Late-Spring Frost and Postfrost Clipping Effects on Corn Growth and Yield

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Research Question

On 21 June 1992 widespread frost-damage to corn occurred throughout the midwestern USA. Lack of documented knowledge regarding frost damage effects on corn regrowth restricted the ability of producers and advisors to make confident decisions regarding replanting and yield expectations after the injury occurred. Therefore, our first objective was to monitor corn growth and yield within fields with a range of injury.

Following this frost, there was substantial debate regarding whether or not to clip plants in frost-damaged fields, to remove dead or deformed tissue above the growing point of plants. Our second objective was to evaluate clipping effects on plant growth and yield in growers' fields, in which field equipment was used to clip damaged corn.

Literature Summary

Field simulation of frost-damage to plants is difficult, therefore, frost injury yield effects are usually estimated using defoliation studies. But regrowth for plants in which both internal and external tissues have frost damage is probably different than for plants with primarily external leaf removal. A Wisconsin study observed corn regrowth and yield differences following a 23 June 1972 frost in a bowl-shaped field with a range in front damage. Nondamaged plants on highest land yielded 30% more and were advanced in maturity compared with damaged plants at the base of a slight slope.

In previous studies, we found inconsistent results with post-frost clipping. Yields were increased by 40%, decreased by 30%, or not affected by clipping in different situations. These studies were conducted in small plots and clipped using scissors, rather than using field equipment practical for use by growers.

Study Description

Frost-damage

Several days after the 21 June 1992 frost, plots were established at five Wisconsin sites in which frost damage to corn with nine to 12 emerged leaves (four to seven emerged collars) ranged from major (65 to 100% of leaves damaged) to minor (less than 5% of leaves damaged) within individual fields. Damage varied within fields primarily due to slight topography differences, with greatest damage in low-lying areas.

Clipping

Clipping vs. not clipping within 3 to 5 d after the frost was compared within uniformly major-damaged fields at six sites. Growers performed clipping at heights of 4 to 12 in. using flail stalk choppers at five sites and a rotary lawn mower at one site.

Full scientific article from which this summary was written begins on page 203 of this issue.

Applied Questions

How did frost-damage influence corn regrowth and yield?

Although nearly all plants recovered from the injury, plants with greatest damage were delayed in silking by 7 to 10 d and had reduced plant (16 to 25 in. shorter) and ear (12 to 20 in. shorter) height than those with least damage. Grain yields were reduced by frost-damage, with the extent of yield loss related to the percentage of exposed leaves which were damaged (Fig. 1). Yield losses from frost may have been particularly large in 1992, because the remaining growing season after the frost was extremely cool. But frost-damage in 1992 reduced yield to similar levels as in 1972, a warmer season that was more favorable for corn production (Fig. 1).

Was there any benefit to clipping frost-damaged corn?

Clipping reduced grain yield by 15 to 34% at three sites, resulted in no differences at two sites, and increased yield about 10% at one site. Based on these results and other studies, there is little consistent benefit to clipping frost-damaged corn.

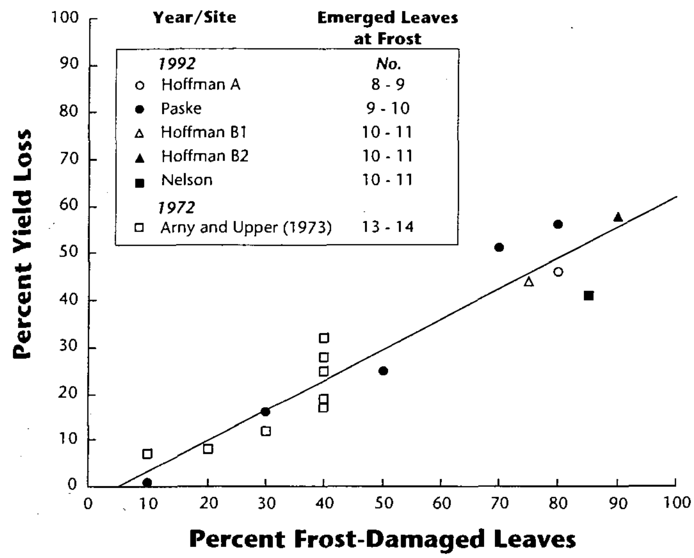

Fig. 1. Relationship between percentage frost-damaged leaves (partially or fully-emerged) and percentage grain yield loss for corn grown in Wisconsin at five sites in 1992 and one site in 1972. Loss is expressed as frost-damaged yield as a percentage of minor-damaged (less than 5% leaves damaged) yield within sites.

