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Effect of Mid-Season Foliar Fungicide and Foliar Insecticide Applied Alone and In-Combination on Soybean Yield

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Abstract

Due to the relatively low cost of foliar insecticide, farmers frequently tank-mix insecticide with fungicide. The objective of this study was to evaluate the effect of mid-season foliar fungicide and insecticide treatments on soybean grain yield, applied alone or in combination. A field trial was conducted in Ohio from 2015 to 2016 at six sites each year (12 sites total). Foliar treatments applied at the R3 soybean growth stage (beginning pod) included: 1) non-treated control, 2) fungicide, 3) insecticide, 4) fungicide + insecticide, 5) fungicide + insecticide (applied separately to examine for synergistic effect), 6) fungicide + crop oil, 7) insecticide + crop oil, and 8) fungicide + insecticide + crop oil. Data were collected for percent leaf area affected by diseases (frogeye leaf spot caused by *Cercospora sojina* and brown spot caused by *Septoria glycines*) and insect defoliation at the R6 soybean growth stage (full seed). Soybean treated with fungicide + insecticide tank-mixed did not yield differently than soybean treated with fungicide and fungicide + crop oil. Fungicide treatments increased soybean yield at 4 of 12 site-years compared to the non-treated control, and at three of these locations, brown spot and frogeye leaf spot disease in the non-treated control accounted for ≥ 6.5% leaf area affected. There was no yield response associated with insecticide treatment due to sub-threshold insect defoliation levels at the time of insecticide treatment. Application of fungicide alone, insecticide alone, or in tank-mix did not improve yields when insects or foliar diseases were not present at threshold levels.

Crop Management

Core Ideas

- Soybeans treated with fungicide + insecticide tank-mixed yielded the same as fungicide only in the absence of insects and defoliation at the economic threshold.
- Fungicide increased yield at 4 of 12 site-years, where leaf area affected by diseases tended to be > 6.5%.
- There was no yield response with insecticide due to low defoliation at the time of application.

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Abbreviations: LAA, leaf area affected.

Conversions: For unit conversions relevant to this article, see Table A.

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Previously Conducted Foliar Fungicide and Insecticide Trials

A survey of soybean growers during 2014 through 2016 indicated approximately 33% of soybean fields in Ohio received a foliar fungicide application (Lindsey, unpublished). Among the 33% of fields sprayed with foliar fungicide, 65% of applications were tank-mixed with foliar insecticide. As a comparison, only 3% of soybean fields received foliar insecticide only. Growers tank-mix insecticide with fungicide applications due to the relatively low cost of insecticide which is estimated at $3.58/acre (anonymous industry source).

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
Length		
0.304	foot, ft	meter, m
25.4	inch	millimeter, mm (10^{-2} m)
1.609	mile, mi	kilometer, km (10^{-3} m)
Area		
0.405	acre	hectare, ha
Volume		
2.96×10^{-2}	ounce (liquid), oz	liter, L (10^{-3} m^3)
3.78	gallon, gal	liter, L (10^{-3} m^3)
Yield and Rate		
67.19	60-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha

Under low yielding (<40 bu/acre) and dry conditions, no differences in soybean yield have been found among treatments of insecticide, fungicide, and tank-mixes (Nelson et al., 2016). In Indiana, soybean yield increased by 1.4, 2.2, and 3.5 bu/acre when pyraclostrobin fungicide, lambda-cyhalothrin insecticide, and tank-mix of pyraclostrobin fungicide + lambda-cyhalothrin insecticide were applied at the R4 soybean growth stage (full pod), respectively, compared to the non-treated control (Henry et al., 2011). In a 60 site-year study conducted in nine states, treatment of foliar fungicide applied at R3 soybean growth stage increased soybean yield by 1.5 bu/acre compared to the control (no treatment) while the tank-mixture of foliar fungicide and insecticide increased soybean yield by 3.0 bu/acre compared to the non-treated control (Orlowski et al., 2016). In Ohio, when foliar fungicide was omitted from a tank-mixture of insecticide and manganese foliar fertilizer, soybean yield decreased at 5 out of 16 site-years by 3.1 to 11.8 bu/acre compared to the non-treated control while fungicide treatment alone increased soybean yield at one out of 16 site-years compared to the control (Bluck et al., 2015).

