Mid-Season Stalk Breakage in Corn: Hybrid and Environmental Factors

Roger W. Elmore and Richard B. Ferguson

Research Question

Mid-season corn stalk breakage occurred in south central Nebraska as a result of winds up to 100 mph on 8 July 1993 and up to 80 mph and on 1 July 1994. Growth stages of the plants ranged from V10 to V14. Although similar stalk breakage has occurred before in Nebraska, these events have been relatively minor. Subsequent to these events, stalk breakage occurred in south central Nebraska in 1996 and 1997, as well as in other years in Ohio, Minnesota, Montana, Iowa, and Illinois. The widespread area of damage in Nebraska in 1993 and 1994 provided a unique opportunity to evaluate factors influencing susceptibility to wind in existing studies. These data were collected to evaluate: (i) the impact of stalk breakage on grain yields for different hybrids; (ii) the relationship between yield loss and stalk breakage; and (iii) the influence of soil and cultural factors on susceptibility to wind damage.

Literature Summary

Mid-season stalk breakage is a type of stem lodging also referred to as green-snap or brittle snap. This typically occurs a few nodes above the soil surface, at or below the primary ear node and, in contrast to other types of stem lodging, usually occurs when stalks are moist and turgid. Little information is published on the impact of mid-season stalk breakage.

Between V6 and V12, corn plants increase in height rapidly through elongation of internodes. By V12, the number of potential kernels and the number of rows per ear are determined. By V17, the number of kernels per row is determined. Kernel weight is determined after pollination. Thus, timing of a storm in relation to a hybrid's growth stage can greatly influence a hybrid's ability to compensate since the potential capacity of the various yield components is determined at different stages of growth. The storm damage we are reporting occurred mainly after rows per ear were determined. However, the breakage occurred early enough that compensation by standing plants could still occur by increased kernels per row and by increased seed weight. The effects of organic matter differences, and N application timing and amounts have not been reported as influencing a hybrid's ability to withstand strong winds.

Study Descriptions

We recorded stalk breakage on over 100 corn hybrids at one site in 1993 and at two sites in 1994. Twelve hybrids were chosen at each site and yield components from broken and standing plants were recorded separately to determine whether standing plants compensated for broken plants at each of the three sites. We also evaluated stalk breakage on a long-term N study and a site-specific N management study.

Applied Questions

Do hybrids differ in susceptibility?

Yes. In 1993 stalk breakage ranged from 7% to 88%. Grain yield was reduced 1.5 bu/acre for every 1% increase in stalk breakage (Fig. 1). Breakage in 1994 ranged from 1 to 37% at one site (1.5 bu/acre yield decrease per 1% breakage increase) and from 5 to 51% at another site (1.8 bu/acre decrease per 1% breakage increase). Producers should plant hybrids less susceptible to mid-season stalk breakage.

Full scientific article from which this summary was written begins on page 293 of this issue.

What yield loss occurs for every percentage increase in stalk breakage?

Yield loss decreased 1% for every 1% increase in stalk breakage. Grain production of standing plants did not compensate for grain loss from broken plants at any site.

Do soil and cultural factors affect susceptibility to wind damage?

Yes. Stalk breakage increased with N rate but was reduced with sidedress N application and no-till. Stalk breakage in the site-specific management study showed a low but significant correlation with soil organic matter content. Factors that accelerated plant growth early in the growing season increased susceptibility to stalk breakage.

What can farmers do to reduce the impact of destructive winds?

1. Plant agronomically sound hybrids that are less susceptible to breakage. Many seed companies are aware of the breakage tolerance of their hybrids based on experimental and in-field experience.
2. Plant crops in addition to corn. Neither grain sorghum nor soybean were affected by the storms.
3. Plant in different row orientations. The 1993 storm damage was worse in north-south rows; the 1994 damage was worse in east-west rows.
4. Plant wind breaks. According to James Brandle, University of Nebraska, Lincoln, wind speeds within corn canopies sheltered by wind breaks near Lincoln, NE, in 1993 were generally less than 20 mph with no stalk breakage while, in exposed areas, wind speeds exceeded 40 mph and stalk breakage was considerable.

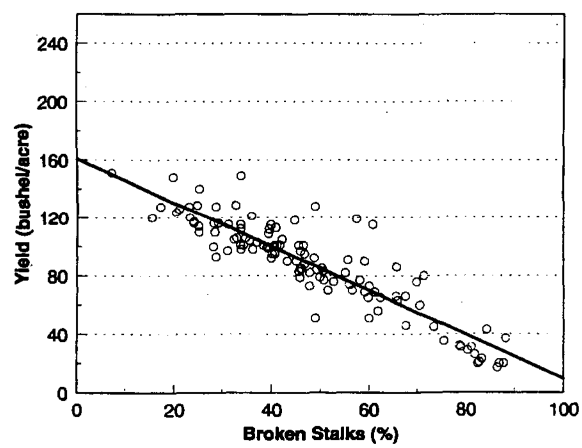

Fig. 1. The effect of stalk breakage on grain yield of different corn hybrids (SCREC, 1993).

