Wind Effect on Corn Leaf Azimuth

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ABSTRACT

Stalk breakage, greensnap, in pretassel corn (*Zea mays* L.) increases when leaf azimuths are parallel to extreme thunderstorm winds. Yet wind effect on leaf azimuth is unknown. Azimuths recorded north of east–west windbreaks changed from 185° to 195° (north = 0°/360°; east = 90°; etc.) as distance from windbreaks increased from 1.4 to 13.6 *H* in 1999 in north–south rows; *H* is the average height of the tallest row of windbreak trees. Plants at 20 to 25 *H* are considered unsheltered. In 2000, leaf azimuth changed from 195° to 178° from 1.5 to 25 *H* in north–south rows. With higher wind speeds and east–west rows in 2002, azimuths ranged 194° to 202° from 3.7 to 23 *H*. In east–west rows windbreak sheltered leaves were oriented in north–south patterns. In contrast, unsheltered plants had few leaves pointing southward. Early-season wind altered corn leaf azimuth. This affects greensnap tolerance and perhaps other physiological traits.

Environmental factors including temperature, rainfall, water availability, crop water use, and light all play a critical role in growth and development of grain crops like corn. Wind on crops tears leaves, causes abrasion, and can result in either root or stem lodging. Wind also has a significant secondary physiological effect on crops (Brandle et al., 2000; Cleugh, 1998; Miller et al., 1995). Faster wind speeds increase transpiration and crop water use. All of these can reduce grain yield (Baker et al., 1998; Berry et al., 2000; Carter and Hudelson, 1988; Cleugh et al., 1998; Ennos et al., 1993). However, wind can improve a plant's mechanical strength through shaking, thigmomorphogenesis (Cleugh et al., 1998). Wind also increases corn root:shoot ratios and causes thicker and wider leaves (Whitehead and Luti, 1962).

Windbreaks are used in cropping systems as a long-standing practice to reduce wind speeds. In relation to exposed areas, sheltered areas will increase day temperatures, humidity, and night CO_2 levels, while reducing soil erosion, night temperatures, and respiration (Grace, 1977, 1988; McNaughton, 1988; Privé and Allain, 2000; Zhang and Brandle, 1996). Additional soil moisture is another benefit as snow is trapped on the leeward side. Grain yield of sheltered crops are often greater than that of nonsheltered crops (Kort, 1988; Zhang and Brandle, 1996; Zohar and Brandle, 1978).

Interplant competition affects leaf placement in most crops. Early corn researchers learned that successive leaves alternate on opposite sides of the stalks and that each leaf slightly overlaps the leaf below it. The leaves form a spiral on the stalk when there is no interplant competition. In today's production fields, however, maize leaves above the ear have a strong tendency to reorient perpendicular rather than parallel to the row (Girardin, 1992; Girardin and Tollenaar, 1992; Elmore et al., 2003; Fortin and Pierce, 1996). This azimuthal shift reportedly begins at the sixth leaf stage and is the result of twisting of the internode because of the orientation of the leaf blade of the same phytomer (Girardin, 1992). Girardin and Tollenaar (1992) observed that the azimuthal shift in sheaths and internodes occurs because the soft tissue is not fully lignified. Drouet and Moulia (1996, 1997) found that azimuth shifts continued until growth stages 11 to 14 (leaf tip method). The azimuthal shift is a shade avoidance mechanism triggered by reduced red:far red light ratios (Ballare et al., 1990).

Girardin (1992) found that seed position at planting did not affect eventual plant orientation. Toler et al. (1999), however, learned that corn kernels planted so leaves were oriented across rows provided more rapid canopy closure and greater yields than kernels placed either with leaves placed parallel to the row or placed randomly. Yet, on the basis of simulations, Drouet et al. (1999) concluded that leaf azimuthal orientation had little effect on daily light absorption efficiency. In another study, random seed positioning at planting resulted in random leaf placement except in a very dry year when leaf azimuths were largely parallel with the row (Fortin and Pierce, 1996). From this observation, the authors speculated that the parallel leaf placement minimized radiation interception and that leaf azimuth may be an indicator of water deficits.

We previously demonstrated that leaf azimuth is an important factor in mid-season corn stalk breakage, greensnap, because of extreme winds associated with thunderstorms before tasseling (Elmore and Ferguson, 1999; Elmore et al., 2003). In 2002 we observed in east–west rows that corn leaf azimuth was less symmetrical than in other years. Leaves on the north sides of the plants overhung the row space to the north and the leaves on the south sides of the plants were placed nearly parallel with the row or were angled to the north.

