Research

Effect of Foliar Fungicides Applied at Silking on Stalk Lodging in Corn

Alison E. Robertson,[1,†] Mauricio Serrano,[1] Jyotsna Acharya,[1] John Shriver,[1] John Beckman,[2] Chad Huffman,[2] Ken Pecinovsky,[2] Myron Rees,[2] Daniel Schaben,[2] Matthew Schnabel,[2] Josh Sievers,[2] and Terry Tuttle[2]

[1] Department of Plant Pathology and Microbiology, Iowa State University, Ames, IA 50011
[2] Research and Demonstration Farms, Iowa State University, Ames, IA 50011

Accepted for publication 29 November 2019.

Abstract

Stalk lodging in corn (*Zea mays* L.) leads to harvest complications and yield losses. Farmers who apply a foliar fungicide to manage leaf diseases have also observed reduced lodging. The goal of this study was to evaluate the effect of a foliar fungicide applied at silking on percent lodging. Field trials were established on Iowa State University Research Farms in 2016 and 2017. Treatments evaluated were foliar fungicide application (with or without) and harvest date (corn harvested at weekly intervals for up to 5 weeks); a split plot design was used with four complete blocks. Across all locations and years, a fungicide application significantly reduced mean lodging ($P < 0.0001$) by 9.3% and increased yields ($P = 0.0043$) by an average of 258.3 kg/ha (4.1 bu/acre). Percent lodging increased as harvest was delayed ($P < 0.0001$). This study demonstrated that foliar fungicides applied at silking reduced lodging and thus confirmed observations of farmers. Applying a fungicide to reduce lodging and favor harvest, however, is not recommended due to risk of fungicide resistance development and the lack of efficacy on stalk rot pathogens.

Keywords: stalk lodging, corn, field crops, yield, fungicide

Stalk lodging in corn (*Zea mays* L.) is commonly defined as the stalk breakage below the ear that occurs after silking (Nielsen and Colville 1988). Lodging is often associated with stalk rot, a disease of corn that results in disintegration of the stalk tissues in the lowest nodes of the plant (Munkvold and White 2016). Several fungal pathogens causing diseases such as Gibberella (*Fusarium graminearum* Schwabe), Diplodia (*Stenocarpella maydis* Berk.), anthracnose (*Colletotrichum graminicola* Ces.), and charcoal (*Macrophomina phaseolina* Tassi [Goid.]) stalk rots have been isolated from lodged plants (Munkvold and White 2016). However, stalk rot development has been attributed to carbon deficiency in the root and lower stalk tissues that arises when stressful conditions occur during grain fill (Dodd 1980). This in turn leads to decaying of lower stalk tissues as they are colonized by opportunistic invaders (Dodd 1980; Munkvold and White 2016).

Stalk rot is an annual problem in corn production. In 2016, over 500 million bushels of corn grain was lost due to stalk rots (Sisson et al. 2017). Yield losses result from reduced grain fill in prematurely dead plants and lodged plants that cannot be appropriately harvested by mechanical equipment (Munkvold and White 2016). Hybrid susceptibility, high population densities, defoliation after silking due to insect damage or disease, fertilization imbalances, and environmental conditions that are unfavorable for grain fill are among the factors that are known to increase the occurrence of stalk rot (Dodd 1980; Mortimore and Ward 1964; Munkvold and White 2016).

[†]Corresponding author: A. E. Robertson; alisonr@iastate.edu

The author(s) declare no conflict of interest.

Up until the mid-2000s, foliar fungicides were rarely applied to hybrid corn. Improved grain prices, increased prevalence of foliar diseases such as gray leaf spot (GLS) and northern corn leaf blight (NCLB), availability of new products, and marketing led to many farmers considering foliar fungicides as a regular input in their production (Wise and Mueller 2011). Apart from managing foliar disease and therefore protecting yield, foliar fungicides are also applied for physiological benefits that may result in greater yields (Mallowa et al. 2015; Paul et al. 2011; Wise et al. 2019). Application of a foliar fungicide may occur at tasseling to silking (crop development stage VT to R1 [Abendroth et al. 2011]) or during early vegetative growth (crop development stage V5 to V8), when it is usually applied together with a postemergence herbicide.

Farmers have reported that applications of a foliar fungicide at VT to R1 reduce lodging. Crops that have low incidence of lodged plants are easier to harvest, and yield loss due to dropped ears is reduced (Wise and Mueller 2011). Moreover, corn crops in fields treated with a fungicide remain greener for a longer period after physiological maturity (crop development stage R6) compared with the corn in fields where no fungicide was applied. This effect is often referred to as "stay green" (Byamukama et al. 2013; Wise and Mueller 2011).

Currently, there is no consensus regarding the potential benefit of the use of foliar fungicides to prevent stalk rot and lodging. There are reports of foliar fungicide applications reducing stalk rot severity (Byamukama et al. 2013; Harbor and Jackson-Ziems 2016b, 2016c; Mueller and Smith 2019; Shriver and Robertson 2009) and still other reports in which no effect of a foliar fungicide application on stalk rot was detected (Harbor and Jackson-Ziems 2016a; Mallowa et al. 2015; Paul and Wallhead 2011; Peltier et al. 2015, 2019; Price et al. 2018). Therefore, to test the effect of a foliar fungicide application on corn lodging at harvest, we established field trials on six Iowa State University Research and Demonstration Farms over 2 years.