Mid-Season Stalk Breakage in Corn: Hybrid and Environmental Factors

Roger W. Elmore* and Richard B. Ferguson

Mid-season corn (*Zea mays* L.) stalk breakage in south central Nebraska resulted from 100 mph winds on 8 July 1993 and 80 mph winds on 1 July 1994. Corn growth stages at the time of damage ranged from V10 to V14. Observations of field studies were taken to determine: (i) the impact of stalk breakage on grain yields of different hybrids; (ii) yield compensation by remaining plants; and (iii) the influence of soil and cultural factors on susceptibility to wind damage. We recorded stalk breakage on over 100 corn hybrids in evaluation trials at one site in 1993 and at two sites in 1994 to address objective i. Twelve hybrids were chosen at each site and yield components from broken and standing plants were recorded separately to determine whether remaining standing plants compensated for broken plants (objective ii). We also evaluated stalk breakage on a N management study and a site-specific management/variable rate study to address objective iii. In 1993 stalk breakage ranged from 7 to 88%, and grain yield was reduced 1.5 bu/acre for every 1% increase in stalk breakage. Breakage in 1994 ranged from 1 to 37% at one site and from 5 to 51% at the other site. Grain yield was reduced by 1.5 and 1.8 bu/acre for every 1% increase in stalk breakage, respectively. Remaining plants did not compensate for grain loss from broken plants at any site. Percentage yield loss is directly related to percentage stalk breakage. Stalk breakage increased with increasing N rate but was reduced with sidedress relative to preplant N application and no-till relative to conventional tillage. Stalk breakage in the site-specific management study correlated (positively) with soil organic matter content. Factors that accelerated plant growth early in the growing season increased susceptibility to stalk breakage. Unfortunately, management practices that result in slow early plant growth also limit yield potential. Planting tolerant hybrids is the best way to avoid losses. More information is needed on why individual plants break and why specific hybrids are more prone than others to mid-season stalk breakage.

SEVERE THUNDERSTORMS and associated heavy rain and high winds on 8 July 1993 and 1 July 1994 resulted in mid-season stalk breakage over a large portion of Nebraska's corn production area. Stalk breakage was a result of winds up to 100 mph in 1993 and up to 80 mph in 1994. Some fields had less than 10% standing plants following the storms. Although 2,4-D and other herbicide applications are often associated with early to mid-season stalk breakage, it was not in these situations. The growth stage of the crop ranged from V10 to V14 (Ritchie et al., 1996) at the time of wind damage in both years. Most breakage occurred at or below the primary ear node. Culms were moist and turgid when plants broke. Windbreaks reduced wind speeds and stalk breakage in 1993 (James Brandle, 1997, University of Nebraska, personal communication). Estimated losses were $200 million in Nebraska from the 1993 storm alone. The destruction in 1994 was more sporadic.

We observed a few occurrences of mid-season stalk breakage before 1993. Stalk breakage in and near a Phelps County corn hybrid trial in early July 1987 ranged up to 27% broken plants (Dreier et al., 1987). In the 1990 Fillmore County corn hybrid trial stalk breakage exceeded 50% on some hybrids from a 25 June storm (Nelson et al., 1991). These incidents were usually confined to a given field or hybrid within a field. In contrast, the 1993 and 1994 storms were widespread in area of destruction and hybrids affected. Other crops were not adversely affected.

Rapidly growing corn is more susceptible to stalk breakage from wind as well as other physical phenomenon such as cultivation, hilling, or fertilizer application where stalks are bent by a low tool bar. Corn is most vulnerable during the 7- to 10-d period prior to tasseling (King and Carda, 1993). Plant growth is correlated with growing degree day accumulation. The "window of susceptibility" apparently varies with hybrids and can range from 50 to 450 growing degree days (Paul Carter, 1993, Pioneer Hi-Bred International, personal communication). Hybrids susceptible to breakage had greater intercellular space in rind parenchyma relative to more resistant hybrids in 1 of 2 yr (Li, 1997). In general, treatments that cause plants to grow more rapidly enhanced susceptibility to stalk breakage (Wilhelm et al., 1999).

Preliminary data based on lab analyses suggest that hybrids with either greater rates of lignification or greater lignin content of mature plants are more prone to stalk breakage (Li, 1997). Above-ground internode elongation and lignification follows a basipetal (top-down) progression (Morrison et al., 1994a, b). Up to four internodes are elongating at any given time before reproduction begins (Morrison et al., 1994a) and internode elongation occurs over 10 to 12 d. Lignification occurs after cell elongation is complete; internodes are completely lignified 13 d after internode elongation commences (Morrison et al., 1994 b).