Wind clearly affects crops and leaf azimuth is a key factor in greensnap incidents. Yet to date, there are no reports on the effect of early-season wind on corn leaf azimuth and the resulting impact on plant growth, development, and grain yield. Our long-term goal is to determine the physiological responses of corn to wind and to mitigate the potential adverse effects of wind on grain yield through improved environmental and genetic management systems. Our central hypothesis is that early-season wind alters corn leaf azimuth, growth, and devel-

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Published in Crop Sci. 45:2598–2604 (2005).
Crop Ecology, Management & Quality
doi:10.2135/cropsci2004.0586

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Table 1. Farms, row orientations, windbreak height, length, and composition. Univ. of Nebraska, 1999 and 2000.

Farm	Corn row orientation	Windbreak Height H† (m)	Windbreak Length (m)	Windbreak Composition (rows and species)
		1999		
Woods I	north–south	13.1	150	multiple rows, deciduous
Woods II	north–south	9.7	280	multiple rows, deciduous and conifer
		2000		
Woods I	north–south	9.2	150	multiple rows, deciduous and conifer
Woods III	north–south	12.3	130	multiple rows, deciduous and conifer
Johnson	north-south	23.1	800	multiple rows, deciduous and conifer
		2002		
Brodrick	east–west	6.1	370	single row, conifer
VonSpreckelsen	east–west	10.0	410	single row, deciduous
Woods IV	east–west	9.1	560	single row, deciduous
Woods I	north–south	6.1	150	multiple rows, deciduous and conifer

† H is the average height of the tallest row of trees in the windbreak.

opment. Considerable support for this hypothesis comes from the field-to-field differences in corn leaf azimuths recorded over the years following greensnap events (data not shown). Leaf azimuth distribution differences among plants in north–south rows were few. We also noted distinct but subtle leaf azimuth distributions among fields planted in east–west rows. Yet, striking differences occurred in leaf azimuth distributions when north–south rows were compared with east–west rows. Although one might suggest that these differences are due to the planters used or perhaps hybrids, we believe these alternatives are unlikely because our observations were relatively consistent in many fields across a large part of Nebraska over several years. Our objective in the work presented here is to determine the effect of early-season wind on corn leaf azimuth.

MATERIALS AND METHODS

A listing of the farms used, corn row orientations, and windbreak heights, lengths, and composition are shown in Table 1 for the 3 yr of the study. The windbreaks were oriented east–west and fairly mature (30–80 yr old). Observations mentioned occurred at points north of the center portions of the windbreaks.

1999

Leaf azimuths were recorded in north–south rows on two fields near Clay Center, NE (Table 2). Each of the three replicates consisted of plants in a single row ranging from 15.2 to 152 m north of the wind break. Replicates were separated by 12 and 13 rows at Woods I and by 24 and 35 rows at Woods II. Since windbreak heights varied at the two fields, equal distances from the windbreak resulted in different H values. Ten data collection positions were systematically spaced in 15.2-m intervals from the windbreak. These positions ranged from approximately 1 to 16 H, where H is the average height of the tallest row of trees in the windbreak. The 20 plants monitored at each of the 10 distances were treated as samples within experimental units (distances). Recording of leaf azimuths began soon after emergence and continued until tasseling. Azimuths of the leaf midrib were recorded on the basis of visual observation at a point 2/3 to 3/4 the length of the leaf from the stalk on a 12-point scale (where 12 = 0°/360° = north; 3 = 90° = east; etc.). Since a plant's first three to four leaves are often lost before Leaves 7 and 9 are fully extended, we used spray paint on Leaf 5 or 6 as a temporary marker to ensure the correct leaves were evaluated over time. Plant populations were similar at all distances and at both farms averaging 6.8 plants m^{-2}. Corn rows were 0.76 m wide.

2000

Leaf azimuths were recorded in north–south rows on three fields near Clay Center, NE (Tables 1 and 2). Three replicates were used at all three fields. Replicates consisted of plants in a single row ranging from 13.8 to 577.5 m north of the windbreaks. Replicates were separated by two to eight rows at the different fields. The four distances were 1.5, 3.0, 6.0, and 25 H. Since windbreak heights varied among fields, actual distances from the windbreaks varied among fields. This approach is consistent with windbreak research methodology (Zhou et al., 2005). Azimuths of six leaves on 20 plants were recorded at the four distances north of windbreaks in each replicate.