Late Spring Frost and Postfrost Clipping Effect on Corn Growth and Yield

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Lack of knowledge regarding early-season frost-damage effects on corn (*Zea mays* L.) restricts the ability of producers to make decisions regarding replanting and yield expectations. Our first objective was to monitor corn growth and yield within fields with a range of late-spring frost injury. The second objective was to evaluate post-frost clipping effects on plant growth and yield. Several days after a severe 21 June 1992 frost, plots were established at several Wisconsin sites in which within-field frost-damage to corn with 9 to 12 emerged leaves ranged from major (65 to 100% of leaves damaged) to minor (less than 5% of leaves damaged). Damage within fields varied primarily due to slight topography differences, with greatest damage in low-lying areas. Although nearly all plants recovered from the injury, plants with greatest damge were delayed in silking (7 to 10 d later), had reduced final plant (16 to 25 in. shorter) and ear (12 to 20 in. shorter) height and lower grain yield (42 to 59% lower) compared with plants with least damage. Postfrost clipping reduced grain yield by 15 to 34% at three sites, resulted in no differences at two sites, and increased yield about 10% at one site. Based on these results and previous studies, there is little consistent benefit to clipping frost-damaged corn.

LATE SPRING frost damage to corn occurs frequently in northern regions, but damage is usually limited to portions of fields in low-lying areas. On 21 June 1992 widespread frost-damage to corn occurred throughout the midwestern USA. Impacts of this frost were compounded by several factors in addition to the advanced corn growth stages when damage occurred.

First, plants were under stress from various sources when the frost occurred. Thousands of corn acres were recently recovered from a late May frost. Due to limited May and June rainfall (Table 1), plants in some regions were beginning to show initial moisture stress symptoms. Post-emergence herbicide application activity was common just before the frost and this may have created additional plant stress in some cases.

Second, two cultural practices clearly contributed to increased frost injury to plants. These included: (i) tillage systems in which heavy previous-crop residue cover remained on the soil surface and (ii) between-row cultivation in the days preceding the frost. Bland (1993) used computer models to simulate corn leaf temperatures near Arlington, WI, between 300 and 400 h on 21 June. The model indicated that with air temperatures (5 ft) near 35 °F (Table 2), temperatures of uppermost corn leaves were 30 °F in residue-free, noncultivated soil and at least 1 °F cooler if the soil had been recently tilled or if residue covered the soil surface. He suggested that drier, looser tilled soil could not supply as much radiation to leaves as did untilled soil. Residue may have intercepted radiant heat from the soil, which resulted in cooler leaf temperatures. Also, residue may have served as a source of ice nucleating bacteria. These bacteria can increase the leaf temperature at which ice formation is initiated (Arny et al., 1976). Corn typically has very low numbers of these bacteria associated with leaves early in the season. A local inoculum source such as crop debris on the soil surface could elevate populations of ice nucleating bacteria, and thus increase the temperature at which ice formation is initiated (C. Upper, 1993, personal communication).

Finally, the days (Table 2) and months (Table 1) after the frost were cool, which slowed plant recovery. This probably increased plant mortality and limited the ability of regrowing plants to compete with weeds. Although abundant rainfall finally occurred during July in many areas, July and August temperatures were among the col-

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Table 1. Mean air temperature and precipitation for the 1992 growing season at Arlington (near Columbia County sites) and Fond du Lac (near Boelk's A and B sites), Wisconsin.

	Temperature		Precipitation	
Month	Arlington	Fond du Lac	Arlington	Fond du Lac
	°F		in.	
May	56.6 (−0.8)†	58.1 (+0.7)	1.4 (−1.8)	0.9 (−2.3)
June	63.6 (−2.8)	64.2 (−2.5)	1.9 (−2.2)	0.3 (−3.1)
July	65.1 (−6.1)	66.8 (−4.5)	5.7 (+2.2)	2.3 (−1.5)
August	64.4 (−4.7)	67.4 (−2.0)	1.3 (−2.7)	1.5 (−2.0)
September	58.2 (−2.7)	61.2 (+0.1)	7.3 (+3.7)	7.9 (+4.7)

† No. in parentheses indicates the deviation from the long-term average.

