Influence of Simulated Wind Lodging on Corn Growth and Grain Yield

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Root lodging of entire stands of corn (*Zea mays* L.) often occurs when strong winds are accompanied by heavy rain and saturated soil. Root lodging is especially severe when plants are in mid-vegetative stages and have not yet developed adequate brace roots to help anchor the plants. The objective of this study was to measure the effects of wind lodging on plant recovery, growth, and grain yield. Root lodging due to wind was simulated in a field experiment by saturating the soil with irrigation water and manually pushing corn plants over at the base, perpendicular to row direction. Treatments applied were a control and simulated wind lodging at V10, V13 to V14, and V17 to R1 stages in 1985 and V11 to V12, V15, and VT stages in 1986. Three hybrids were included. The upper region of plants straightened to vertical within two days following lodging, and lodging did not affect subsequent timing of plant development. The angle between the below-ear stalk and soil surface at harvest decreased from 73 to 85° with lodging at early (V10-V12) stages to 22 to 36° at late (V17-R1) stages due to more pronounced lower stalk curvature. This resulted in ear height reductions from 52 to 57 in. for controls to less than 30 in. when lodging occurred after V17. These results indicate that mechanical harvest of corn wind lodged during V10 to R1 stages will likely be possible, but slow harvest speeds may be necessary to minimize losses. Compared to hand-harvested grain yields of control plots, grain yield decreased by 2 to 6%, 5 to 15%, and 13 to 31% when lodging occurred at early (V10-V12), medium (V13-V15), and late (V17-R1) stages, respectively. Hybrid differences in yield response to lodging appeared to be related primarily to variations in developmental stages at the time lodging treatments were applied. Further research is needed to determine the physiological factors responsible for reduced yield following wind-induced root lodging and to assess whether the yield loss percentages in this study apply under different levels of crop productivity and variable environmental conditions.

WIND-INDUCED corn (*Zea mays* L.) root lodging often occurs during the mid-growing season, when soils are saturated by heavy rainfall and the rainfall is accompanied or followed by high wind speeds. In severe situations, entire corn stands are blown nearly horizontal away from the direction of the wind. Initially, producers are concerned about how much recovery they can expect. After a few days, the plants usually move upward such that the upper stalk is vertical, but curvature occurs in the lower stalk area. The primary concern of corn producers after plants curve upward is over potential losses from mechanical harvesting root-lodged corn. We were interested in learning whether wind-induced root lodging might reduce grain yield due to physiological factors which would be separate from, or additive to harvest losses.

Investigations of wind lodging effects on grain yield and quality, nutrient uptake, and harvest losses have been conducted for many crop species including wheat (*Triticum aestivum* L.) (8, 15), rice (*Oryza sativa* L.) (1), oats (*Avena sativa* L.) (11), barley (*Hordeum vulgare* L.) (4, 5), soybeans [*Glycine max* (L.) Merr] (3, 10, 14, 16), and grain sorghum (*Sorghum bicolor* L. Moench) (7). For these crops, grain yield losses in conjunction with lodging were attributed to (i) inhibited uptake and translocation of nutrients, primarily when lower-stalk breakage occurred; and (ii) reduced light interception, despite lack of any apparent stem injury.

With corn, lodging has been evaluated in relation to corn rootworm (*Diabrotica longicornis* Say.) injury (2) or to late-season stalk breakage caused by stalk-rotting organisms (6). We were unable to find studies evaluating wind root lodging in the absence of insect or disease-induced lodging.

Wind lodging of corn is most likely to occur when plants are in mid-vegetative stages, and have not yet developed adequate brace roots to provide firm anchorage during severe wind and rain storms (13). Therefore, the objective of our study was to quantify effects of wind-induced root lodging during these stages on corn development and grain yield.

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Table 1. Dates, growth stages, and canopy heights at treatment applications, and dates of silking, leaf number, and grain moisture in 1985 and 1986.