Table 2. Farms, row orientations, windbreak height, distances, hybrids, and leaves whose azimuths were recorded. Univ. of Nebraska, 1999 and 2000.

Farm	Corn row orientation	H† (m)	Distances from windbreak (× H = distance in meters)	Hybrid‡	Leaf recorded§ 1	3	5	7	9	11
			1999							
Woods I	north–south	13.1	$\{1.16\ H + [15.2\ (n - 1)]\}/H$¶	P33A14	+			+	+	
Woods II	north–south	9.7	$\{1.56\ H + [15.2\ (n - 1)]\}/H$¶	Novartis 7639Bt	+			+	+	
			2000							
Woods I	north–south	9.2	1.5, 3.0, 6.0, 25.0	DK595Bt	+	+	+	+	+	+
Woods III	north–south	12.3	1.5, 3.0, 6.0, 25.0	GH9230Bt	+	+	+	+	+	+
Johnson	north–south	23.1	1.5, 3.0, 6.0, 25.0	N.A.	+	+	+	+	+	+

† H is the average height of the tallest row of trees in the windbreak.
‡ Hybrid P33A14 is from Pioneer Hi-bred Intl. Inc.; DK = DeKalb; GH = Golden Harvest; N.A. = Not Available.
§ Actual plant leaf recorded, i.e. Leaf 1 is the first leaf of the plant.
¶ Where n = 1 to 10.

Table 3. Farms, row orientations, windbreak height, distances, hybrids, and leaves whose azimuths were recorded. Univ. of Nebraska. 2002.

Farm	Corn row orientation	*H*† (m)	Distances from windbreak (× *H* = distance in meters)				Hybrid‡	Leaf recorded relative to ear leaf§					
								−4	−3	−2	−1	+1	+2
Brodrick	east–west	6.1	4.5	6	10	25	P33B51	+	+	+	+		
VonSpreckelsen	east–west	10.0	3	6	10	25	P32R42	+	+	+	+		
Woods IV	east–west	9.1	3.7	6	10	20	P32M38			+	+	+	+
Woods I	north–south	6.1	4	6	10	25	Crows	+	+	+	+		

† *H* is the average height of the tallest row of trees in the windbreak.

‡ Hybrids starting with 'P' are from Pioneer Hi-bred Intl.; the Crows hybrid planted at Woods I is not known.

§ We considered the ear leaf as '0'; thus, the third leaf below the ear leaf = Leaf − 3, etc.

Leaves were marked and azimuths were determined as in 1999. Rows were 0.76 m apart. Cup anemometers were maintained about 0.5 m above the crop canopy at all four distances in a single replicate at each farm until tasseling. They were first calibrated by comparing them in an open field for several days before placing them in the experimental fields. Recordings for each anemometer were adjusted on the basis of the test runs. Plant populations varied with farms and with distance from the windbreaks. Crop plant stands at the two Woods' farms were similar ranging between 5.8 and 6.4 plants m^{-2}, while at Johnson's it averaged 7.3 plants m^{-2}. Averaged across farms plant stands at 1.5, 3, and 25 *H* distances were similar, 6.3 plants m^{-2}, while at the 6 *H* it was 7.2 plants m^{-2}. This increased population was observed at all three farms.

2002

We recorded leaf azimuths of corn plants on the north side of windbreaks in four fields near Clay Center, NE (Table 3). In contrast to both 1999 and 2000 where leaf azimuths were recorded beginning shortly after emergence, leaf azimuths in 2002 were recorded in August and September. Since lower leaves of corn plants begin to dry and fall off in the latter weeks of the growing season, we varied the leaves monitored at the individual farms to ensure that the same leaves relative to the ear leaf were used at each farm (Table 3).

North–South Rows

Measurements on north–south oriented rows were recorded at distances of 4, 6, 10, and 25 *H* north of an east–west oriented windbreak at Woods I. The average height of the tallest trees in the windbreak south of the field was 6.1 m. Thus the distances where plants were sampled were between 24 and 152 m north of the windbreak. Four adjacent leaves below the ear were evaluated from 25 plants from each of the four distances. Thus, 100 leaves were evaluated at each *H* distance. Each leaf was considered an experimental unit.