Between V6 and V12, corn plants increase in height rapidly through elongation of internodes (Ritchie et al., 1996). By V12, the number of potential kernels and the number of rows per ear are determined. By V17, the number of kernels per row is determined. Kernel weight is determined after pollination. Thus, timing of a storm in relation to a hybrid's growth stage can greatly influence its ability to compensate. The storm damage we are reporting occurred mainly after rows per ear were determined. However, the breakage occurred early enough that compensation by

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Abbreviations: SCREC, South Central Research and Extension Center.

Table 1. Hybrids, entry numbers, broken stalk percentage, ear node, internode of break, and machine-harvest yields from the yield compensation study, SCREC, 1993, 1994, and Merrick County, 1994†.

			SCREC						Merrick County	
			1993				1994		1994	
Brand	Hybrid	Entry number	Broken stalks	Yield	Internode of break	Ear node	Broken stalks	Yield	Broken stalks	Yield
			%	bu/acre			%	bu/acre	%	bu/acre
Asgrow	RX699	1	70	76	11.7	13.2	39	134	36	157
Asgrow	RX801	2	49	128	11.5	14.7	16	162	6	214
Cargill	7697	3	61	115	12.0	13.7	14	183	7	210
Ciba	4225x	4	--	--	--	--	11	176	3	205
Ciba	4494	5	45	118	12.2	14.3	12	170	4	213
Crow's	490	6	--	--	--	--	28	146	25	155
DeKalb	DK652	7	7	151	11.9	13.5	10	215	8	246
Golden Harvest	H-2573	8	--	--	--	--	9	165	3	209
Golden Harvest	H-2493	9	33	129	11.6	12.4	18	162	4	211
Northrup King	N6330	10	34	149	12.1	13.5	15	167	9	203
Ottlie	2448	11	--	--	--	--	46	104	37	146
Pioneer	3394	12	71	80	12.8	13.5	31	146	15	186
Golden Harvest	H2544	13	20	148	12.2	13.9	--	--	--	--
DeKalb	DK657	14	66	86	11.0	13.3	--	--	--	--
Pioneer	3417	15	88	37	12.3	11.7	--	--	--	--
Pioneer	3162	16	58	119	11.5	13.2	--	--	--	--
LSD $P < 0.05$			15	27	0.8	0.8	10	30	10	22

† Broken stalks and yield data are from Nelson et al. (1994, 1995).

standing plants could still occur by increased kernels per row and by increased seed weight.

Row direction, as well as planting dates and other cultural practices, have varying impacts on a crop's ability to withstand the wind. For example, small grains sown in rows parallel to prevailing strong winds may reduce the incidence of stem lodging (Pinthus, 1973). Corn plant displacement by wind (regardless of wind direction) was greater perpendicular to the row direction than parallel to the row direction (Flesch and Grant, 1992). The across-row (perpendicular) variance was more than four times larger than the along-row (parallel) variance. Actual wind direction had little effect on corn plant displacement.

The two windstorms gave us a unique opportunity to examine the effects of hybrid, soil, and other cultural factors on the susceptibility of corn to wind damage at the V10 to V14 growth stages. This report summarizes data collected in 1993 and 1994. These data were collected to: determine the impact of stalk breakage on grain yields of different hybrids (Exp. 1); determine whether standing plants compensated for broken plants (Exp. 2); and assess the influence of soil and cultural factors on susceptibility to wind damage (Exp. 3 and 4).

MATERIALS AND METHODS

Hybrid Differences

Experiment 1. To assess hybrid differences in stalk breakage resulting from high winds, we recorded number of stalks broken and yield on 113 hybrids at the University of Nebraska South Central Research and Extension Center (SCREC) (Hastings silt loam [fine montmorillonitic, mesic udic Argiustolls]), Clay Center, NE, in 1993 and on 105 hybrids at SCREC and in Merrick County, Nebraska, in 1994 (Fonner sandy loam [sandy, mixed, mesic Cumulic Haplustolls]). Experimental design was a randomized com-

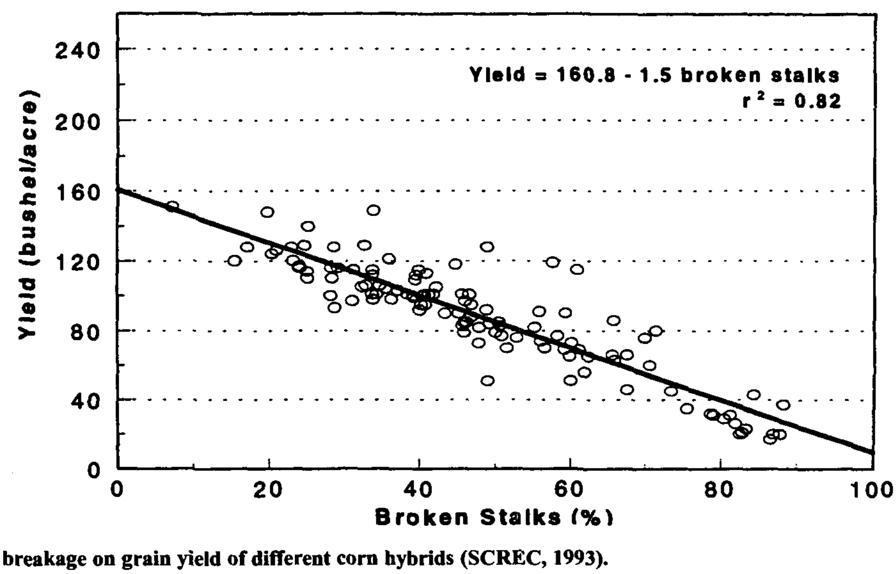

Fig. 1. The effect of stalk breakage on grain yield of different corn hybrids (SCREC, 1993).