	Lodging treatments					
Hybrid	Date	Growth stage†	Canopy height before treatment‡	Silk date (July)	Final leaf no.‡	Grain moisture‡
			in.			%
		1985				
Sokota brand 680	28 June	V10	37	21	20	34.8
	8 July	V13	66	21		
	17 July	V17	95	21		
FR23 × FR27	28 June	V10	47	18	19	33.7
	8 July	V14	76	18		
	17 July	R1	99	18		
Pioneer brand 3732	28 June	V10	40	19	19–20	32.7
	8 July	V14	69	19		
	17 July	VT	93	19		
		1986				
Sokota brand 680	7 July	V11	50	26	20	31.5
	16 July	V15	74	26		
	25 July	VT	102	26		
FR23 × FR27	7 July	V12	55	23	19	30.7
	16 July	V15	82	23		
	21 July	VT	102	23		
Pioneer brand 3732	7 July	V11	50	23	19	31.2
	16 July	V15	77	23		
	21 July	VT	98	23		

† Stages based on Ritchie and Hanway (13).
‡ Average of four lodging treatments.

Simulated corn wind lodging experiments were conducted at Arlington, WI, in 1985 and 1986. Planting dates were 1 May 1985 and 3 May 1986. The previous crop in each year was soybeans and the experiments were conducted on a Plano silt loam (fine-silty, mixed, mesic, Typic Argiudoll). Soil tests, performed as described by Liegel et al. (9), indicated a pH of 7.0, 120 lb available P/acre, and 460 lb exchangeable K/acre. Starter fertilizer in a 2-in.-by-2-in. placement in relation to seeds was applied at a rate of 9, 16, and 30 lb/acre of N, P, and K, respectively. Ammonium nitrate was broadcast at a rate of 150 lb N/acre before planting. Weeds were controlled chemically with labelled rates of alachlor (Lasso) and cyanazine (Bladex).

Three corn hybrids of similar maturity, 'Sokota brand 680', 'FR23 × FR27', and 'Pioneer brand 3732', and four lodging treatments were included in a factorial combination of a randomized complete block design with three replicates. The FR23 × FR27 hybrid was obtained from Illinois Foundation Seeds, Champaign. Lodging treatments were a control (no treatment) and simulated wind lodging on three dates during V10 to R1 stages (13) (Table 1). In 1985, all hybrids were treated on the same dates, which resulted in a range in developmental stages among hybrids from V17 to R1 at the third treatment date (17 July, Table 1). Treatment dates were altered at the third date in 1986, so that each hybrid was treated at the VT stage.

Plots were overplanted and then thinned to final stands of 25 000 plants/acre. Each plot was 25 ft long and eight rows wide with a 20-in. spacing between the rows.

Table 2. Summary of statistical significance of analyses of variance for 1985 and 1986.

Source of variation	df	Ear-node height	Below-ear stalk angle	Stalk length	Ears/plant	Grain moisture	Grain yield
				1985			
Replicate	2	*	NS	**	NS	NS	NS
Hybrid (H)	2	**	**	*	**	**	*
Treatment (T)	3	**	**	**	**	NS	**
H × T	6	(0.08)	**	NS	NS	NS	(0.08)
Error	22						
CV, %		6.8	6.3	2.4	3.6	2.3	6.7
				1986			
Replicate	2	NS	NS	NS	NS	NS	**
H	2	*	*	*	**	(0.06)	**
T	3	**	**	**	**	NS	**
H × T	6	NS	*	NS	*	NS	NS
Error	22						
CV, %		10.5	9.2	3.4	4.5	2.6	3.3

*,** Significance at the 0.05 and 0.01 probability levels, respectively. NS = nonsignificant.

On each lodging date, the entire experimental area was sprinkler-irrigated with 0.75 to 1 acre-in. of water. Immediately after the water application, plants in the center six rows of treated plots were manually pushed over perpendicular to row-direction. Rows were oriented east/west and plants were lodged in a northerly direction, to simulate the effects of southwesterly winds that prevail during wind and rainstorms in Wisconsin summers. A preliminary study in 1984 indicated similar grain yield responses to simulated root lodging either parallel with or perpendicular to row direction, thus only the perpendicular direction was used in 1985 and 1986. To lodge the plants, each plant was individually grasped about the lower stalk, just above the soil surface, and pushed as far as possible until the mid- to upper stalk reached the root lodged plants in the adjacent row. Stalk angle after root lodging was 20 to 30° from the soil surface. Care was exercised during manual lodging to avoid breaking or cracking the lower stalk or crown region. In spite of the care exercised, some breakage of a few large brace roots still occurred at V16 to R1 stages.

