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# INFLUENCE OF SNOW FENCE AND CORN WINDBREAKS ON MICROCLIMATE AND GROWTH OF IRRIGATED SUGAR BEETS

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# Influence of Snow Fence and Corn Windbreaks on Microclimate and Growth of Irrigated Sugar Beets[1]

Norman J. Rosenberg[2]




## ABSTRACT

During the 1964 growing season, irrigated sugar beets were sheltered against wind at the Scotts Bluff Experiment Station, University of Nebraska, by snow fence erected at planting time and by double rows of corn planted as early in the season as possible.

Germination was improved in areas protected by snow fence, although the effect was not uniform throughout the sheltered area. Both types of shelter increased root and total weight of beets over that in an unsheltered site. Top weight was not affected. Root/top ratio was greatest in corn-sheltered beets. Sugar content at harvest was depressed in beets grown in the snow fence sheltered areas. Press juice samples of corn-sheltered beets showed greatest purity.

Air temperature above the sheltered beets was higher by day and lower by night than in the open site. Absolute humidity content of air above the beets was not influenced by shelter.

The snow fence shelter altered the wind profile, raising the zero plane to within the top quarter of the sheltered beet canopy. Wind shear in that plot suggested a reduction in turbulent exchange. In the corn-sheltered plot, wind profiles were similar to those in the open with a moderate reduction of wind speed at the two levels above the canopy at which measurements were made. An intensification of temperature lapse rate in the corn shelter may have increased rate and extent of turbulent exchange processes.


WIND SHELTER is an effective technique for improving growth, yield, and quality of sugar beets. An ample literature of agronomic studies verifies this fact.

Andersen, as reported by Van der Linde (11), summarized 6 years of data collected in Denmark during the period 1909–1924 showing that the yield of sugar beets protected from west winds was increased by 23% over yields in the open. A maximum yield increase of 41% and a minimum yield increase of 9% were found during these years. In Denmark, Jensen (5) found that protected sugar beets outyielded unprotected beets by 3 to 9% in fresh weight of roots and by 12 to 16% in tops, depending on the degree of wind protection. Two years of experimentation on sandy soils in northwest Germany by Bender, as reported by Van der Linde (11), indicated that beet and top yields could be increased some 12 to 16% by wind shelter. Sugar content increases as great as 20% were noted in these studies.

Results of research in western Europe indicate, perhaps, the smallest benefits. In the maritime climates of western Europe, moisture stress caused by inadequate rainfall and/or excessive transpirational demand is far less intense than in any other region in which sugar beets are normally grown. Recent reviewers (Van Eimern, 12; Van der Linde, 11) suggest the major influence of shelterbelts on plant growth to be due to soil moisture conservation. Therefore, even more striking results should be expected from the arid and semi-arid regions of the world where sugar beets are grown.

Suss (10) reported the yield of table beets increased by 226% when grown in the shelter of young trees in the Saratove region of the USSR. Gorshenin et al. (4) reported that shelter on irrigated land in the Volga region raised the yield of fodder beets by 7.1% in 1930 and by 106% in 1931. Sokolova (8) found that shelter increased the mean stand of table beets by 65% and raised yield by 46% over that of beets grown in the open in the Gusel District of the USSR. Quality (size distribution) of the beets grown in shelter was also superior to that of unprotected beets.

To determine whether influences other than moisture conservation account for their improved growth, sugar beets were grown in shelter under a minimal-stress irrigation regime during 1964 at the Scotts Bluff Experiment Station of the University of Nebraska. Two types of shelter were provided and plant response, microclimate, and alteration of wind passage and wind profile in their lee were studied and compared with conditions in an open location.

## METHODS AND MATERIALS

### Design

On April 13, 1964, sugar beets were planted in an irrigated field on the Scotts Bluff Experiment Station of the University of Nebraska. Wind shelters of the following kinds were evaluated during the growing season:

- (SF) Snow fences 4 feet high, 150 feet long, 50 feet apart, and of 57% permeability in 3 north-south rows, to provide shelter from before germination until the end of the growing season, erected on April 14
- (CN) Corn in 2 rows spaced at 22 inches, 150 feet long and 50 feet apart, in 3 north-south oriented strips to provide mid and late season protection for beets growing between the barriers. (Planted on May 7, the corn plants emerged on May 17 and reached a mean height of 6½ feet after tasseling.)
- (CK) A third and unprotected area of beets to serve as a check. (The check plots were placed so that a distance equal to at least 20 H (20 times the height) separated them from the nearest windbreak.)

The snow fence originally protected an area of 12 H. As the beets gained in height, the effective height of the barrier over the sheltered plants decreased so that the area between fences became equal to approximately 18 H. The corn, after it was fully grown, protected an area of roughly 7.5 H. The treatments were randomized in two replicate tiers. Because of improper leveling in part of one tier, plant observations and micrometeorological studies were restricted to the remaining tier.

Each main plot (except for CK) was protected by three windbreaks and, therefore, comprised two subplots labeled west (W) and east (E). Within each of these subplots, plant samples were taken from the west, center, and east portions. Differences due to the cumulative degree of protection afforded by single or double barriers were to be evaluated through this sampling procedure.