Results of previously conducted trials indicate that there may be a synergistic effect of tank-mixing the fungicide and insecticide (Bluck et al., 2015; Henry et al., 2011; Orlowski et al., 2016); however, the previously conducted trials did not directly compare fungicide only treatments to fungicide + insecticide tank-mixes. Therefore, the objective of this study was to evaluate the effect of mid-season foliar fungicide and insecticide treatment on soybean yield, applied alone or in combination.

Methods Used to Evaluate Mid-Season Foliar Fungicide and Insecticide Treatments

The study was conducted in 2015 and 2016 at six on-farm locations each year in Clinton, Henry, Marion, Mercer, Preble, and Sandusky Counties in Ohio. The trials were performed in a different field each year. Trials were established in a randomized complete block design with four replications of treatments in 2015 and five replications in 2016. Fungicide and insecticide treatments included: 1) non-treated control, 2) fungicide, 3) insecticide, 4) fungicide + insecticide, 5) fungicide + insecticide (applied separately), 6) fungicide + crop oil, 7) insecticide + crop oil, and 8) fungicide + insecticide + and crop oil. All combinations were tank-mixed except treatment 5 where fungicide + insecticide were applied using separate tanks.

The fungicide applied was Priaxor consisting of pyraclostrobin at 14.33% active ingredient and fluxapyroxad at 28.58% active ingredient (BASF Corporation, Research Triangle Park, NC) applied at the label rate of 4 fl oz/acre. The insecticide applied was the synthetic pyrethroid Warrior II with Zeon Technology consisting of lambda-cyhalothrin at 22.8% active ingredient (Syngenta, Research Triangle Park, NC) applied at the label rate of 1.92 fl oz/acre. Superb HC crop oil (Winfield United, Arden Hills, MN), which contains phytobland paraffinic oil, high-fructose corn syrup, and polyoxyethylene sorbitan fatty esters, was applied at the label rate of 1 pt/acre. Treatments were applied to the four center rows of each plot at the R3 growth stage (Fehr et al., 1971) regardless of insect and disease pressure using a handheld carbon dioxide pressurized backpack sprayer calibrated at 15 gal/acre with a three nozzle boom with 20 inches between each nozzle. Nozzles were Turbo Teejet Induction TTI110015 (Teejet Technologies, Springfield, IL).

All locations had corn as the previous crop and were in no-tillage production systems prior to planting except Marion County in 2015, which was chisel plowed in the fall and field cultivated in the spring. Pre-emergence herbicide program varied by site-year. Post-emergence herbicide application included bentazon (44% active ingredient at 1 qt/acre), fomesafen (22.1% active ingredient at 1.3 pt/acre), cloransulam-methyl (84% active ingredient at 0.3 fl oz/acre), and clethodim (12.6% active ingredient at 20 fl oz/acre). Soybean seed treated with fungicide and insecticide, 'Asgrow 3334' (relative maturity 3.3), was planted using an Almaco plot planter (Almaco, Nevada, IA) at 150,000 seeds/acre. The cultivar had a disease rating of 6 for resistance to frogeye leaf spot disease (caused by *Cercospora sojina*) (1 = Excellent; 9 = Poor) (Asgrow dealer, personal communication). For both years, planting dates were between 13 May and 25 May. Each plot was 6.25 ft wide and 28 ft long consisting of six rows of soybean spaced 15 inches apart with the four center rows harvested for yield using a Massey Ferguson Kincaid 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS). Grain yield was adjusted to 13% moisture concentration. Average monthly temperature and cumulative monthly precipitation from May through August were collected from the National Oceanic and Atmospheric Administration (NOAA, 2016). All weather stations were located within the county where the field trials were conducted, except for the Henry County trial where the weather station was located in Defiance County, about 10 miles from the 2015 field site and 20 miles from the 2016 field site.