Field Experiments

Four and nine field trials were planted in 2016 and 2017, respectively, at the following Iowa State University Research and Demonstration Farms: Northwest Research Farm (NWRF), Sutherland; Northern Research Farm (NRF), Kanawha; Northeast Research Farm (NERF), Nashua; Central Iowa Research Farms (CRF), Boone; Armstrong Memorial Research Farm (ARF), Lewis; and Southeast Research Farm (SERF), Crawfordsville. Details regarding cropping history, hybrid planted, planting, fungicide application, and harvest dates are shown in Table 1. Location of the Iowa State University Research Farms is shown in Figure 1. Field trials were laid out in randomized complete block design with split plot arrangement (2 × 5 treatments) with four replications. Main plot treatments were foliar fungicide application (with or without), and subplot treatments were harvest date (corn harvested at approximately weekly intervals for up to 5 weeks). Plots were 3.05 m (10 ft) wide (four rows spaced 76.2 cm [30 in.] apart) by 15.2 to 30.5 m (50 to 100 ft) long. A 15.25-m (50-ft) border of corn was planted between each subplot to allow the combine to travel among subplots at each harvest date. At developmental stage R1 (silking), the foliar fungicide Headline AMP (pyraclostrobin [FRAC group 11] and metconazole [FRAC group 3]; BASF Corporation, Research Triangle Park, NC; 0.73 liter/ha [10 fl oz/acre]) was applied using either a self-propelled sprayer fitted with Tee Jet flat fan sprayer nozzles (XR11003VS) spaced 50.8 cm (20 in.) apart and delivering 140.3 liter/ha (15 gal/acre) of water (CRF and NWRF), or a CO_2-powered backpack applicator with an overhead boom extending over the top of the plants, fitted with Tee Jet flat fan sprayer nozzles (XR11003VS), spaced 50.8 cm (20 in.) apart and delivering 187.1 liter/ha (20 gal/acre) at 165.5 kPa (24 psi) at NERF or 140.3 liter/ha (15 gal/acre) at ARF, NRF, and SERF. Research plots were managed according to Iowa State University recommended agronomic practices for fertilizer and weed management.

Data Collection and Statistical Analysis

Foliar disease severity in all subplots of two of the four replicates (n = 20 subplots; 10 with and 10 without fungicide application) at each location except NRF was assessed at crop development stage R5 (dent) in 2017. Foliar disease severity ratings were not done in 2016. Percent diseased leaf tissue was assessed on a plot basis. Disease severity in the lower canopy (all leaves below the ear leaf), and the upper canopy (ear leaf and all leaves above) was estimated visually. In both years, percent lodging data were collected at all locations. On the day of harvest, in each plot being harvested that day, a "push test" (Anderson and White 1994) was done to estimate percent lodging in the plot. Briefly, 50 consecutive plants in each of the middle two rows of each plot were pushed at shoulder height to the two o'clock position. Percent lodging in each plot was recorded as the numbers of stalks that broke or collapsed (lodged) or that were already lodged. All four rows of each plot were harvested using a John Deere 9450 Harvest Master system (CRF, ARF, NRF, and SERF), a John Deere 9450 combine fitted with an Avery Weigh-Tronix weigh scale and Shivvers 5010 moisture meter (NERF), and a Case IH 1660 Axial-Flow combine fitted with an Avery Weigh-Tronix weigh scale and Ag Leader 2000 moisture meter (NWRF).

All data were analyzed in SAS 9.4 (SAS Institute, Cary, NC). After inspection of the residual plots, percent lodging data were square-root transformed to meet the assumption of normal residuals and homogenous variances. Transformed lodging data and yield data were analyzed using PROC GLIMMIX with previous crop, NCLB resistance, GLS resistance, stalk strength, stay green, year, fungicide application, and harvest date as fixed factors, and all interactions between year, fungicide application, and harvest date. Site and replication nested within site were treated as random

TABLE 1
Previous crop, hybrid number and characteristics scores, and dates of planting, fungicide application, and harvests for 13 field trials established on Iowa State University (ISU) Research Farms in 2016 and 2017

				Company scores for hybrid characteristic[x]						Harvest dates				
Year	Farm[w]	Previous crop	Hybrid	NCLB res.[y]	GLS res.[y]	Stalk strength	Stay green	Planting date	Fung. appl. date[z]	1	2	3	4	5
2016	ARF	Soybean	P0937 AM	6	7	6	7	4/24	7/14	10/3	10/14	10/20	10/28	11/4
	CRF	Soybean	P0589 AMX	5	4	5	6	5/7	8/8	10/3	10/10	10/17	10/24	10/31
	NERF	Soybean	P0407 AMXT	4	4	6	3	4/27	7/22	10/5	10/15	10/23	10/30	11/6
	NRF	Corn	P0193 AM	4	4	8	6	4/24	7/15	10/6	10/13	10/21	11/1	11/7
2017	ARF	Soybean	P0937 AM	6	7	6	7	4/24	7/21	10/17	10/23	10/30	11/7	11/13
	CRF	Corn	P0589 AMX	5	4	5	6	4/25	7/18	10/12	10/19	10/27	11/2	11/9
	NERF	Soybean	P0157 AMX	5	4	7	4	5/6	7/25	10/10	10/17	10/24	10/31	11/7
	NRF	Corn	P0193 AM	4	4	8	6	5/7	7/19	10/9	10/16	10/23	11/3	11/9
	NWRF-1	Corn	P0407 AMXT	4	4	6	3	5/8	7/24	10/17	10/21	10/25	10/31	11/6
	NWRF-2	Corn	P0339 AMXT	5	6	6	6	5/8	7/24					
	NWRF-3	Soybean	P0407 AMXT	4	4	6	3	5/11	7/24					
	NWRF-4	Soybean	P0339 AMXT	5	6	6	6	5/11	7/24					
	SERF	Corn	P0589 AMX	5	4	5	6	5/18	7/25	10/5	10/13	10/19	10/25	11/2