East–West Rows

We recorded data at four distances due north of the east–west windbreaks in three fields. At each distance, leaf azimuths of all plants in a 46-m section of a row parallel to the windbreak were recorded. We were not able to record data at the planned distances of 3, 6, 10, and 25 *H* because of limitations on the number of rows of the same hybrid (Woods) and a dryland pivot corner (at Brodrick). Leaf azimuths on corn plants were thus recorded at distances of about 3.7, 6, 10, and 23 *H* north of east–west oriented windbreaks averaged over three farms. Four adjacent leaves from more than 230 plants were evaluated at each distance north of the windbreak in each field. Thus, over nine hundred leaves were evaluated at each distance in each field. Corn row width was 0.76 m.

Plant populations in north–south rows were consistent at different distances from the windbreak, 7 plants m^{-2}. Plant population averaged 6.4, 6.8, and 7.0 plants m^{-2} for Brodrick, VonSpreckelsen, and Woods (east–west rows), respectively. They were similar at all distances from the windbreak.

All Years

Summarizing, analyzing, and graphing circular data is not a trivial effort (Fisher, 1993). For example, averaging two data points 20 and 350 can result in quite different results depending if one thinks linearly (e.g., meters = 185) or circularly (e.g., leaf azimuth degrees on a 360° scale = 5°). According to Fisher, "... this is the notorious crossover problem familiar to meteorologists (p. 31, 1993)."

Florence Nightingale used a variety of methods to argue her case for medical reform in the 1850s including a graphical device she called coxcomb (because of its various colors). Commonly referred to now as a rose- or polar-area diagram this graphical method has been mostly used in biology and geology (Fisher, 1993). A web search provides many references to Nightingale's rose diagram (see Small, 2004, for one example). In this paper, we have chosen to present raw data plots of leaf azimuth data in much the same way as Nightingale with one exception. We grouped the data in 30° arcs, plotted a point at a radial distance proportional to the frequency of data in that interval and finally joined the points with a line (Fig. 1 and 2).

Azimuth data were statistically analyzed by the von Mises distribution of circular data (Fisher, 1993). For this distribution, the mean direction μ is calculated from cosine and sine of angles (Drouet and Moulia, 1997). The dispersion is quantified by a concentration parameter κ, with $\kappa = 0$ corresponding to uniformity and increasing κ to increasing concentration about the reference direction (Fisher, 1993).

Parameters resulting from this analysis were subsequently analyzed by PROC Mixed (Littell et al., 1996). Plants from distances 20 to 25 *H* and greater are unsheltered and unaffected by the windbreak. Plants at and beyond these distances are controls. Differences mentioned are significant at $P \leq 0.05$ unless specified otherwise. All farms were managed and irrigated by the farmers.

RESULTS

Wind Speed and Direction

Wind speeds in early May 1999 were greater than long-term averages and greater than those of either 2000 or 2002 (Table 4). Otherwise wind speeds in 1999 were similar to normal. Wind speed in 2000 was similar to long-term averages except for June; wind speeds the first half of the month were greater than normal and were less than normal the last half of the month. Overall though, wind speed trends and variation in 2000 were similar to long-term averages. Pretassel wind speeds in 2000 recorded by our cup anemometers averaged 1.5,

