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Influence of Windbreak-shelter on Soybean Production under Rainfed Conditions[1]

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ABSTRACT

Research indicates that a combination of windbreak and irrigation gives significant soybean yield increases in comparison to an irrigated open field. Little data is available to determine the yield advantage of soybean production under sheltered and rainfed conditions. The field study reported here was conducted at the University of Nebraska Field Laboratory, Mead, Nebraska, during 1978 and 1979 growing seasons to determine the influence of windbreak-shelter on soil water content and soybean [*Glycine max* (L.) Merr.] yield under rainfed conditions. Shelter from wind was provided by a system of east-west oriented shelterbelts, 6 m high, 60% dense, and consisting of green ash (*Fraxinus pennsylvanica* L.), Austrian pine (*Pinus nigra* Arnold), and eastern red cedar (*Juniperus virginiana* L.). The prevailing winds in Nebraska during the summer months come mainly from the south. The soil was a Typic Argiudoll.

There were no statistically significant differences (P = 0.05) between treatments in available soil water and plant water use. In spite of this, sheltered soybeans had higher leaf water potential and stomatal conductance, and lower leaf temperature. These differences between treatments were attributable, entirely, to shelter-induced modification of the growing season microclimate. Leaf area index, dry matter production, and bean yield were significantly increased in shelter during both years. Bean yield in shelter was 20 and 26% higher than in exposed plots in 1978 and 1979, respectively. Bean production per ha-cm of water used in 1979 was 58 kg for sheltered soybeans and 47 kg for those in exposed plots.

Results of this study indicated that under rainfed conditions, increased water-use efficiency, and significant increases in bean yield can be expected from sheltered soybeans.

Additional index words: Soil water content, Plant water status, Water-use efficiency.

AVAILABLE soil water is an important factor in crop production (1, 13) and the use of windbreaks to conserve this valuable resource is well documented (5, 6, 7). Plant water status is a function of soil water content and atmospheric evaporative demand, and influences crop growth, development, and yield (14). Wind reduction by windbreaks decreases atmospheric evaporative demand and creates a more favorable plant water status (2, 4, 11, 15).

Several reports indicate that soybean [*Glycine max* (L.) Merr.] respond to the windbreak microclimate with improved plant water status, growth, and yield (3, 8). Radke and Hagstrom (9), however, did not observe improved plant water status in soybeans sheltered by temporary corn windbreaks, even though growth and bean yield were increased. Frank et al. (3) reported that a combination of shelter and irrigation resulted in the most favorable soybean plant water status and the highest growth and yield responses. Their results indicated no significant growth and yield responses to shelter under rainfed conditions. Little data is available to determine the yield advantage of soybean production under sheltered and rainfed conditions. The objectives of this study were to determine the effect of windbreak-shelter on soil water content and soybean production under rainfed conditions.

MATERIALS AND METHODS

'Wayne' soybeans were planted on 19 May during 1978 and 1979 growing seasons under windbreak-sheltered and exposed conditions. Plant rows, 92 cm apart, were oriented in a north-south direction. The study was carried out at the University of Nebraska-Lincoln Field Laboratory, Mead, Nebraska (41° 29′ N., 96° 30′ W., 354 m above mean sea level) under dryland field conditions. The soil was a Typic Argiudoll (Sharpsburg silty clay loam). Soil water at one-third and 15 bars was 35 and 16%, respectively. A system of east-west oriented shelterbelts (6 m high and about 60% dense), established in 1964 for windbreak research, provided shelter from wind. The prevailing winds in Nebraska during the summer months come mainly from the south. Each windbreak consisted of two rows of green ash (*Fraxinus pennsylvanica* L.), Austrian pine (*Pinus nigra* Arnold), and estern red cedar (*Juniperus virginiana* L.). Experimental plots (9 m × 10 m) were randomly selected within an approximately 1.6 ha bean field. The sheltered plots were located at distances of 1 H, 2.5 H, 4 H, and 6.5 H (H = windbreak height) leeward from the windbreaks. The exposed plots were located about 0.5 km east of the windbreaks, and thus, outside their area of influence. Soil chemical analyses for N, P, K, and pH were similar for all plots. The layout was a completely randomized design with four replications.

In 1978, soil water content determinations were based on gravimetric soil samples taken to a depth of 30 cm once a week, starting at the one leaf growth stage. Two soil samples

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were taken from the center of each plot. In 1979, profile soil water determinations were made based on gravimetric samples of the top 30 cm and neutron attenuation meter (Troxler Model — 1255) data taken to a depth of 150 cm at 30-cm depth increments. One access tube was located in the center of each plot. Soil water measurements were made at planting time and at the following dates and stages of plant development: 6 June (one leaf stage), 27 June (three leaf stage), 19 July (early flowering), 27 July (commencement of podding), 10 August (pods at upper nodes about 2 cm long), 23 August (commencement of bean development), and 20 September (pod maturity). The wilting coefficient determined for every 10-cm depth increment to 150-cm soil depth was used to calculate the available soil water content. Available soil water in any increment was taken as the water in excess of the wilting coefficient.