[w] ARF = Armstrong Memorial Research and Demonstration Farm, Lewis; CRF = ISU Central Iowa Research and Demonstration Farms, Boone; NERF = ISU Northeast Research and Demonstration Farm, Nashua; NRF = ISU Northern Research and Demonstration Farm, Kanawha; NWRF = ISU Northwest Research and Demonstration Farm, Sutherland; and SERF = ISU Southeast Research and Demonstration Farm, Crawfordsville.

[x] Data were taken from company literature regarding each hybrid. Scores for each characteristic are given on a 1 to 9 scale were 1 = poor and 9 = excellent.

[y] NCLB = northern corn leaf blight; GLS = gray leaf spot; and res. = resistance.

[z] Headline AMP (pyraclostrobin and metconazole; 0.73 liter/ha [10 fl oz/acre]) was applied at silking. Fung. appl. = fungicide application.

factors in the model. LSMEANS for lodging and yield by year and site were calculated using the PROC GLIMMIX analysis with the statement "by year site". If treatment effects were detected, pairwise difference with *t* test (α = 0.05) was used for means comparison. Interaction year × harvest was analyzed for each year using the "slice" statement. LSMEANS for lodging data were back transformed for presentation of results. Similarly, GLS severity data were cubic-root transformed to meet the assumption of normality and homogeneous variances and then analyzed using PROC GLIMMIX with fungicide treatment as a fixed factor and replication as a random factor in the model. LSMEANS were back transformed accordingly, and pairwise difference with *t* test (α = 0.05) was used for means comparison.

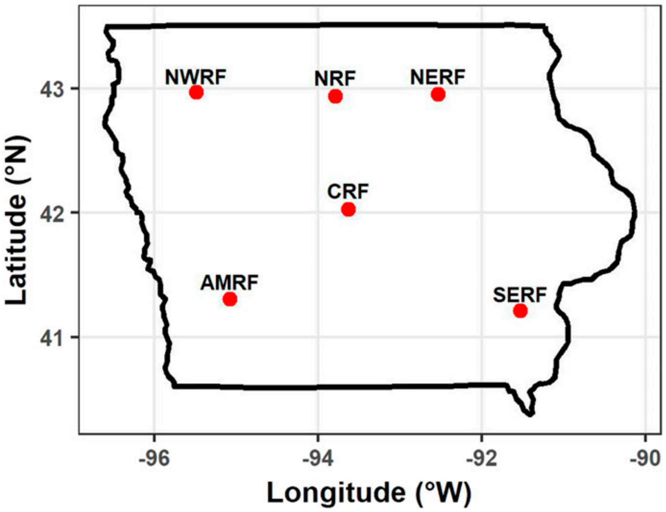

FIGURE 1

Location of 13 field trials done in 2016 and 2017 at six Iowa State University Research Farms. NWRF = Iowa State University (ISU) Northwest Research and Demonstration Farm, Sutherland; NRF = ISU Northern Research and Demonstration Farm, Kanawha; NERF = ISU Northeast Research and Demonstration Farm, Nashua; CRF = ISU Central Iowa Research and Demonstration Farms (CRF), Boone; ARF = Armstrong Memorial Research and Demonstration Farm, Lewis; and SERF = ISU Southeast Research and Demonstration Farm, Crawfordsville.

Effect of Fungicides on Foliar Disease

Foliar disease severity was not assessed in 2016. In 2017, GLS (caused by *Cercospora zeae-maydis* Tehon & E.Y. Daniels) was present in the trials at all locations that were assessed. Disease severity was low (<5%) at all locations except ARF (Table 2). An application of fungicide at silking significantly reduced disease severity observed at dent in three out of seven trials (Table 2). High foliar disease severity may increase the risk of stalk rot (Dodd 1980; Ward et al. 1999). Even though we observed that fungicide application reduced GLS severity, it is unlikely that such low disease levels affected stalk rot development. Furthermore, hybrids with low resistance to GLS were planted in many of the trials (Table 1), and no effect of GLS resistance on lodging (P = 0.7111) and yield (P = 0.6911) was detected (Table 3).

