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Soybean Yield Response to In-furrow Fungicides, Fertilizers, and Their Combinations

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Crop Management

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Core Ideas

- Fungicide in-furrow and starter fertilzer individually did not increase yield.
- Fungicide and starter fertilizer combined in-furrow increased yield marginally.
- Fungicide and starter fertilizer in-furrow may not be economical without disease.

Abstract

Planting into cool and wet conditions exposes soybean [*Glycine max* (L.) Merr.] seed and seedlings to pathogens that may reduce plant populations, resulting in lower yield. Recently, fungicides have been labeled for in-furrow applications and marketed to provide additional broad-spectrum protection from soilborne fungi and enhance seedling vigor. Additionally, liquid fertilizers have been promoted recently as a carrier for fungicides to improve yield in some soybean producing areas in the United States. The objective of this study was to evaluate the effect of a fungicide, starter fertilizer, and a combination of fungicide and starter fertilizer on soybean yield. Field experiments were laid out in Arkansas, Indiana, Iowa, and Mississippi in the United States and Ontario, Canada, with a total of 14 site-years. A positive yield response was observed with the fungicide and starter fertilizer treatment combination in Arkansas in 2014; however, there was no effect of treatment on soybean yield at any other location or year. Overall, a yield benefit of 1.6 bu/acre (107.6 kg/ha) (P = 0.02) with the fungicide and starter fertilizer treatment was observed across all locations when combined using meta-analysis. In conclusion, our study suggests that the prophylactic application of fungicide and starter fertilizer may not be profitable without the risk of soilborne diseases and nutrient deficiencies.

Planting soybean into cool and wet soils slows emergence and early season growth, reduces nutrient uptake, and lengthens the time that seedlings are exposed to common soilborne pathogens (Broders et al., 2007; Mackay and Barber, 1984). Soybean plant population is affected by several soilborne plant pathogens including species of *Fusarium*, *Phytophthora*, *Pythium*, and *Rhizoctonia* (Broders et al., 2007; Dorrance and McClure, 2001). Recently, fungicides have been labeled for in-furrow applications and marketed to provide additional broad-spectrum protection from soilborne pathogens and enhance seedling vigor. Farmers who have had issues with seedling diseases and have in-furrow application capability are interested in applying fungicides in-furrow.

Corn (*Zea mays* L.) and soybean planters may have one of several liquid in-furrow application systems used to place nutrients, fungicide, insecticide, or a combination near the corn or soybean seed. These systems have various in–furrow placement including (i) a direct stream of product into the furrow before the seed tube or closing wheels, (ii) Keeton Seed Firmer, that places the product on both

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sides of the furrow sidewalls (Precision Planting, Tremont, IL), (iii) a flat fan nozzle mounted parallel to the seed furrow, directing the application over the seed, and (iv) a T-banding system in which a spray nozzle is mounted in front of the closing wheels and sprays product into the furrow and on soil on either side of the furrow. These systems vary in their placement of treatments that may affect the efficacy of treatments, however, we did not compare in-furrow placements in this study.

Starter fertilizers generally include nutrients placed near or in-furrow at planting. Placement of nutrients near the seed of various crops when planting early has often been justified due to cool and wet soils limiting nutrient uptake and reduced early season root growth (Mackay and Barber, 1984). In this study, we are specifically looking at fertilizer placed in contact with the seed that have been called "pop-up" or in-furrow fertilizers. Early season growth responses to starter fertilizers have been reported in soybean (Ham et al., 1973; Touchton and Rickerl, 1986); however, yield responses are inconsistent. A study by Lauzon and Miller (1997) reported that soybean did not respond to nitrogen (N) and phosphorus (P) fertilizer in seed emergence or yield at various soil test phosphorus (P) levels (Lauzon and Miller, 1997). Stands were reduced with liquid "pop-up" fertilizer by 57.8% 1 yr, and yields reduced by 20.3% averaged over five site-years (Clapp and Small 1970). Stanton (2012) reported liquid starter fertilizer (NACHURS 2–20–18) applied at two gallons per acre in-furrow significantly increased yield in soybean at one of eight locations. Various grades of fertilizer placed with the seed reduced plant population, however, did not reduce yield in Minnesota on fields with high levels of soil test P and potassium (K) (Rehm and Lamb, 2010). Placement of fertilizer in-furrow or near the seed is generally not recommended in soybean because seedling injury and/or reduced stands can occur, and these effects can be more severe in sandy soils (Clapp and Small, 1970; Randall and Hoeft, 1988; Rehm and Lamb, 2010).