Table 2. Maximum and minimum air temperatures during tbe period from 3 d prefrost to 9 d postfrost at Arlington (near Columbia County sites) and Fond du Lac (near Boelk's A and B sites), Wisconsin.

	Arlington		Fond du Lac	
Date	Maximum	Minimum	Maximum	Minimum
	°F			
18 June	82	59	74	63
19 June	74	49	63	49
20 June	65	40	60	44
21 June	66	34	63	42
22 June	66	51	69	44
23 June	64	42	65	51
24 June	70	44	61	43
25 June	78	45	75	45
26 June	78	49	69	53
27 June	72	39	69	47
28 June	82	46	83	52
29 June	82	57	69	54
30 June	78	52	77	53

dest in the last century (Table 1). Regrowing plants were delayed in development by the frost, and the limited post-frost growing season may have magnified yield losses caused by direct frost injury to plant tissue.

Lack of documented knowledge regarding frost-damage effects on corn regrowth and yield seriously restricts the ability of producers and advisors to make confident decisions regarding replanting and yield expectations after injury occurs. Field simulation of frost-damage to plants is difficult, therefore, yield effects are usually estimated using defoliation studies conducted to assess hail injury (Shapiro et al., 1986). But regrowth for plants subjected to damage of both internal and external tissues by frost is probably different than for plants with primarily external leaf removal. Arny and Upper (1973) observed corn growth and yield differences following a 23 June 1972 frost in a bowl-shaped Wisconsin field with a range of frost damage. Down-slope plants were not killed, but had at least 6 of 11 fully-emerged leaves damaged by the frost. Nondamaged plants on highest land yielded about 30% more and were advanced in maturity compared with damaged plants at the base of the slight slope. These authors suggested that the value of such leaf damage assessments in predicting yield reductions can only be determined through additional, similar observations. Therefore, our first objective was to monitor corn growth and yield within fields with a range of frost injury related to topography differences after the 21 June 1992 frost.

Following the 21 June frost there was uncertainty regarding whether or not to clip plants in frosted fields, to remove dead or deformed tissue above the growing point of plants. Some corn producers used rotary or flail

Table 3. Plot layout for eight post-frost observations.

		Randomized			Plot size	
Site	Treatments	Yes	No	No. replicates	Width	Length
					ft	
Paske	Range in frost damage		X	4	2.5 (1 row)	60
Manthe	Range in frost damage		X	4	2.5 (1 row)	30
Hoffman A	Major damage					
	Not clipped		X	4	2.5	30
	Clipped		X	4	(1 row)	
	Minor damage		X	4		
Hoffman B1	Major damage					
	Not clipped		X	5	2.5	35
	Clipped		X	7	(1 row)	
	Minor damage		X	3		
Hoffman B2	Major damage					
	Not clipped		X	5	2.5	35
	Clipped		X	7	(1 row)	
	Minor damage		X	3		
Nelson	Major damage					
	Not clipped, weeded	X		2	7.5 (3 rows)	40
	Not clipped, not weeded	X		2		
	Clipped, weeded	X		2		
	Clipped, not weeded	X		2		
	Minor damage		X	2		
Boelk A	Major damage					
	Not clipped		X	1	30	1500
	Clipped, 8 in.		X	1	(12 rows)	
	Clipped, 12 in.		X	1		
Boelk B	Major damage					
	Not clipped	X		4	15	350
	Clipped	X		4	(6 rows)	

mowers to clip corn, usually within a few days after the frost before any new growth was observed. These growers were concerned that pathogens which invaded damaged rotting tissue would spread to healthy tissue, and ultimately kill the plant if not removed. Growers were also concerned that dead, collapsed tissue would restrict normal emergence of new leaves and result in deformed, barren plants with knotted whorls.

In previous studies (Carter, 1990), at one of three sites we found that clipping at 4 in. following a severe frost increased grain yield 40% compared with not clipping. But at the same site, clipping at 2 in. decreased yields by 30%. At two other sites, clipping had no positive or negative effect on yield. Those studies were conducted in very small plots and clipped using scissors without bruising or lacerating plant tissue. Our second objective was to evaluate clipping effects on plant growth and yield in growers' fields, in which field equipment was used to clip frost-damaged corn.

MATERIALS AND METHODS

Several days after the frost, plots were established at eight Wisconsin sites to evaluate either frost damage or clipping effects alone, or to evaluate both effects (Table 3).