All plant and micrometeorological observations were made within the inner 50 feet of the plots. Figure 1 illustrates the rationale for this choice. The area of the inner section was fully sheltered when winds blew from the east in an arc of 45 to 135° and from the west in an arc of 225 to 315°. Three-fourths of this internal section was sheltered when winds blew from the sectors 27–45°, 135–153°, 207–225°, and 315–333°. Appendix I gives a weekly account of average and resultant wind speeds, resultant wind direction, constancy of wind direction, and percentage distribution of degree of wind protection (including calm). Results are presented by climatic week and were calculated by methods given in Brooks and Carruthers (1). The analyses of average and vector winds were programmed in Fortran for use with an IBM

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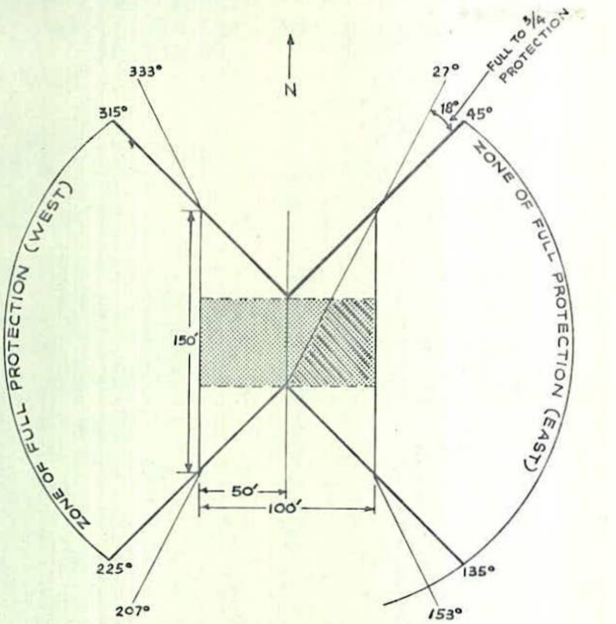


Fig. 1. Degree of protection afforded central sections of the triple windbreak plots.

1620 computer. The National Weather Records Center, Asheville, North Carolina, supplied data on hourly wind speed and direction at the Scottsbluff First Order Station, 8 miles SSE of the experimental site.

During the almost 29 weeks of the growing season, only once did less than three-fourths protection prevail for 25% of the time. The inner section was fully protected for more than 50% of the time during each week of the growing season. Mean weekly wind speed was about 10 to 16 mph from the beginning of the season until mid-May, 8 to 11 mph from mid-May until early August, 10 to 12 mph for the remainder of August and generally lower until the end of the season.

Constancy of wind direction (defined by the relation $V_r/V_s \times 100$, where $0\%$ = perfect circular distribution and $100\%$ = unidirectional flow) was quite low during the sugar beet growing season at Scotts Bluff in 1964. Except for occasional weeks in spring when winds blew almost entirely out of the north and west, no one direction predominated. The resultant of mid-May to mid-September winds was south and east. During the final weeks of the season, wind direction returned to the north and west quadrants.

## Soil

The sugar beets grew on Tripp v.f.s.l. The soil is uniform to a depth of 60 cm. Bulk density varies between 1.14 and 1.17 g $cm^{-3}$. Field capacity (1/10 bar suction) is about 28% water by weight. About 13% water by weight is held at a suction of 1 bar. At 15 bars suction, 7.5% water by weight is retained in the soil. Irrigation was guided by mercury-manometer tensiometers placed with the center of their ceramic cups at the 30 cm depth. Water was applied before suction registered by tensiometers reached 0.8 bars.

Gravimetric soil moisture samples were taken on August 27 and again on September 9 to determine if the barriers in any way influenced soil water removal by the beet plants which had then made complete canopy cover over the surface.

## Plant Observations

Stand counts were made in early May in randomly located strips 10 feet in length in each third row in all of the sheltered and exposed plots. Counts were made every second day for a period of about 2 weeks. Root and top weight of beets in each of the west, central, and eastern thirds of each treatment subplot were determined on 10 feet of row in late July. Root/top ratios were calculated.

In late August, early September, and mid-October (harvest time) 10 randomly selected beets were removed from each section of the plots. Root and top weight was determined and root/top ratio calculated. Sugar percentage was detertmined from an aliquot of the 10 beet sample. Press juice was extracted from each set of beet samples. "Juice dry substance," a measure of concentration of dissolved substances or solids, was determined from refractive index of the solutions. "Juice sucrose content" was determined by means of a polariscope. "Juice purity" was calculated from the relation

$$\text{purity} = .026 \text{ juice sucrose } \%/d \times \text{RDS}$$

where d = solution density at 20 C and RDS = refractometer dry substance. These techniques are described fully in the literature of sugar beet technology which will not be cited here.

## Statistical

The change in sampling procedure from 10 feet of row to 10 random beets was made to avoid undesirable alteration in canopy cover of the plots. The analysis of variance applicable to crop responses in this design has, as its only complication, the fact that position within the barrier is meaningless in CK and, therefore, unequal numbers of samples were required. Tukey's test for significant differences given by Snedecor (9) has been used to test treatment induced differences in plant yield and quality.