Effect of Fungicides on Lodging and Yield

A significant effect on lodging was detected for year (P = 0.0245), fungicide (P < 0.0001), harvest date (P < 0.0001), and the interactions year × fungicide application (P = 0.0016) and year × harvest date (P < 0.0001) (Table 3). More lodging occurred in all

TABLE 3
Main effects and interactions for square-root-transformed lodging, and yield data for 13 field trials established on six Iowa State University Research Farms in 2016 and 2017

Source of variation	Percent lodging *P* value	Yield *P* value
Previous crop	0.5310	<0.0001
NCLB[z] resistance	0.3241	0.4466
GLS[z] resistance	0.7111	0.6911
Stalk strength	0.1788	0.0488
Stay green	0.3719	0.9663
Year	0.0245	0.1424
Fungicide	<0.0001	0.0043
Year × fungicide	0.0016	0.8818
Harvest	<0.0001	0.6853
Year × harvest	<0.0001	0.6357
Fungicide × harvest	0.3161	0.5928
Year × fungicide × harvest	0.3301	0.9016

[z] NCLB = northern corn leaf blight, and GLS = gray leaf spot.

TABLE 2
Disease severity (%) (back transformed data) of gray leaf spot in the upper canopy and lower canopy of corn in field trials at four Iowa State University (ISU) Research Farms in 2017

	Disease (%)							
Fungicide applied	All farms	ARF[x]	NERF	NWRF-1	NWRF-2	NWRF-3	NWRF-4	SERF
Upper canopy								
No	3.6 a[y]	24.2	4.5	3.2 a	1.8 a	2.1	1.4	1.5 a
Yes	2.5 b	22.1	3.7	1.6 b	0.6 b	1.6	1.4	0.7 b
P value	<0.0001	0.4443	0.0837	0.0018	0.0001	0.6610	1.000	0.0006
Lower canopy								
No	6.3 a	…[z]	8.5 a	4.6 a	2.9 a	…	…	11.5 a
Yes	3.2 b	…	6.1 b	2.0 b	0.8 b	…	…	6.6 b
P value	<0.0001	…	0.0281	0.0007	<0.0001	…	…	<0.0001

[x] ARF = Armstrong Memorial Research and Demonstration Farm, Lewis; NERF = ISU Northeast Research and Demonstration Farm, Nashua; NWRF = ISU Northwest Research and Demonstration Farm, Sutherland; and SERF = ISU Southeast Research and Demonstration Farm, Crawfordsville.

[y] Different letters within the same column indicate significant difference according to *t* test α = 0.05.

[z] Data were not taken because the lower canopy had senesced due to nitrogen deficiency.

sites in 2016 compared with 2017 (Table 4), suggesting that stalk rot may have been more prevalent in 2016. It is possible that greater precipitation that occurred in 2016 compared with 2017, particularly toward the end of the growing season (Fig. 2), may have played a role. Weather conditions, cloud cover, and moisture conditions can affect stalk rot development (Dodd 1980; Munkvold and White 2016); however, there are numerous other factors, including soil fertility, cultural practices, foliar disease, and insect damage, that may also contribute to stalk rot (Munkvold and White 2016). We did not collect foliar disease data in these trials in 2016, but in other trials at some of these locations disease severity was assessed. In 2016, NCLB (*Setosphaeria turcica* [Pass.] K. J. Leonard & Suggs), which is favored by frequent precipitation, was the most prevalent foliar disease throughout Iowa. Across all locations and years, a fungicide application significantly reduced mean lodging ($P < 0.0001$) by 9.3% (Table 4). In three of four trials in 2016 and seven of nine trials in 2017, less lodging occurred in the fungicide-treated corn compared with the nontreated corn ($P < 0.05$) (Fig. 3). No fungicide × harvest date interaction was detected on lodging ($P = 0.3161$) (Table 3).

TABLE 4
Mean percent lodging for year and fungicide treatment across all harvest dates for 13 field trials established on six Iowa State University Research Farms in 2016 and 2017

Effect		Percent lodging
Year	2016	14.8 a[y]
	2017	12.1 b
	P value	0.0245
Fungicide applied[z]	No	18.5 a
	Yes	9.2 b
	P value	<0.0001

[y] Different letters within the same column indicate significant difference according to *t* test $\alpha = 0.05$.

[z] Headline AMP (pyraclostrobin and metconazole; 0.73 liter/ha [10 fl oz/acre]) was applied at silking.

It is unlikely that the fungicide directly reduced stalk rot disease in these trials by reducing infection and colonization of the stalk tissues by pathogens. Although pyraclostrobin and metconazole both have some systemic activity, they move either translaminarly or acropetally in the leaf, respectively (Mueller et al. 2013). Neither move in the phloem and, therefore, cannot be translocated to the stalk tissues. Early work on stalk rot reported the disease was more severe when sugar content in the lower stalk and root tissues was low (Mortimore and Ward 1964). We propose that the fungicide application maintained the health of the canopy after physiological maturity, and photoassimilates no longer required for grain fill were translocated to the lower stalk internodes and roots, thus maintaining the sugar content of these tissues. Consequently, those tissues were more resistant to colonization by stalk rot pathogens (Craig and Hooker 1961; Mortimore and Ward 1964; Pappelis 1965).

No fungicide × harvest or year × fungicide × harvest interactions were detected on yield. In addition, NCLB resistance, GLS resistance, stalk strength, or stay green had no effect on lodging ($P > 0.05$).