Frost damage differences were due primarily to slight differences in slope within fields (Table 4), with greatest damage in low-lying areas. At Paske's and Manthe's seven or eight sucessive plots (each consisting of 30 or 60 ft sections of row) were marked out in four adjacent

Table 4. Field characteristics and production practices at eight sites, 1992.

Item	Site					
	Paske	Manthe	Hoffman A	Hoggman B1/B2	Nelson	Boelk A/B
County	Columbia	Columbia	Columbia	Columbia	Columbia	Fond du Lac
Soil type†	Joy silt loam	Ringwood silt loam	Ossian silt loam	Ossian silt loam	Plano silt loam	Elliot silt loam
Slope %	0–4	1–6	0–3	0–3	2–6	2–6
Previous crop	soybean	corn	corn	corn	corn	corn
Hybrid (relative maturity)	Pioneer brand 3702 (101 d)	Pioneer brand 3578 (104 d)	Dairyland brand 1103 (103 d)	Pioneer brand 3508E (108 d)	Pioneer brand 3563 (103 d)	Spangler brand 4700 (100 d))
Tillage/time						
Primary	Field cultivate/ spring	Chisel plow/fall	Chisel plow/fall	Chisel plow/fall	Chisel cultivate/fall	Moldboard plow/fall
Secondary	Field cultivate/ spring	Field cultivate/ spring	Field cultivate/ spring	Field cultivate/ spring	Field cultivate/ spring	Field cultivate/ spring
Planting date	4 May	10 May	15 May	3 May	7 May	3 May
Row cultivation date	--	19–20 June	19 June	17 June	18–29 June	20 May
Harvest date	28 October	6 November	28 October	28 October	7 October	5 November
Harvest method	Combine	Hand	Hand	Hand	Hand	Combine

† Joy (fine-silty, mixed, mesic Aquic Hapludolls); Ringwood (fine-loamy, mixed mesic Typic Argiudolls); Ossian (fine-silty, mixed, mesic Typic Haplaquolls); Plano (fine-silty, mixed mesic Typic Argiudolls); Elliot (fine, illitic, mesic Aquic Argiudolls).

Table 5. Data summary from Paske's field in Columbia County. Frost occurred the morning of 21 June 1992. Most plants had six fully-emerged leaves (visible collars) and about 10 total emerged leaves when damaged.

	Plot no.†						
	1	2	3	4	5	6	7
No. damaged leaves, average	8.0	8.0	7.0	5.0	3.0	1.0	0.5
% leaves damaged, average	80	80	70	50	30	10	5
Canopy height (9 July), in.	22	25	25	31	41	41	44
Silk date	7 August	10 August	9 August	2 August	31 July	29 July	28 July
Harvest							
Final stand, plants/acre × 1000	26	26	24	26	26	27	28
Ears/plant	0.92	0.95	0.96	0.99	0.98	0.99	0.98
Ear height, in.	22	25	25	32	36	38	37
Plant height, in.	71	74	80	86	88	90	90
Kernel moisture, %	33	35	37	32	33	31	32
Grain yield, bu/acre	70	70	78	118	132	156	158
S.E.	7	6	9	9	4	1	7

† Plots 1 and 2 were on the nearly level floor of a frost-damaged field. Plots 3 to 6 were successively higher on a slight slope. Plot 7 was on relatively high ground at the edge of the frost-damaged area.

Table 6. Data summary from Manthe's field in Columbia County. Frost occurred the morning of 21 June 1992. Most plants had four to five fully emerged leaves (visible collars) and about nine total emerged leaves when damaged.

	Plot no.†							
	1	2	3	4	5	6	7	8
No. damaged leaves, average	9	9	9	8	7	6	5	5
% leaves damaged, average	100	100	100	89	78	67	56	56
Canopy height (9 July), in.	9	9	9	12	18	22	25	25
Silk date	19 August	21 August	19 August	17 August	12 August	10 August	7 August	8 August
Harvest								
Final stand, plants/acre × 1000	11	11	9	17	23	24	25	26
Ears/plant	1.01	1.05	1.14	1.01	0.98	0.96	0.99	0.98
Ear height, in.	11	14	12	17	22	26	31	31
Plant height, in.	54	57	54	63	70	73	82	82
Kernel moisture, %	39	39	36	38	41	33	33	36
Grain yield, bu/acre	24	29	18	50	81	102	123	123
S.E.	2	9	3	8	4	8	9	6

† Plots 1 to 3 were on the nearly level floor of a frost-damaged field. Plots 4 to 8 were successively higher on a slight slope.

rows (Tables 3, 5, and 6), similar to the procedure used by Arny and Upper (1973). At Hoffman sites (A, B1, and B2) and Nelson's only the two most extreme areas, with major vs. minor damage, were compared (Table 3). Minor damage areas at these sites were located about 100 (Hoffman A) to 300 (Nelson) ft from major-damage plots. At all sites, all plots were within the same soil series classification based on USDA Soil Conservation Service survey maps (Table 4).