Appendix 1. Average and vector wind speed and direction at Scotts Bluff during the 1964 sugar beet growing season and degree of protection afforded the crop by snow fence and corn barriers.

| Climatic week | Dates | $V_s$, mph | $V_r$, mph | Resultant direction, 16 pts. | Constancy % | Degree of protection, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Calm | Full east | Full west | 3/4 east | 3/4 west | <3/4 |
| 5 | 4/1 - 4/4 | 11.4 | 5.8 | N | 51 | 8.3 | 26.0 | 26.0 | 11.5 | 8.3 | 19.9 |
| 6 | 4/5 - 4/11 | 11.4 | 9.0 | NW | 79 | 3.6 | 14.9 | 48.8 | 1.2 | 25.0 | 6.5 |
| 7 | 4/12 - 4/18 | 16.4 | 8.2 | WNW | 50 | 0.6 | 20.2 | 56.5 | 4.2 | 10.1 | 8.4 |
| 8 | 4/19 - 4/25 | 14.5 | 2.3 | ESE | 16 | 0.6 | 41.7 | 30.3 | 11.3 | 6.0 | 10.1 |
| 9 | 4/26 - 5/2 | 16.1 | 4.2 | N | 26 | 0.6 | 45.2 | 14.3 | 9.5 | 17.9 | 12.5 |
| 10 | 5/3 - 5/9 | 15.4 | 10.9 | WNW | 71 | 1.2 | 10.1 | 58.9 | 3.0 | 9.5 | 17.3 |
| 11 | 5/10 - 5/16 | 10.9 | 0.7 | ESE | 6 | 2.4 | 33.9 | 30.3 | 7.1 | 11.9 | 14.4 |
| 12 | 5/17 - 5/23 | 8.6 | 1.9 | ESE | 23 | 3.6 | 37.5 | 19.6 | 14.3 | 6.5 | 18.5 |
| 13 | 5/24 - 5/30 | 10.9 | 6.8 | SE | 62 | 1.8 | 55.9 | 4.8 | 16.1 | 6.5 | 14.9 |
| 14 | 5/31 - 6/6 | 8.3 | 0.9 | E | 11 | 4.2 | 28.0 | 23.8 | 13.1 | 5.4 | 25.5 |
| 15 | 6/7 - 6/13 | 11.0 | 0.7 | WNW | 6 | 0.6 | 40.5 | 37.5 | 8.3 | 4.8 | 8.3 |
| 16 | 6/14 - 6/20 | 10.0 | 1.6 | W | 16 | 2.4 | 25.6 | 45.8 | 10.1 | 5.4 | 10.7 |
| 17 | 6/21 - 6/27 | 8.9 | 1.7 | SSE | 19 | 0.6 | 48.2 | 21.4 | 5.4 | 7.7 | 16.7 |
| 18 | 6/28 - 7/4 | 7.8 | 1.4 | SE | 18 | 2.4 | 41.7 | 27.4 | 7.7 | 7.1 | 13.7 |
| 19 | 7/5 - 7/11 | 8.2 | 2.5 | ENE | 31 | 1.8 | 35.7 | 20.8 | 13.1 | 6.5 | 22.1 |
| 20 | 7/12 - 7/18 | 7.8 | 1.6 | SE | 21 | 1.2 | 47.6 | 30.3 | 3.6 | 6.0 | 11.3 |
| 21 | 7/19 - 7/25 | 8.7 | 4.5 | ESE | 52 | 1.8 | 59.5 | 16.1 | 7.1 | 2.4 | 13.1 |
| 22 | 7/26 - 8/1 | 8.3 | 3.9 | SE | 47 | 1.8 | 49.4 | 17.3 | 8.9 | 6.5 | 16.1 |
| 23 | 8/2 - 8/8 | 8.3 | 4.4 | SE | 53 | 1.8 | 58.3 | 11.3 | 6.5 | 1.8 | 20.3 |
| 24 | 8/9 - 8/15 | 10.2 | 4.1 | E | 41 | 0.6 | 60.7 | 21.4 | 0.6 | 4.8 | 11.9 |
| 25 | 8/16 - 8/22 | 12.3 | 3.9 | W | 31 | 0.0 | 35.7 | 50.0 | 1.2 | 2.4 | 10.7 |
| 26 | 8/23 - 8/29 | 10.3 | 2.0 | NW | 20 | 2.4 | 36.3 | 26.2 | 7.7 | 9.5 | 17.9 |
| 27 | 8/30 - 9/5 | 9.6 | 2.6 | ESE | 27 | 0.0 | 48.2 | 21.4 | 10.1 | 5.4 | 14.9 |
| 28 | 9/6 - 9/12 | 8.5 | 5.1 | E | 60 | 0.0 | 69.0 | 10.7 | 8.3 | 1.8 | 10.2 |
| 29 | 9/13 - 9/19 | 6.7 | 2.3 | E | 34 | 0.0 | 53.0 | 17.3 | 7.1 | 6.0 | 16.6 |
| 30 | 9/20 - 9/26 | 8.9 | 4.4 | NW | 49 | 0.0 | 26.8 | 41.1 | 2.4 | 11.3 | 18.4 |
| 31 | 9/27 - 10/3 | 10.3 | 1.1 | WNW | 11 | 0.0 | 27.4 | 20.8 | 8.3 | 8.9 | 34.6 |
| 32 | 10/4 - 10/10 | 9.3 | 2.1 | NW | 22 | 0.6 | 28.0 | 40.5 | 3.0 | 9.5 | 18.4 |
| 33 | 10/11 - 10/14 | 8.5 | 3.7 | NW | 44 | 0.0 | 25.3 | 48.3 | 4.6 | 8.0 | 13.8 |

### Microclimate and Aerodynamic Observations

Wind speed was monitored in one subplot of each treatment throughout the growing season with S.C.S. 3-cup anemometers coupled to an Esterline-Angus event meter. Each one-fourth-mile wind passage was recorded. A simultaneous record of wind direction was made with an 8-directional vane coupled to the same recorder.

During the period August 28 to September 15 a trailer-housed climatological research laboratory was in place in the Scotts Bluff sugar beet field. Wind speed was then monitored by means of Cassella 'sensitive' 3-cup anemometers placed at 60 and 120 cm above ground surface in one subplot of each of the three treatments. Wind direction was monitored with an 8-directional vane which has a voltage output proportional to direction.