Data for disease and insect defoliation ratings were collected at each location one wk before treatment and four wk after treatment at the R6 soybean growth stage. Five soybean trifoliates from the bottom, middle, and top of the soybean canopy were randomly selected in each plot and visually rated for the percentage of leaf area affected (LAA) by foliar disease and insect defoliation. Brown spot disease (caused by *Septoria glycines*) was assessed in the bottom and middle canopy using the evaluation scale described by Cruz et al. (2010). The middle and top third of the plant canopy were evaluated for frogeye leaf spot disease and insect defoliation using an evaluation scale described by Dorrance and Mills (2010) and Hunt and Jarvi (2007), respectively. The same day as visual disease and insect defoliation assessments, a sweep net was used to collect the number of insect pests including bean leaf beetle, stink bug, Japanese beetle, green cloverworm, and grasshopper, with 10 sweeps performed in each plot. Aphid pressure was also assessed by speed scouting (Hodgson et al., 2007). Prior to harvest at soybean growth stage R8, 10 plants per plot were collected to evaluate for the level of pod damage caused by bean leaf beetle, in which the total number of pods, number of pods with feeding damage, and the percentage of pod damaged were calculated (Hammond et al., 2014).

There were significant interactions between treatment, location, and year, hence all data were analyzed by site-year using PROC MIXED of SAS 9.3 (SAS Inst. Inc., Cary, NC) at $\alpha = 0.05$. All treatments were treated as fixed effects while replication was treated as a random effect. The contrast statement in PROC MIXED was used to compare grain yield of the fungicide treatment to each of the following treatments: fungicide + insecticide, fungicide + insecticide (applied separately), fungicide + crop oil, and fungicide + insecticide + crop oil. The contrast statement was also used to compare yield of the non-treated control to fungicide only combinations (fungicide and fungicide + crop oil treatments) and insecticide only combinations (insecticide and insecticide + crop oil treatments). Percentage of LAA by disease was log-transformed and control treatment compared to fungicide only combinations using the contrast statement in SAS. Back-transformed means are presented.

Growing Conditions

Average monthly temperatures during 2015 and 2016 were close to the 30-yr average with the exception of May temperatures in 2015 (3.7 to 6.0°F above normal) and August temperatures in 2016 (3.1 to 5.3°F above normal) (Table 1). Mean monthly precipitation varied among site-years (Table 2). In general, precipitation from May through August in 2015 was close to the 30-yr average, except June 2015 where locations experienced 2.7 to 8.9 inches above the 30-yr average. In 2016, rainfall from May to July was below the 30-yr average, but rainfall in August was above average in four out of six locations.

Fungicide Only Treatment Compared to Fungicide Applied with Insecticide and/or Crop Oil

The treatments of fungicide + insecticide, fungicide + insecticide applied separately, fungicide + crop oil, and fungicide + insecticide + crop oil resulted in grain yield that was not statistically different than the fungicide treatment (Table 3). These results indicated that there was no yield benefit associated with combining fungicide with insecticide, crop oil, and insecticide + crop oil when insect pressure and LAA by insect defoliation were sub-threshold. Use of foliar insecticide (especially repeated use of a single chemical or mode of action) is discouraged when insect populations are below the economic threshold level due to concerns of insecticide resistance from overuse (Elzen and Hardee, 2003; Hodgson et al., 2012).

Effect of Fungicide on Soybean Yield and Disease

During 2015, the mean of fungicide only combinations (fungicide only and fungicide + crop oil) significantly increased yield by 7.9, 6.3, and 4.4 bu/acre when compared to the non-treated control in Clinton, Marion, and Preble County, respectively (Table 4). In 2016, the fungicide only combinations significantly increased yield by 7.1 bu/acre at the Mercer County location. In 2015 at the Clinton, Marion, and Preble County locations, LAA by brown spot and frogeye leaf spot combined in the bottom, middle, and top of the canopy was > 6.5% in the non-treated control treatments, and disease was significantly reduced with fungicide only combinations compared to the non-treated control (Table 5). Despite the 7.1 bu/acre yield increase with fungicide treatment compared to the non-treated control at the Mercer County location in 2016, fungicide only and fungicide + crop oil treatment did not significantly reduce disease (Table 5).