Clipping vs. not clipping was compared within uniformly major-damaged areas at six sites (Tables 3 and 7). Growers performed clipping using their equipment (Table 7). At Hoffman A, B1, and B2 sites, comparisons consisted of a single set of adjacent clipped vs. not-clipped areas (Table 3). Within interior rows of clipped and not-clipped strips, adjacent 30- to 55-ft single-row plots were laid out. At Nelson's , the grower left several alternating six-row clipped vs. not-clipped strips. Within two randomly-chosen strips for each clipping treatment, three-row plots were marked. Beginning 1 July, the in-row area of half of the plot length was kept weed-free by hand-pulling and hoeing and the other half was left weedy

Table 7. Morphological status of plants when frost-damaged on 21 June 1992, extent of damage, and clipping practices at six sites.

Site	Status of plants when frost-damaged: Leaf stage, emerged: Collars	Leaf stage, emerged: Leaves	Growing point location	Leaves damaged: No.	Leaves damaged: %	Clipping practices: Days post-frost	Height	Implement
	—— no.	——	in.†				in.	
Hoffman A	4-5	8-9	0	6-7	75-85	4	4	Rotary lawn mower
Hoffman B1	6-7	10-11	1-2	6-8	65-80	3	7	Flail stalk chopper
Hoffman B2	6-7	10-11	1-2	9-10	80-95	3	7	Flail stalk chopper
Nelson	6-7	10-11	1-2	9-10	75-90	5	9	Flail stalk chopper
Boelk A	7	11-12	2-3	7-11	75-90	3	8, 12	Flail stalk chopper
Boelk B	7	11-12	2-3	7-11	75-90	5	8	Flail stalk chopper

† Above soil surface.

Table 8. Effect of clipping treatments following 21 June 1992 frost on corn growth and grain yield at four Columbis County sites.

	Site: Hoffman A, Major damage: Not clipped	Hoffman A, Major damage: Clipped	Hoffman A: Minor damage	Hoffman B1, Major damage: Not clipped	Hoffman B1, Major damage: Clipped	Hoffman B1: Minor damage	Hoffman B2, Major damage: Not clipped	Hoffman B2, Major damage: Clipped	Hoffman B2: Minor damage	Nelson, Major damage: Not clipped	Nelson, Major damage: Clipped	Nelson: Minor damage
Tied whorls (%)												
2 July	82	5	0	--	--	--	76	61	0	77	1	0
11 July	43	5	0	--	--	--	50	50	0	11	9	0
22 July	29	1	0	4	12	0	15	21	0	--	--	--
Canopy height, in.												
2 July	10	11	--	--	--	--	--	--	--	--	--	--
11 July	21	22	49	--	--	54	15	17	54	45	33	--
22 July	33	36	72	43	33	77	32	29	77	--	--	--
Silk date	--	--	--	--	--	--	--	--	--	1 Aug.	5 Aug.	--
Harvest												
Final stand, plants/acre × 1000	28	27	27	23	21	23	20	18	23	27	25	28
Ears/plant	1.16	1.24	1.36	1.03	1.03	1.03	1.04	1.13	1.03	0.96	0.90	1.00
Ear height, in.	24	29	44	22	15	34	20	16	34	21	16	34
Plant height, in.	61	66	86	62	56	83	60	55	83	73	66	89
Kernel moisture, %	41	41	32	30	29	32	32	32	32	31	35	37
Grain yield, bu/acre	97	107	179	92	63	165	70	60	165	118	78	200
S.E.	7	4	3	9	6	3	5	4	3	10	7	2

(Table 3). Boelk A was a single replicate of three clipping treatments in 12-row strips (Table 3). Boelk B was four replicates of two clipping treatments in strips within the field in a randomized complete block design (Table 3).

Corn at all sites was grown on highly productive soils with optimum management by cooperating producers (Table 4). Herbicides were applied for weed control at all sites, and a soil-applied insecticide was applied at planting when the previous crop was corn, to control corn rootworm (*Diabroticus* spp.) larvae. Soil tests indicated pH ranging from 6.1 to 6.5, and high levels of P and K at all sites. Starter fertilizer was row-applied at planting. Seeding rate was about 30 000 kernels/acre at all sites.