A significant effect on yield was detected with the use of fungicide ($P = 0.0043$) (Table 3). Across all locations and years, the average yield was improved by 258.3 kg/ha (4.1 bu/acre), which represents a 1.75% yield increase. However, the analysis for each farm revealed that greater yields ($P < 0.05$) with a fungicide application occurred at only one out of four trials in 2016 and at three of nine trials in 2017 (Fig. 4). Greater yields with a foliar fungicide application have been reported more often when foliar

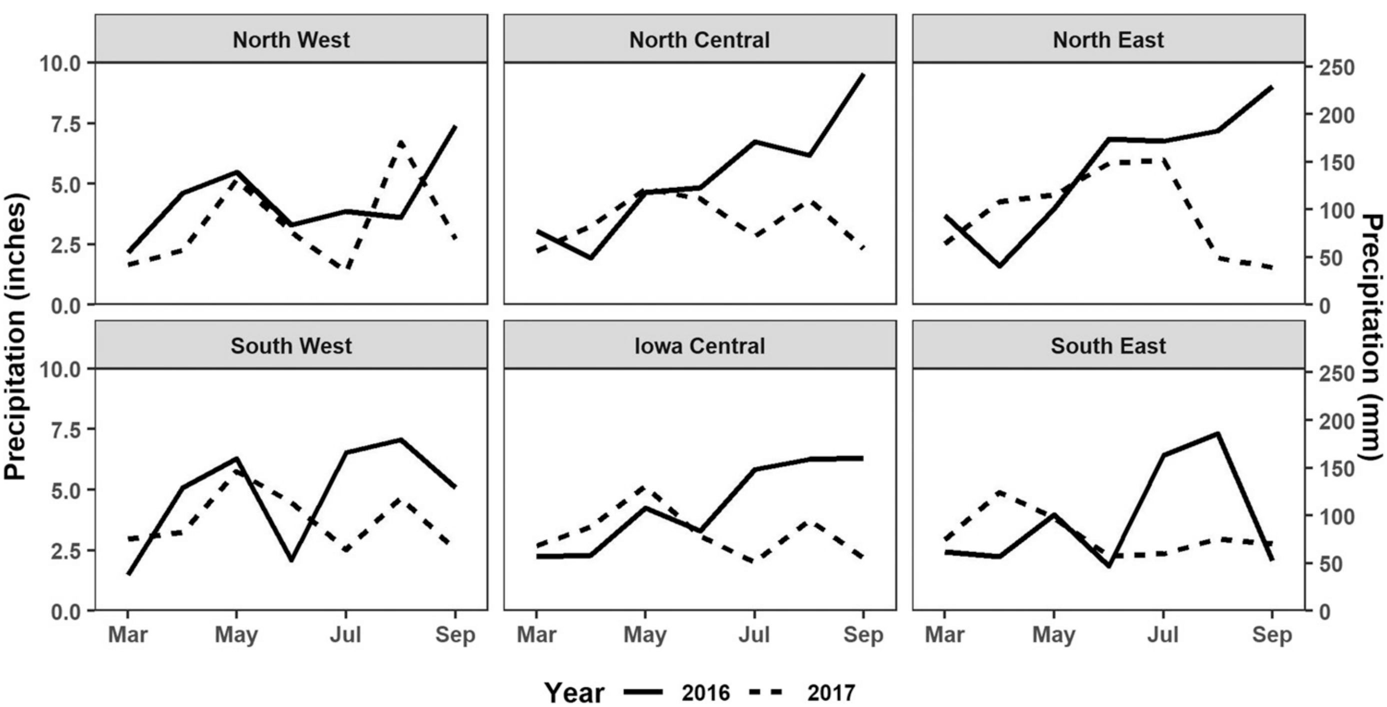

FIGURE 2

Accumulated monthly precipitation for six regions of Iowa in 2016 and 2017. Data from Iowa Environmental Mesonet “Climodat” reports (https://mesonet.agron.iastate.edu).

disease is high (Mallowa et al. 2015; Paul et al. 2011), although greater yields when disease severity is low have also been reported (Wise et al. 2019). Low GLS severity was recorded in the 2017 trials, and yet yields were numerically greater in all but two trials (NWRF-3 and NWRF-4). In addition, greater yields were not necessarily associated with reduced lodging. In fact, in the NWRF-3 and NWRF-4 trials, lodging was reduced approximately 25%, yet numerically lower yields occurred in the fungicide-treated corn in comparison with the corn to which a fungicide was not applied.

Other factors that had a significant effect on yield were previous crop ($P < 0.0001$) and stalk strength ($P = 0.0488$) (Table 3). When the previous crop was soybean, the average yield was 5,670 kg/ha