During this period, soil and air temperature was measured with 24 gauge copper-constantan thermocouples placed at —10, 60, 120, and 200 cm. Dew point temperature was measured with Honeywell 'dew probes' at an elevation of 60 cm. Net radiation was measured with 'miniature net radiometers' designed by Fritschen (2). These were at an elevation of 160 cm above the ridge surface in one subplot of each treatment.

A Datex meteorological data recording system described by Fritschen and van Bavel (3) monitored and recorded emf-producing sensors and recorded accumulated contact signals from the anemometers. For details of instrumentation, see Rosenberg (7) and Rosenberg and Allington (6). All microclimatic and wind profile observations were made on the half hour, 24 hours a day, throughout the period, except during the daylight hours of August 29, when a 15-minute sampling sequence was used.

Air temperature and wind speed data were used to compute Richardson number (Ri) on a mean hourly basis. Ri is given by the relation:

$$Ri = g(T_{120} - T_{60})/(T_a + 273°)\ (u_{120} - u_{60})^2$$

where $g$ = acceleration due to gravity, $T_{120}$, $T_{60}$, $u_{120}$, $u_{60}$ are temperatures (°C) and wind speeds (m sec$^{-1}$) at the levels 120 and 60 cm, respectively, and $T_a$ was taken as the temperature at an intermediate level, ~ 85 cm (determined by linear interpolation from the measured temperature lapse rate).

## RESULTS

### Plant Observations

*Germination and stand.* The mean plant count per 10 feet of row in SF for six sampling times is compared in Fig. 2 to the mean for all other treatments. Since CN had not yet been planted, counts from these plots constituted a further check on SF influence on stand. Near the fences and in the middle of SF stand count was significantly greater than in CK. In the region of 7 to 10 rows from the west and about 5 rows from the eastern barriers, stand count was no better than in CK and in one case it was worse.

The increase of stand count with time in SF and CK plots is illustrated in Fig. 3. When the first observations were made (May 7), stands were significantly greater in SF than in CK. Differences continued to be significant until May 13. After that time differences diminished although stand count remained higher in SF until observations were discontinued on May 17.

*Plant growth and yield.* The influence of SF and CN barrier shelter on total, top, and root weight, and on root/top ratio for each of the four dates on which these measurements were made is shown in Table 1. The influence of subplot position is also shown.

The total weight of beets growing in shelter was significantly increased above that in CK on July 23. Beets were consistently heavier in shelter throughout the season except on September 14, when weight of beets in SF was not different from that in CK. Position in the sheltered plots had no influence on total weight at any time during the season. Total weight did not change in any of the treatments during the period August 28 to October 12.

Table 1. Effect of shelter type, position within shelter, and period of growing season on growth and yield of sugar beets.

| Trait and dates | | Treatment | | | Position | |
|---|---|---|---|---|---|---|
| | | CK | SF | CN | West | East |
| Total weight, lb. | July 23 | 15.7 a* | 21.2 b | 24.3 b | 21.5 a | 23.9 a |
| | Aug. 28 | 30.4 aA | 36.2 bA | 36.6 bA | 36.1 aA | 36.8 aA |
| | Sept. 14 | 36.0 aA | 33.4 aA | 42.1 bA | 38.9 aA | 36.5 aA |
| | Oct. 12 | 33.8 aA | 37.5 bA | 37.7 bA | 40.5 aA | 34.7 aA |
| Root weight, lb. | July 23 | 4.7 a | 6.1 b | 7.0 b | 6.5 a | 6.6 a |
| | Aug. 28 | 11.7 aA | 14.7 bA | 15.5 bA | 15.3 aA | 14.9 aA |
| | Sept. 14 | 14.4 aAB | 15.1 aA | 20.4 bB | 18.6 aAB | 16.8 aAB |
| | Oct. 12 | 17.8 aB | 20.5 bB | 22.6 cB | 22.9 aB | 20.1 aB |
| Top weight, lb. | July 23 | 11.0 a | 15.1 b | 17.3 b | 15.1 a | 17.4 b |
| | Aug. 28 | 18.7 aAB | 21.5 aA | 22.8 aB | 22.4 aA | 21.8 aB |
| | Sept. 14 | 21.9 aB | 18.3 aA | 21.7 aB | 20.3 aA | 19.7 aAB |
| | Oct. 12 | 15.8 aA | 17.1 aA | 15.2 aA | 17.6 aA | 14.6 aA |
| Root/top ratio | July 23 | 0.43 a | 0.41 a | 0.40 a | 0.43 b | 0.38 a |
| | Aug. 28 | 0.63 aA | 0.68 aA | 0.69 aA | 0.68 aA | 0.69 aA |
| | Sept. 14 | 0.53 aA | 0.82 bA | 0.94 cB | 0.92 aB | 0.84 aA |
| | Oct. 12 | 1.12 aB | 1.21 aB | 1.49 bC | 1.31 aC | 1.39 aB |

* Lower case letters indicate treatment differences on each sampling date. Upper case letters indicate differences between dates within each treatment. Means having no letters in common are significantly different at the 5% probability level.

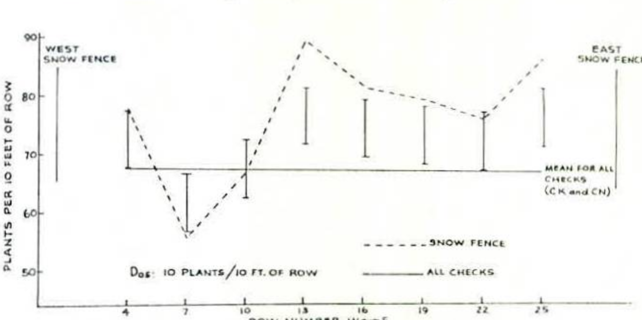


Fig. 2. Influence of location within snow fence barrier on stand of sugar beets.