At least five typical plants at each site (from rows immediately adjacent to the plot area) were observed to determine growth stage when frost damage occurred. Plants were dissected, and growing point position was determined. Leaf damage assessments (Tables 5, 6, and 7) were made by counting the number of emerged leaf blades with damage, expressed as a percentage of total emerged leaves. A leaf was counted as damaged if any dead tissue was present, regardless of the proportion of the unemerged or emerged leaf tissue that was killed (Arny and Upper, 1973).

At Paske's and Manthe's, canopy height on 9 July and ear and plant (uppermost collar) height at harvest were measured for five plants per plot. Date when 50% of plants in each plot were silking was also recorded. At Hoffman A, B1, B2, and Nelson sites, the number of plants in each plot with tied whorls was counted two to three times during July. July canopy height and harvest ear and plant height were also measured at these sites, with the same procedure used at Paske's and Manthe's.

At harvest, stand and ear counts were made, and ears were either hand-harvested or combine-shelled (Table 4). Grain moisture was determined after shelling and drying for hand-harvested sites or using an electronic moisture meter at combine-harvested sites. Grain yields were adjusted to 15.5% moisture content.

Similar to Arny and Upper (1973), for frost-damage comparisons and most clipping treatments it was not possible to randomize treatments, because replicates were adjacent rows (Table 3). Therefore, analyses of variance were only computed at Boelk B. Standard errors were computed for grain yield data to provide a measure of variability across replicates within treatments.

RESULTS AND DISCUSSION

Frost-Damage Effects on Growth and Yield

In the lowest part of the fields, 80% of the emerged upper leaves were at least partially damaged at Paske's (Table 5) and all leaves were damaged at Manthe's (Table

6). Nearly all plants in this part of these fields collapsed 0 to 2 (Manthe's) or 4 to 5 (Paske's) in. above the soil surface. Injury extent decreased up the slope, with only slight damage to tips of upper leaves on high ground at Paske's (Table 5). At this site, whorls of plants in plots 4 to 7 remained upright and intact despite 30 to 50% of upper leaves with frost injury in plots 4 and 5. At Manthe's (Table 6), only plants in plots 6 to 8 remained upright. Even in plot 8 at the slope apex, plants had 50% upper leaf damage.

By 9 July, nearly 3 wk after the frost, plants with most severe frost injury were less than half the height of least-damaged plants (Tables 5 and 6). Many plants which collapsed in plots 1 to 3 at Paske's and plots 1 to 5 at Manthe's became tied as emerging leaves encountered constricted or deformed whorls. Most of these plants were unraveled by 9 July at Paske's, but at Manthe's about 10% of the surviving plants in plots 1 to 3 did not unwind until early August. Silking was delayed about 1 wk at Paske's (Table 5) and nearly 2 wk at Manthe's (Table 6) for most- compared with least-damaged plants.

At Paske's, plant stands were not reduced due to frost damage (Table 5), but at Manthe's stands were reduced from 60 to 30% in plots 1 to 4 compared with plots 5 to 8 (Table 6). Plants were at a less advanced growth stage at Manthe's than at Paske's when the frost occurred. Consequently, corn growing points were more protected at or slightly below the soil surface at Manthe's compared with about 1 in. above the surface at Paske's. The severity of injury was evidently greater at Manthe's, however, causing stand losses despite the apparent lower susceptibility to plant mortality.

Plant death at Manthe's did not seem due to direct frost injury to growing points. For many plants that eventually died in plots 1 to 4, growing points appeared healthy up to 3 wk after the frost, but there was little or no evidence of regrowth. Similar experiences with postfrost regrowth failures were observed by growers and crop advisors throughout the Midwest in 1992. Cool weather immediately after the frost (Table 2) may have reduced the ability of plants to use limited energy reserves or could have predisposed plants to invasion by secondary pathogens. Another possibility is that visible deterioration of damaged growing points may have been slow in cool temperatures. At Manthe's, plants in plots 1 to 4 partially compensated for reduced stands by increasing ears per plant (Table 4).

