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Seedbed Design for Minimizing Sugar Beet (*Beta vulgaris*) Seedling Damage by Mild Radiation Freezes[1]

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ABSTRACT

Greenhouse and field tests were made to evaluate the frost protection afforded by various seedbed designs. Planting in pockets was the most effective in reducing radiative freeze damage to sugar beet (*Beta vulgaris*) seedlings in the two-leaf stage. Pockets were 7.5 cm in diameter by 5 cm deep, formed at 45° to the horizon in 45° south-facing slopes on sides of 20-cm-high soil ridges. During freeze periods, leaf temperatures of the plants in the pockets averaged 3.4 C and 2.2 C higher than leaf temperatures of plants in the conventional seedbed under greenhouse and field conditions, respectively. Temperature differences were not as great under field conditions because of low soil temperatures. The planting system could, however, add 2 weeks to the spring growing season for sugar beets in southern Idaho, provided soil temperatures are high enough for germination.

Additional index words: **leaf temperature, air temperature, frost protection.**

HEAT is lost from plants by three distinctly different mechanisms: molecular conduction, latent heat transfer, and electro-magnetic radiation (1, 5). Radiation cooling of soil and plant surfaces is a continuous process. The influx of solar energy more than compensates for radiation cooling during the daylight hours, but at night the longwave terrestrial radiation results in net heat loss to the sky. Climatological conditions favoring nocturnal cooling include clear skies or high clouds (6.4 km), wind absence, low vapor pressures with subzero dew point temperatures, low thermal conductivities, and low specific heat capacities of the soil and plant (2). Nocturnal cooling by longwave radiation is pronounced in desert climates and results in such low night temperatures that surface freezing may occur even though daytime temperatures reach 40 C (10). Shaw (9) demonstrated that longwave radiation to a cold sky may result in leaf temperatures 4.5 C cooler than the adjacent air temperature.

Under radiant freeze conditions, leaves may be at the same or cooler temperature than the underlying soil surface. The net radiant heat exchange between the plant and soil is dependent upon the differences in surface temperatures. Conditions resulting in greater soil heat capacity and subsequent higher soil surface temperatures would favor a net radiation to the plant. There should be, therefore, an optimum seedbed geometry for which the leaves would receive maximum energy from the soil while losing the least energy to the sky.

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EXPERIMENTAL PROCEDURE

Sugar beets (*Beta vulgaris*) were planted in the greenhouse during late winter in preirrigated silt loam soil contained in boxes 75 by 180 by 35 cm. Sugar beets were also planted in the field on April 18, which was about 1 week after the normal planting date. The three principal seedbed geometries and planting designs for both experiments (as shown in Fig. 1) were:

a. Conventional planting — seeds planted 1.5 cm deep under a level soil surface adajacent to an irrigation furrow
b. Punch planting (3) — seeds dropped in open holes 0.6 cm in diameter and 2.5 cm deep on a level surface adjacent to an irrigation furrow
c. Pocket planting — seeds planted 1 cm deep near the bottom of holes 7.5 cm in diameter and 5 cm deep placed at 45° to the southern horizon on 20-cm-high soil ridges having slopes of 45°

Plants in all three seedbed designs were exposed to the same freeze treatment for a given greenhouse test.

Other designs tested in the greenhouse included seeds planted in holes 5 cm or 2.5 cm in diameter and 3 cm deep. These tests were made with the holes on level surfaces and in the south-facing slope. Trenches 2.5 cm wide and 3 to 4 cm deep, small terraces, benches, and slots shaped on the 20-cm-high soil ridge were also tested.

In a third study, air and soil temperatures associated with treatments a and c were measured in the field very early in the spring (March 30) before seedlings normally could be established.

Radiation cooling in greenhouse tests was simulated by a dry ice technique (7). The metal chamber-ceiling was modified to give an arc of 90° on a 50-cm radius. The simulated cold sky was partially insulated during tests by the accumulation of frost from water vapor condensation, but was measured on one occasion at less than −35 C.

Temperatures were measured with 127 μ copper-constantan thermocouples. For leaf temperature measurements, the thermocouple leads were curved upward, forcing the junction to be held against the underside of the leaf by weak spring tension. Cooling rate, from ambient to 0 C, was 0.1 to 0.3 C per minute. Temperatures were adjusted by regulating the quantity of dry

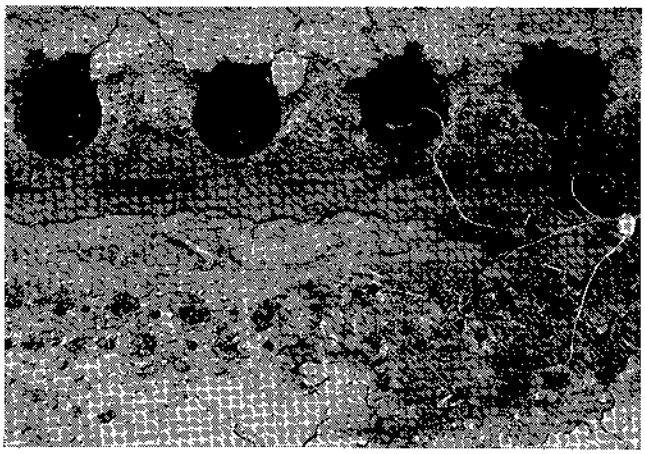

Fig. 1. Conventionally planted seedlings alternated with punch planted seedlings are shown in the foreground. Seedlings in pockets may be seen on the soil ridge. The wires lead to the 127 μ thermocouples.

