Minimizing the Risk of Producing Winter Wheat in North Dakota.
I. The Effect of Tillage on Snow Depth, Soil Temperature, and Winter Wheat Survival

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Winter wheat production in North Dakota has the reputation of being "risky" because of the inability of winter wheat plants to survive typical North Dakota winters. Salmon (1917) found a strong correlation between the northern boundary of winter wheat production and an average annual air temperature of 48°F. Erickson (1974) redefined this temperature as 42°F for newer, more hardy varieties. Only the southwestern corner of North Dakota is normally this warm and historically has been the only area of significant winter wheat production in the state.

Winter wheat survival is dependent on the plant's crown surviving the winter. Gusta and Fowler (1977) and Gullard et al. (1975), using growth chambers, found that crown damage occurs at temperatures ranging from 2 to − 5°F for the hardiest varieties. Variation in the critical temperature may be attributed to varietal differences, time of exposure, fall hardening conditions, and soil moisture. The crown is located approximately 1 inch below the soil surface making soil temperature at this depth an important consideration (Fowler et al., 1976).

Soil temperature at or near the surface is similar to air temperature but the presence of snow cover drastically alters this relationship. Regression equations describing the relationship between air and soil temperatures for a given snow depth (Larsen at al., 1983, Aase and Siddoway, 1979) suggest that as little as 3 inches of uniform snow cover will protect winter wheat from air temperatures as low as − 40°F.

The amount of snow retained depends on the amount of surface residue or surface roughness. Studies in North Dakota and eastern Montana showed increased survival of winter wheat when sown with a hoe drill because snow trapped in the bottom of the furrows insulated the plants from lethal air temperatures (Alessi and Power, 1965; Aase and Siddoway, 1979). Reduced or no-tillage systems trap snow because of increased surface residue. As a result, large increases in acreage of winter wheat have occurred in all areas of North Dakota as reduced or no-tillage systems have increased in popularity (Cox, 1985).

Incorporating winter wheat into a spring seeded crop rotation provides producers the opportunity to perform field operations over a longer time period. Winter wheat also competes with annual weeds and has the potential to outyield spring wheat. In addition, snow management will provide additional soil moisture and in some years allows continuous cropping rather than fallow, reducing soil erosion and saline seeps (Black et al., 1976).

The intent of this article is: 1) to present results of a field study designed to examine the effect of tillage on snow depth, soil temperature, and winter wheat survival and 2) to report on the probability of occurrence of weather conditions conducive to winter wheat production.

MATERIALS AND METHODS

A field trial to determine effects of tillage systems on winter wheat survival was initiated in 1981 at the Microclimatic Research Station (MRS) located on the main station of the North Dakota State University Agricultural Experiment Station at Fargo. Three tillage systems, implemented just prior to September seeding, were conventional (plow, disk, and harrow), reduced (disked barley stubble), and no-till tall stubble (seeding directly into 7-inch barley stubble). Conventional tillage was discontinued in 1983 (due to poor seedbed conditions) and replaced with a no-till short stubble treatment (seeding directly into 2 inch flax stubble). Flax stubble was used in 1983-84 and 1984-85 to minimize developing disease problems associated with the barley - winter wheat rotation.

Two varieties of hard red winter wheat, Roughrider (good winterhardiness) and Centurk 78 (moderate winterhardiness), were seeded in side-by-side strips replicated three times within each tillage treatment. Seeding dates ranged from September 2 to September 18. The seeding rate was 60 pounds per acre.

Hourly soil temperatures at 1-inch depths (approximately crown depth) were measured with copper-constantan thermocouples at three locations within each tillage treatment along with an air temperature at the standard 5-foot height. Wooden dowels painted in 1-inch bicolor increments were used to measure snow depths immediately above the location of the measured soil temperatures and at nine other fixed locations within the plot area. The painted dowels allowed measurements to be observed from outside the plot area without compacting the snow within the plots. Daily values were obtained by measuring snow depth several times a week or at times when snow depths would change due to snowfall, high winds, or melt.