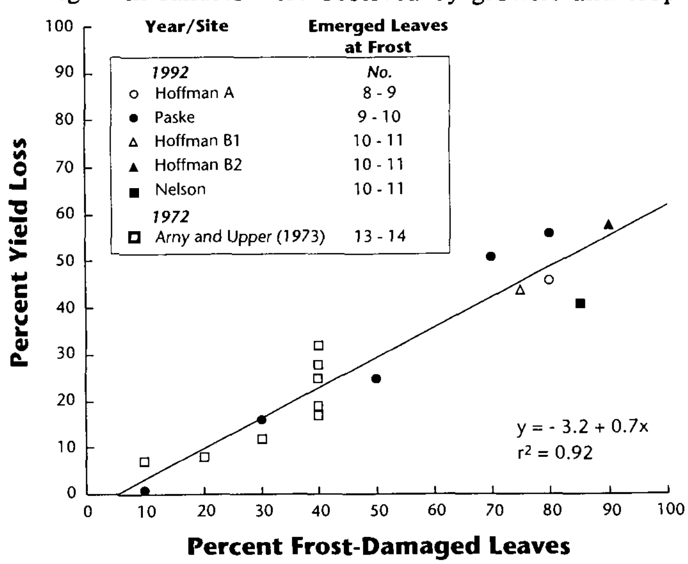

Fig. 1. Relationship between percentage frost-damaged leaves (partially or fully-emerged) and percentage grain yield loss for corn grown in Wisconsin at five sites in 1983 and one site in 1972. Loss is expressed as frost-damaged yield as a percentage of minor-damaged (less than 5% leaves damaged) yield within sites.

Table 9. Effect of clipping treatments following 21 June 1992 frost on corn grain moisture and yield at Boelk's Fond du Lac County sites.

	Site					
	Boelk A			Boelk B		
	Not clipped	8 in.	12 in.	Not clipped	clipped	P > F
Kernel moisture, %	25	25	25	27	28	NS
Grain yield, bu/acre	71	72	72	83	80	NS

Ear and plant height at harvest were reduced by frost injury at both sites (Tables 5 and 6). Ears for plots 1 to 3 at Manthe's were only about 12 in. above the soil surface (Table 6), which limited the ability of the grower to combine-harvest this portion of the field.

Harvest kernel moisture averaged about 3 to 5% units wetter for corn at the lower vs. upper slope positions (Tables 5 and 6). This developmental delay was expected given the lag in silk date in plots with most severe frost injury. This delay may have been partially caused by cooler temperatures in the low areas of these fields, but was mostly related to the frost damage. Other reports indicate similar season-long developmental delays due to destruction of corn leaf tissue at early stages due to flaming or clipping (Green, 1949; Dungan and Gausman, 1951; and Cloninger et al., 1974).

Grain yield was reduced by more than 50% in plots with most vs. least frost injury (Tables 5 and 6), even at Paske's where stands were similar for all plots (Table 5). At Manthe's plot 5 (78% leaf damage) yielded 35% lower than plot 8 (56% leaf damage), with stands only 12% lower for plot 5.

Among the additional sites where comparisons were made of frost damage effects, injury ranged from 65 to 90% leaves damaged in low areas (Table 7) to less than 10% leaves damaged at slightly higher elevations. Stand loss in major- vs. minor-damage areas only occurred at Hoffman B2 (14% reduction) (Table 8). But corn with major damage showed growth delays and reductions in ear and plant height and grain yield, which were generally similar in extent to those at Paske's and Manthe's (Tables 5, 6, and 8). One exception was for kernel moisture, with wetter grain for major- vs. minor-damaged corn at Hoffman A, but small differences or drier grain with major damage at the other sites (Table 8).

At Nelson's, broadleaf (mostly velvetleaf, *Abatilon theophrasti* Medic) and grass (mostly foxtail, *Setaria* spp.) weeds proliferated after canopy shading by corn leaves was removed by frost-damage. Weeds were almost nonexistent in the minor damage area. Values shown in Table 8 for the Nelson site are averages of weedy and weed-free rows. Grain yields were reduced about 15% for weedy vs. weed-free rows (data not shown). This indicates that reduced ability of regrowing corn plants to compete with weeds is an important consideration in assessing yield loss due to frost injury.