Brown spot and frogeye leaf spot severity were greater in 2015 compared to 2016 likely due to greater precipitation in 2015 (>2 inches above the 30-yr average) (Table 2). Periods of wet conditions created a conducive environment for brown spot and frogeye leaf spot disease development (Cruz et al., 2010). Kyveryga et al. (2013) reported that greater yield responses to fungicide treatment were found in trials that experienced high rainfall amounts of more than 12 inches cumulative from March to May, and also attributed this to favorable environments for fungal foliar diseases. This study confirms earlier reports from Ohio that the presence of foliar diseases and above average rainfall will favor the probability of economic recovery of costs

Table 1. The 30-yr average temperature from May through August for each location and deviation from the average in 2015 and 2016 (NOAA, 2016).

Site	Year	May	June	July	August
(°F)	(°F)	Average temperature			
		°F			
Clinton	30-yr	61.2	70.2	73.3	71.6
	2015	+5.3	+0.8	-0.8	-1.6
	2016	-1.2	+2.3	+1.2	+3.9
Henry	30-yr	59.8	69.9	73.7	71.7
	2015	+4.2	-1.4	-2.2	-0.7
	2016	-0.3	+1.6	+1.8	+3.8
Marion	30-yr	60.0	69.1	72.6	70.7
	2015	+6.0	+1.4	-0.6	-1.2
	2016	-1.0	+2.4	+2.4	+5.3
Mercer	30-yr	61.7	70.6	73.6	71.9
	2015	+4.3	-0.6	-2.1	-1.4
	2016	+0.3	+2.4	+0.9	+3.1
Preble	30-yr	61.3	70.5	73.9	72.6
	2015	+3.7	-0.5	-1.9	-2.6
	2016	-2.8	+1.0	-0.4	+2.9
Sandusky	30-yr	59.9	69.9	73.7	71.8
	2015	+4.6	-0.9	-2.2	-1.3
	2016	-0.4	+1.6	+2.3	+4.2

Table 2. The 30-yr average cumulative precipitation for each location from May through August and deviation from the 30-yr average in 2015 and 2016 (NOAA, 2016).

		May	June	July	August
Site	Year	Cumulative precipitation			
		inches			
Clinton	30-yr average	5.29	3.85	4.22	3.03
	2015	-3.27	+4.91	+1.77	+0.68
	2016	-1.15	-1.85	-0.78	+1.58
Henry	30-yr average	3.96	3.64	4.09	3.02
	2015	+0.88	+6.57	+1.09	+0.52
	2016	-1.29	+2.04	-2.49	-0.46
Marion	30-yr average	4.15	4.37	4.27	3.02
	2015	+0.15	+2.69	-0.52	-0.87
	2016	-1.09	-1.46	-2.75	+0.05
Mercer	30-yr average	3.98	4.07	4.81	3.55
	2015	+0.01	+8.91	+1.50	+0.14
	2016	-1.00	-2.55	-3.52	+1.71
Preble	30-yr average	5.10	4.15	4.33	2.93
	2015	-1.54	+4.92	+0.19	-0.64
	2016	-1.90	-1.19	-1.14	+1.70
Sandusky	30-yr average	3.96	4.07	3.54	3.15
	2015	-1.02	+5.63	+2.20	+0.07
	2016	-0.23	-1.57	-1.46	-0.09

Table 3. Average soybean yield of fungicide treatment and change in yield when fungicide was applied with insecticide and/or crop oil.

