plant densities were significantly greater ($P<0.05$) on the 12-inch sweep treatments than on the 16-inch sweep treatments (table 3). The 16-inch sweep undercut a larger area of the established plant community than the 12-inch sweep, but use of the larger sweep did not improve the density of established alfalfa plants. The treatment with 12-inch cultivator sweeps had the greatest plant density during each year of the study (figures 7, 8, 9, and 10).

Alfalfa plant heights (table 4) were not significantly different ($P<0.05$) among the furrow-width trial I treatments during each growing season of the study. Alfalfa plant heights (table 5) were not significantly different ($P<0.05$) among the furrow-width trial II treatments during each growing season after the first year. Alfalfa plant heights were greater during 1987 than during the other growing seasons on both furrow-width trials (tables 4 and 5).

Evaluation of the effects from interseeding treatments is very different from interpretation of data collected from undisturbed plant communities, because the disturbed portion of the interseeded study area is different from the intact portion of the treatment area. The data collected from the intact portion and the data collected from the disturbed area represent variable proportions of the entire treatment. The size of the seedbed, the size of the total area disturbed, and the size of the intact plant community need to be determined for each treatment, and the values for the collected data require appropriate adjustments in order to correspond to the proportions of the different areas within the total treatment plot. The theoretical size of the interseeded seedbed in square feet and the percent of land area per acre can be determined based on the furrow width and the number of rows per rod (table 6).

The measured total area of actual disturbance, including the width of the furrow and the area of the deposited sod clods, was greater than the theoretical calculations for the disturbed portion of the treatment plots of furrow-width trial I (table 7). The differences between the measured percent disturbance and the calculated theoretical area of disturbance increased as the width of the chisels decreased. The percent seedbed area disturbed was 36.3%, 77.5%, and 115% greater than the width of the chisel for the 4-inch, 3-inch, and 2-inch chisels, respectively. Chisel plow shovels do not cut clean edges but rip out areas of sod wider than the chisel (figures 1, 2, 3, 4, 5, and 6). The problem of creation of a furrow width larger than the chisel width can be corrected by cutting the sod with two straight coulters placed side by side ahead of chisel plow shovels; the chisels will then remove the cut furrow sod strips cleanly.

Herbage production data were collected from frames placed central to the furrows, on the intact plant community portion of the plots. The raw data from this method provided information on herbage biomass production for the intact portion of the treatment only. Prorating these values to reflect the percent land area with an intact plant community provided information on herbage biomass production for the entire treatment area.

The effects of the interseeding mechanical treatment did result in increased herbage production by the plants on the intact plant community of the 3- and 4-inch chisel treatments (table 8). Herbage production for the interseeded treatments ranged from about 2% to 11% greater than the herbage production on the control treatment, which had no mechanical disturbance. A portion of each treatment area except the control was disturbed by interseeding and produced no grassland herbage. The loss of herbage production from the disturbed area was greater than the percent herbage increase on the intact portion for all furrow-width treatments. The prorated herbage biomass production was greatest on the 3-inch twisted chisel plow shovel treatment (table 8). The increase in herbage production on the intact portion of interseeded treatments was presumably caused by the increase in the amount of nitrogen released by the decaying organic matter in the overturned sod and the increase in availability of soil water from the removal of some plant competition during the mechanical interseeding treatment.

Herbage biomass produced by each biotype category for all of the furrow-width trial I treatments was not significantly different ($P<0.05$) from the herbage biomass produced by the same biotype category on the control treatment (table 9), except the 3-inch treatment produced greater warm-season short grass herbage and less warm-season mid grass herbage than the control treatment, and the 2- and 3-inch treatments produced less sedge herbage than the control treatment. The 4-inch treatment produced more warm-season mid grass herbage than the 3-inch treatment. The 3-inch treatment produced more cool-season short grass and warm-season short grass herbage than the 4-inch treatment. The 3-inch treatment produced more cool-season mid grass herbage than the 2-inch treatment (table 9).

Grass basal cover and total plant basal cover (table 10) on the 4-inch furrow width treatments were significantly lower ($P<0.05$) than the respective basal cover on the control treatment. The grass basal cover and total plant basal cover on the 2- and 3-inch furrow-width treatments were not significantly different ($P<0.05$) from those on the control treatment (table 10). Total forb basal cover for each of the furrow-width treatments was not significantly different ($P<0.05$) from that for the control treatment (table 10). All of the furrow-width treatments had less grass, forb, and total plant basal cover than the control treatment. The 3-inch treatment had greater grass basal cover and total plant basal cover than the 4-inch treatment (table 10).