Percent survival of winter wheat was determined by fall and spring stand counts and by visual estimation at spring regrowth and harvest. Snowfall normals and the probability of obtaining continuous snow cover were determined by analyzing records from 12 National Weather Service (NWS)

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stations. These stations were chosen because they had nearly complete records and were distributed fairly uniformly across the state.

Continuous snow cover was arbitrarily defined as at least 30 continuous days with snow depths of 3 inches or more. A computer program was written to find periods of continuous snow cover from 1949-1983. It was noted, especially in the southwest, that periods of continuous snow cover would often be broken by one or two days with depths less than 3 inches. Therefore, the definition of continuous snow cover was modified to accept up to three days with snow depths less than 3 inches and still be considered continuous.

EXPERIMENTAL RESULTS

Climatic conditions varied widely during the study and represented both extreme and near normal conditions (Table 1). The first winter (1981-82) was the most severe as the minimum daily air temperature fell below −20°F sixteen times and December through February snowfall totaled 51 inches, or more than 200 percent of normal (Table 1). However, winds removed most of the snow from the conventional tilled plot leaving between 0 and 2 inches during most of the winter. This sparse snow cover resulted in soil temperatures below −10°F on January 16 and February 5, well below the critical temperature for winter wheat survival (Figure 1).

Snow depth in the reduced tillage plot was generally 1 inch or more greater than the conventional tilled plot. This additional snow cover provided enough insulation to maintain soil temperatures near 0°F. The no-till tall stubble plot retained more than 6 inches of snow and the lowest soil temperature recorded was 16°F, well above the critical temperature for winter wheat. Average snow depths, minimum soil temperature, and percent winter wheat survival for each tillage treatment and year are listed in Table 2.

During the 1984-85 winter, air temperatures approached −20°F on only five days. Total snowfall for December through February was 14 inches or 67 percent of normal. No snowfall event was greater than 3 inches. The light snows were generally blown from the reduced and no-till short stubble plots almost as quickly as they fell, resulting in 2 inches or less snow cover. Air temperature measured −26°F on January 19 and near −20°F the first four days of February. Minimum crown depth soil temperatures were −4°F in the reduced and no-till short stubble treatments on January 19 and February 4 (Figure 2). The no-till tall stubble treatment retained 4 to 5 inches of snow and the lowest soil temperature was 14°F.

Table 1. Selected climatic conditions and departure from normal (Dep) for the months December, January, and February at Fargo, ND.

	Temperature		Snowfall		Minimum Temperature < −10 F		Minimum Temperature < −20 F	
Year	Average (in)	Dep	Total (in)	Dep	Freq (days)	Dep	Freq (days)	Dep
1981-82	3.4	−5.9	51	+30	43	+17	16	+8
1982-83	19.5	+10.2	6	−15	4	−22	0	−8
1983-84	11.3	+2.0	26	+6	23	−3	9	+1
1984-85	8.5	−0.8	14	−7	24	−2	3	−5