Fungicide applications in soybean typically consist of seed-applied products or foliar-applied products at beginning pod (R3) (Bestor, 2011; Fehr et al., 1971). However, a few fungicides including azoxystrobin (Quadris) (Syngenta Crop Protection, LLC, Greensboro, NC) and fluxapyroxad + pyraclostrobin (Priaxor) (BASF Corporation, Research Triangle Park, NC) have been labeled for in-furrow application to suppress *Rhizoctonia solani* seed and seedling rot and *Fusarium* spp. seed rot in soybean (BASF Corporation, 2016; Syngenta Crop Protection LLC, 2016). These applications could be combined with other treatments including starter fertilizers and/or insecticide to reduce the individual application costs of these treatments.

In-furrow fungicide applications have been evaluated in other crops including barley (*Hordeum vulgare* L.), cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), and sugar beet (*Beta vulgaris* L.) for management of Rhizoctonia root rot (Cotterill, 1991; Cotterill, 1993; Hancock et al., 2004; Kiewnick et al., 2001; Stump et al., 2004). Azoxystrobin in-furrow application at the time of planting had no effect on Rhizoctonia crown rot development of sugar beet (Stump et al., 2004). A 1997 study in Montana showed in-furrow applications of azoxystrobin had higher Rhizoctonia disease index, reduced stands, and reduced root yield than crown application at the four-leaf stage in sugar beet (Kiewnick et al., 2001). In-furrow fungicide applications are relatively new in soybean production, and efficacy of labeled products applied with this application method is not well understood. A few studies (Anderson and Buzzell, 1982; Guy et al., 1989) compared efficacy of in-furrow treatments to seed-applied fungicides. Guy et al. (1989) reported that in-furrow treatments of metalaxyl resulted in stand reductions as well as yield loss in the absence of Phytophthora root rot in some cultivars. Others showed that metalaxyl applied in-furrow reduced stand loss in susceptible varieties, but not in varieties with some level of resistance (Anderson and Buzzell, 1982). In-furrow fungicide application provided effective management of sudden death syndrome caused by *Fusarium virguliforme* (Kandel et al., 2016). Fluxapyroxad + pyraclostrobin applied in-furrow to soybeans did not provide an added yield benefit in 2015 in Wisconsin (Conley and Gaska, 2015). Similarly, in an Illinois field trial, no yield response to a fungicide, starter fertilizer, or a combination of fungicide and starter fertilizer was reported at two different planting dates in 2014 (Mansfield et al., 2015).

There is limited information available regarding how in-furrow fungicide alone and in combination with starter fertilizer affect soybean growth and yield. Farmers often combine different pesticides such as foliar fungicides, herbicides, and insecticides to reduce application costs by minimizing trips across a field. Others have investigated prophylactic use of in-furrow applications of insecticide and fertilizer in Ohio and Minnesota and treatments did not affect plant population, plant heights, or yield (Koch et al., 2016). Testing the effect of in-furrow fungicide with a starter fertilizer on soybean across a broad geographic area would help soybean farmers understand the role of these inputs in soybean production. The objective of this study was to evaluate the effect of a fungicide, starter fertilizer, and a combination of fungicide and starter fertilizer on soybean yield across multiple states in the United States and Ontario, Canada.

Field Experiments, Treatment Combinations, and Data Collection

During the 2014 and 2015 cropping seasons, a total of 14 field experiments were established in the states of Arkansas, Indiana, Iowa, and Mississippi and the province of Ontario, Canada (Table 1). Prior to planting, ten to fifteen 1-inch (2.5-cm) diameter and 6-inch (15-cm) deep soil cores were arbitrarily collected from each replication to use for soil nutrient testing. Soil samples were analyzed locally; Arkansas samples were analyzed by the University of Arkansas, Division of Agriculture, Soil Testing and Research Laboratory (Mariana, AR), Iowa samples were analyzed by the Iowa State University Soil and Plant Analysis Lab (Ames, IA), and Ontario samples were analyzed by SGS Agrifood Laboratories (Guelph, Ontario, Canada), and results provided a baseline nutrient status for all

Table 1. Experiment locations, cultivars, seed treatments, and additional field information for experiments carried out in the states of Arkansas, Iowa, Indiana, Mississippi, and province of Ontario, Canada in 2014 and 2015.