Precipitation and windspeed (at 2 m above the crop) were monitored daily with standard meteorological instruments installed at each plot site. Evapotranspiration during 1979 growing season was calculated by adding the precipitation received during a measurement period to the amount of water in the profile at the beginning of that period and subtracting the amount of water in the profile at the end of the measurement period. Experimental plots were level and no runoff could be observed during the growing seasons. Water loss from deep percolation was assumed absent because water in the lowest soil profiles was always below field capacity.

Leaf water potential, stomatal diffusive resistance (R), and leaf temperature were evaluated one day each week at 0800, 1000, 1200, 1400, 1600, and 1800 hours (solar time). The center leaflet of the uppermost fully expanded trifoliates was used for all measurements. At each sampling period, each of the above measurements was made on four randomly selected leaves in each plot. Leaf water potential was measured with the pressure chamber (12); leaf temperature (of abaxial surface) with copper-constantan thermocouples; and leaf diffusive resistance with Model LI-20S porometer (Lambda Instr. Corp.). Measurements of stomatal diffusive resistance were made on both leaf surfaces. Leaf conductance (1/R) was calculated as follows:

$$1/R = 1/R_{ad} + 1/R_{ab}$$

where, Rad and Rab are adaxial and abaxial leaf diffusive resistance, respectively.

Starting at the two leaf growth stage, estimates of dry matter production and leaf area index were made once a week by cutting plants at ground level from four randomly selected meter-length row segments within each plot. The samples were taken to the laboratory where the leaves were spearated from the stems, Leaf area was measured with Model LI-3000 area meter, and an accessory transparent belt conveyor, Model LI-3050 (Lambda Instr. Corp.). Plant parts were oven-dried to constant weight

Table 1. Mean monthly available soil water and windspeed in sheltered and exposed soybean plots during 1978 and 1979 growing seasons.

Year	Month	Available water† Exposed	Available water† Sheltered	Avg. 24-hour wind Exposed	Avg. 24-hour wind Sheltered
		mm	mm	km/hr	km/hr
1978	June	10.3 a*	11.5 a	--	--
	July	8.1 a	8.4 a	7.5 a	3.9 b
	Aug.	5.2 a	6.1 a	7.7 a	3.9 b
	Avg.	7.8 a	8.6 a	7.6 a	3.9 b
1979	June	8.9 a	10.4 a	13.5 a	8.1 b
	July	6.6 a	7.3 a	7.1 a	3.6 b
	Aug.	3.1 a	3.5 a	8.6 a	4.9 b
	Avg.	6.2 a	7.7 a	9.7 a	5.5 b

* Means in rows under the same variable followed by the same letter are not significantly different at the 5% level using L.S.D.
† 0 to 30-cm soil depth. Average of 32 measurements.

Table 2. Available soil water at different dates during 1979 growing season in sheltered and exposed soybean plots.

Date	Available soil water† Exposed	Available soil water† Sheltered	L.S.D. (0.05)
	mm	mm	
19 May	136.8	141.6	6.8
6 June	152.6	158.4	13.2
27 June	154.9	162.1	15.9
19 July	99.9	113.1	11.5
27 July	82.3	86.4	8.5
10 Aug.	82.0	85.0	16.8
23 Aug.	70.1	70.2	6.5
20 Sept.	65.3	68.8	4.4

† 0 to 150 cm depth. Average of 40 measurements.