Data recorded included growth stage and canopy height before lodging on treatment dates, days after treatment until the upper-third of stalks returned to a vertical position, 50% silk date, and final leaf number. At harvest, 11 Oct. 1985 and 22 Oct. 1986, ear and plant numbers were counted and curved stalk length, from the plant base to the lowest tassel branch, was measured. Several parameters were measured to characterize lodging effects on lower stalk curvature. These parameters included ear node height vertically above the soil surface, and the angle between the soil surface and the below-ear stalk. The below-ear stalk angle was calculated using measurements of ear node height and the straight-line distance between the plant base and the ear node. Grain yields were determined by hand-harvesting the center two rows and calculating grain moisture. Data were subjected to analyses of variance and means were separated using the least significant difference.

Table 3. Influence of simulated wind lodging at various corn growth stages on stalk development, ear number, grain moisture, and grain yield in 1985 and 1986. Each value is the average of three hybrids.

Lodging treatment growth stage	Ear node height	Below-ear stalk angle	Stalk length	Ears/ plant	Grain moisture	Grain yield
	in.	degrees	in.	no.	%	bu/acre
			1985			
Control	57	90	103	1.04	33.6	199
V10	52	85	100	1.06	33.6	191
V13-V14	40	61	97	1.05	33.7	182
V17-R1	29	36	97	0.91	34.0	151
LSD (0.05)	3	4	2	0.03	NS	20
			1986			
Control	52	90	102	1.14	31.0	187
V11-V12	41	73	94	1.15	31.1	181
V15	33	50	96	1.08	31.2	168
VT	18	22	90	1.00	31.4	160
LSD (0.05)	6	9	6	0.08	NS	10

† Stages based on Ritchie and Hanway (13).

RESULTS AND DISCUSSION

The upper region of plants straightened to vertical within 2 d following lodging for all hybrids and lodging treatments both years. lodging did not alter the timing of plant development, as silk dates were identical for all treatments (Table 1) and harvest grain moisture was not influenced by lodging (Tables 2 and 3). However, the angle between the below-ear stalk and the soil surface at harvest decreased the later lodging occurred, due to more pronounced lower-stalk curvature (Table 3 and Fig. 1). This resulted in ear height reductions from control values of 52 in. (1986) and 57 in. (1985) to less than 30 in. when lodging occurred after V17.

Upright movement of plants after lodging was associated with altered growth and bending of several consecutive lower-stalk nodes. The portion of affected nodes toward the lower side of the stalk was observed to thicken, which curved the stalk upward. We observed that the stalk was always vertical or nearly vertical at or above the ear, even for the V17 to R1 lodging treatment (Fig. 1). Internodes appeared relatively unaffected by lodging, since stalk curving resulted from altered nodal growth (Fig. 1). But lodging decreased overall stalk length, especially at later stages (Table 3).

A hybrid × lodging treatment interaction occurred both years for the angle between the below-ear stalk and the soil surface at harvest (Table 2). In 1985, Sokota brand 680 had the greatest below-ear stalk angle at the last two lodging dates (V13-V14 and V17-R1 stages), likely due to less advanced development when lodged compared with other hybrids (Table 4). For the final lodging

