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AGRONOMY AND SOILS

Evaluation of Early Season Foliar Fungicide Applications to Support Non-Fungicidal 'Plant Health' Benefits

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ABSTRACT

The recent labeling of a new fungicide and rumors of non-fungicidal 'plant health' benefits achieved through early-season foliar applications of certain fungicides have led to inquiries concerning the practice. The objective of this research was to determine the impact of an early-season fungicide application on early-season growth or end-of-season lint yields, turnout, and/or fiber quality when disease symptoms are not present. During the 2014-2016 growing seasons, a total of ten trials were established in Alexandria, LA; Starkville, MS; Fort Cobb, OK; Jackson, TN; and Snook, TX. Fungicide treatments included an untreated control, a foliar application of 0.11 kg ai ha^{-1} azoxystrobin, and a foliar application of 0.07 kg ai ha^{-1} fluxapyroxad + 0.15 kg ai ha^{-1} pyraclostrobin. All treatments targeted the two through four true leaf growth stage. A significant interaction between fungicide treatment and site-year was observed from node counts collected at 14 and 28 DAA. Site-year analysis indicated a significant reduction in node counts observed with the azoxystrobin treatment in one site-year in the 14 DAA data and one site-year in the 28 DAA data. Fungicide treatment did not impact plant height or vigor ratings collected at 14 or 28 DAA, chlorophyll meter readings, lint yield, turnout, or fiber quality parameters in any site-year. Failure of fungicide treatments to positively impact in-season growth measurements, yield, and yield parameters suggests the evaluated fungicides should not be applied early-season for the purpose of improving 'plant health' and should instead be reserved to target above-threshold levels of disease incidence/severity.

While seed-applied applications of fungicides to cotton are common and often warranted (Rothrock et al., 2012), post-bloom foliar applications of fungicides are only occasionally applied to combat various diseases and pre-bloom foliar applications are very uncommon, particularly when disease is not present. However, the recent labeling of a new fungicide and rumors of non-fungicidal 'plant health' benefits achieved through early-season foliar applications of certain fungicides have led to inquiries concerning the practice. Although specific perceived benefits categorized under the term 'plant health' vary, an early-season topical application is typically thought to decrease negative responses to plant stressors, increase the efficiency of physiological processes, decrease time between emergence and first square, and congruently increase lint yields.

In 2012, the Environmental Protection Agency (EPA) granted BASF Corp. (Research Triangle Park, NC) a label for Priaxor (fluxapyroxad + pyraclostrobin; BASF Corp.). The EPA expanded this label to cover cotton in 2015 (BASF, 2012 & 2015). Web-based promotional materials associating the product with 'advanced health benefits' for canola (*Brassica napus)*, corn (*Zea mays)*, lentils (*Lens culinaris)*, peas (*Pisum sativum)*, soybeans (*Glycine max*), sunflowers (*Helianthus annuus*) and wheat (*Triticum aestivum*) are available at the BASF Priaxor website (www.agriculture.basf.com/us/en/Crop-Protection/Priaxor.html, accessed 23 Apr 2018). Non-fungicidal benefits are also highlighted locally across other commodities, including cotton. Although 'plant health' and non-fungicidal benefits are not specifically mentioned on the Quadris website (azoxystrobin, Syngenta Crop Protection, Wilmington, DE), an application of Quadris is said to, "enable crops to utilize resources like air, water and nutrients more efficiently." (website (www.syngenta-us.com/fungicides/quadris, accessed 23 Apr 2018).

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Field research trials examining non-fungicidal increases in yields across major commodities have shown mixed results. Several multi-state efforts examining the use of foliar fungicides along with other inputs typically incorporated into a high-input management soybean system have recently been published. Orlowski et al. (2016) examined input impacts on soybean yield and yield components in a 60 site-year, multi-state project during the 2012-2014 seasons. While their results favored the incorporation of insecticides over fungicides, authors did suggest foliar fungicides occasionally provided yield increases at sub-threshold levels of pest pressure. Similarly, Kandel et al. (2016) summarized responses from topical fungicide and insecticide applications in soybeans across 14 site-years in the North Central United States to find the application of a fungicide, insecticide or the combination of the two increased yields in 7 out of the 14 evaluated site-years. Low levels of disease pressure led authors to suggest the foliar fungicide application provided physiological benefits to the plant but did not identify the mechanism or pathway which supported the increased yields.