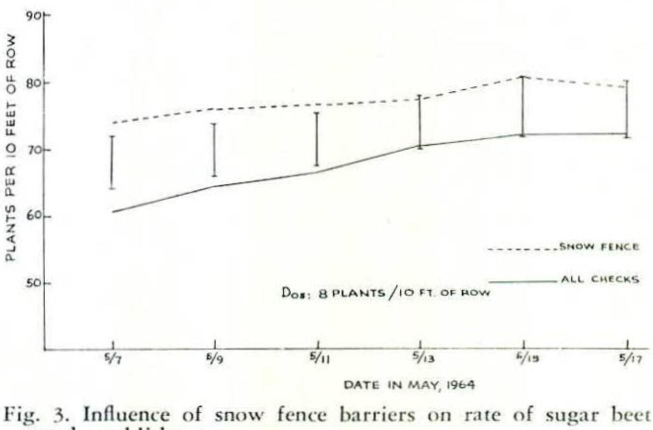


Fig. 3. Influence of snow fence barriers on rate of sugar beet stand establishment.

Beets grown in shelter had by July 23 significantly increased root weight. This situation prevailed on August 28, but on September 14 root weight of beets in SF was no greater than that in CK. At harvest, root weight in CN was greater than in SF which in turn had larger beets than did CK. Yield in CN was 26% greater than that in CK. Position in the shelters had no influence on root weight. Root weight increased consistently during the latter part of the season, but during the period August 28 to September 14, at a significantly slower rate in SF than in either of the other treatments. Rate of root weight increase was not influenced by position in shelter.

Top weight was greater in shelter than in CK on July 23. After August 28 and until the end of the season, top weight was not different among treatments. On July 23, top weight of beets in the eastern subplots of the sheltered treatments was significantly greater than in the western subplots. The

Table 2. Effect of shelter type, position within shelter, and period of growing season on quality traits of sugar beets.

| Trait and dates | | Treatment | | | Position | |
|---|---|---|---|---|---|---|
| | | CK | SF | CN | West | East |
| Sugar content, % | Aug. 28 | 11.7aA* | 12.2bA | 12.5bA | 12.5aA | 12.2aA |
| | Sept. 14 | 13.8aB | 14.0aB | 14.6bB | 14.4aB | 14.1aB |
| | Oct. 12 | 16.2bC | 15.5aC | 16.1bC | 15.6aC | 16.0aC |
| Juice dry substance, % | Aug. 28 | 7.7aA | 8.3aA | 8.4aA | 7.9aA | 8.7aA |
| | Sept. 14 | 7.2aA | 7.1aA | 8.1bA | 7.5aA | 7.7aA |
| | Oct. 12 | 10.8aB | 10.6aB | 10.1aB | 10.3aB | 10.1aB |
| Juice sucrose, % | Aug. 28 | 27.8aA | 29.8aA | 30.8aA | 28.9aA | 31.7aA |
| | Sept. 14 | 25.7aA | 25.1aA | 29.3aA | 26.9aA | 27.5aA |
| | Oct. 12 | 40.7aB | 40.2aB | 38.8aB | 39.2aB | 39.9aB |
| Juice purity, % | Aug. 28 | 91.1aA | 91.0aA | 92.6bA | 92.2aA | 91.4aA |
| | Sept. 14 | 90.6aA | 90.0aA | 91.4aA | 91.1aA | 90.4aA |
| | Oct. 12 | 94.0aB | 94.9abB | 96.1bB | 95.1aB | 95.8aB |

* Lower case letters indicate treatment differences on each sampling date. Upper case letters indicate differences between dates within each treatment. Means having no letters in common are significantly different at the 5% probability level.

effect had disappeared by August 28 and did not recur during the remainder of the season. Top weight decreased in all treatments during the period August 28 to October 12. The decrease during this period was significant in CK and CN but not in SF. Top weight of beets growing in the eastern subplots decreased significantly between August 28 and October 12.

Root/top ratios were not different among treatments on July 23 or on August 28. On September 14, the ratio increased in the order CK, SF, CN. By harvest CK and SF were not different. The ratio was significantly highest in CN. Root/top ratio was higher in the western sections of shelter than in the eastern sections on July 23, but no differences were observed later. Ratios increased during the period August 28 to October 12. Ratios increased significantly between August 28 and harvest in CK and SF. A significant increase in ratio occurred between each sampling period in CN. In the eastern portions of the sheltered plots, final root/top ratio was significantly greater than on August 28. In the western portion, a significant increase in ratio occurred during each sampling period.

*Sugar content and beet quality.* Results of sugar content and beet quality tests made only on beets sampied on the final three dates are presented in Table 2. Data are organized to illustrate the effect of treatment and position within shelter on sugar content and quality.

Sugar content of sheltered beets was greater than in CK beets on August 28. By September 14, no difference between CK and SF was noted. Sugar content remained significantly greater in CN at this time. By harvest, sugar content in CK was not different from that in CN. Both were significantly superior to SF in this regard. Position in shelter had no effect on sugar content. Rate of increase in sugar content between sampling periods was significant in all treatments and positions within shelter.

Dry substance was not different among treatments except on September 14, when CN was significantly superior to CK and SF. Position within shelter had no effect. Only between September 14 and October 12 was the rate of change in dry substance significant in all treatments and positions within shelter.