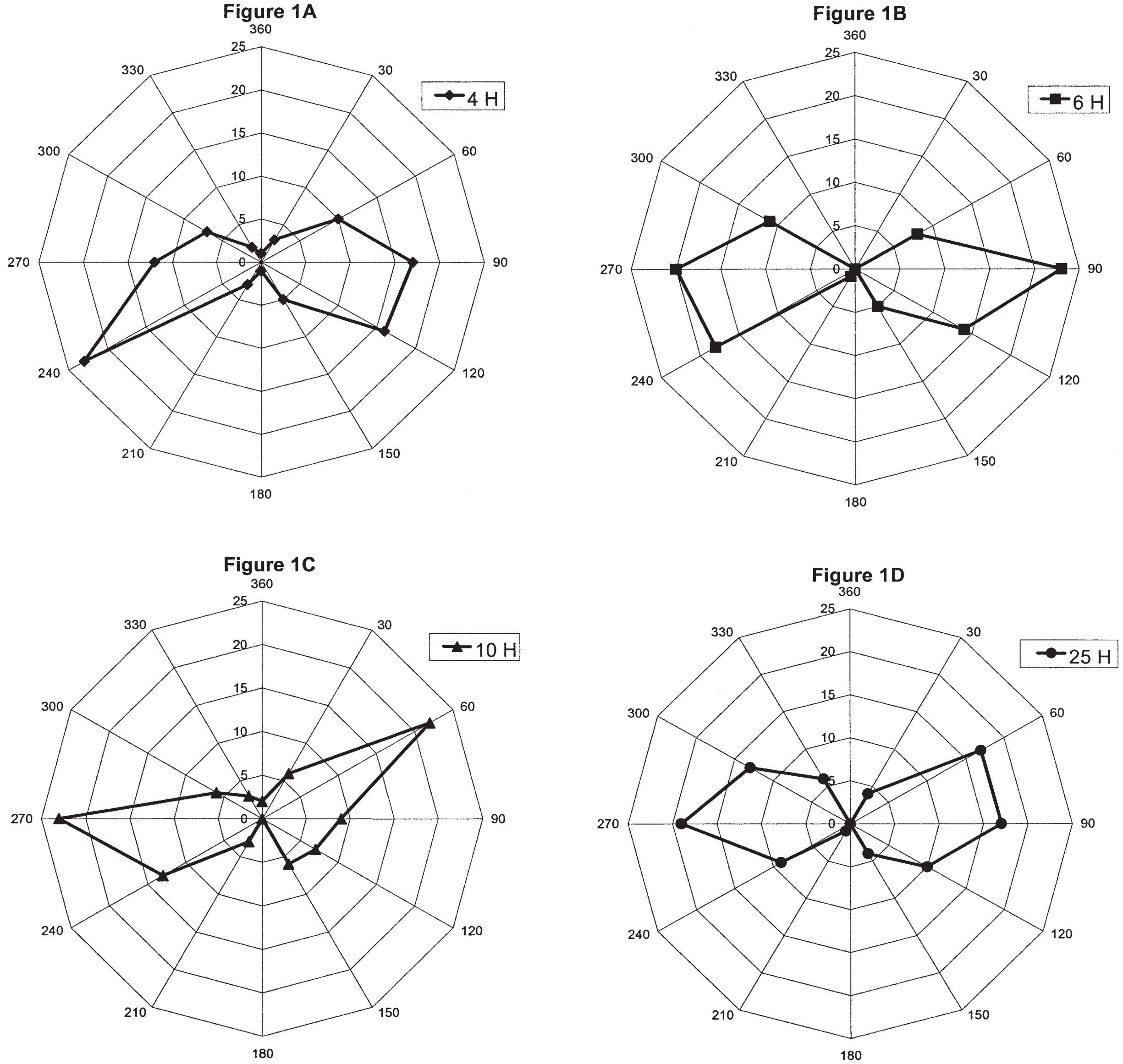

Fig. 1. Corn leaf placement (i.e., azimuth) frequencies in north–south rows at four distances north of an east–west windbreak. Woods I, Nebraska, 2002. *H* is the average height of the tallest row of trees in the windbreak. Numbers on the outside of the largest concentric circle are leaf azimuths, North = 0°/360°; East = 90°; etc. Numbers on the concentric circles within the chart are frequencies of leaves at the various azimuths. Methods: Four adjacent leaves below the ear were evaluated from 25 plants at each distance.

1.7, 2.3, and 2.8 m s^{-1} at the four distances 1.5, 3.6, and 25 *H*, respectively.

Average May–June 2002 wind speeds were 0.5 m s^{-1} greater than the long-term average. This was mainly due to greater wind speeds in June (Table 4). Five days in 1999 had average daily wind speeds greater than 7 m s^{-1}, six in 2002 and only one in 2000. The 20-yr average of days with average wind speeds greater than 7 m s^{-1} for the two-month period is just 2.5 d. Estimated silk dates are shown in Table 4 to allow correlation of crop development and wind speed.

Prevailing spring–summer winds in south central Nebraska have a bimodal distribution with highest frequencies from the south and the north. The ratio between these two modes changes some with different months. For example, normally 39% of the winds in May are from SE to SW (135–225°) while 36% are from NW to NE (315–45°) (7-yr sample, Clay Center NE, data not shown). In June, 47% are from SE to SW while 31% are from NW to NE. Wind directions were different in 2002. In May, 45% were from SE to SW while 34% were from NW to NE similar to normal. However, in June 64% were from SE to SW while only 21% were from NW to NE. Winds in June 2002 were not only were stronger than normal but also more southerly than normal.