Similar results were noted in Wisconsin by Mourtzinis et al. (2017); while the V5 application of pyraclostrobin (Headline, BASF Corp.) and fluxapyroxad + pyraclostrobin (Priaxor) in corn failed to increase yields in any three of the tested years, applications to soybeans increased yields in two of three years and applications to wheat increased yields in all three tested years. Similar to testing environments of Orlowski et al. (2016), and Kandel et al. (2016), very little disease pressure was noted during this project. Subsequently, Mourtzinis et al. (2017) also suggested the yield increases noted in soybeans and wheat were likely due to non-fungicidal crop physiological changes.

In contrast, several recent studies have failed to capture significant increases in yield from foliar fungicide applications when disease was either not present or present at below-threshold levels. Joe Ng et al. (2018) evaluated the response of soybean yields to applications of foliar fungicides and insecticides across 12 site-years in Ohio. While fungicides increased yields in 4 out of 12 years, authors concluded the applications of fungicides and/or insecticides failed to improve yields when insects or foliar diseases were not present. Swoboda and Pedersen (2009) evaluated the effect of tebuconazole and strobilurin alone and in combination to soybeans in three site-years within Iowa. Although slight differences in growth and yield components were noted, the applications of fungicides did not produce yield-impacting, positive, non-fungicidal, physiological effects. Additionally, Paul et al. (2011) evaluated the response of corn to foliar fungicides across 187 site-years and concluded fungicides should not be applied when disease risk is low.

While numerous studies are conducted annually to evaluate the impacts of foliar fungicides in cotton to combat disease, few studies have been published which examine the response of cotton to foliar fungicide applications which increase ‘plant health’. One such study was published by Woodward et al. (2016), who examined the response of cotton growth, maturity, lint yield, turnout and fiber quality to different rates and post-bloom timings of strobilurin fungicides targeting ‘plant health’ across 15 site years during the period from 2008-2010. Lint yields, turnouts, and fiber quality were not impacted by any evaluated fungicide rate or timing. Authors concluded, ‘Due to the lack of a consistent increase in yield or quality, fungicides should not be applied to cotton to promote ‘plant health’ (Woodward et al., 2016). Still, Woodward et al. (2016) did not evaluate fluxapyroxad + pyraclostrobin (Priaxor) and application timings evaluated began at flower.

Research evaluating the early-season response of cotton to foliar applications of fluxapyroxad + pyraclostrobin or azoxystrobin for the purposes of increasing ‘plant health’ would provide producers with valuable information. Therefore, the objective of this research was to determine if an early season application of a fungicide without the presence of a disease could create positive impacts on early season growth or end-of-season lint yields, turnout, and/or fiber quality.

MATERIALS AND METHODS

During the 2014-2016 seasons, trials were established in Alexandria, LA; Starkville, MS; Fort Cobb, OK; Jackson, TN; and Snook, TX. In total, data was collected from ten site-years. Treatments consisted of foliar applications of fluxapyroxad + pyraclostrobin (Priaxor) applied at 420 mL/ha and azoxystrobin (Quadris) applied at 420 mL/ha compared to an untreated control. Application timings targeted the two through four leaf growth stage. Trial design within each site year was a randomized complete block with a minimum of four replicates. Soil texture, irrigation, row spacing, seeding rate, spray tip information, spray volume, and speed at which each product was applied is summarized in Table 1. Planting date, application timing, harvest date, and dates at which assessments were made are listed in Table 2. Fertility, insects and all other agronomic management factors were managed according to each state's extension recommendations. All trial locations were planted with the cultivar Phytogen 499 WRF (Dow AgroSciences, Indianapolis, IN). At the time of application, disease symptoms were not present.

While measurements varied by location, most locations collected vigor ratings, node counts, and plant heights at 0, 14 and 28 days after application (DAA). Additionally, chlorophyll meter readings (Minolta SPAD meter 502, Minolta Camera Co., Ltd., Japan) and Leaf Area Index (LAI) measurements were collected from the Alexandria, LA locations at 0, 14 and 28 DAA. All locations utilized a randomized complete block design. Treatments were made with either a CO_2 pressurized backpack sprayer or a high-clearance research sprayer. Plots in LA, MS, TX and TN were harvested with a spindle picker. Plots in OK were harvested with a stripper harvester. After harvest, subsamples from each plot were ginned to determine turnout. Lint samples were then processed by high volume instrumentation (HVI) to determine fiber quality parameters.