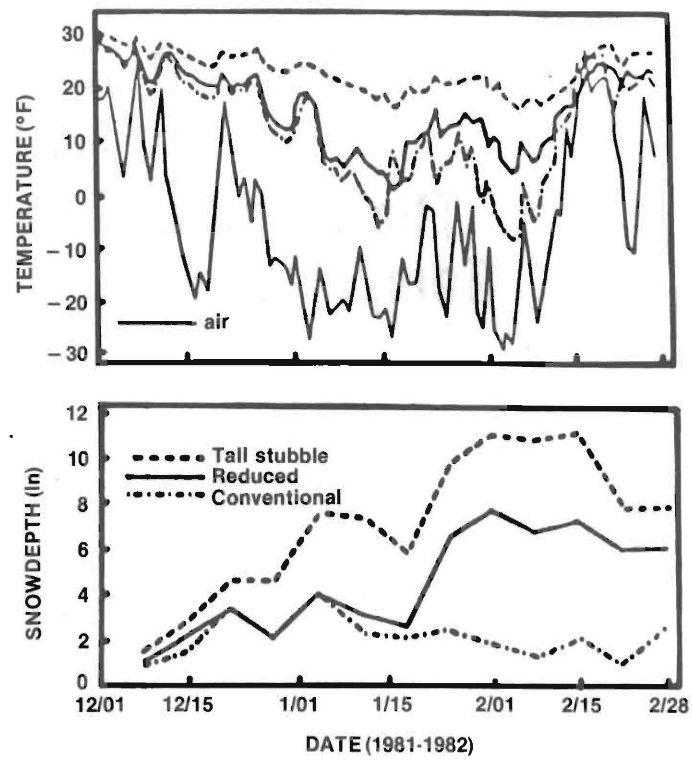

Figure 1. Daily snow depth and minimum air and 1 inch depth soil temperature measured within different tillage systems in 1981-82 at Fargo, ND.

Table 2. Effect of tillage on snow depth, minimum soil temperature, and winter wheat survival at Fargo, ND.

		Tillage Treatment			
Year	Variable[1]	Conventional	Reduced	Short Stubble	Tall Stubble
	SD(in.)	2.1	3.4	NA	7.1
1981-82	MST(F)	−10.1	0	NA	16.3
	WWS(%)	10	50	NA	100
	SD(in.)	0.1	0.2	NA	2.3
1982-83	MST(F)	2.7	−0.4	NA	11.7
	WWS(%)	100	100	NA	100
	SD(in.)	NA	4.8	4.5	8.3
1983-84	MST(F)	NA	5.5	8.2	21.0
	WWS(%)	NA	100	100	100
	SD(in.)	NA	1.2	1.0	4.0
1984-85	MST(F)	NA	−6.9	−8.0	9.5
	WWS(%)	NA	49	44	100

[1]snow depth = SD, minimum soil temperature = MST, winter wheat survival = WWS

Survival percentages at spring regrowth were 5, 40, and 100 percent for conventional, reduced, and no-till tall stubble treatments, respectively, in 1982, and 50, 50, and 100 percent in the reduced, no-till short stubble, and no-till tall stubble, respectively, in 1985. Crown depth soil temperature proved to be a good indicator of winter wheat survival. Complete kill occurred in areas where soil temperature reached −10°F. In 1981-82 and 1984-85 soil

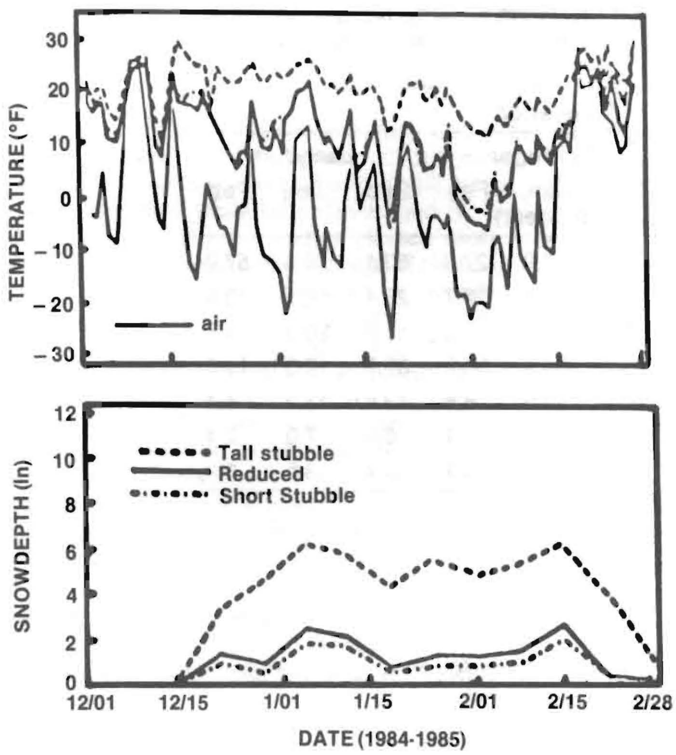

Figure 2. Daily snow depth and minimum air and 1 inch depth soil temperature measured within different tillage systems in 1984-85 at Fargo, ND.

temperatures between 0 and −4°F resulted in average survival rates of 20 and 70 percent for Centurk 78 and Roughrider, respectively. However, in February 1983, soil temperatures fell to −0.4°F and no winterkill was detected, but the time of exposure to temperatures below 5°F was only 30 hours in 1983 compared to 125 hours in 1982 and 243 hours in 1985. These data agree with those from growth chamber experiments (Gusta et al., 1983). They found that the hardiest crowns could tolerate −9°F for 12 hours but would only tolerate −0.4°F for 24 hours and 5°F for six to seven days.