	Clinton	Henry	Marion	Mercer	Preble	Sandusky
Treatment	Yield					
	bu/acre					
	2015					
Fungicide	52.6	56.2	60.1	61.0	62.0	61.9
Fungicide + insecticide (tank-mix)	-3.7†	+0.5	-0.3	+4.3	+3.0	+0.7
Fungicide + insecticide (separate)	-0.8	+3.2	+1.2	-2.4	+0.8	+8.5
Fungicide + crop oil	+0.1	+1.4	+0.7	+3.2	+2.9	+5.2
Fungicide + insecticide + crop oil	-0.1	+0.6	+2.0	+2.5	+4.0	+5.4
	2016					
Fungicide	58.3	58.1	54.5	61.5	59.4	56.9
Fungicide + insecticide (tank-mix)	+0.1	+1.1	-0.3	-1.3	+3.6	-1.0
Fungicide + insecticide (separate)	+3.5	+2.8	-2.5	-2.2	+1.0	+0.1
Fungicide + crop oil	+0.6	+1.0	+1.9	+1.1	+4.0	-2.7
Fungicide + insecticide + crop oil	+3.8	+1.3	+0.6	-2.8	+0.2	+0.5

†All treatment comparisons are nonsignificant at $\alpha = 0.05$.

associated with fungicide treatments (Bluck et al., 2015; Cruz et al., 2010; Dorrance et al., 2010) and other studies in the north central region (Henry et al., 2011; Kandel et al., 2016; Kyveryga et al., 2013; Nelson et al., 2016; Orlowski et al., 2016).

Effect of Insecticide on Insects and Yield

Insecticide only combinations (insecticide and insecticide + crop oil) did not influence soybean grain yield compared to the non-treated control (Table 4). The lack of yield response was likely due to sub-threshold defoliation and insect populations below the economic threshold level at the time of insecticide treatment. Gregg et al. (2015) also noted a lack of yield response to insecticide treatment at sub-threshold insect population levels. Based on foliar ratings at the R3 soybean growth stage, the highest percentage of LAA by insect defoliation was 10.5% in the top of the soybean canopy and 9.8% in the middle of the soybean canopy across 12 site-years (data not shown). The maximum levels of defoliation that can be tolerated by soybean without significant yield loss was 40% from seedling to R1 (initial bloom), 15% from R1 to R5 (initial pod fill), and 25% from R5 to maturation (Hunt and Jarvi, 2007). Soybean aphids were below the economic threshold of 250 aphids/plant during the R1-R5 soybean growth stages (Hodgson et al., 2012), and a previously conducted study documented that soybean aphid would cause significant yield reduction if present at high levels

Table 4. Soybean grain yield of non-treated control and change in yield of fungicide only combinations at each site-year.

Treatment	Clinton	Henry	Marion	Mercer	Preble	Sandusky
	Yield					
	bu/acre					
	2015					
Control	44.8	56.3	54.1	59.1	59	60.2
Fungicide only combinations†	+7.9*	+0.6	+6.3*	+3.5	+4.4*	+4.3
Insecticide only combinations‡	+0.5	+0.3	+4.2	+0.4	+3.4	+2.3
	2016					
Control	59.5	56.7	53.3	55	55.1	53.3
Fungicide only combinations	-0.9	+1.9	+2.2	+7.1*	+6.3	+1.0
Insecticide only combinations	-0.8	+0.4	-1.0	+3.1	+0.7	+0.8

*Significantly different at $\alpha = 0.05$ compared to the control treatment within each site-year.

†Fungicide only combinations include the average of fungicide and fungicide + crop oil treatments.

‡Insecticide only combinations include the average of insecticide and insecticide + crop oil treatments.

Table 5. Percent soybean leaf area affected (LAA) by brown spot and frogeye leaf spot at the R6 growth stage (full seed) for the non-treated control and fungicide treatment.