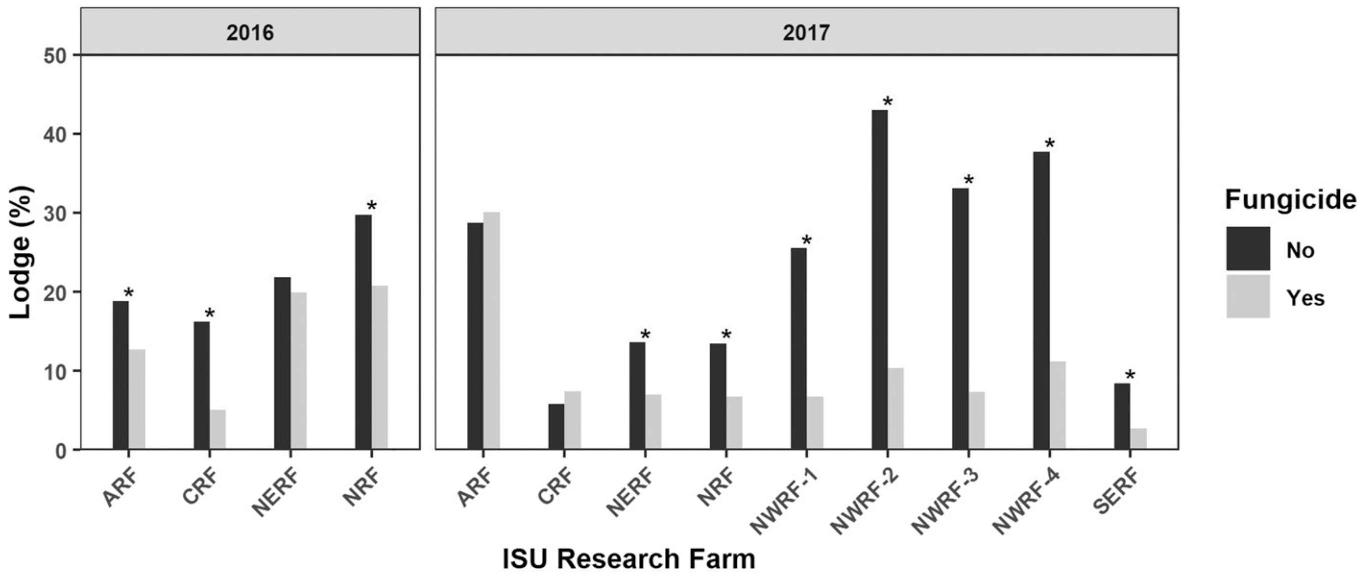

FIGURE 3

Mean percent lodging (back transformed data) of corn that was sprayed with a fungicide at silking or not sprayed at 13 trials done in 2016 and 2017 at six Iowa State University (ISU) Research Farms. ARF = Armstrong Memorial Research and Demonstration Farm, Lewis; CRF = ISU Central Iowa Research and Demonstration Farms, Boone; NERF = ISU Northeast Research and Demonstration Farm, Nashua; NRF = ISU Northern Research and Demonstration Farm, Kanawha; NWRF = ISU Northwest Research and Demonstration Farm, Sutherland; and SERF = ISU Southeast Research and Demonstration Farm, Crawfordsville. Asterisk (*) indicates significant differences at $P < 0.05$ using t test.

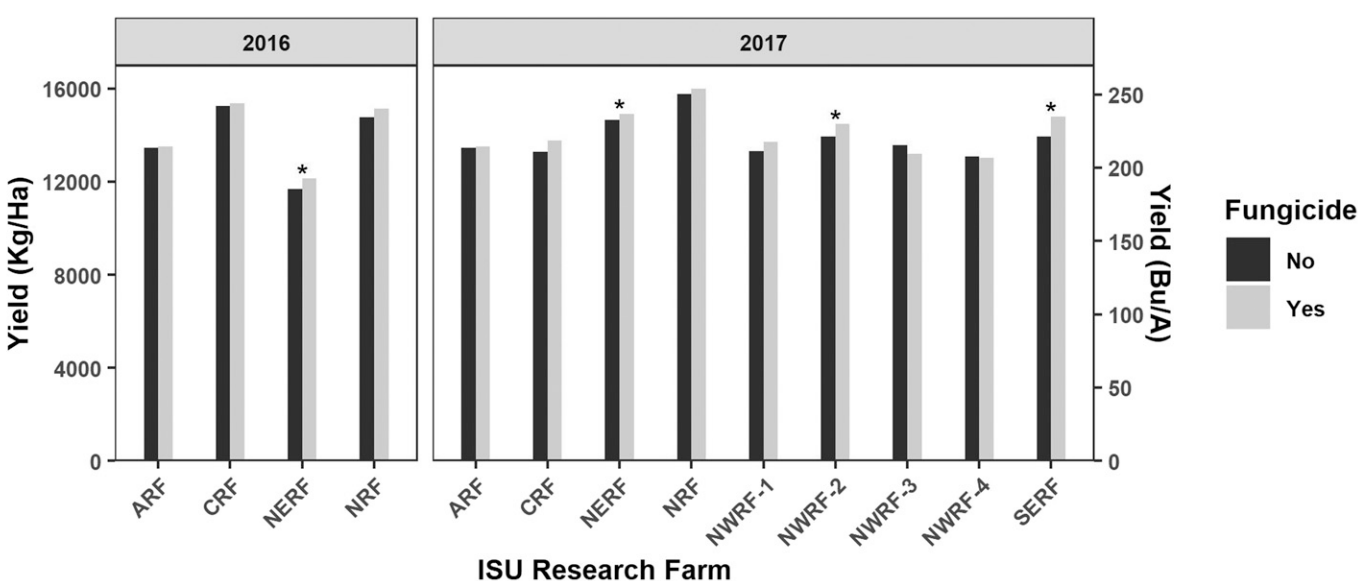

FIGURE 4

Mean yields of corn sprayed with a fungicide at silking or not sprayed for 13 field trials done in 2016 and 2017 at six Iowa State University (ISU) Research Farms. ARF = Armstrong Memorial Research and Demonstration Farm, Lewis; CRF = ISU Central Iowa Research and Demonstration Farms, Boone; NERF = ISU Northeast Research and Demonstration Farm, Nashua; NRF = ISU Northern Research and Demonstration Farm, Kanawha; NWRF = ISU Northwest Research and Demonstration Farm, Sutherland; and SERF = ISU Southeast Research and Demonstration Farm, Crawfordsville. Asterisk (*) indicates significant differences at $P < 0.05$ using t test.