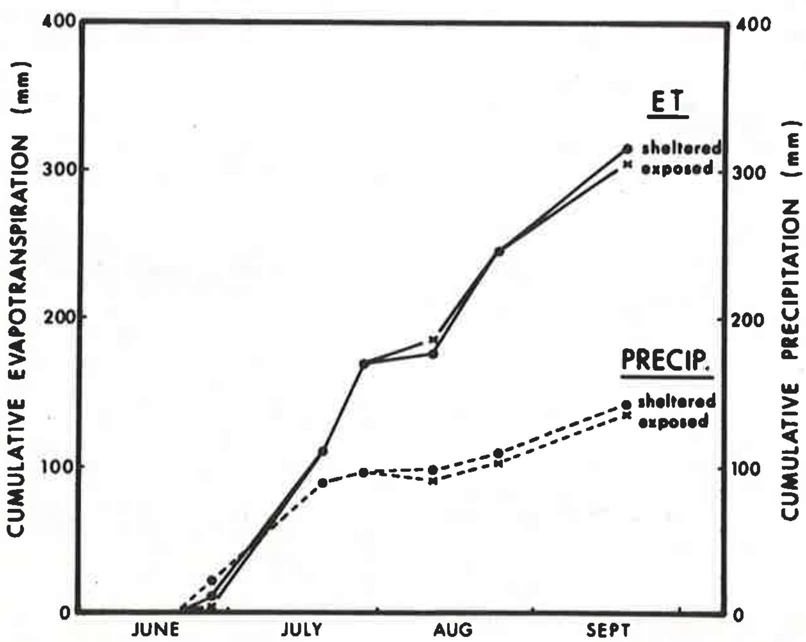

Fig. 1. Cumulative evapotranspiration and precipitation in sheltered and exposed soybean plots during 1979 growing season.

at 70 C. At maturity, bean yield estimations were made on plants clipped from four meter-length row segment randomly selected within each plot.

Because shelter effect varies with distance from windbreak (15), data from the sheltered plots were pooled to average out the effect of location. The pooled data provides a better estimate of the overall windbreak influence on soybean production than data obtained from only one location in shelter.

RESULTS AND DISCUSSION

The main effect of a windbreak is reduction of surface windspeed in the sheltered zone. This causes changes in the microclimate that have been proven conducive to improved crop growth and yield (5, 15). In the study reported here, windspeed was significantly reduced in the sheltered plots (Table 1). The percentage windspeed reduction in shelter averaged 49 and 43% of the exposed site windspeed during 1978 and 1979, respectively. There were no significant differences between treatments in available soil water during the study periods (Tables 1 and 2). Even though many researchers have found greater soil water content in sheltered plots (15), this has not always been the case (3, 11). Soil water relationships are a function of the factors that enrich the soil with water (snow and precipitation) and those that cause water loss from the soil (evapotranspiration). Windbreaks influence soil water content in the sheltered zone through efficient snow trapping and distribution over the adjacent field in winter, and reduced evapotranspiration in summer (5, 15). At densities of 50% and less, windbreaks are efficient in trapping snow over a wide cropping area and thus contribute to soil water recharge (4). The density of our windbreak was about 60% and this would partly explain the absence of any significant differences in available soil water between our sheltered and exposed plots. Large snow drifts (1 to 2 m deep) were observed adjacent to these windbreaks during early spring in 1978 and 1979; an indication of their inefficiency in the distribution of trapped snow over the adjacent land.

Evapotranspiration and precipitation were also the same for both treatments (Fig. 1). For each treatment, evapotranspiration exceeded precipitation during most of the growing season; and differences between these increased as the season progressed. By the end of the study period, net loss of available water from the 0 to 150-cm soil profile amounted to 150 and 145 mm for sheltered and exposed plots, respectively. This 5-mm difference in water use was not significant (P = 0.05). Radke and Burrows (8) working with temporary corn windbreaks also found no significant differences in water use between their dryland sheltered and exposed soybeans.

Despite the absence of any significant differences between treatments in available soil water; leaf area index, dry matter production, and bean yield were significantly increased in shelter during both years (Tables 3 and 4). This growth and yield advantage of sheltered soybeans was completely attributed to