1999

As the distance from the windbreak increased, leaves shifted from the south to the southwest ($y = 177 + 0.1073x$, $r^2 = 0.33$, where x is the distance from the windbreak in meters) (Table 5). At the measurement point nearest the windbreak, 1.2 to 1.6 *H*, leaf azimuths

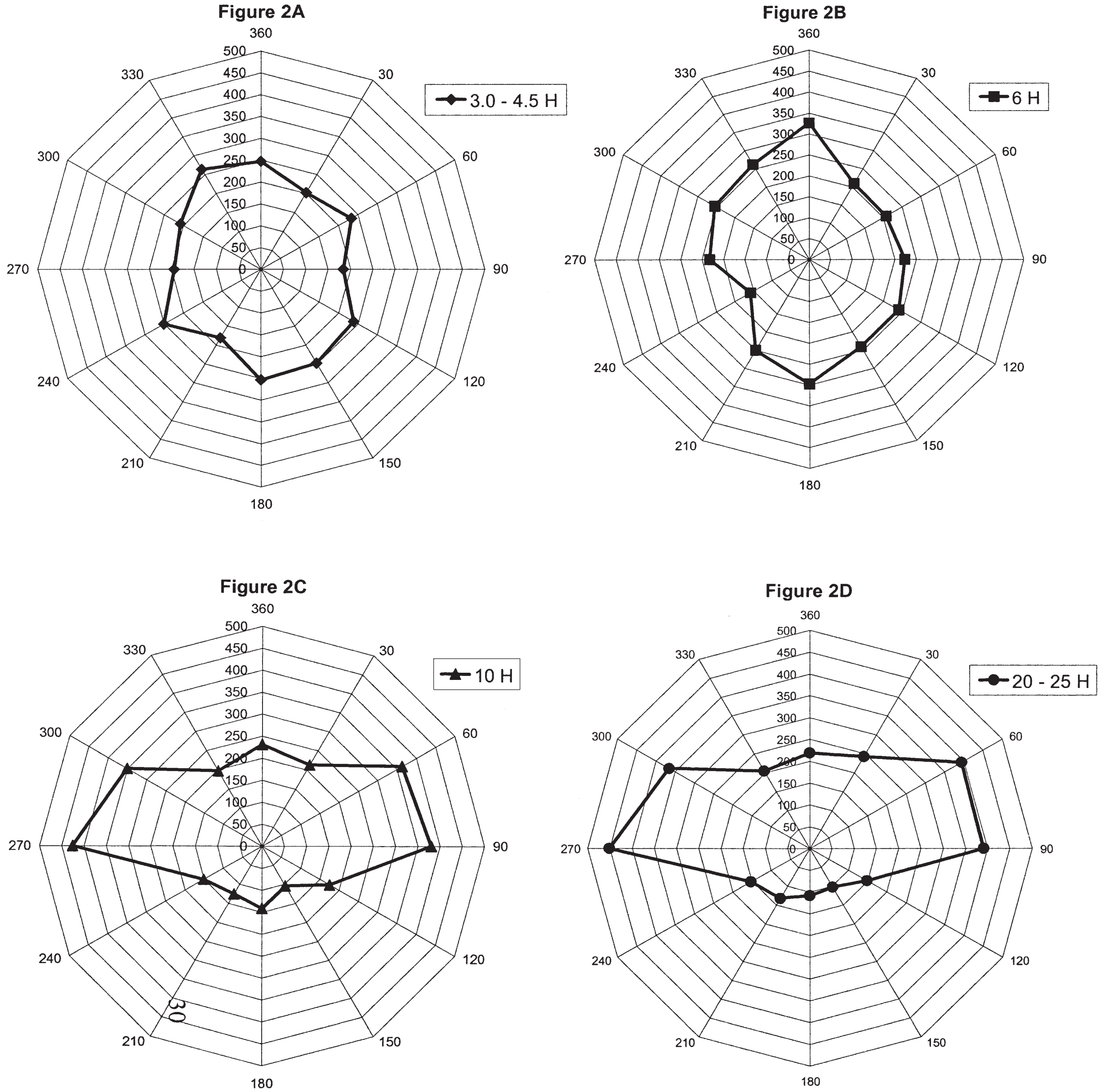

Fig. 2. Corn leaf placement (i.e., azimuth) frequencies in east–west rows at four distances north of an east–west windbreak averaged across three fields, Nebraska, 2002. *H* is the average height of the tallest row of trees in the windbreak. Numbers on the outside of the largest concentric circle are leaf azimuths, North = 0°/360°; East = 90°; etc. Numbers on the concentric circles within the chart are frequencies of leaves at the various azimuths. Methods: Four adjacent leaves below the ear were evaluated from approximately 230 plants at each distance in each field.

averaged 185°; at the measurement point furthest from the windbreak, 11.5 to 15.5 *H*, leaf azimuths averaged 195°. Azimuths of the three leaves monitored (1, 7, and 9) were the same and are averaged together in Table 5. They also responded the same as the distance from the windbreak increased (data not shown).