plete block. Linear regression analysis was used to determine the relationship between corn yield and broken stalks. Measurements were taken within plots established as part of the University of Nebraska Corn Hybrid Tests (Nelson et al., 1994, 1995). The SCREC hybrid tests were planted using a ridge-till tillage system into soybean residue and furrow irrigated. Preplant N was applied at 150 lb/acre in both years. Alachlor and atrazine (along with nicosulfuron and bromoxynil in 1994) were used to control weeds. The Merrick County plots were also furrow irrigated and 125 lb/N, 20 lb P_2O_5, and 22 lb K_2O, 20 lb S, 2 lb Zn, and 0.1 lb Mg were applied per acre divided between a liquid starter and sidedress application. The irrigation water nitrate N content was 35 ppm at this site, resulting in the application of an additional 210 lb N by irrigation over the growing season. Alachlor and atrazine were used to control weeds. Plots at SCREC were planted on 27 Apr. 1993 and 26 Apr. 1994 and at Merrick County on 25 Apr. 1994.

Broken stalks were counted within a few days of the storm. Yield was determined by machine harvest and adjusted to 15.5% moisture content. Rows at SCREC were oriented north-south in both years, while rows at the Merrick County site were oriented east-west. Observations from several locations in south central Nebraska were that north-south rows were damaged more by the storm in 1993 and east-west rows were damaged more in 1994. Winds during the storms were from the west-northwest in 1993 and from the north in 1994. This was also true at our experimental sites discussed here.

Yield Compensation by Standing Plants

Experiment 2. Twelve hybrids were chosen at each location described in Exp. 1 to determine whether yield of standing plants compensated for the plants broken by the storms. The hybrids were chosen to represent a range of broken stalk damage (Table 1) and maturities. All ears in one of the two harvest rows were hand harvested. Ears harvested from broken plants of most hybrids were secondary ears since stalks of most hybrids broke below the primary ear node. Ears from broken plants were collected and handled separately from those of standing plants. Yield components measured were plant population, ears per plant (at SCREC only), rows per ear, kernels per row, and seed weight. Number of nodes below the breakage point and the primary ear node (of standing plants) were recorded. Hybrids were considered main plots; broken and standing plants were considered subplots. Means were compared using FLSDs; that is, LSDs were used to separate means only when the F-test for that effect was significant ($P \leq 0.05$). Correlations of percentage broken plants and yield components of standing plants were calculated at each site. The key to assessing compensation is whether standing plants of hybrids with high numbers of broken stalks had similar yield components as hybrids with low numbers of broken stalks.

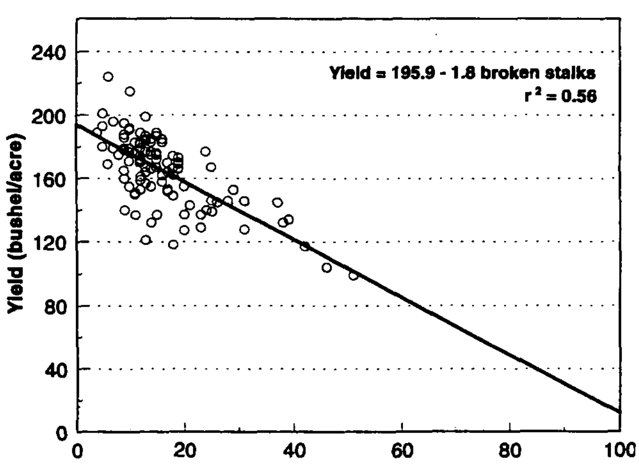

Fig. 2. The effect of stalk breakage on grain yield of different hybrids (SCREC, 1994).

Effect of Soil and Cultural Factors

Experiment 3. This is a long-term N study initiated at SCREC in 1986 to evaluate the main and interactive effects of N fertilizer rate, tillage, N application timing, and the use of the nitrification inhibitor nitrapyrin on N use efficiency of irrigated corn and to monitor the accumulation and movement of nitrate in the soil (Crete silt loam, fine montmorillonitic mesic Pachic Argiustolls) (Ferguson et al., 1991; Gotway et al., 1996). In 1993, Pioneer 3417 was planted 18 May with preplant treatments fertilized 4 May and sidedress treatments fertilized 29 June. In 1994, Golden Harvest H-2530 was planted 5 May, with preplant treatments fertilized 1 April and sidedress treatments fertilized 11 June. The influence of existing treatments on stalk breakage was evaluated using multiple regression in SAS, separating means using FLSD, and fitting quadratic response curves to N rate each year.