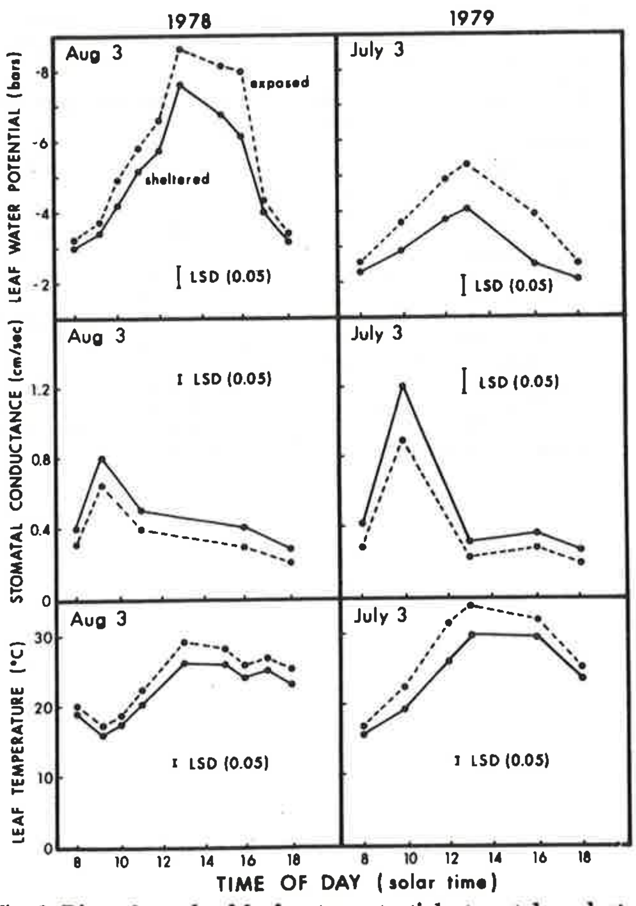

Fig. 2. Diurnal trends of leaf water potential, stomatal conductance, and leaf temperature in sheltered and exposed soybeans on 3 Aug. 1978 and 3 July 1979.

Table 3. Mean monthly leaf area index and plant dry weight of sheltered and exposed soybeans during 1978 and 1979 growing seasons.

Year	Month	Leaf area index†		Plant dry matter†	
		Exposed	Sheltered	Exposed	Sheltered
				g/m²	
1978	June	0.4 a*	0.5 a	20.8 a	24.0 a
	July	2.7 a	3.3 b	214.4 a	251.0 b
	Aug.	4.1 a	5.8 b	543.8 a	568.3 b
	Avg.	2.4 a	3.2 b	259.7 a	281.1 b
1979	June	0.2 a	0.2 a	9.3 a	12.5 a
	July	1.7 a	2.0 a	110.2 a	145.2 b
	Aug.	3.7 a	4.5 b	399.3 a	445.3 b
	Avg.	1.8 a	2.2 b	172.9 a	201.0 b

* Means in rows under the same variable followed by the same letter are not significantly different at the 5% level using L.S.D.
† Average of 64 measurements.

Table 4. Soybean yield in sheltered and exposed plots during 1978 and 1979 growing seasons.

Year	Bean yield†	
	Exposed	Sheltered
	kg/ha	
1978	1647 a*	1980 b
1979	1436 a	1815 b

* Means in rows followed by the same letter are not significantly different at the 5% level using L.S.D. † Average of 16 measurements.

Table 5. Mean monthly leaf water potential (Ψ_L), stomatal conductance ($1/R_L$), and leaf temperature (T_L) at 0800 to 1800 hours, of sheltered and exposed soybeans during 1978 and 1979 growing seasons.

Measurement	Month	1978 Exposed	1978 Sheltered	1979 Exposed	1979 Sheltered
T_L† (C)	June	27.0 a*	25.0 a	29.8 a	28.1 a
	July	33.0 a	30.5 b	34.0 a	31.0 b
	Aug.	34.2 a	30.8 b	37.0 a	33.8 b
	Avg.	31.4 a	28.8 b	33.6 a	31.0 b
Ψ_L† (bars)	June	−4.5 a	−3.3 b	−4.8 a	−3.6 a
	July	−5.7 a	−4.2 b	−6.8 a	−5.2 b
	Aug.	−8.5 a	−6.6 b	−10.8 a	−8.3 b
	Avg.	−6.2 a	−4.7 b	−7.5 a	−5.7 b
$1/R_L$† (cm/s)	June	0.27 a	0.50 b	0.20 a	0.31 b
	July	0.15 a	0.24 b	0.13 a	0.18 b
	Aug.	0.11 a	0.16 b	0.07 a	0.19 b
	Avg.	0.18 a	0.30 b	0.13 a	0.19 b

* Means in rows under 1978 or 1979 followed by the same letter are not significantly different at the 5% level using L.S.D.
† Average of 384 measurements.

greater plant water status, higher stomatal conductance, and lower leaf temperature (Fig. 2 and Table 5). These physiological differences between treatments would be a consequence of the shelter-induced modification of the growing season microclimate (10). Better plant water status in shelter has not always been reflected in crop yield (5, 10); nor have improved growth and yield of the sheltered crop always been associated with greater available soil water (9). These findings are testimony of the complexity of the microclimatic interactions in the sheltered zone. Under dryland conditions, sheltered plants could use up more soil water and experience greater water stress than those in exposed plots (3, 11).

In the study reported here, shelter increased bean yield above that of the exposed plots by 20 and 26% in 1978 and 1979, respectively. Frank et al. (3) and Radke and Burrows (8) obtained bean yield increases in dryland sheltered soybeans ranging from 8 to 30%. Bean production per ha-cm of water used in 1979 was 58 and 47 kg for sheltered and exposed plots, respectively. Windbreaks represent a practical means of increasing the water-use efficiency of crops (2, 8). Our results indicated that under rainfed conditions, increased water-use efficiency and significant increases in bean yield can be expected from windbreak-sheltered soybeans.

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