Cool-season grass basal cover on the 4-inch furrow-width treatment was greater than, but not significantly different from, that on the control treatment (table 11). Cool-season grass basal cover on the 2- and 3-inch furrow-width treatments was less than, but not significantly different from, that on the control treatment (table 11). Warm-season grass basal cover on the 4-inch furrow-width treatment was significantly less ($P<0.05$) than that on the control treatment (table 11). Warm-season grass basal cover on the 2- and 3-inch furrow-width treatments was greater than, but not significantly different from, that on the control treatment (table 11). Sedge basal cover on the 2-, 3-, and 4-inch furrow-width treatments was less than, but not significantly different from, that on the control treatment (table 11). The 2-inch treatment had less cool-season grass basal cover than the 4-inch treatment. The 3-inch treatment had greater warm-season grass basal cover than the 4-inch treatment (table 11).

Late-succession forb basal cover on the 2-, 3-, and 4-inch furrow-width treatments was less than, but not significantly different from, that on the control treatment (table 11). Mid and early succession forb basal covers on the 2-, 3-, and 4-inch furrow-width treatments were not significantly different ($P<0.05$) from those on the control treatment (table 11).

Late-succession forb density per square meter on the 2-, 3-, and 4-inch furrow-width treatments was lower than, but not significantly different from, that on the control treatment (table 12). Mid and early succession forb density on the 2-, 3-, and 4-inch furrow-width treatments was greater than, but not significantly different from, that on the control treatment (table 12). Total forb density per square meter on the 2-, 3-, and 4-inch furrow-width treatments was lower than, but not significantly different from, that on the control treatment (table 12).

The 2-inch straight spike prepared a furrow that was extremely narrow at the bottom and much wider near the soil surface. The sides of the furrow were irregular because the 2-inch spike ripped out large pieces of sod. The sod did not roll out of the furrow onto the intact plant community. Instead, the straight spike directed the sod strips into the air above the furrow and some of the sod clods fell back into the furrow.

The 3-inch twisted chisel plow shovel prepared an excellent seedbed with a “V” bottom, and the furrow had adequate width near the soil surface. The sod strips were removed from the furrow, and the sod clods were deposited on the adjacent intact plant community satisfactorily.

The 4-inch twisted chisel plow shovel removed the sod strips from the furrow and deposited the sod clods on the adjacent intact plant community satisfactorily. The quality of the seedbed produced by the 4-inch chisel was less than desirable because the tool had a flat cutting edge like the plowshare on a moldboard plow.

The 6-inch twisted chisel plow shovel removed the sod strips from the furrow satisfactorily. The furrow had a “V” bottom, but the furrow was wider than necessary and the great width of the chisel caused a large portion of the treatment area to be disturbed.

Alfalfa plant density per meter of row on the treatment with the tip of the cultivator sweep removed was 33.6% greater than, but not significantly different ($P<0.05$) from, alfalfa plant density on the treatment with the tip of the cultivator sweep left on (table 13).

Alfalfa plant height (table 13) was not significantly different (P<0.05) between the cultivator sweep tip treatments. The results of this small study did not conclusively show the importance of removing the tip from the cultivator sweeps.

The function of the cultivator sweep is sod control of the established plant community adjacent to both sides of the furrow. The sweep fins undercut the sod and separate the crowns of grass plants from a large portion of the grass plants' roots. The undercut sod remains in place, and the result is a relatively smooth land surface unlike the extremely rough terrain produced by lister-type interseeding machines. The grass plants are not killed, but their growth processes are greatly impaired, and the result is a reduction in competition from the established plant community for soil water and nutrients. The 6-inch sweeps do not undercut a large enough area on each side of the furrow to reduce the competition from the established plant community adequately. The area the 12-inch sweeps undercut on each side of the furrow is adequate to reduce the competition sufficiently. The 16-inch sweeps undercut an area larger than the 12-inch sweeps, but the effects are not greater than those resulting from use of the 12-inch sweep.