Experiment 4. Stalk breakage data was recorded from a site-specific N management (Ferguson et al., 1991; Gotway et al., 1996) study located on a producer's field in Clay County (Hastings silt loam soil, fine, montmorillonitic, mesic Udic Argiustolls). In the fall of 1993, the field had been soil sampled on an alternating grid design (20 ft by 100 ft offset intervals) for several parameters. Following the wind damage in 1994, counts of broken stalks were collected around each soil sample grid point (20 ft of one row adjacent to and centered on the soil core location). Correlations were determined between measured soil parameters Bray-1 P, K, Zn, pH, and soil organic matter content with percentage broken stalks. Maps of the spatial distribution of soil organic matter and broken stalks were created using SURFER and using an inverse distance squared interpolation method.

RESULTS AND DISCUSSION

Hybrid Differences

Experiment 1. Stalk breakage averaged over all hybrids was 48% in the 1993 corn hybrid plots at SCREC in 1993, and ranged from 7% to 88%. Yield decreased by 1.5 bu/acre for every percentage increase in stalk breakage (Fig. 1). In 1994 at SCREC stalk breakage averaged 16% and ranged from 5 to 51% (Fig. 2). Yield decreased by 1.8 bu/acre for every percentage increase in stalk breakage. At Merrick County in 1994, stalk breakage averaged 10% and damage from 1 to 35% (Fig. 3). Yield decreased by 1.5 bu/acre for

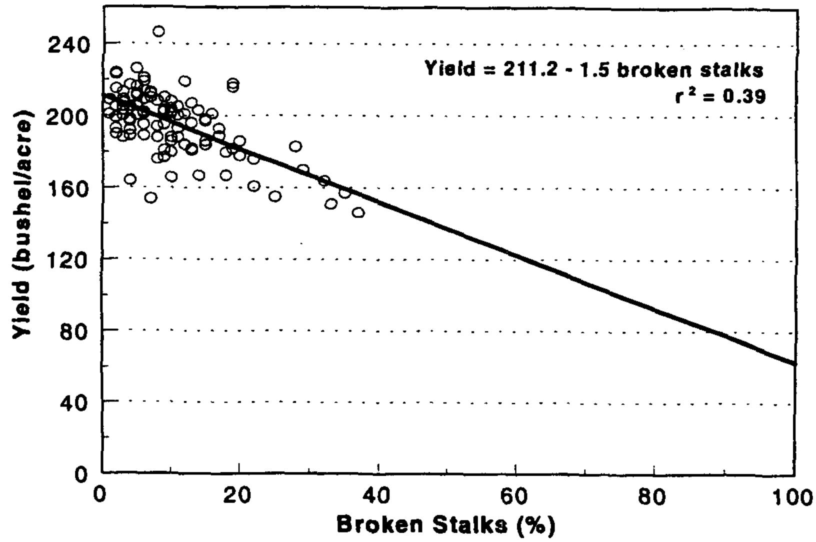

Fig. 3. The effect of stalk breakage on grain yield of different hybrids (Merrick County, 1994).

every percentage increase in stalk breakage. Stalk breakage at all sites usually occurred in the lower part of the internode, immediately above the intercalary meristem. This observation supports the suggestion that the weakest part of a stalk is at the base of a fully elongated, but not yet fully lignified, internode (Dwayne R. Buxton, 1997, USDA, personal communication). Producers in areas with potentially high mid-season winds should attempt to plant agronomically sound hybrids with tolerance to mid-season stalk breakage. Many seed companies score hybrids based on experimental and in-field experience.

Yield Compensation by Standing Plants

Experiment 2. Average point of stalk breakage was 1.5 nodes below the ear node (Table 1). Entries, however, differed in both internode within which breakage occurred and upper-most ear node. The internode of break was below the ear node in all but Entry 15, the entry with the greatest amount of stalk breakage. Other entries broke at similar internodes and had similar ear nodes.

Broken plants contributed little to yield (Tables 2, 3, 4). This was expected since stalks of all but Entry 15 were broken below the primary ear node (Table 1) and a large portion of the leaf area was lost when the plant tops were severed. Entry 15 had similar yield from broken and standing plants (unbroken) in contrast to the other entries (Table 2). Averaged over all entries, standing plant yield components were greater than those of the broken plants at all locations.

In 1993, ears per plant on standing plants were less with Entries 13 and 15 than with the other entries (Table 3). The other entries had similar values yet Entry 13 had one of the

Table 2 . Yield components of standing (S) and broken (B) plants in yield compensation study. SCREC, 1993.