Collected data was analyzed in SAS Version 9.4 (SAS Institute, Cary, NC) with the PROC GLM procedure. Replication was nested within each site-year for the analysis and both replication and site year were analyzed as random effects. Fungicide by site-year interactions were only significant for the node counts collected at the second and third assessment timings. All other data was pooled across site-years. Treatment means were separated from the control using Dunnett's t Test at an alpha level equal to 0.1.

Table 1: General agronomic information and application details for each location during the 2014-2016 growing seasons

Location	Year(s)	Soil texture	Irrigation	Row spacing, cm	Seeding rate, seed ha^{-1}	Spray tip	Spray volume, L ha^{-1}	Speed, km hr^{-1}
Alexandria, LA	2014, 2015, 2016	Clay	none	97	101,313	Flat fan	94	4.8
Starkville, MS	2014, 2016	Silty clay loam	none	97	111,197	Air induction	103	4.8
Fort Cobb, OK	2014	Sandy loam	overhead	91	143,519	Flat fan	94	4.8
Jackson, TN	2016	Silt loam	none	97	118,610	Air induction	140	4.8
Snook, TX	2014, 2015, 2016	Silty clay loam	furrow	102	111,197	Flat fan	103	6.4

Table 2: Location planting, harvest, application, rating and measurement dates. Days after planting abbreviated DAP. Days after application abbreviated DAA

Year	Location	Planting	Harvest	Application Timing	Application Timing, DAP	First Assessment Timing, DAA [Z]	Second Assessment Timing, DAA	Third Assessment Timing, DAA
2014	Alexandria, LA	1-May	24-Oct	26-May	25	0	14	28
2015	Alexandria, LA	7-May	10-Sep	28-May	21	1	11	22
2016	Alexandria, LA	6-May	1-Oct	26-May	20	0	14	25
2014	Starkville, MS	8-May	5-Oct	6-Jun	29	-1	11	31
2016	Starkville, MS	7-May	13-Oct	31-May	24	0	21	28
2014	Fort Cobb, OK	3-Jun	25-Nov	3-Jul	30	0	13	28
2016	Jackson, TN	12-May	10-Oct	3-Jun	22	0	13	27
2014	Snook, TX	16-Apr	14-Oct	19-May	33	.	.	.
2015	Snook, TX	31-Mar	9-Sep	19-May	49	.	.	.
2016	Snook, TX	26-Apr	14-Sep	23-May	27	.	.	.

[Z] **Assessments collected at the first, second and third timings included vigor ratings, node counts, and plant height. Additionally, chlorophyll meter and leaf area measurements were collected from the Alexandria, LA – 2014, 2015, and 2016 site years.**

RESULTS

Vigor, node counts and plant height. Collected vigor ratings (1-9 scale with 9 being excellent vigor and 1 being very poor vigor), node counts, and plant heights from each site-year suggested growing conditions were at or above optimum levels prior-to and during assessment timings (Figs. 1-3). Average vigor across all treatments reported at 0, 14 and 28 DAA was 8.1, 7.9, and 8.0, respectively. Node counts and plant heights increased at a normal pace within each site year. Vigor ratings collected prior to the applications indicated all plots within a given location fell within 1 point of all other plots within the same locations on a 1-9 point scale. Additionally, node counts and plant height data collected prior to application of the treatments indicated no substantial differences in plots existed before the experiments were initiated (Table 3).

A significant interaction between fungicide treatment and site year was observed from node counts collected at 14 and 28 DAA (Fig. 1). Site-year analysis of the 14 DAA node count data indicated a significant decrease in nodes per plant with the azoxystrobin application in the Starkville, MS 2014 site year. Site-year analysis of the 28 DAA node count data indicated a significant decrease in nodes per plant for the azoxystrobin application in the Jackson, TN 2016 site year. Fungicide treatment did not impact node counts collected at 14 and 28 DAA for any other site years. Furthermore, fungicide treatment did not impact plant height or vigor ratings collected at 14 or 28 DAA in any site year (Figs. 2 & 3, Table 3).