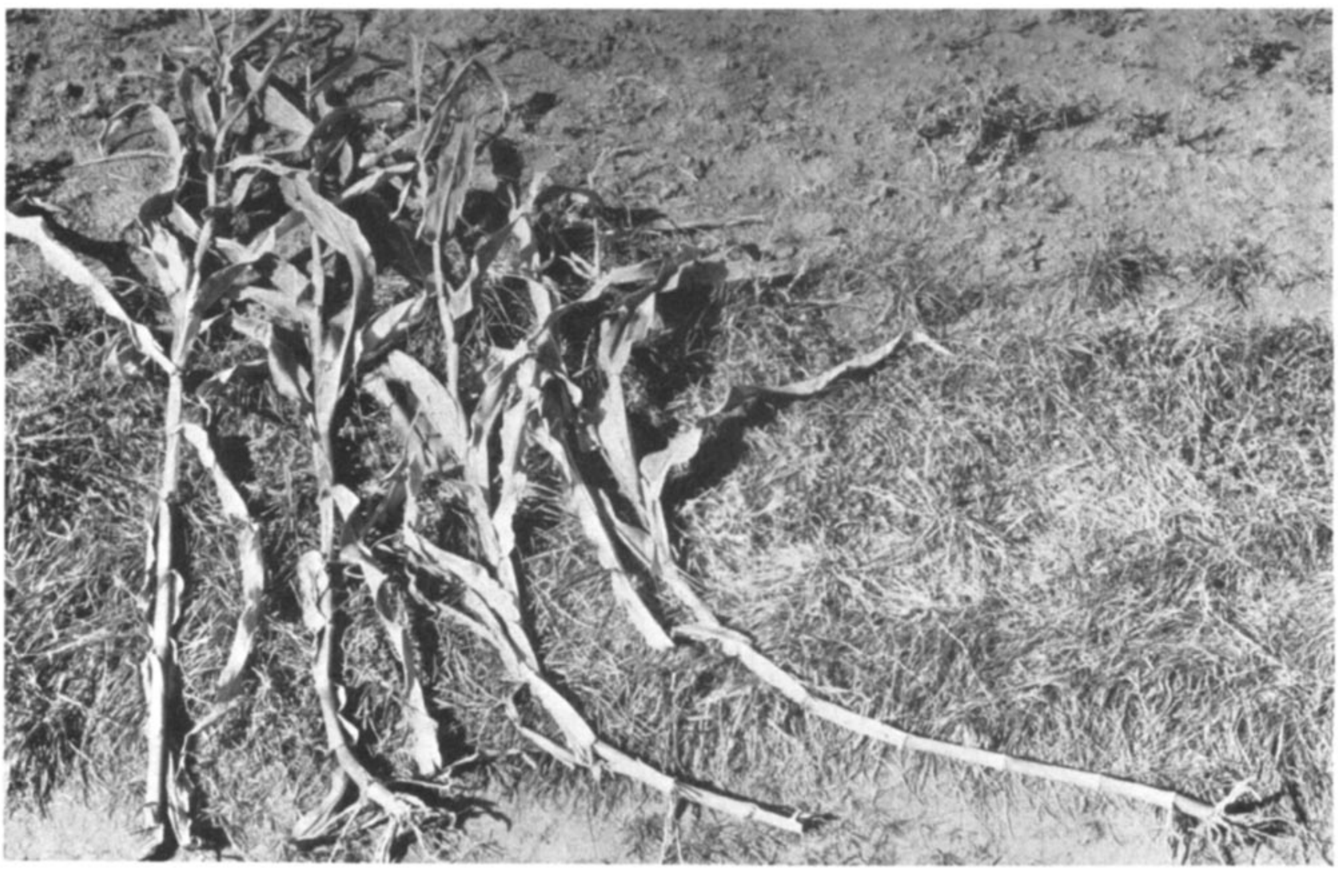

Fig. 1. Individual plants of Sokota brand 680 during early September 1985 following simulated wind lodging for (from left to right) the control, and for lodging treatments at V10, V13, and V17 stages.

Table 4. Influence of simulated wind lodging at various corn growth stages on the angle between the below-ear stalk and the soil surface at harvest.

Hybrid	Lodging treatment growth stage†		Below-ear stalk angle (degrees)	
	1985	1986	1985	1986
Sokota brand 680	Control	Control	90	90
	V10	V11	86	80
	V13	V15	72	58
	V17	VT	41	21
FR23 × FR27	Control	Control	90	90
	V10	V12	81	72
	V14	V15	52	44
	R1	VT	28	18
Pioneer brand 3732	Control	Control	90	90
	V10	V11	88	67
	V14	V15	61	47
	VT	VT	38	28
LSD (0.05)			7	9

† Stages based on Ritchie and Hanway (13).

treatment, hybrid FR23 × FR27 had the smallest below-ear stalk angle at harvest and was most advanced in development (R1 stage) when lodged, followed by Pioneer brand 3732 (VT stage), and Sokota brand 680 (V17 stage). In 1986, when hybrids were lodged at similar growth stages, Sokota brand 680 had a greater below-ear stalk angle at harvest than the two other hybrids for the first two lodging times (V11-V12 and V15 stages). Pioneer brand 3732 had the greatest angle at the final (VT) stage.

All three hybrids produced high grain yields both years, with control yields of 191, 213, and 192 bu/acre in 1985 and 195, 182, and 185 bu/acre in 1986 for Sokota brand 680, FR23 × FR27, and Pioneer brand 3732 respectively. Grain yields were reduced due to lodging both years and reductions were greater as time of lodging was delayed (Table 3 and Fig. 2). Yield was decreased only 2 to 6% by lodging at V10 to V12 stages, but yield losses increased to 5 to 15% for lodging at V13 to V15 stages, and 12 to 31% for lodging at or after V17. At the final lodging date in 1985, the range in hybrid development (Table 1) appeared to influence yield response to lodging. Only a 12% yield loss compared with the control occurred for Sokota brand 680 (V17 stage), but yields were reduced 31 and 29% for Pioneer brand 3732 (VT stage) and FR23 × FR27 (R1 stage), respectively (Fig. 2). Yield losses were similar for all hybrids in 1986 when lodging occurred at the same growth stages.