Treatment and position within shelter had no influence on juice sucrose percentage. The rate of change of juice sucrose percentage was significant in all treatments and positions within shelter during the period September 14 to October 12.

Juice purity percentage, a parameter derived from dry substance and sucrose percentage of the limed press juice, was not different between CK and SF on August 28, but both treatments were inferior to CN on that date. No differences between treatments were observed on September 14. On October 12, however, purity in CN was superior to that in CK. Position within shelter had no influence on juice purity. Significant differences in rate of purity increase were found only during the September 14 to October 12 period. This held true for all treatments and positions within shelter.

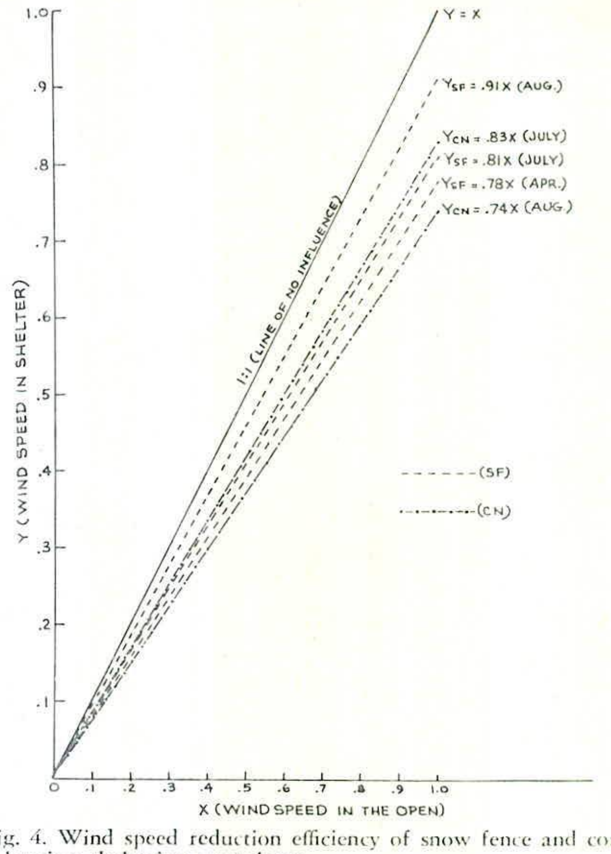


Fig. 4. Wind speed reduction efficiency of snow fence and corn barriers sheltering sugar beets.

## Aerodynamic Influence of the Shelters

*Windbreak efficiency.* Wind speed records obtained with the S.C.S. anemometers were utilized to evaluate the efficiency of the windbreaks throughout the growing season. Data for analysis were selected from three periods: April 19–27, July 1–22, and August 14–26. During the first of these periods, only the SF barrier existed and beet plants had not yet emerged. By the July period, plants had made about two-thirds full canopy growth. The CN barrier had by this time grown into a dense, virtually impenetrable wall. Subsequently, the CN rows were thinned to one plant per six inches of row to make them more penetrable to wind. By August the corn had achieved full height and beet canopy growth was complete. The S.C.S. anemometers remained at a height of 1 m above the soil throughout the entire season. Thus, in April the anemometer was 1 m above a relatively smooth soil surface, while in July and August it stood only 40 to 50 cm above the fully rough plant canopy. The April, July, and August analyses used 243, 513, and 313 mean hourly wind speeds. Linear regressions of wind speed in SF and CN are plotted as functions of wind speed in the open in Fig. 4.

The influence of SF on wind speed midway across the plot decreased with increasing age and height of the beet plants. On the other hand, the influence of CN on wind speed midway across the plot increased between the July

Table 3. Temperature and wind profiles over sheltered and exposed sugar beets.

| Date and hour | Radiation $R_s$ | Radiation $R_n$ | Wind direction | Plot | Wind speed (u), 120 cm | Wind speed (u), 60 cm | Gradients* 120-60 cm $\Delta u$, m sec$^{-1}$ | Gradients* 120-60 cm $\Delta T$, °C | $\frac{\Delta T}{(\Delta u)^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| | Ly. day$^{-1}$ | | | | m sec$^{-1}$ | | | | |
| Aug. 29 (06-17) | 612 | 277 | W | CK | 6.38 | 1.34 | 3.34 | -0.21 | -0.02 |
| | | | | SF | 4.98 | 2.84 | 3.52 | -0.63 | -0.05 |
| | | | | CN | 5.81 | 3.88 | 3.29 | -0.36 | -0.03 |
| Sept. 3 (08-17) | 596 | 273 | NW | CK | 3.07 | 2.04 | 1.94 | -0.35 | -0.09 |
| | | | | SF | 2.61 | 1.34 | 2.04 | -1.37 | -0.33 |
| | | | | CN | 2.74 | 1.81 | 1.36 | -1.32 | -0.71 |
| Sept. 10 (07-17) | 498 | 240 | E & SE | CK | 2.26 | 1.63 | 1.14 | -0.52 | -0.10 |
| | | | | SF | 2.25 | 1.00 | 2.06 | -1.58 | -0.37 |
| | | | | CN | 2.31 | 1.41 | 1.51 | -1.59 | -0.70 |

* Expressed on a per meter basis.

and August observations. As a structure for wind protection, the solid CN planting was least efficient. When thinned to make it permeable, its performance was creditable.