The cultivator sweeps follow the 3-inch twisted chisel plow shovels, which are set to produce a furrow 3 inches wide and 3 inches deep. The cultivator sweeps are set to undercut the sod at a depth of 1.5 to 2 inches below the soil surface. The cultivator sweep passes over the seedbed, 1 to 1.5 inches above the deposited alfalfa seed. The portion of the sweep directly over the furrow serves no function and can cause seedbed disturbance that results in reduced seedling emergence and fewer seedlings per meter of row. Removal of the tip of the cultivator sweep by cutting a reverse "V" shape that mirrors the angle of the sweep, with the widest part of the cut at three inches, the same width as the furrow, can eliminate potential seedbed disturbances.

Alfalfa plant density per meter of row and alfalfa plant height were not different (P<0.05) between the pack wheel (figure 11) and drag chain (figure 12) treatments (table 14). The small seeds of grasses and legumes can desiccate easily when they are directly exposed to air. The rate of desiccation is greatly reduced when the seeds are covered completely with soil. A drag chain used following the deposition of the seeds into the seedbed helps cover the small seeds with soil. A pack wheel used following the deposition of seeds into the seedbed firms the soil above the seed; the firming helps the soil act like a blotter, allowing moisture to move upward and helping maintain moisture closer to the soil surface (Goplen et al. 1980).

Alfalfa plant density per meter of row (table 15) on the crested wheatgrass hay and the oat straw mulch treatments was significantly lower (P<0.05) during the first year of the trial than that on the control treatment with no mulch. During the second year, the alfalfa plant density per meter of row on the crested wheatgrass hay mulch treatment was significantly lower (P<0.05) than that on the control treatment, but the alfalfa density on the oat straw mulch treatment was not significantly different (P<0.05) from that on the control treatment. Alfalfa plant height (table 16) on the crested wheatgrass hay and the oat straw mulch treatments was not significantly different (P<0.05) from that on the control treatment. Alfalfa plant density per meter of row on the black plastic mulch treatment was lower than, but not significantly different from, that on the control treatment (table 15). Alfalfa plant height on the black plastic mulch treatment was greater than, but not significantly different from, that on the control treatment (table 16).

The intention of the mulch treatments (figures 13, 14, 15, 16, 17, and 18) was to conserve soil moisture in the furrows and increase the amount of available water to the alfalfa seedlings. The hay and straw mulch treatments were very detrimental to alfalfa plant establishment. The black plastic mulch treatment was less detrimental than the hay and straw mulch treatments but also did not benefit alfalfa plant establishment.

Conclusion

The combination of toolbar plow shank tools that prepared an adequate seedbed and effectively controlled competition from the sod required the addition of a third toolbar onto the interseeding machine (figure 19). The plow shank on the front toolbar carried double straight coulters that were placed side by side and three inches apart and were set to cut the sod to a 3-inch depth. The plow shank on the middle toolbar carried a 3-inch twisted chisel plow shovel set to produce a furrow 3 inches wide and 3 inches deep, with the "V" point extending a little deeper. The plow shank on the back toolbar carried a 12-inch cultivator sweep with the tip removed by a cut in a reverse "V" and the fins of the sweep set to undercut the sod at a depth of 1.5 to 2 inches below the soil surface.

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Table 1. Precipitation in inches for growing-season months at DREC Ranch Headquarters, North Dakota.

Years	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season
Long-term mean	1.41	2.15	3.27	2.72	1.80	1.44	1.22	14.01
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59
% of LTM	14.9	71.2	100.0	94.1	247.2	59.7	59.0	97.0
1984	2.87	0.00	5.30	0.11	1.92	0.53	0.96	11.69
% of LTM	203.5	0.0	162.1	4.0	106.7	36.8	78.7	83.4
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80
% of LTM	87.9	151.2	48.3	39.3	102.2	117.4	174.6	91.4
1986	3.13	3.68	2.58	3.04	0.46	6.32	0.18	19.39
% of LTM	222.0	171.2	78.9	111.8	25.6	438.9	14.8	138.4
1987	0.15	1.38	1.15	5.39	2.65	0.78	0.08	11.58
% of LTM	10.6	64.2	35.2	198.2	147.2	54.2	6.6	82.7
1988	0.00	1.85	1.70	0.88	0.03	0.73	0.11	5.30
% of LTM	0.0	86.0	52.0	32.4	1.7	50.7	9.0	37.8
1989	2.92	1.73	1.63	1.30	1.36	0.70	0.96	10.60
% of LTM	207.1	80.5	49.8	47.8	75.6	48.6	78.7	75.7

Table 2. Alfalfa plant density per meter of row for the furrow-width trial I.