	Yield†		Initial plants per acre	Ears/plant		Rows/ear		Kernels/row		Seed weight		Broken stalks
Entry number	B	S	B+S	B	S	B	S	B	S	B	S	
	bu/acre		× 1000							g/100 seed		%
1	9	53	24.85	0.30	0.95	13.4	17.6	12	42	32	30	70
2	1	107	26.73	0.08	1.02	6.2	14.9	5	41	26	36	49
3	1	99	26.68	0.05	1.08	5.6	15.6	6	40	14	34	61
5	3	105	25.51	0.18	0.95	10.0	14.8	15	42	34	36	45
7	5	140	24.19	0.18	0.95	11.8	17.4	19	44	31	30	7
9	8	118	25.17	0.30	0.95	11.0	16.1	18	39	30	33	33
10	3	127	26.01	0.20	0.98	7.2	14.9	10	47	24	33	34
12	24	66	25.87	0.58	0.95	13.5	16.5	16	38	36	35	71
13	3	133	24.91	0.20	0.88	12.0	14.2	16	41	31	37	20
14	2	62	25.06	0.08	1.02	6.0	15.8	10	43	16	33	66
15	29	20	25.87	0.58	0.58	11.7	13.9	24	31	32	33	88
16	12	96	26.49	0.58	0.98	13.5	17.0	14	42	35	33	58
Average	8*	94	25.43‡	0.27*	0.94	10.2*	15.7	14*	41	28*	34	49‡
FLSD $P \leq 0.05$												
• for hybrid‡	--		2.04	--		--		--		--		15
• for standing vs. broken within hybrid	19		--	0.23		3.5		7		10		--
• for standing or broken among hybrids	18		--	0.19		3.5		7		10		--

* B vs. S is significant at $P \leq 0.05$.
† Sum of hand-harvest yields (B + S) do not correspond exactly to the machine-harvest yields reported in Table 1 and Nelson et al. (1994).
‡ n = 115, data from Nelson et al. (1994).

Table 3 . Yield components of standing (S) and broken (B) plants in yield compensation study. SCREC, 1994.

Entry number	Yield†		Initial plants per acre	Ears/plant		Rows/ear		Kernels/row		Seed weight		Broken stalks
	B	S	B+S	B	S	B	S	B	S	B	S	
	bu/acre		× 1000							g/100 seed		%
1	18	119	26.75	0.41	0.96	11.4	17.0	13	43	27	29	39
2	0	184	25.28	0.06	0.79	3.5	14.2	4	46	10	35	16
3	10	185	26.62	0.38	1.00	10.0	15.6	22	43	22	33	14
4	6	174	28.31	0.17	0.81	9.5	14.5	22	41	24	35	11
5	3	174	26.57	0.12	0.77	6.4	14.4	20	46	17	36	12
6	7	140	24.42	0.20	0.71	11.2	16.0	18	46	20	35	28
7	8	226	26.99	0.60	0.92	14.2	17.1	34	45	25	30	10
8	8	168	25.62	0.33	0.82	12.5	14.4	43	44	29	34	9
9	8	170	24.40	0.23	0.87	8.3	15.8	24	43	21	34	18
10	12	161	25.09	0.38	0.88	11.9	14.1	41	49	28	35	15
11	3	100	25.09	0.15	0.60	7.8	14.6	11	48	37	38	46
12	10	136	26.77	0.26	0.80	11.1	15.8	17	42	35	34	31
Average	8*	161	25.35‡	0.27*	0.83	9.8*	15.3	23*	45	25*	34	16‡
FLSD $P \leq 0.05$												
• for hybrid‡	--		2.85	--		--		--		--		10
• for standing vs. broken within hybrid	31		--	0.24		ns		14		ns		--
• for standing or broken among hybrids	28		--	0.25		ns		14		ns		--

* B vs S is significant at $P \leq 0.05$; ns = not significant.
† Sum of hand-harvest yields (B + S) do not correspond exactly to the machine-harvest yields reported in Table 1 and Nelson et al. (1995).
‡ n = 67, data from Nelson et al. (1995).

lowest amounts of broken stalks and Entry 15 the largest. Several entries had a similar number of rows per ear in standing and broken plants (Entries 12, 13, 15, and 16), but, among all entries, only Entry 15 had fewer rows per ear in standing plants than the others. Entry 15 had similar kernels per row in both standing and broken plants and, along with Entries 9 and 12, had fewer kernels per row in standing plants than the other entries. Seed weight of all entries was similar for standing plants. Several entries had similar seed weights in standing and broken plants.

In 1994 at SCREC the only major difference between broken and standing plant yield components among entries was ears per plant (Table 3). Entries 6 and 11 had fewer ears per plant on the standing plants than did the other entries. These entries were two of the four entries that had the most stalk breakage at that location. Other entries had similar yield components in the standing plants. Entries had similar yield components among the standing plants in Merrick County in 1994 (Table 4). Standing plants did not compensate for broken plants by producing more ears per plant, rows per ear, kernels per row, or seed weight. Correlation analyses confirm this conclusion (Table 5). Standing plant yield components either were not affected or were reduced by increased stalk breakage.

Yield components of all entries were generally similar regardless of the frequency of stalk breakage. We expected increases in either ear length (kernels per row) or kernel weights in entries with the highest breakage levels if compensation by standing plants occurred. This did not happen. Standing plants did not compensate for broken plants.