*Wind profiles and stability.* Temperature and wind speed profiles were recorded continuously during the period August 28 to September 14. Data on aerodynamic influence of the shelters during 3 days of largely clear skies are presented in Table 3. Winds blew predominately out of the west or east on these days, so that full protection prevailed. Insolation of about 600 cal cm$^{-2}$ was recorded during two of these days (August 29 and September 3). On September 10, cloudiness lowered total incoming energy to about 500 cal cm$^{-2}$. The net radiation ranged from 240 to 280 cal cm$^{-2}$ during the three days.

The mean temperature gradient ($\Delta T$) between the 120 and 60 cm levels was most strongly super-adiabatic in SF during the first 2 days, but the difference between SF and CN on September 3 was not great. On September 10, however, temperature gradient was identical in SF and CN and differed greatly from that in CK.

Wind shear ($\Delta u$) above the plants was always greatest in SF. Shear in CN was not greatly different from that in CK. The range of wind shear among treatments was smallest on August 29 when winds were most severe. Shear in all plots was, however, greatest on that day. On September 10, when winds were most calm, little influence was exerted by either barrier on wind speed at the 120-cm level. SF was, however, most effective in reducing wind speed near the top of the plant canopy. The barriers were increasingly efficient in reducing wind speeds at both levels as windiness increased.

The parameter $\Delta T/(\Delta u)^2$ is proportional to Richardson number and, therefore, indicative of degree of atmospheric stability. On the windiest of the days studied (August 29), air in SF was only slightly more unstable than in CN or CK. With decreasing wind speed, instability was greatest in CN. On one of these days (September 10), instability of air in CK and SF was not different.

A distribution of Richardson number for the entire August 28 to September 14 period is given in Table 4.

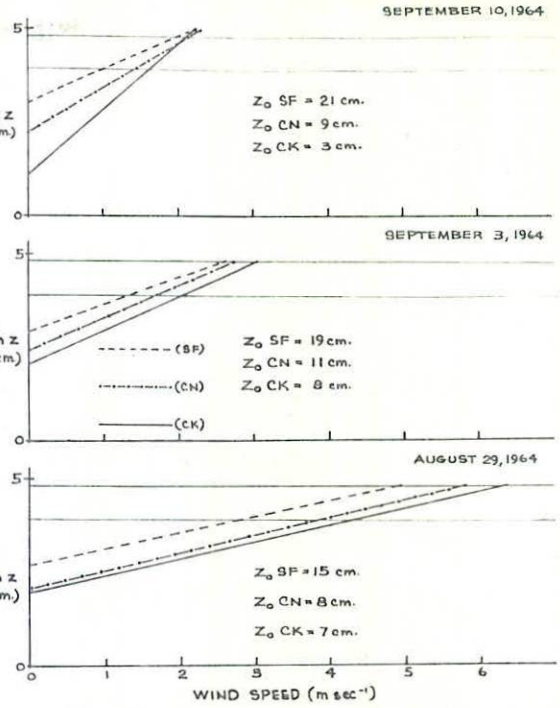


Fig. 5. Wind profiles over corn sheltered, snow fence sheltered, and unsheltered sugar beets on days of calm, moderate, and strong winds.

These data indicate that shelter had little influence on number of daytime hours of instability. Hours of daytime stability were reduced by shelter and hours of neutral stability thereby increased. Hours of nocturnal stability were more numerous in CN than in either of the other treatments, although differences were not great.

*Wind penetration into the plant canopy.* Wind speed in the lower layers of the atmosphere increases logarithmically with height above the ground. This relationship is generally applicable to conditions of neutral stability and can be used to estimate the elevation at which wind speed is reduced to zero. Data graphed in Fig. 5 show wind speed at two levels above the sheltered and exposed canopies as functions of the natural log (ln) of height. The Y intercept is ln height at which the zero wind speed is predicted i.e., the zero plane ($Z_o$). Zero plane estimates are noted in Fig. 5 for each of the treatments on the 3 days studied. On each of these days, the zero plane is predicted at a level higher in the canopy of SF than in CN or CK. Increasing wind speed deepens wind penetration into the canopy of beets in SF. CN protected beets experience air movement deeper in the canopy than do SF protected beets. With increasing wind speed the zero plane in CN approaches that in CK.

Table 4. Distribution of day and night hourly convective stability conditions over sheltered and exposed sugar beets (August 28 to September 14, 1964).

| Stability class | Limits of Ri | Day (06-17 hrs.) CK | Day SF | Day CN | Night (19-04 hrs.) CK | Night SF | Night CN |
|---|---|---|---|---|---|---|---|
| Extr. unstable | < -1.01 | 7 | 0 | 4 | 0 | 0 | 2 |
| Strongly unstable | -.51 to -1.00 | 3 | 1 | 4 | 0 | 0 | 0 |
| Moderately unstable | -.26 to -.50 | 3 | 2 | 7 | 0 | 0 | 0 |
| Weakly unstable | -.036 to -.25 | 18 | 30 | 20 | 3 | 1 | 2 |
| Subtotal unstable | | 31 = 34% | 33 = 35% | 35 = 38% | 3 = 4% | 1 = 1% | 2 = 3% |
| Neutral | Zero to -.035 | 33 = 36% | 50 = 54% | 42 = 45% | 6 = 8% | 10 = 14% | 3 = 4% |
| Subtotal stable | | 28 = 30% | 10 = 11% | 16 = 17% | 65 = 88% | 62 = 85% | 68 = 93% |
| Weakly stable | Zero to .25 | 27 | 10 | 16 | 63 | 62 | 66 |
| Mod. stable | .26 to .50 | 1 | 0 | 0 | 2 | 0 | 2 |
| Totals | | 92 = 100% | 93 = 100% | 93 = 100% | 74 = 100% | 73 = 100% | 73 = 100% |

### Influence of the Barriers on Microclimate

Table 5 contains data on average daytime and nocturnal microclimatic conditions which prevailed in and above the canopy of beet plants in the sheltered and exposed plots. These data represent conditions during the 17-day period of intensive observation at Scotts Bluff. Winds blew out of the east or west for approximately 75% of the hours during which observations were made.