Furrow Width	1st year 1983	2nd year 1984	3rd year 1985	4th year 1986	5th year 1987	6th year 1988	Means of growing seasons after 1st year
2 inch	14.82a	0.76a	0.15a	0.29a	0.51a	0.35a	0.41a
3 inch	13.85a	0.74a	0.20a	0.31a	0.34a	0.32a	0.38a
4 inch	11.47a	0.63a	0.24a	0.26a	0.46a	0.38a	0.39a

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 3. Alfalfa plant density per meter of row for the furrow-width trial II.

Furrow Width	1st year 1985	2nd year 1986	3rd year 1987	4th year 1988	5th year 1989	Means of growing seasons after 1st year
2 inch	16.93a	2.97bc	1.57c	1.37c	1.02b	1.73ab
3 inch	14.88a	1.77c	0.83cd	0.80d	0.50b	0.98ab
4 inch	14.12a	1.33c	0.67d	0.87d	0.88b	0.94b
6 inch	15.93a	1.17c	0.70d	0.73d	0.76b	0.84b
6 inch sweep	24.98a	4.30ab	1.60bc	1.73bc	0.93b	2.14ab
12 inch sweep	29.72a	6.87a	3.23a	2.37a	1.90a	3.59a
16 inch sweep	28.87a	6.87a	2.83ab	2.07ab	0.87b	3.16ab

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 4. Alfalfa plant height (inches) for the furrow-width trial I.

Furrow Width	3rd year 1985	4th year 1986	5th year 1987	6th year 1988	Means of growing seasons
2 inch	7.68a	13.62a	16.99a	10.19a	12.12a
3 inch	8.63a	12.82a	18.52a	9.88a	12.46a
4 inch	7.30a	11.64a	14.71a	9.58a	10.81a

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 5. Alfalfa plant height (inches) for the furrow-width trial II.

Furrow Width	1st year 1985	2nd year 1986	3rd year 1987	4th year 1988	5th year 1989	Means of growing seasons after 1st year
2 inch	1.53ab	6.65a	15.74a	10.20a	12.25a	11.21a
3 inch	1.61ab	5.69a	14.71a	7.75a	10.71a	9.72a
4 inch	1.41b	6.01a	16.33a	10.14a	11.23a	10.93a
6 inch	1.10b	5.64a	16.02a	10.15a	9.85a	10.42a
6 inch sweep	1.49b	5.58a	14.20a	8.89a	10.51a	9.80a
12 inch sweep	1.77ab	6.19a	14.97a	8.25a	10.44a	9.96a
16 inch sweep	1.81a	5.86a	15.11a	7.49a	9.33a	9.45a

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 6. Theoretical calculations for land area of seedbed prepared by interseeding machine in square feet and percentage of an acre for four furrow widths and six row spacings.

		Row Spacing					
Furrow Width		2 foot	3 foot	4 foot	5 foot	8 foot	10 foot
2 inch	sq ft	3703	2468	1854	1481	925	741
	%	8.50	5.67	4.26	3.40	2.12	1.70
3 inch	sq ft	5445	3630	2726	2178	1362	1089
	%	12.50	8.34	6.25	5.00	3.13	2.50
4 inch	sq ft	7187	4792	3598	2875	1795	1437
	%	16.50	11.00	8.26	6.60	4.12	3.30
6 inch	sq ft	10890	7260	5452	4356	2723	2178
	%	25.00	16.67	12.52	10.00	6.25	5.00

Table 7. Theoretical and measured percent seedbed, total disturbance, and intact area per acre of furrow-width treatments.

	Percent seedbed area per acre		Percent total disturbance per acre		Percent intact area per acre	
	Theoretical Calculation	Measured	Theoretical Calculation	Measured	Theoretical Calculation	Measured
Furrow Width	%	%	%	%	%	%
Control		0.0		0.0		100.00
2 inch	5.67	12.19	11.34	22.73	88.66	77.27
3 inch	8.34	14.80	16.68	23.11	83.32	76.89
4 inch	11.00	14.99	22.00	26.85	78.00	73.15

Table 8. Total herbage biomass determined for only the intact portion and for the combined intact and disturbed portions of each treatment.