Table 4. Yield components of standing (S) and broken (B) plants in yield compensation study. Merrick County, 1994.

Entry number	Yield†	Initial plants per acre		Rows/ear		Kernels/row		Seed weight		Broken stalks
	B	S	B+S	B	S	B	S	B	S	
	bu/acre	× 1000						g/100 seed		%
1	29	145	26.81	15.3	16.2	20	41	30	31	36
2	1	222	25.84	7.8	15.1	14	45	12	37	6
3	8	217	28.20	15.1	15.9	25	44	26	35	7
4	7	207	26.35	13.2	14.8	26	40	36	40	3
5	8	209	28.39	10.2	15.0	26	42	25	37	4
6	7	146	25.59	14.2	15.9	32	44	31	38	25
7	20	213	31.66	15.2	17.6	31	44	26	32	8
8	1	218	26.41	3.5	14.8	6	46	7	36	3
9	19	210	27.60	11.4	16.1	28	42	23	35	4
10	17	196	27.09	13.5	14.4	31	50	34	37	9
11	8	141	25.09	8.2	14.2	14	50	22	38	37
12	11	174	26.56	12.9	15.4	20	41	36	38	15
Average	11*	192	26.04‡	11.7*	15.4	23*	44	26*	36	16‡
FLSD $P \leq 0.05$										
• for hybrid‡	--	2.87		--		--		--		10
• for standing vs. broken within hybrid	38	--		5.6		12		ns		--
• for standing vs. broken among hybrids	31	--		5.2		12		ns		--

*B vs. S is significant at $P \leq 0.05$.
† Sum of hand-harvest yields (B + S) do not correspond exactly to the machine-harvest yields reported in Table 1 and Nelson et al. (1995).
‡ n = 67, data from Nelson et al. (1995).

Table 5. Correlation coefficients, means, and ranges of standing plant yield components correlated with percentage broken plants at three sites in Nebraska.

Site/ statistics	Ears/plant	Rows/ear	Kernels/row	Seed wt
				g/100
1993 SCREC				
r	–0.27	–0.03	–0.51**	–0.03
Yield component:				
minimum	0.35	11.0	25	28
maximum	1.44	18.0	49	40
mean	0.94	15.7	41	34
1994 SCREC				
r	–0.34*	0.22	0.11	0.09
Yield component:				
minimum	0.46	13.5	38	26
maximum	1.14	18.0	52	41
mean	0.83	15.3	45	34
1994 Merrick County				
r	--	0.03	0.08	–0.21
Yield component:				
minimum	--	13.0	38	29
maximum	--	18.0	52	44
mean	--	15.4	44	36

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Percentage yield loss is directly related to percentage stalk breakage since no compensation occurred by standing plants and broken plants contributed little to yield.

Effect of Soil and Cultural Practices

Experiment 3. The use of nitrapyrin did not significantly influence stalk breakage in either year. Breakage increased quadratically with N rate in both 1993 and 1994 (Fig. 4). Breakage was less with sidedress N application than with preplant N application each year. Sidedress N was applied at a relatively late growth stage each year; consequently, plants had less time to respond to applied N with sidedress application relative to preplant. There was a 9 d interval between sidedress application and the windstorm in 1993, and a 20 d interval in 1994. Breakage was less with no-till than with conventional tillage in 1993. Initial crop growth in this study has often been slower with no-till, possibly related to slower mineralization rates early in the season compared with conventional tillage. Delayed N application, and no-till in 1993 apparently resulted in less mature plants that were less susceptible to breakage.

Yield increased with N rate each year, even though broken stalks increased as well (Fig. 5). In 1993, preplant N treatments were not harvested. In 1994, the sidedress N application had fewer broken stalks and greater yield than preplant application. In both 1993 and 1994, no-till yielded less than conventional tillage, even though stalk breakage was higher with conventional tillage. This trend is similar to other years in this study where no-till typically yields less than conventional tillage.

Experiment 4. Figures 6 and 7 illustrate the spatial distribution of soil organic matter and broken stalks, respectively, at this site in 1994. Mean values at the site were 2.68% soil organic matter and 27% broken stalks. The occurrence of broken stalks was significantly correlated ($R = 0.2715$, $P \leq 0.0001$) to soil organic matter. No other soil

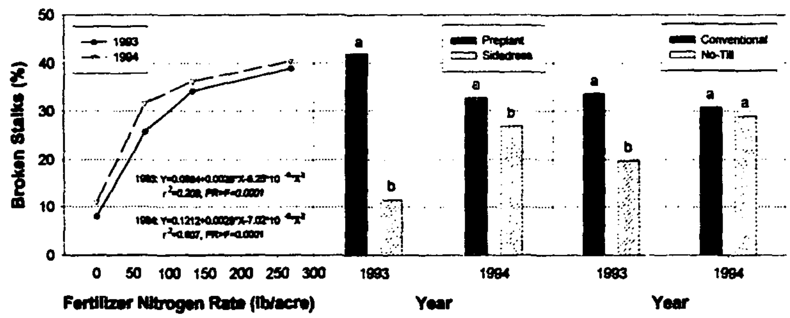

Fig. 4. Broken stalks as influenced by fertilizer N rate, N application timing and tillage method (SCREC 1993, 1994). Bars within years with different letters are significantly different at an alpha level of 0.05 according to Fisher's LSD.