Treatment	Clinton	Henry	Marion	Mercer	Preble	Sandusky
	2015					
	% LAA by brown spot in middle canopy					
Control	2.8	0.7	0.9	0.3	0.6	0.7
Fungicide only combinations†	1.3*	0.5	0.5	0.1	0.1*	0.6
	%LAA by brown spot in bottom canopy					
Control	10.3	2.6	12.4	3.6	4.9	4.9
Fungicide only combinations	4.0*	1.8	11.3	3.9	3.0*	1.6*
	%LAA by frogeye leaf spot in top canopy					
Control	0.7	0.2	1.9	1.9	0.6	0.0
Fungicide only combinations	0.5	0.0	0.9*	0.5*	0.3*	0.0
	%LAA by frogeye leaf spot in middle canopy					
Control	0.9	0.2	0.9	0.6	0.5	0.1
Fungicide only combinations	0.2*	0.0	0.2*	0.1*	0.3*	0.0*
	2016					
	%LAA by brown spot in bottom canopy					
Control	0.4	0.9	0.4	0.8	0.3	0.0
Fungicide only combinations	0.3	0.3	0.1	0.7	0.0	0.0
	%LAA by frogeye leaf spot in top canopy					
Control	1.0	1.2	0.2	0.0	0.7	0.5
Fungicide only combinations	0.4*	0.3*	0.0	0.0	0.3*	0.2*
	%LAA by frogeye leaf spot in middle canopy					
Control	0.6	0.3	0.3	0.2	0.8	0.3
Fungicide only combinations	0.1*	0.1*	0.0*	0.1	0.3*	0.0*

*Significantly different at $\alpha = 0.05$ compared to the control treatment within each location. †Fungicide only combinations include fungicide and fungicide + crop oil treatments.

(Dorrance et al., 2010). Mean number of Japanese beetle, stink bug, green cloverworm, and grasshopper per 10 sweeps were < 3 at all 12 site-years at all sampling times (data not shown).

The bean leaf beetle population was greater in 2016 than 2015. In 2015, only 1 of 6 site-years (Marion County) experienced a high number of bean leaf beetles 4 wk after insecticide treatment, ranging from 2 to 7 bean leaf beetles per 10 sweeps (data not shown). However, in 2016, Henry County, Marion County, and Sandusky County had a high bean leaf beetle population 4 wk after insecticide treatment, ranging from 12 to 22, 14 to 21, and 5 to 7 bean leaf beetles per 10 sweeps, respectively. Locations with high bean leaf beetle pressure 4 wk after treatment had a greater amount of pod damage caused by bean leaf beetle, compared to locations with low bean leaf beetle pressure. Bean leaf beetle pod damage at Marion County in 2015 ranged from 13 to 18%, while in 2016 at the Henry County, Marion County, and Sandusky County locations bean leaf beetle pod damage ranged from 24 to 37%, 4 to 9%, and 6 to 11%, respectively (data not shown).

Yield reductions likely occurred due to soybean pod damage by bean leaf beetle at locations with 10 to 15% pod injury (Hammond et al., 2014). However, there was no yield benefit associated with the R3 insecticide treatment (Table 4) because second generation bean leaf beetle populations began in late August through early September and the pyrethroid insecticide applied at the R3 soybean growth stage (late July) likely did not have sufficient residual activity to control late season pests (Hammond, 1996; Hammond et al., 2014).

Implications

Foliar fungicide treatment increased soybean yield at 4 out of 12 site-years with the majority of yield responses occurring in 2015 when the environment was conducive to frogeye leaf spot and brown spot disease development. Prophylactic applications of fungicide are unlikely to increase soybean yield (Gregg et al., 2015; Mourtzinis et al., 2016; Nelson et al., 2016). Instead, integrated pest management strategies should be implemented that consider disease history of the field, susceptibility of the soybean cultivar, and environmental conditions.

No significant yield response occurred when insecticide was applied due to insect populations below the economic threshold level and sub-threshold defoliation at the time of insecticide treatment. However, at the end of the growing season, the number of bean leaf beetles and pod injury was high at 4 out of 12 site-years. Treatment of insecticide at the R3 soybean growth stage (late July) was too early to be effective against bean leaf beetle which generally appear during late August through early September in Ohio (Hammond et al., 2014). Despite the low cost of tank-mixing insecticide with fungicide, this practice is not recommended unless insect pests and/or leaf defoliation is at the economic threshold due to concerns of insecticide resistance and risk to beneficial insects (Hodgson et al., 2012; Nelson et al., 2016). Application of fungicide alone, insecticide alone, or in tank-mix should not be applied unless insects or foliar diseases are present at threshold levels.

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