Table 4. Average wind speeds (m s^{-1}) in south central Nebraska. Clay Center, NE, SCREC.†

Month	Days	1999 m s^{-1} ±SD	2000 m s^{-1} ±SD	2002 m s^{-1} ±SD	1983–2002 m s^{-1} ±SD
May	**1–15**	**5.5 ± 2.4**	**4.5 ± 1.4**	**4.8 ± 1.1**	**4.6 ± 0.3**
	16–31	**3.6 ± 1.1**	**3.7 ± 0.9**	**4.2 ± 2.1**	**4.0 ± 0.4**
June	**1–15**	**4.1 ± 1.7**	**4.7 ± 1.4**	**4.7 ± 1.9**	**3.9 ± 0.2**
	16–30	**3.6 ± 1.1**	**3.0 ± 1.1**	**4.6 ± 1.5**	**3.7 ± 0.3**
July	**1–15**	**4.1 ± 1.4**	**3.1 ± 0.9**	**3.5 ± 1.1**	**3.3 ± 1.1**
	16–31	**2.8 ± 0.5**	**2.4 ± 0.6**	**3.2 ± 0.8**	**2.9 ± 0.9**
Estimated silk dates‡		**18 July**	**10 July**	**9 July**	**5 July**

† Univ. of NE South Central Research and Extension Center. Data from Automated weather network, High Plains Regional Climate Center, School of Natural Resources, University of Nebraska–Lincoln.

‡ Silking data from Yang et al. 2004 (Assumptions: 1 May emergence date, Hybrid = 2700 GDD; Clay Center, NE).

Table 5. Effects of plant distance relative to windbreaks on leaf azimuth. Azimuths are in degrees with 0/360° = North. 1999, 2000, 2002. Univ. of Nebraska.

1999 Corn in north–south rows		2000 Corn in north–south rows		2002 Corn in north–south rows		2002 Corn in east–west rows	
Distance (× *H*)[†]	**Azimuth**	**Distance (× *H*)**	**Azimuth**	**Distance (× *H*)**	**Azimuth**	**Distance (× *H*)**	**Azimuth**
1.4	185[‡]	1.5	195a[§]				
2.7	182	3	173b				
4.1	175			4	176a	3.7	202a
5.5	181	6	177b	6	182a	6	206a
6.8	189						
8.2	183						
9.5	173			10	175a	10	195b
10.9	196						
12.3	198						
13.6	195						
		25	178b	25	178a	23	194b
SE	8.7		7.0		9.1		4.5

[†] *H* is the average height of the tallest row of trees in the windbreaks averaged over locations within a year and corn row orientation. Distance (m) from windbreaks was obtained by multiplying the number in the distance columns above by the windbreak heights provided in Tables 1 and 2.

[‡] The linear effect of distance from the windbreak on leaf azimuth was significant ($P \leq 0.05$) in 1999: $y = 177 + 0.1071x$ (in meters); $R^2 = 0.33$.

[§] Means followed by the same letter within a year are not different ($P \leq 0.05$ in 2000; all others: $P \leq 0.05$).

2000

Average leaf azimuths of the six leaves monitored (Table 3) were similar to each other, 181°; averages are shown in Table 5. Azimuths of the different leaves monitored were also the same at all distances. However, average azimuth at 1.5 *H*, 195°, was different than those at 3, 6, and 25 *H*, 176° ($P = 0.10$) (Table 5).

2002

Leaf azimuths were affected by the distance from windbreaks in east–west rows but not in north–south rows (Table 5). Leaf azimuths in north–south rows averaged 178°, while those in east–west rows were ranged from 194 to 206°.

Averages of leaf azimuths over large numbers of plants hide the site-specific responses that occur. Diagrams showing frequency distributions are thus useful to determine if patterns exist. Figure 1 contains diagrams of 2002 leaf azimuths in north–south rows of the four adjacent leaves below the ear leaf at four distances north of an east–west windbreak. Frequency distributions were the same at all four distances. Leaf azimuths were also the same for all four leaves. These observations are similar to those we observed in north–south rows in fields without windbreaks (Elmore et al., 2003).