*Net radiation.* Nocturnal net radiation was unaffected by the presence of barriers in the sugar beet field, while daytime net radiation may have been increased very slightly. Calibration and recording errors for net radiometers used were in the order of .02 Ly. $min^{-1}$. Net radiation was positive from 0600 through 1700 hours and negative from 1800 to 0500 hours during this late August to mid-September part of the growing season. The reversal in sign of the radiation balance was used to divide "night" from "day" to facilitate description of microclimatic conditions in sheltered and exposed plots.

*Temperature.* Soil temperature at the 10-cm depth was slightly higher during the day and slightly lower at night in CK than in either of the other treatments. Air temperature above the plant canopy in both SF and CN was higher by day and lower by night than in CK.

*Humidity.* Only negligible differences in vapor pressure were observed above the plant canopies (60 cm). Errors in measurement of vapor pressure may equal 1 mbar. Differences in relative humidity above the canopy of sheltered and exposed plants reflect the differing temperature and vapor pressure regimes which prevailed. For example, the lower daytime relative humidity at 60 cm in SF and CN is due to higher air temperature in the sheltered plots, since vapor pressure was almost identical in all treatments.

Table 5. Average microclimatic conditions in snow fence sheltered, corn sheltered, and exposed sugar beets.

| Parameter | Unit | CK | | SF | | CN | |
|---|---|---|---|---|---|---|---|
| | | Day (06–17) | Night (18–05) | Day (06–17) | Night (18–05) | Day (06–17) | Night (18–05) |
| Net radiation (160 cm) | Ly. $min^{-1}$ | .34 | -.01 | .38 | -.01 | .37 | -.01 |
| Soil temp. (-10 cm) | °C | 18.0 | 16.8 | 17.4 | 16.9 | 17.7 | 17.2 |
| Air temp. (60 cm) | °C | 23.0 | 14.0 | 24.6 | 13.9 | 24.6 | 13.4 |
| Vapor pressure (60 cm) | mbar | 13 | 10 | 13 | 10 | 14 | 11 |
| Relative humidity (60 cm) | % | 49 | 66 | 44 | 65 | 46 | 68 |

## DISCUSSION AND CONCLUSIONS

Beneficial effects of wind shelter on sugar beet growth may stem from any of a number of causes. Rapid and uniform germination and emergence of seedlings, reduced mechanical motion of the leaves, particularly in high winds, and altered microclimatic and/or aerodynamic conditions may be most important. Rosenberg (7) has shown that microclimatic conditions in a snow fence shelter also favor increased stomatal opening and maintenance of high relative turgidity in irrigated bean plants. Transpiration in sheltered beans was greater, therefore, than in exposed plants. However, direct evidence of altered moisture economy in the sugar beets sheltered by snow fence and corn was not obtained in the study reported here.

The snow fence barrier, spaced at 12H, noticeably affected rate and extent of stand development. At a distance of about 3H from the west and, to a lesser extent, at 3H from the east, the influence of the barrier was negligible. Winds overtopping the fence may have generated excessive turbulence in these locations. During the germination period, winds were predominately from the west and northwest. Germination was more restricted near the western side of the sheltered plots. The advantageous rate of emergence became statistically insignificant by mid-May.

At harvest, CN- and SF-protected beets yielded larger roots than did CK. Top growth was not different among treatments. Root/top ratio of CN sheltered beets was significantly greater than that in either SF or CK. Sugar content of the SF protected beets at harvest was significantly lower than that in either CN or CK. Purity of limed press juice samples of beets grown in CN was superior to that of beets grown in CK.

Microclimate was altered by the presence of wind barriers in the sugar beet field. Daytime air temperatures were slightly elevated and nighttime temperatures slightly depressed by shelter. Daytime soil temperature, on the other hand, was lowered by shelter, and nighttime soil temperature was raised slightly. Vapor pressure above the canopy was not influenced by shelter. Relative humidity, because of higher daytime air temperature in shelter, was lower than in the check. The relation of the shelter-induced microclimatic conditions to plant performance is not clear. Measured differences may in fact have been of negligible importance or unrepresentative of conditions throughout the entire season.

The aerodynamic influence of SF differed from that of CN in one important way. Wind shear over the SF protected plants was so great that the vertical transfer of horizontal momentum was probably completed in the upper levels of the beet canopy. While wind speeds were considerably reduced below those in the open in the CN sheltered plot, shear was not so extreme and wind should have penetrated the canopy almost as well as in the unsheltered site. The strong wind shear in SF tended to reduce the degree of atmospheric instability in that plot.

The habit of the sugar beet plant, erectness of its leaves, and roughness of its canopy cover leads to the supposition that wind penetration into this canopy may be desirable. As the lower leaves are partially illuminated, wind supplied $CO_2$ may be essential for optimum photosynthetic activity. Wind penetration into the canopy of the CN sheltered beets was nearly normal. It appears likely that near normal turbulent diffusion of $CO_2$ occurred in corn-sheltered beets. Snow fence may have created a shelter regime more extreme than necessary. These aerodynamic considerations may explain the generally beneficial influence of the corn shelter on sugar beet growth.


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