(30.3 bu/acre) greater than when corn was the previous crop. Numerous studies have similarly reported that yields are greater when corn is grown following soybean than corn following corn (Crookston et al. 1991; Meese et al. 1991; Pedersen and Lauer 2003; Stanger and Lauer 2008).

No significant interactions were detected on yield. In addition, no effect of NCLB resistance, GLS resistance, or stay green were detected on yield. Although ANOVA detected an effect of stalk strength on yield ($P = 0.0488$), means comparison for pairwise difference with t test ($\alpha = 0.05$) did not show differences.

Effect of Harvest Date on Lodging and Yield

Harvest date had a significant effect on lodging ($P < 0.0001$). A significant interaction of year × harvest date was also observed for lodging ($P < 0.0001$) (Table 3). In general, percent lodging increased as harvest was delayed. In both 2016 and 2017 the lowest percent lodging was observed on the earliest harvest date. In 2017 percent lodging increased with later harvest dates ($P < 0.05$); in 2016 percent lodging numerically increased but did not differ among the last four harvest dates ($P > 0.05$) (Tables 3 and 5). This suggests that stalk rot became more prevalent the longer the corn remained in the field, and consequently lodging increased as the harvest season progressed. Most pathogens that cause stalk rot are opportunistic invaders of senescing root and stalk tissues (Munkvold and White 2016). Increased colonization of senescing stalk tissues by these organisms and associated rotting of the pith tissue would have destroyed the structural integrity of the stalks, predisposing them to lodging (Munkvold and White 2016), especially when subjected to the push test (Anderson and White 1994) we used in this study.

Yield was not affected by harvest date ($P = 0.6853$). Thus, the increased lodging detected at later harvest dates did not result in reduced yield. Greater yield loss is usually associated with lodging because lodged plants may be difficult to harvest using mechanical equipment (Munkvold and White 2016). Because this study was done on relatively small plots (15.2 to 30.5 m long [50 to 100 ft long]), the yield loss in plots with a higher prevalence of lodged corn might have been underestimated. Harvest speed in small plots is slower than harvest speed in commercial fields, and consequently dropped ears are more likely to be picked up by the combine.

Conclusions and Recommendations

In this study, foliar fungicides applied to corn at tasseling/silking reduced lodging and confirmed observations of farmers. Applying a fungicide to reduce lodging and favor harvest, however, is not recommended. First and foremost, foliar fungicides are not labeled for management of stalk rot pathogens. Second, there is concern for fungicide resistance development. Almost all fungicides used on corn contain quinone outside inhibitor fungicides that are at high risk of resistance (FRAC 2019). In addition, the "greening effect" associated with a fungicide application may lead to high-moisture corn at harvest, which can ultimately reduce profitability, especially if farmers need to pay dryer costs to prepare grain for storage (Wise and Mueller 2011). Fields that have a history of difficult harvests should be scouted at physiological maturity to determine the prevalence of lodging and stalk disease. In years with stressful growing conditions, scouting fields for lodging and stalk rot is encouraged. Scheduling an earlier harvest will reduce lodging associated with pathogens colonizing senescing stalks and yield losses from unharvested ears on lodged plants.

TABLE 5
Mean percent lodging for five harvest dates across all fungicide treatment for 13 field trials established on six Iowa State University Research Farms in 2016 and 2017

Harvest[y]	Percent lodging 2016	Percent lodging 2017
1	6.8 b[z]	3.6 e
2	14.9 a	9.0 d
3	18.6 a	12.2 c
4	18.9 a	17.4 b
5	16.6 a	23.6 a
P value	<0.0001	<0.0001

[y] Corn plants were harvested at weekly intervals for up to 5 weeks; see Table 1 for dates for each field trial.

[z] Different letters within the same column indicate significant difference according to t test $\alpha = 0.05$.

Acknowledgments

We thank Yuba Kandel for reviewing an earlier version of this manuscript.

Literature Cited

Abendroth, L. J., Elmore, R. W., Boyer, M. J., and Marlay, S. K. 2011. Corn Growth and Development. PMR 1009. Iowa State University Extension, Ames, IA.

Anderson, B., and White, D. G. 1994. Evaluation of methods for identification of corn genotypes with stalk rot and lodging resistance. Plant Dis. 78:590-593.

Byamukama, E., Abendroth, L. J., Elmore, R. W., and Robertson, A. E. 2013. Quantifying the effect of pyraclostrobin on grain-fill period and kernel dry matter accumulation in maize. Plant Health Prog. 14. doi: 10.1094/PHP-2013-1024-02-RS.

Craig, J., and Hooker, A. L. 1961. Relation of sugar trends and pith density to Diplodia stalk rot in dent corn. Phytopathology 51:376-382.

Crookston, R. K., Kurle, J. E., Copeland, P. J., Ford, J. H., and Lueschen, W. E. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108-113.

Dodd, J. 1980. The role of plant stresses in development of corn stalk rots. Plant Dis. 64:533-537.