Chlorophyll meter and Leaf Area. Chlorophyll meter and leaf area measurements were only collected from the Alexandria, LA site years. Analysis of chlorophyll meter readings indicated chlorophyll content was not impacted by fungicide treatment (Table 3). However, analysis of leaf area measurements collected at 14 DAA suggested the azoxystrobin treatment caused a significant decrease in leaf area relative to the untreated control (Table 3). Significant differences in leaf area measurements collected at 14 DAA were not noted between the azoxystrobin and fluxapyroxad + pyraclostrobin treatments or between the fluxapyroxad + pyraclostrobin and non-treated control treatments. By 28 DAA, leaf area measurements indicated no differences from treatments were present.

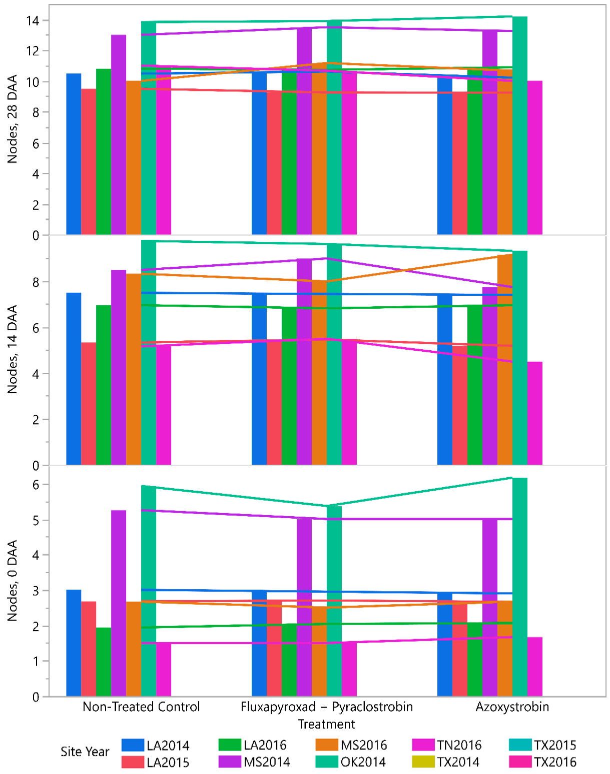

Figure 1: Node counts collected at 0, 14 and 28 days after application of fungicide treatments graphed by site year.

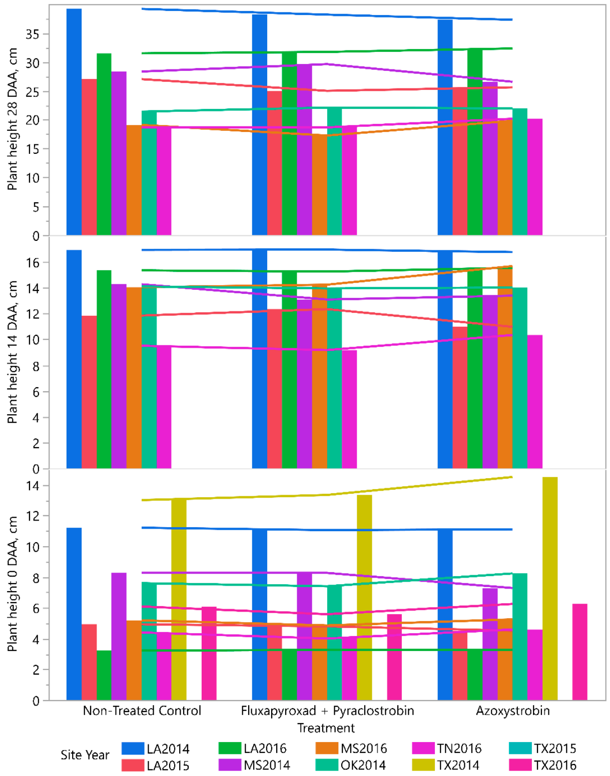

Figure 2: Plant height collected at 0, 14 and 28 days after application of fungicide treatments graphed by site year.