Year	Location	DOS†	Cultivar‡	PRR§	ST¶	RS#	SR††	Soil temp‡‡	Tillage	PC§§	AD1¶¶	AD2	HD##
						inches	seeds/acre	°F					
2014	Newport, AR	18 June	AG4934	5	AC	30	150	78.1	Disk, scratch, bed	Corn	8 July	30 July	21 Oct
	Ames, IA	24 May	P92Y11	4	UT	30	125	63.0	Disk, field cultivation	Corn	16 June	3 July	19 Oct
	Lafayette, IN	17 June	W3103	2	UT	30	140	73.6	Disk, field cultivation	Soybean	30 June	30 June	10 Nov
	Stoneville, MS	19 June	Armor DK 4744	M	UT	40	156.6	82.9	Disk, field cultivation	Soybean/wheat	3 July	22 July	21 Oct
	Rodney, ON	30 May	P19T01R	3	UT	15	250	66.2	Disk, field cultivation	Corn	13 June	27 June	30 Oct
	Rodney, ON	5 June	P19T01R	3	UT	15	250	67.3	Disk, field cultivation	Corn	20 June	9 July	30 Oct
	Ridgetown, ON	23 May	P19T01R	3	UT	15	250	58.6	Disk, field cultivation	Corn	11 June	20 June	3 Nov
	Ridgetown, ON	23 June	P19T01R	3	UT	15	250	70.9	Disk, field cultivation	Corn	9 July	21 July	3 Nov
2015	Altheimer, AR	6 May	AG47R13	. †††	AC	30	150	73.2	Rip, bed	Corn	9 July	3 June	29 Sept
	Ames, IA	19 May	AG2431	5	AC	30	125	53.0	Field cultivation	Corn	5 June	.	9 Oct
	Nashua, IA	18 May	K2–2402RR	.	UT	30	160	58.0	Chisel, field cultivation	Corn	.	.	7 Oct
	Stoneville, MS	18 June	DG 37RY47	7	UT	40	156.6	86.9	Disk, field cultivation	Soybean/wheat	.	.	9 Oct
	Ridgetown, ON	29 May	P19T01R	3	UT	15	250	73.2	Disk, field cultivation	Corn	12 June	26 June	15 Oct
	Rodney, ON	15 May	P19T01R	3	UT	15	250	64.2	Disk, field cultivation	Corn	24 May	12 June	13 Oct

† DOS = Date of seeding.

‡ First letters of cultivars indicate cultivar company: Asgrow (AG), Pioneer (P), Wyckoff (W), Kruger (K), and DynaGro (DG).

§ Phytophthora root rot (PRR) field tolerance provided by companies and scales varied with Asgrow (1–9 with 1 being resistant), Pioneer (1–9 with 9 being resistant), Wyckoff (1–5 with, 1 being resistant), DynaGro (1–9 with 9 being resistant), and Armor (m = moderately resistant).

¶ Seed treatment (ST) was pyraclostrobin + fluxapyroxad + metalaxyl (Accleron, Monsanto, St. Louis, MO). Acceleron (AC) and untreated (UT).

Row spacing (RS).

†† Seeding rate (SR), seeds per acre in thousands.

‡‡ Average daily soil temperature (temp) at 6-inch depth, recorded daily at nearby locations, was downloaded from the National Centers for Environmental Information, Iowa Environmental Mesonet, or National Water and Climate Center website for each site-year.

§§ PC = Previous crop.

¶¶ AD = Assessment date.

HD = Harvest date.

††† Missing data points within the table are noted with “.”.

Table 2. Information regarding in-furrow systems, fertilizers, and soil test nutrient concentration (ppm) used in field experiments carried out in Arkansas, Iowa, Indiana, Mississippi, and Ontario, Canada in 2014 and 2015.