	Total herbage biomass on only the intact portion of each treatment		Total herbage biomass on the combined intact and disturbed areas of each treatment	
Furrow Width	lbs/ac	% of control	lbs/ac	% of control
Control	1075.40	100.00	1075.40	100.00
2 inch	1072.50	99.73	795.55	73.98
3 inch	1191.90	110.83	897.99	83.50
4 inch	1093.45	101.68	764.60	71.10

Table 9. Mean herbage biomass production (lbs/ac) from intact and disturbed areas of furrow-width treatments and percentage of herbage biomass from control treatments.

Furrow Width		Cool Short	Warm Short	Cool Mid	Warm Mid	Sedge	Forb	Total
Control	lbs/ac	167.20ab	135.75b	244.00ab	59.75a	233.15a	235.55a	1075.40a
2 inch	lbs/ac	167.80ab	192.38ab	139.63b	22.08ab	132.82b	140.83a	795.55a
	%	100.36	141.72	57.23	36.95	56.97	59.79	73.98
3 inch	lbs/ac	187.47a	261.02a	188.04a	4.05b	118.67b	138.77a	897.99a
	%	112.12	192.28	77.07	6.78	50.90	58.91	83.50
4 inch	lbs/ac	123.73b	102.87b	227.04a	37.90a	138.45ab	134.63a	764.60a
	%	74.00	75.78	93.05	63.43	59.38	57.16	71.10

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 10. Mean basal cover for grasses, forbs, and total live plants (including woody and succulent species) for furrow-width treatments and percentage of basal cover for control treatments.

	Grasses		Forbs		Total	
Furrow Width	Basal Cover	% of Control	Basal Cover	% of Control	Basal Cover	% of Control
Control	24.73a		3.00a		27.97a	
2 inch	21.91ab	88.60	2.25a	75.00	24.29ab	86.84
3 inch	24.32a	98.34	2.48a	82.67	27.02a	96.60
4 inch	20.38b	82.41	2.27a	75.67	22.85b	81.69

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11. Mean basal cover for graminoid and forb biotypes and percentage of the control treatment for furrow-width treatments.

	Graminoids			Forbs		
Furrow Width	Cool Season	Warm Season	Sedge	Late Succession	Mid Succession	Early Succession
Control	6.02ab	11.68a	7.03a	2.80a	0.10a	0.10a
2 inch	4.28b	12.70ab	4.92b	2.09a	0.10a	0.06a
% of Control	71.10	108.73	69.99	74.64	100.00	60.00
3 inch	5.80ab	13.29a	5.23b	2.26a	0.20a	0.02a
% of Control	96.35	113.78	74.40	80.71	200.00	20.00
4 inch	7.36a	8.45b	4.58b	2.08a	0.12a	0.07a
% of Control	122.26	72.35	65.15	74.29	120.00	70.00

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 12. Forb density per square meter and percentage of control treatment for furrow-width treatments.

	Forbs				
Furrow Width	Late Succession	Mid Succession	Early Succession	Mid and Early Succession	Total Forbs
Control	64.8a	6.9	2.8	9.7a	74.5a
2 inch	33.6a	10.9	1.8	12.7a	46.3a
% of Control	51.85			130.93	62.15
3 inch	24.7a	10.9	3.7	14.6a	39.4a
% of Control	38.12			150.52	52.89
4 inch	37.8a	12.9	0.6	13.5a	51.3a
% of Control	58.33			139.18	68.86

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 13. Alfalfa plant density per meter of row and plant height (inches) for the cultivator sweep tip trial.

Sweep Tip Status	1986	1987	1988	1989	Mean
Plants/meter of row					
Sweep Tip off	21.01a	5.92a	4.64a	1.81a	8.35a
Sweep Tip on	13.55a	5.15b	4.57a	1.72a	6.25a
Plant height (in)					
Sweep Tip off	4.61x	12.59x	7.66x	8.06x	8.23x
Sweep Tip on	5.08x	12.60x	8.08x	7.22x	8.24x

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 14. Alfalfa plant density per meter of row and plant height (inches) for the seedbed firming trial.