We recognize that soil differences along the slope in these plots could have influenced yields in addition to frost-damage effects. But the lowest parts of these fields had good drainage in 1992 and equal to or higher yield potential than the areas with slightly higher elevation (based on long-term experiences of the growers). There was no visible evidence of soil erosion at the top of these slopes, and 1992 rainfall was near long-term averages at the sites. Therefore, soil moisture availability probably did not influence the yields of least-damaged plants. If soil moisture availability was limiting for these up-slope plots the yield reductions measured may be a conservative estimate of frost-damage effects. Assuming that soil characteristics and topography had a small effect on the yields described in Tables 5, 6, and 8, grain yield reductions caused by frost in 1992 were up to 50% units greater than those predicted for similar leaf stages and leaf damage levels based on hail adjustment charts (National Crop Insurance Service, 1984).

We found a strong linear relationship between percentage frost-damaged leaves and percentage yield loss, when the field observations of frost damage were combined (Fig. 1). This occurred despite a range in leaf stages when corn was injured in various comparisons. Data from 1972 (Arny and Upper, 1973) are also shown in Fig. 1 to indicate yield response to frost at more advanced leaf stages in a year when seasonal temperatures after frost injury were more favorable for corn growth than in 1992. Our 1992 results generally agree with their 1972 data in the range from 10 to 30% frost-damaged leaves. But Arny and Upper (1973) found a progressive decrease in yield across the level floor of their bowl-shaped field, despite a constant external leaf damage rating of 40%. Therefore, they had a range in yield loss from 17 to 32% at the 40% leaf damage level (Fig. 1). More frost-damage vs. yield loss observations across a range of growth stages and growing conditions would be useful to improve confidence in this relationship.

At Boelk's A site (Table 9), nearly all main plants were killed by frost injury, but large tillers had developed from below-ground crown nodes and had three to four visible leaf collars when the frost occurred. These tillers encountered little leaf damage (probably due to protection from larger main plants) and growing points were below the soil surface. Despite eventual death of the main plants, these tillers produced grain yields near 70 bu/acre. In a few other fields, we noticed that tillers developed after the main plant was dead at nodes 1 to 2 in. above the soil surface. Many of these plants developed both tassel-ears and normal ears, but others had normal ears and tassels. Plant height reached less than 4 ft and grain yield was below 10 bu/acre.

Clipping vs. Not Clipping

Clipping reduced the number of tied whorls initially (2 July, Table 8), but at Hoffman B2 about 60% of the clipped plants still developed tied whorls. By 22 July, there were few tied whorls remaining in not-clipped areas, except at Hoffman A where nearly 30% of not-clipped plants were still tied.

Removal of tissue by clipping resulted in more rapid appearance of new growth, but by 22 July canopy height for clipped plants was usually similar to, or shorter than, that for not-clipped areas (Table 8). At harvest, ear and plant heights were 4 to 7 in. shorter for clipped than for not-clipped plants. An exception occurred at Hoffman A, where clipped plants averaged 5 in. taller. Although the growers' goal was to sever only dead tissue when clipping, plant and ear height reductions indicate that some unexposed, living leaf tissue was also inadvertently removed.

Silk date was determined at Nelson's, and indicated a 4-d silking delay for clipped plants (Table 8). At this site, about 70% of clipped plants were male sterile. These plants developed a small tassel without anthers. Among not-clipped plants, only about 10% of the plants showed this deformity. Apparently, pollen availability did not limit fertilization, as nearly all plants developed normal, grain-bearing ears.

Final plant stand and ear number were not influenced greatly by clipping, although there was a tendency for slightly lower harvest plant populations with clipping vs. not clipping (Table 8). Kernel moisture was 4% units wetter for clipping vs. not clipping at Nelson's (Table 8), but differences were within 1% unit at the other sites (Tables 8 and 9).

Clipping reduced grain yield by 15 to 34% at three sites (Hoffman B1 and B2 and Nelson's, Table 8), resulted in no difference at two sites (Boelk's A and B, Table 9), and increased yield slightly at one site (Hoffman A, Table 8). Participating growers indicated that ear height reductions in clipped areas made it more difficult to pick up ears with the combine head than in not-clipped areas. Therefore, combine-harvested yields may have been reduced more than those measured with hand-harvest at Hoffman B1 and B2 and Nelson's (Table 8).

In 1992 studies at three sites in Nebraska, clipping reduced corn yields by 8, 18, and 36% compared with not clipping following a severe late May frost when corn was at slightly less advanced leaf stages (R. Elmore, 1993, personal communication). Based on these and previous Wisconsin results (Carter, 1990), there is little consistent benefit to clipping frost-damaged corn. And, the potential exists to decrease yields substantially, even when growers are careful to clip well-above corn growing points.

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