ice on the ceiling and by adjusting a small air gap between the soil surface and the bottom of the freeze chamber. The latter adjustment was minimized to decrease advective heat exchange with the outside air.

Treatment effects on sugar beet seedlings were visually evaluated 1 or 2 days after the frost period. Seedlings that were damaged at the apical point or that were blackened below the terminal growing tip were classified as frozen. Leaf temperatures reported in this study were the data points obtained at 15-minute increments on the continuous temperature curves. Differences between leaf temperatures of two designs in an individual freezing test were evaluated by the t-test (6). Differences in survival were evaluated by this same test.

Survey experiments showed that sugar beet seedlings in the 2-leaf (cotyledonal) stage were more susceptible to radiative freeze damage than were plants in the 4- to 10-leaf stage. Seedlings in the 6- to 10-leaf stage were only slightly damaged by 4- to 5-hour exposure to −1.8 C leaf temperatures, whereas the plants with two leaves were frozen at −0.5 to −1.0 C temperatures. The experimental data reported here represent studies on plants in the 2-leaf stage.

RESULTS AND DISCUSSION

The results of the greenhouse freezing tests are shown in Table 1. An average of 84% of the seedlings planted in pockets survived compared to only 10% of those conventionally planted. Differences in survival in these two designs were found to be significantly different from zero at .015 level. Plants in the pockets were favored because of smaller radiation exposure to the cold roof, higher air temperatures and by receiving more radiation energy from the sides of the pocket. The mean leaf temperatures of plants in the pockets were 3.4 C warmer than the mean leaf temperatures of plants in the conventional planting. Leaf temperatures of the punch-planted (temperature data not presented) and conventionally planted treatments were not detectably different. There was, however, a tendency for the punch-planted seedlings to survive better than the conventionally seeded plants, although the differences were not statistically significant. Frost damage to seedlings occurs if ice crystals, growing from the freezing soil, penetrate the seedling stem. This would not happen in punch planting. However, the soil surface did not freeze in most of these greenhouse experiments.

Preliminary results indicated that pockets with 5-cm diameters were as effective as those with 7.5-cm diameters. However, when the diameter was reduced to 2.5 cm, seedling survival was decreased. Seedling survival on miniature benches, in slots, and trenches was no better than in the conventional planting. All leaf temperatures, regardless of seedbed design, varied by ±0.5 C during any 15-minute period of the freezing cycle. This variation was caused by advective heat exchange with the air. Leaf temperatures were slightly lower than the surrounding air temperatures, suggesting a significant radiative heat loss to the chamber.

Air temperature measurements in the field during the very early spring verified the trends shown in the greenhouse experiment (Fig. 2). Even though the soil was still quite cold (− 1 and + 18 C mean minimum and maximum, respectively), pocket air temperatures were consistently higher than tempartures 2.5 cm above the conventional seedbed. When the weather was windy and overcast, there was about 1 C difference between the minimums. On calm, clear nights there was as much as a 5 C difference between the minimums, and the freezing period in the pockets was shorter than over the conventional seedbed. Afternoon temperatures in the pockets were also warmer than those above the conventional bed. While minimum seed zone temperatures in the pockets were warmer, the mean soil temperature was about 1.8 C cooler than the conventional seedbed. This could adversely affect the emergence of sugar beets if they were planted very early. Available data indicate that the time required for germination increases sharply as the soil temperature falls from 9 to 6 C (4, 8).

On April 18, after the soil in the field had warmed enough for good germination, the trends noted in the greenhouse experiment were again verified with seedling leaf temperatures. Emergence was also observed in this field trial. On May 3, average emergence counts for the four replicates were 31, 16, and 2% for pocket, punch, and conventional designs, respectively. These differences were significant at the .05 level when checked by analysis of variance. Emergence by May 9 was not significantly different for any of the three designs. A natural frost occured on May 11. As shown in Fig. 3, the minimum leaf temperature in the pocket was 1 C higher during this night than for plants in the conventional seedbed. The period of freezing temperature in the pockets was 1 hour shorter than for the conventional planting, however, none of the temperatures were low enough to freeze any of the plants in either treatment. On May 22, some dead seedlings were observed in both the pocket and con-

Table 1. Leaf temperatures and survival of sugar beet seedlings in three seedbed designs exposed to simulated radiative freezes in the greenhouse.