In contrast to these observations from north–south rows are those from three fields with corn planted in east–west rows on the north side of east–west windbreaks in 2002. Figure 2 contains diagrams of leaf azimuth frequency averaged across four leaves at four distances from a windbreak averaged across the three fields. Leaf azimuths were asymmetrical to the row and had a bimodal distribution parallel to the row at the two distances furthest from the windbreaks (Fig. 2c and 2d, 10, and 20–25 *H*). At the distances closest to the windbreaks (Fig. 2a and 2b, 3–4.5 and 6 *H*) leaves also had a bimodal distribution, but in contrast to the more distant locations, these distributions were more perpendicular and symmetrical to the row. The wind-sheltering effect of the windbreak appears to have allowed normal leaf placement, that is, leaves perpendicular to the row. In unsheltered areas, increased wind speeds appear to alter leaf distances by turning them away from the wind.

DISCUSSION

Leaf distribution at the distances farthest from the windbreaks in the east–west rows not only contrasts with those of the distances closer to the windbreaks (Fig. 2) but also with data from the north–south rows where leaves were more nearly perpendicular with the row at all distances monitored north of a windbreak (Fig. 1). The 2002 leaf azimuths from east–west rows also contrast with what we have observed in previous studies where leaf distribution patterns were bimodal but nearly perpendicular to the row (Elmore et al., 2003).

Interplant competition affects leaf azimuth in several crops including corn. This azimuthal shift in corn begins during early vegetative stages and continues until shortly before tasseling and is a shade avoidance mechanism (Ballare et al., 1990; Drouet and Moulia, 1996, 1997; Girardin, 1992; Girardin and Tollenaar, 1992). It appears that a factor other than interplant competition affected leaf placement in unsheltered east–west rows in 2002.

Researchers and producers alike wonder if original seed position at planting affects later leaf orientation. Results vary on this. At least two reports state that seed position at planting did not affect eventual plant orientation in certain environments (Fortin and Pierce, 1996; Girardin, 1992). Yet others have found that seed positioning at planting resulted in systematic leaf placement (Fortin and Pierce, 1996; Toler et al., 1999). Environmental factors such as water deficits appear to interact with seed placement effects. Yet, leaf azimuthal orientation probably has little effect on daily light absorption efficiency (Drouet et al., 1999). Thus, the shifts in leaf azimuth we document here may not affect photosynthesis and yield. This has not been confirmed in field research. We assume random seed placement in our study. On the basis of the literature, interplant competition, seed position at planting, and water deficits may all affect leaf azimuth. Our research reported here suggests that early-season wind affects corn leaf azimuth.

CONCLUSIONS

Environmental factors clearly play a critical role in the growth and development of grain crops. Wind, as one of several environmental factors, affects evapotranspiration and crop water use. Until this time, no reports have documented wind's effect on leaf azimuth with an annual crop. Corn leaf azimuth in east–west rows clearly differed as distances increased from areas sheltered by windbreaks to unsheltered areas. In unsheltered areas, most leaves in east–west rows pointed in east–west or northerly directions; in sheltered areas, leaf distributions were more bimodal and symmetrical to the row with more of the leaves pointing either north or south than either east or west. To a limited extent some change in leaf azimuths appears to occur in north–south rows as well. Corn plant position relative to windbreaks affects corn leaf azimuth. This positional effect is apparently due to early-season winds.

The results we present in this paper are possibly confounded by variation in soils and environmental variables that obviously do change as distance from windbreaks increase. Studies are needed with artificial windbreaks in homogenous environments to eliminate these confounding factors. Canopy and crop variables such as leaf area and grain yield were not measured in these studies and are integral to understanding the environmental dynamics near windbreaks. Understanding the critical role early season wind has on leaf azimuth will potentially lead to improved management programs and increased tolerance to greensnap.

ACKNOWLEDGMENTS

We thank Jim Brandle, Wally Wilhelm, and Jim Pavelka, from the Univ. of Nebraska, for their intellectual and physical inputs into this study, which made it possible and to producers Mike Brodrick, Wayne Johnson, Doug Livgren, Lyle and Scot VonSpreckelsen, and Dave Woods who graciously allowed us access to their fields.

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