FRAC. 2019. FRAC Code List 2019: Fungal control agents sorted by cross resistance pattern and mode of action (including FRAC Code numbering). Fungicide Resistance Action Committee. https://www.frac.info/publications/downloads

Harbour, J. D., and Jackson-Ziems, T. A. 2016a. Foliar fungicide comparison for gray leaf spot management and lodging in Nebraska field corn, 2014. Plant Dis. Manage. Rep. 10:FC095.

Harbour, J. D., and Jackson-Ziems, T. A. 2016b. Foliar fungicide comparison for southern rust management, stay green, push lodging, and yield in Nebraska, 2015. Plant Dis. Manage. Rep. 10:FC102.

Harbour, J. D., and Jackson-Ziems, T. A. 2016c. Foliar fungicide modes of action for southern rust management, push lodging, and yield in Nebraska, 2015. Plant Dis. Manage. Rep. 10:FC100.

Mallowa, S. O., Esker, P. D., Paul, P. A., Bradley, C. A., Chapara, V. P., Conley, S. P., and Robertson, A. E. 2015. Effect of maize hybrid and foliar fungicides on yield under low foliar disease severity conditions. Phytopathology 105:1080-1089.

Meese, B. G., Carter, P. R., Oplinger, E. S., and Pendleton, J. W. 1991. Corn/soybean rotation effect as influenced by tillage, nitrogen, and hybrid/cultivar. J. Prod. Agric. 4:74-80.

Mortimore, C. G., and Ward, G. M. 1964. Root and stalk rot of corn in southwestern Ontario III: Sugar levels as a measure of plant vigor and resistance. Can. J. Plant Sci. 44:451-457.

Mueller, B., and Smith, D. L. 2019. Evaluation of foliar fungicides for the control of diseases of dent corn in Wisconsin, 2018. Plant Dis. Manage. Rep. 13: CF017.

Mueller, D. S., Wise, K. A., Dufault, N. S., Bradley, C. A., and Chlvers, M. I. 2013. Fungicides for Field Crops. APS Press, St Paul, MN.

Munkvold, G. P., and White, D. G., eds. 2016. Compendium of Corn Diseases, 4th Ed. APS Press, St. Paul, MN.

Nielsen, B., and Colville, D. 1988. Stalk Lodging in Corn: Guidelines for Preventive Management. Agronomy Guide, AY-262. Purdue University, West Lafayette, IN

Pappelis, A. J. 1965. Relationship in seasonal changes in pith condition ratings and density to Gibberella stalk rot of corn. Phytopathology 55:623-626.

Paul, P. A., Madden, L. V., Bradley, C. A., Robertson, A. E., Munkvold, G. P., Malvick, D. K., Allen, T., Vincelli, P., and Esker, P. D. 2011. Meta-analysis of yield response of hybrid field corn to foliar fungicides in the U.S. Corn Belt. Phytopathology 101:1122-1132.

Paul, P. A., and Wallhead, M. W. 2011. Fungicide effect on foliar diseases and stalk rot severity and yield of hybrid corn in Ohio, 2009. Plant Dis. Manage. Rep. 5:FC086.

Pedersen, P., and Lauer, J. G. 2003. Corn and soybean response to rotation sequence, row spacing, and tillage system. Agron. J. 95:965-971.

Peltier, A. J., Mansfield, B. D., and Johnson, M. L. 2015. Comparison of fungicide products and application timings (in-furrow, V6 R1) for corn disease management and yield in Monmouth, Illinois in 2014. Plant Dis. Manage. Rep. 9:FC131.

Peltier, A. J., Potter, B. D. and Malvick, D. K. 2019. Effects of foliar fungicide and hybrids on yield and lodging of corn in Crookston, Minnesota in 2018. Plant Dis. Manage. Rep. 13:CF032.

Price, P., Parvis, M. A., and Washam, P. S. 2018. Effect of fungicide application timing of southern rust, lodging and yield, 2017. Plant Dis. Manage. Rep. 12: CF191.

Shriver, J. M., and Robertson, A. E. 2009. Comparison of fungicide products for disease control and yield in corn at Crawfordsville, Iowa 2008. Plant Dis. Manage. Rep. 3:FC015.

Sisson, A., Mueller, D. S., and Wise, K. A. 2017. Corn disease loss estimates from the United States and Ontario, Canada – 2016. Crop Protection Network CPN 2007-16-W.

Stanger, T. F., and Lauer, J. G. 2008. Corn grain yield response to crop rotation and nitrogen over 35 years. Agron. J. 100:643-650.

Ward, J. M. J., Stromberg, E. L., Nowell, D. C., and Nutter, F. W., Jr. 1999. Gray leaf spot: A disease of global importance in maize production. Plant Dis. 83: 884-895.

Wise, K., and Mueller, D. 2011. Are fungicides no longer just for fungi? An analysis of foliar fungicide use in corn. APSnet. doi: 10.1094/APSnetFeature-2011-0531. American Phytopathological Society, Saint Paul, MN.

Wise, K. A., Smith, D., Frejie, A., Mueller, D. S., Kandel, Y., Allen, T., Bradley, C. A., Byamukama, E., Chilvers, M., Faske, T., Friskop, A., Hollier, C., Jackson-Ziewms, T. A., Kelly, H., Kemerait, B., Price, P., Robertson, A. E., and Tenuta, A. 2019. Meta-analysis of yield response of foliar fungicide-treated hybrid corn in the United States and Ontario, Canada. PLoS One 14: e0217510.