Test	Duration of freeze	Mean leaf temperature: Conventional	Mean leaf temperature: Pocket	P(Δ T≠0)*	Survival: Conventional	Survival: Punch	Survival: Pocket
	hours	C	C	%	%	%	%
1	5.0	−2.2	+1.7	> 99	0	0	100
2	4.5	−4.4	+2.1	> 99	0	25	42
3	4.8	−1.3	+0.1	90	35	41	80
4	3.5	−2.0	+1.5	> 99	18	33	96
5	3.0	−1.9	+1.0	98	0	16	88
6	6.0	−2.0	+0.3	> 99	11	16	79
7	5.8	−3.1	+0.6	90	18	4	86
8	5.2	−2.7	+0.5	> 99	0	--	100
Mean	4.7	−2.4	+1.0		10	19	84

* Probability that differences in leaf temperatures of conventional and pocket planting are not equal to zero as determined by t-test.

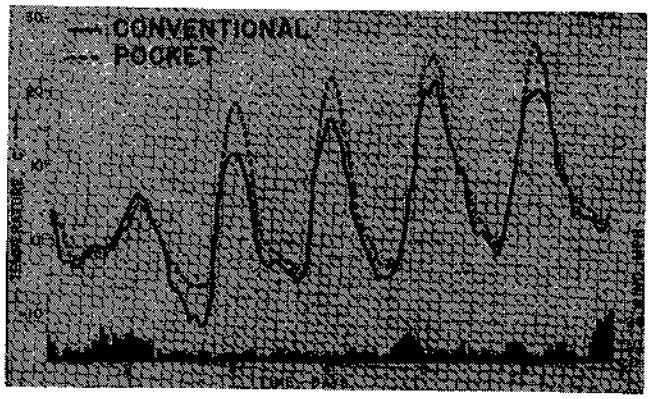

Fig. 2. Sequence of thermocouple temperatures in plant-simulating positions and climatological conditions for conventional and pocket planting design. Windspeed at height of 1.5 m is indicated by the bar graph. The weather during the first day was heavy overcast, followed by 2.5 cm of snow just before dark on the second evening. Clearing followed and fair weather prevailed for the next 2-1/2 days. Partly cloudy conditions then developed and increased until a light rain set in during the early morning hours of the last day.

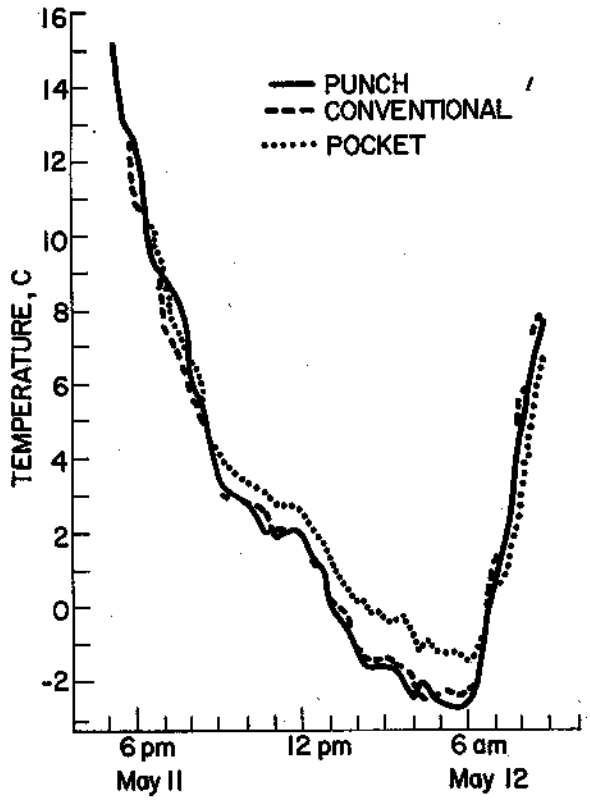

Fig. 3. Sugar beet leaf temperature for punch, conventional, and pocket seedbed designs during the night on which frost occurred.

ventional seedbeds. Mortality was higher in the pockets where wilting had been observed during a short period of unseasonably warm weather. This mortality may have resulted from a lack of soil moisture during the afternoons when high temperatures prevailed in the pockets, from covering of seedlings by sloughing of soil into the pockets, or from disease.

Other possible field problems associated with the pocket planting, in addition to possible lower average seedbed temperature, include the shading of the seedlings during the early morning and later afternoon hours, and the requirement for a stable soil surface so that the pockets do not cave in. However, the method does offer some economical frost protection because no additional labor or materials would be required other than the development of appropriate planting machinery.

The higher minimum leaf temperature afforded by the pocket planting method, in contrast to conventional planting, is small, yet important. For example, weather records in the Twin Falls, Idaho, area show that a protection of 2.2 C has a 90% probability of increasing the frost-free spring growing season by 2 weeks. Consequently, the pocket planting method warrants further investigation where early spring radiation frosts are a hazard.

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