Treatment Type	1986	1987	1988	1989	Mean
Plants/meter of row					
Pack wheel	25.80a	6.26a	4.78a	1.67a	9.63a
Drag chain	23.70a	5.98a	4.91a	2.02a	9.15a
Plant height (in)					
Pack wheel	4.54x	12.40x	7.38x	8.02x	8.09x
Drag chain	4.98x	13.81x	8.22x	7.38x	8.60x

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 15. Alfalfa plant density per meter of row for the furrow mulch trial.

Mulch Type	1988	1989	Mean
Control	11.62a	1.15a	6.39
Black Plastic	10.14a	0.59a	5.36
% of Control	87.26	51.30	83.88
Crested Wheat Hay	0.77b	0.17b	0.47
% of Control	6.63	14.78	7.36
Oat Straw	0.58b	0.78a	0.68
% of Control	4.99	67.83	10.64

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 16. Alfalfa plant height (inches) for the furrow mulch trial.

Mulch Type	1988	1989	Mean
Control	1.02a	6.56a	3.79
Black Plastic	1.23a	9.51a	5.37
% of Control	120.59	144.97	141.69
Crested Wheat Hay	1.03a	6.07a	3.55
% of Control	100.98	92.53	93.67
Oat Straw	0.87a	6.22a	3.55
% of Control	85.29	94.82	93.40

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Fig. 1. Two-inch straight spike chisel.

Fig. 2. Furrow made with two-inch straight spike chisel.

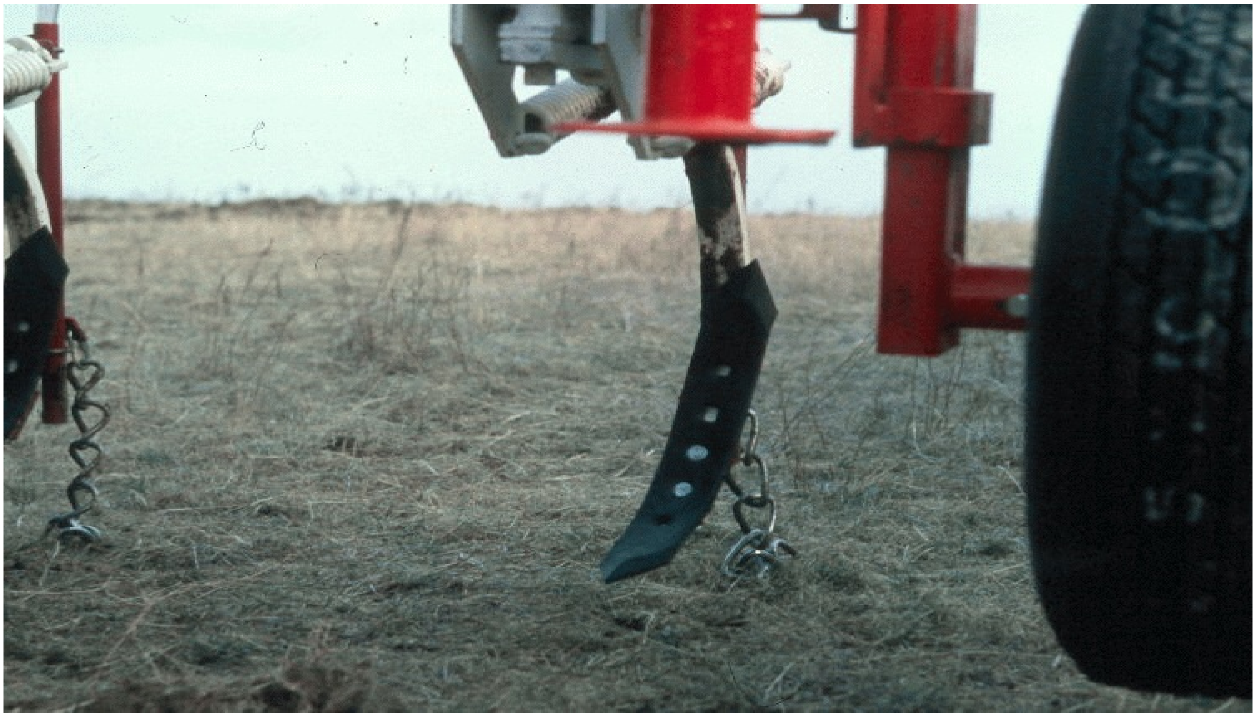

Fig. 3. Three-inch twisted chisel plow shovel.