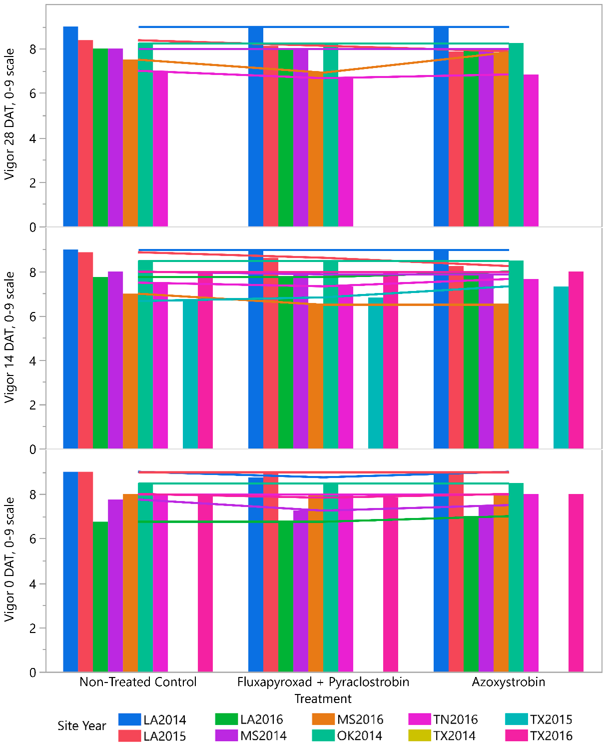

Figure 3: Vigor ratings collected at 0, 14 and 28 days after application of fungicide treatments graphed by site year.

Lint yield, turnout and fiber quality. Average lint yield across all site years equaled 1683 kg lint ha-1 (Table 4). Average lint yield of each site year ranged from 2550 kg lint ha-1 at the Jackson, TN – 2016 site year to 474 kg lint ha-1 at the Alexandria, LA – 2015 site year. Data indicates a sufficient range of low-yield environments to high-yield environments were included within the analysis. Turnout from spindle-harvested locations ranged from 46.3 % in the Alexandria, LA – 2014 site year to 41.4% in the Alexandria, LA – 2016 site year. The lowest turnout was reported from the stripper-harvested Altus, OK – 2014 site-year at 28.1%. Strength ranged from 36.6 g/tex in the Alexandria, LA -2015 site-year to 30.2 g/tex in the Snook, TX – 2016 site-year (Table 4). Micronaire, length, and uniformity varied only slightly between site years, likely due to the large influence of cultivar on that parameter.

Fungicide treatment did not impact lint yield, turnout, and fiber quality parameters of micronaire, length, strength and uniformity (Table 4).

Table 3: Analysis of cotton growth and development parameters prior to, two weeks after, and four weeks after application of the foliar fungicide treatments

Fungicide	0 Days After Application					14 Days After Application					28 Days After Application				
	Height[Z] cm	Nodes[Y] #	Vigor[X] 0-9	SPAD[W]	LAI[W]	Height[Y] cm	Nodes[Y] #	Vigor[V] 0-9	SPAD[W]	LAI[W]	Height[Y] cm	Nodes[Y] #	Vigor[Y] 0-9	SPAD[W]	LAI[W]
Untreated control	6.99	3.10	8.15	33.78	269	13.83	7.22	7.98	32.29	1901	27.18	11.02	8.08	33.63	7986
Azoxystrobin	7.12	3.13	8.15	34.20	253	13.91	7.08	7.96	31.74	1715[T]	26.96	10.98	8.01	33.55	7557
Fluxapyroxad + Pyraclostrobin	6.84	2.99	8.06	34.30	269	13.76	7.23	7.89	31.84	1764	26.66	11.15	7.91	32.70	7965
Minimum Significant Difference[U]	0.48 (ns)	0.19 (ns)	0.10 (ns)	1.03 (ns)	27	0.65 (ns)	0.26 (ns)	0.15 (ns)	0.633 (ns)	155	0.98 (ns)	0.24 (ns)	0.17 (ns)	1.20 (ns)	686 (ns)

[Z] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014, 2016; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX- 2014, 2016.

[Y] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014, 2016; Altus, OK - 2014; Jackson, TN - 2016.

[X] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014, 2016; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX - 2016.