No winterkill occurred during the 1982-83 winter. The December-February average air temperature was the second warmest in a 105-year record at Fargo. Survival was near 100 percent in 1983-84 as November snowfall provided protection from record low temperatures that occurred in December 1983. For the remainder of the winter, temperatures moderated and 4 inches or more snow cover existed across all treatments. More information on survival and yields for this experiment is reported by Cox et al. (1987).

SNOW COVER AND MINIMUM AIR TEMPERATURES IN NORTH DAKOTA

Winter wheat survival will not be affected by low air temperatures if 3 inches or more snow cover is maintained on the field. A snow climatology for the state was prepared to find the probability of receiving and maintaining continuous snow cover. Mean seasonal snowfall is approximately 35 inches for most of the state but decreases to 25 inches in the southwest corner. The probability of continuous snow cover of at least 3 inches by January 1, shown in Figure 3, ranges from just 30 percent in the southwest to 75 percent in the north central and northeast. Furthermore, the possiblity of having continuous snowcover at any time during the winter can be expected in less then 50 percent of the winters at Hettinger, while at Bottineau, continuous snow would be expected in 95 percent of the winters (Figure 4). This implies that with proper snow management the likelihood of winter wheat survival may in fact be better in other areas of the state than the traditional winter wheat area of the southwest.

However, potentially lethal air temperatures do not necessarily occur in North Dakota every year, especially in the south and southwest. A long term risk factor would be better determined analyzing snow depth and air temperature together. A joint frequency distribution was determined for daily minimum air temperature and snow depth. The percent frequency of minimum daily air temperature less than 0, −10, and −20°F, snow depths less than 3 inches, and low air temperatures occurring on days with low snow depths at Fargo, Hettinger, and Langdon are contained in Table 3.

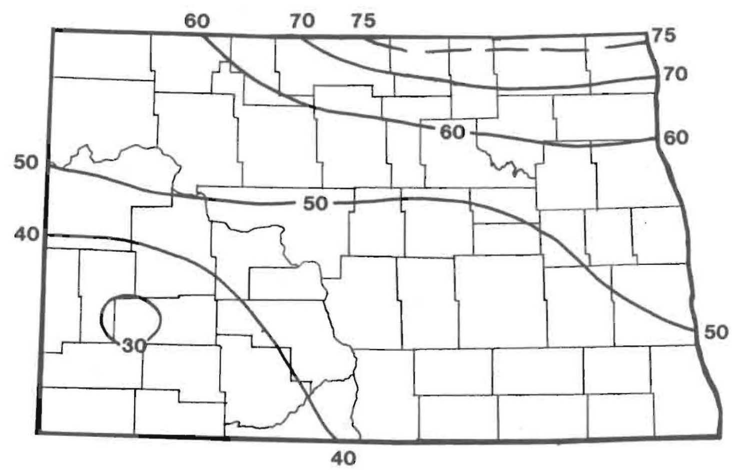

Figure 3. The probability of receiving 3 inches of continuous snow cover by January 1 in North Dakota.