A combined analysis over years was conducted for grain yield, including only the two hybrids, FR23 × FR27 and Pioneer brand 3732, which had similar growth stages at treatment dates both years. This analysis indicated a significant ($P < 0.001$) year × treatment stage interaction. Yield reductions for these hybrids at the final lodging treatment date averaged 30% in 1985, but only 15% in 1986 (Fig. 2). The reason for this difference is unclear. Soil moisture shortages and/or high evaporative demand could exacerbate reductions in moisture uptake due to root injury following wind lodging. Rainfall was above normal and temperatures were favorable for corn growth throughout the 1985 and 1986 seasons. Soil moisture conditions were further enhanced by irrigation of the experimental area before lodging treatments were applied.

INTERPRETIVE SUMMARY

The results of this study will assist corn producers in assessing expected corn grain yield losses due to wind-induced root lodging. Hand-harvested yield reductions were generally 10% or less when wind lodging was simulated at or before mid-vegetative growth stages, but losses increased to 15 to 30% with lodging at late vegetative or early reproductive stages.

Although wind lodging effects on mechanical harvest losses were not quantified in this research, several harvest considerations can be made from the observations. Following simulated wind lodging between V10 and R1 stages, plants straightened such that ears were 18 in. or more above the soil surface at harvest (Table 4). This indicates that mechanical harvest will likely be possible following wind lodging during these stages. Harvest speed may need to be reduced to minimize harvest losses, especially if the lodging occurred at VT or R1 stages when stalk curvature will likely be pronounced and ear heights reduced. Lodging treatments did not change subsequent silk dates or grain moisture compared with the control. Therefore, it is unlikely that harvest will need to begin later due to slower crop development when wind lodging occurs during vegetative to early reproductive stages.

Further research is needed to determine the specific

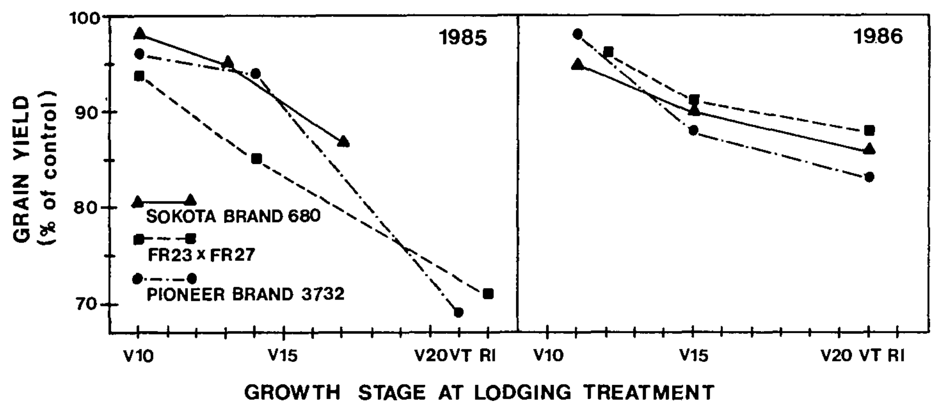

Fig. 2. Relationship between corn growth stage when lodged and grain yield reduction due to simulated wind lodging.

physiological factors causing reduced yield due to root lodging. Energy expended in altered growth to curve the stalk upward following lodging may limit grain production. Uptake of soil moisture and/or nutrients might be altered, and decreased light penetration through root-lodged canopies may also decrease yields. Ear number was reduced when lodging occurred during late vegetative to early reproductive stages (Table 3), primarily due to increased numbers of barren plants. Pendleton (12) showed increased barrenness when light penetration through the corn canopy was limited.

More studies are also needed to assess whether the yield loss percentages found in our research apply under diverse conditions. Our experiments were conducted under relatively high productivity levels on well-drained silt-loam soils. Responses may vary with factors such as soil type, soil moisture availability, soil fertility, plant density, hybrid maturity, corn rootworm injury, etc. Also, in our studies, entire stands were pushed over when simulating wind lodging. This occurs with severe wind lodging, but yield responses will likely be variable when only a portion of plants within fields are root lodged following wind storms.

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