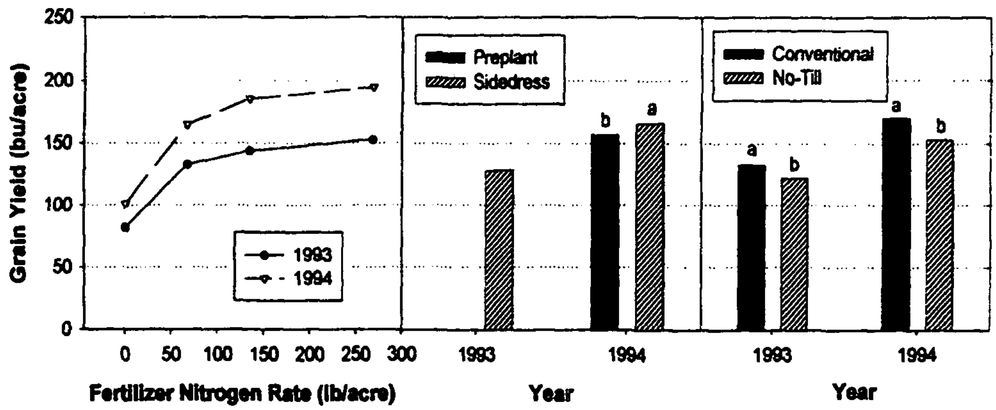

Fig. 5. Grain yield as influenced by fertilizer N rate, N application timing and tillage method (SCREC 1993, 1994). Preplant treatments were not harvested for yield in 1993 due to damage. Bars within years with different letters are significantly different at an alpha level of 0.05 according to Fisher's LSD.

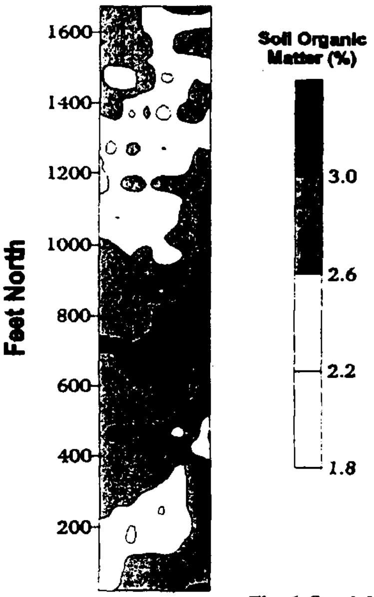

Fig. 6. Spatial distribution of organic matter Clay County site specific N-management study, 1994.

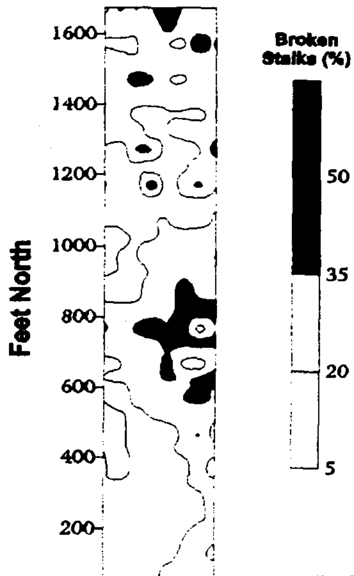

Fig. 7. Spatial distribution of broken stalks, Clay County site-specific N management study, 1994.

factors (Bray-1 P, K, Zn, pH) were related statistically to the frequency of broken stalks. This is consistent with observations at this and other sites that early plant growth is more rapid in areas of higher soil organic matter, often regardless of other soil fertility factors.

Factors that accelerated crop growth early in the season also increased the susceptibility of the crop to stalk breakage, similar to results of Wilhelm et al. (1999). For example, plants receiving greater N rates, earlier N application, or with more N available due to mineralized organic matter were taller and growing more rapidly, and thus more likely damaged at the time the storms occurred.

SUMMARY

We report here observations on the impact of high winds on corn during a phase of rapid internode elongation and growth. Hybrids responded differently with stalk breakage ranging from 7% or less to 88%. Thus, selecting hybrids with some tolerance may be important. Standing plants did not compensate for broken plants. Percentage yield loss is directly proportional to percentage stalk breakage. In addition, we've shown that factors that accelerate early-season plant growth also increase susceptibility to stalk breakage. Unfortunately, management practices that result in slow early plant growth also limit yield potential. Planting agronomically sound, tolerant hybrids is the best way to avoid losses. More information is needed on why individual plants break and why specific hybrids are more prone than others to mid-season stalk breakage.

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