Fig. 4. Furrow made with three-inch twisted chisel plow shovel.

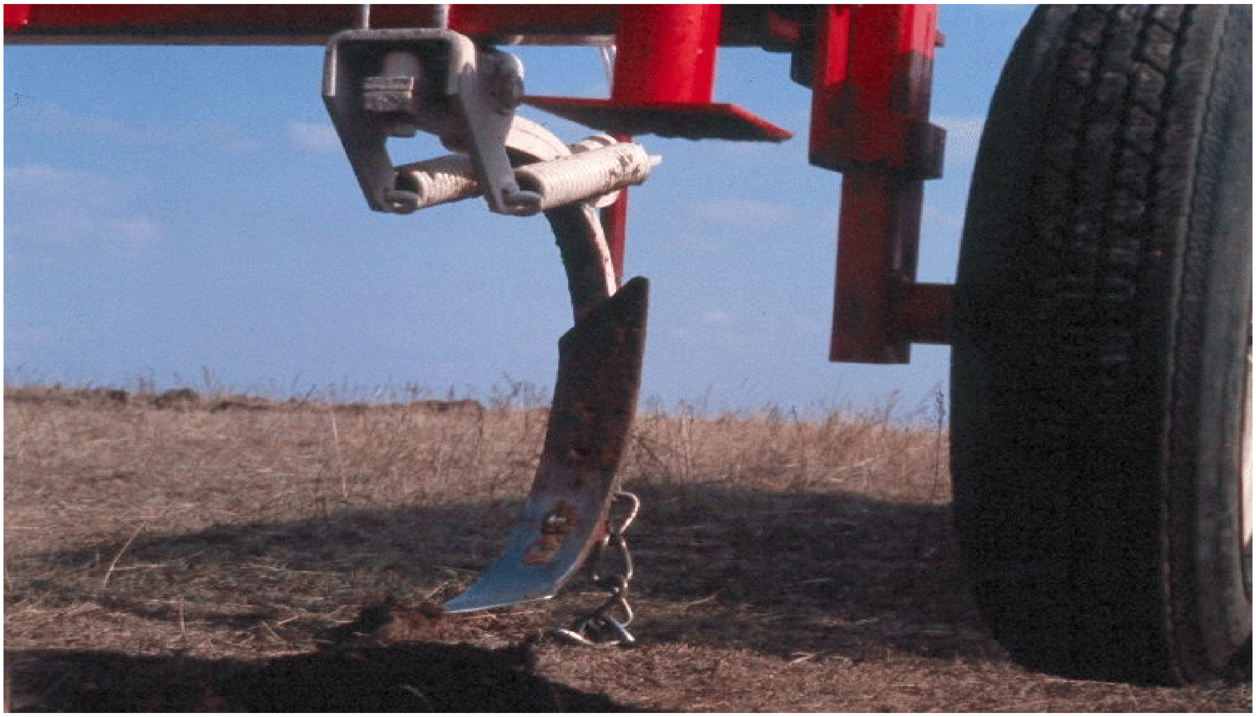

Fig. 5. Four-inch twisted chisel plow shovel.

Fig. 6. Furrow made with four-inch twisted chisel plow shovel.

Fig. 7. Interseeded furrow, year one.

Fig. 8. Interseeded furrow, year two.

Fig. 9. Interseeded furrow, year three.

Fig. 10. Interseeded mature alfalfa plant.

Fig. 11. Seedbed firmed with pack wheel.

Fig. 12. Seedbed firmed with drag chain.

Fig. 13. Black plastic furrow mulch.

Fig. 14. Furrow mulched with black plastic.

Fig. 15. Chopped crested wheatgrass hay furrow mulch.

Fig. 16. Furrow mulched with chopped hay.

Fig. 17. Chopped oat straw furrow mulch.

Fig. 18. Furrow mulched with chopped straw.

Fig. 19. Modified three toolbar interseeding machine. The front toolbar carries the double straight coulters placed side by side and three inches apart. The middle toolbar carries the three-inch twisted chisel plow shovel, the seed tube, and the pack wheel. The back toolbar carries the 12-inch cultivator sweep with the tip removed and the fertilizer tube.

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