[W] Data obtained from: Alexandria, LA - 2014, 2015, 2016.

[V] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014, 2016; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX- 2015, 2016.

[U] Minimum significant difference from the untreated control as calculated by the Dunnett's t Test at an alpha level equal to 0.10.

[T] Significantly different than the untreated control as calculated by the Dunnett's t Test at an alpha level equal to 0.10.

Table 4: Analysis of cotton lint yield and fiber quality parameters

Fungicide	Lint Yield[Z] kg ha^{-1}	Turnout[Y] %	Micronaire[X] reading	Length[X] mm	Strength[X] kN m kg^{-1}	Uniformity[X] %
Untreated Control	1685	42.19	4.7	29.2	328	83.9
Azoxystrobin	1689	42.29	4.7	29.0	327	84.3
Fluxapyroxad + Pyraclostrobin	1671	42.51	4.7	29.1	328	84.3
Minimum Significant Difference[W]	67 (ns)	0.37 (ns)	0.1 (ns)	0.2 (ns)	5 (ns)	0.4 (ns)

[Z] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014, 2016; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX- 2014, 2016.

[Y] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Starkville, MS - 2014; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX- 2014, 2016.

[X] Data obtained from: Alexandria, LA - 2014, 2015, 2016; Altus, OK - 2014; Jackson, TN - 2016; Snook, TX- 2014, 2016.

[W] Minimum significant difference from the untreated control as calculated by the Dunnett's t Test at an alpha level equal to 0.10.

DISCUSSION

Decreases in node counts associated with azoxystrobin applications from the 14 DAA data in the Starkville, MS – 2014 site year and the 28 DAA data in the Jackson, TN – 2016 site year as well as the reduction in leaf area collected 14 DAA in the Alexandria, LA -2014, 2015 and 2016 site years may be due to phytotoxicity associated with the application. Sensitivity to azoxystrobin varies by plant species (Nithyameenakshi et al., 2006). While several studies have found no to very slight phytotoxicity associated with the application of azoxystrobin in cucumber (*Cucumis sativus* L.) (Anand et al., 2008), peanuts (*Arachis hypogea* L.) (Barnett, 2011; Jordan et al., 2003), or soybean (Bradley et al., 2008), phytotoxicity is not uncommon when azoxystrobin is applied; the Quadris label mentions phytotoxicity as a possible crop response multiple times throughout the label (Syngenta Crop Protection, 2006). Previous research has indicated azoxystrobin exhibits concentration-dependent phytotoxicity and can impact the membrane stability of plant tissue (Nithyameenakshi et al., 2006). Stump et al. (2002) evaluated the combinations of azoxystrobin and herbicides in sugar beet (*Beta vulgaris*, L.) and found the fungicide caused a temporary increase in phytotoxicity and stunting. It is suspected environmental conditions surrounding the time of application supported a phytotoxic response which reduced node counts at the Starkville, MS – 2014 and Jackson, TN – 2016 site years. In the Alexandria, LA – 2014, 2015 and 2016 site years, the phytotoxic plant response was not strong enough to negatively impact plant height or node counts but did reduce leaf area. Failure to capture decreases in node counts or plant height at other locations may be due to environmental conditions which failed to support the phytotoxic plant response and/or the sensitivity of the leaf area measurement to changes in plant vigor relative to node counts and plant height.

The failure of foliar fungicides to consistently increase yields when disease pressure is non-existent or low has been identified previously in cotton by Woodward et al. (2016), in corn by Mourtzinis et al. (2017), and in soybeans by Joe Ng et al. (2018), Swoboda and Pedersen (2009, and Paul et al. (2011). Similarly, analysis of a 42 site-year wheat dataset by Weisz et al. (2011) led authors to conclude no economic benefit was provided by the application of fungicide for the purpose of 'plant health' when disease was absent. Results also mirror those found by Yandel et al. (2016), who noted inconsistent yield responses from the application of fungicides and only found applications to be profitable 14% of the time they were applied.

The failure of fungicide treatments to positively impact parameters of interest- particularly yield parameters, suggests the evaluated fungicides should not be applied topically pre-square for the purpose of enhancing 'plant health'. Instead, these chemistries should be reserved to target above-threshold levels of disease incidence/severity.

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