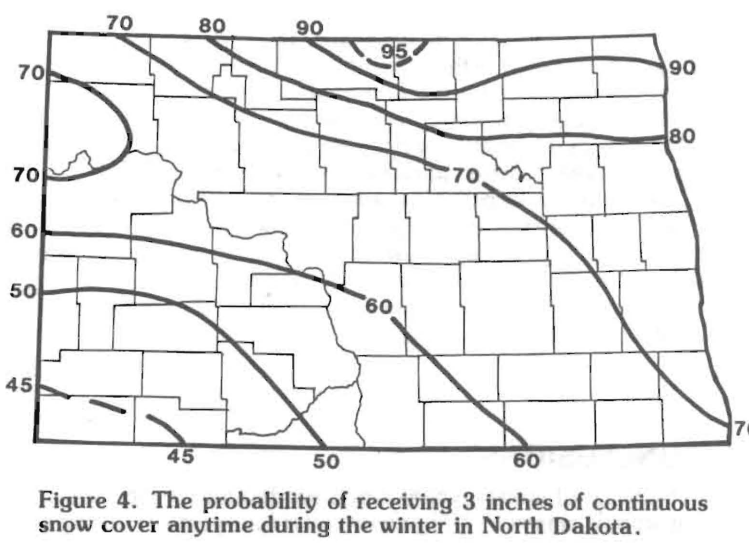

Figure 4. The probability of receiving 3 inches of continuous snow cover anytime during the winter in North Dakota.

Table 3. Frequency and joint frequency of selected minimum air temperature and 3 inch snow depth recorded at three locations from 1949-1983 by National Weather Service observers.

	Location								
	Fargo			Hettinger			Langdon		
Criteria	Dec.	Jan.	Feb.	Dec.	Jan. (percent)	Feb.	Dec.	Jan.	Feb.
Min temp <0 F.	38.0	62.0	45.3	26.3	43.9	27.3	53.1	74.3	57.0
Min temp < −10 F.	17.2	39.2	22.7	11.6	26.5	10.7	29.4	52.7	33.6
Min temp < −20 F.	3.5	14.8	6.7	3.2	9.0	2.0	11.0	26.9	14.8
Snow Depth <3 in.	54.0	28.9	30.7	64.7	54.4	55.5	37.7	19.3	11.0
<0 F and <3 in.	12.7	12.4	8.1	10.0	13.9	8.8	13.8	11.2	4.4
< −10 F and <3 in.	4.1	6.6	2.6	3.5	8.1	2.1	6.5	7.0	2.4
< −20 F and <3 in.	0.2	0.9	0.4	1.0	1.9	0.1	1.7	3.5	1.0

Minimum temperatures less than or equal to −20°F occurred on 14.8 percent of January days at Fargo. Snow depths less than 3 inches occurred on 28.9 percent of the days. The combined effect of these percentages (0.148*0.289) indicates that 4.3 percent of January days should have minimum air temperatures below −20°F and snow depths less than 3 inches, but actually this occurs on only 0.9 percent of the days. This tendency for low air temperatures to occur when snow depths are greater than 3 inches can be attributed to small amounts of absorbed solar radiation and reduced heat transfer from the soil due to the snow. Note the slightly higher risk at Hettinger than at Fargo (1.9 percent vs. 0.9 percent) and the small difference between the risk factor at Hettinger and Langdon despite a four times greater probability that minimum temperatures less than or equal to −20°F occur at Langdon than at Hettinger.

SNOW DEPTH COMPARISONS

One problem with using NWS snow depth values to study the feasibility of winter wheat production is the relationship between these measurements and the depth of snow maintained in standing stubble or on an open field. Snow depth values measured during the winter wheat experiment were compared with NWS measurements at Fargo, located just 2 miles north of the site.

Analysis indicates that the days the NWS reported no snow, snow depth in the tall stuble averaged 3.7 inches, and there is a tendency for the two measurements to equalize as the snow depths increase. The comparison of the NWS data with plots that had little or no residue showed very little correlation. This occurs because the NWS procedure is to measure snow depth in a somewhat protected location. These measurements may approximate snow conditions in a reduced or no-tillage system better than that of a bare field. This comparison points out that some form of snow management is necessary to keep risks as low as those indicated in Table 3.

CONCLUSIONS

Survival of winter wheat when seeded into 7-inch standing stubble was near 100 percent over four years of testing at Fargo. The stubble trapped adequate snowcover to maintain crown depth soil temperatures above a critical level. Winter wheat survival in adjacent tilled plots was less than 50 percent in two of four years.

An analysis of 34 years of air temperature and snow depth records indicate near equal but small risks of winterkill exist in all areas of the state if snow management is practiced. Using no-tillage, flax strips, or thinly seeded cover crops are recommended snow management practices for winter wheat production in North Dakota (Ball et al., 1985).

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Continued from page 8

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