Year	Location†	In-furrow system‡	Starter fertilizer§	Rate	Soil test concentration	
					P¶	K
				lb/acre	ppm	
2014	Newport, AR	Rebounder	6–24–6	33.3	102	292
	Ames, IA	Keeton Seed Firmer	6–24–6 -1% Su	33.5	42	163.5
	Lafayette, IN	Direct stream	19–17–0	34.1	. #	.
	Stoneville, MS	Nozzle- TeeJet TP2501SS	10–20–5- 1% Su 0.43% Zn	32.8	.	.
	Rodney, ON	Direct stream	6–24–6	33.3	18	149
	Rodney, ON	Direct stream	6–24–6	33.3	16	134
	Ridgetown, ON	Direct stream	6–24–6	33.3	52	181
	Ridgetown, ON	Direct stream	6–24–6	33.3	52	181
2015	Altheimer, AR	Rebounder	6–24–6	33.3	83.5	270
	Ames, IA	Keeton Seed Firmer	6–24–6- 1% Su	33.5	52.8	258.1
	Nashua, IA	Direct stream	9–18–9	33.4	.	.
	Stoneville, MS	Nozzle- TeeJet TP2501SS	10–20–5- 1% Su 0.43% Zn	32.8	.	.
	Ridgetown, ON	Direct stream	6–24–6	33.3	16	117
	Rodney, ON	Direct stream	6–24–6	33.3	11	187

† Soil samples were analyzed locally. The Arkansas samples were analyzed by the University of Arkansas, Division of Agriculture, Soil Testing and Research Laboratory (Mariana, AR); the Iowa samples were analyzed by the Iowa State University Soil and Plant Analysis Lab (Ames, IA); and the Ontario samples were analyzed by SGS Agrifood Laboratories (Guelph, Ontario, Canada).

‡ Keeton Seed Firmers with in-furrow capabilities (Precision Planting, Tremont, IL), Rebounder with Y-Not divider (Schaffert Manufacturing Co. Inc., Indianola, NE) direct stream in the furrow, or a nozzle mounted in front of the closing wheels directing the product in the furrow.

§ Fertilizers are listed as percentage of weight (N) – (P_2O_5) – (K_2O) with other elements listed such as sulfur and zinc.

¶ Arkansas and Iowa soil testing labs used the Mehlich-3 extractant for P and K (Mehlich, 1984). The Ontario lab used the Olsen P extractant (Olsen et al., 1954) and ammonium acetate extractant for K (Merwin and Peech, 1951).

Missing data points within the table are noted with ".".

trials (Table 2). The Arkansas and Iowa labs analyzed P and K using the Mehlich-3 extract (Mehlich, 1984) while the Guelph lab used the Olsen extract for P (Olsen et al., 1954) and ammonium acetate extract for K (Merwin and Peech, 1951). Soil test categories vary based on the nutrient extraction method used and the categories are calibrated based on research within that region. Arkansas soil P and K levels were above optimum ($P > 50$ ppm) (K > 175 ppm) (Espinoza et al., 2011) while the Iowa soil P levels were high (36–45 ppm P) and very high ($P > 46$ ppm) and K levels were optimum (161–200 ppm K) and very high (K > 200 ppm) (Mallarino et al., 2013). In Ontario, one site-year fell within the medium response (10–14 ppm P), three site-years within the low response (16–30 ppm P), and two site-years tested within the rare response (31–60 ppm P) category for P (OMAFRA, 2017). Soil tests for K measured within the medium response (61–100 ppm K) category at one site-year, within the low response (121–150 ppm K) category at two site-years, and in the rare response (151–250 ppm K) category at 3 site-years (OMAFRA, 2017). Planting dates, cultivars, row spacing, and other field information across the experiment sites are provided in Table 1.

Four treatments including a non-treated control (NTC), a fungicide, a locally available starter fertilizer, and a combination of starter fertilizer and fungicide were compared at each location. Treatments were applied in-furrow at locations differently using a direct stream in-furrow before the seed tube or the closing wheels, Keeton Seed Firmers (Precision Planting, Tremont, IL) or Rebounder Y-Not dividers (Schaffert Manufacturing Co. Inc., Indianola, NE) that place products on both sides of the furrow walls, or with a flat fan nozzle mounted parallel to the seed furrow, directing the application over the seed (Table 2). Fungicides tested were either fluxapyroxad (0.043 lb/acre) (0.048 kg/ha) + pyraclostrobin (0.087 lb/acre) (0.097 kg/ha) (Priaxor), [Fungicide Resistance Action Group (FRAC) 7 + 11; BASF Corporation, Research Triangle Park, NC] at 4 fl oz/acre (292.4 mL/ha) or pyraclostrobin (0.049 lb/acre) (0.055 kg/ha) (Headline), (FRAC group 11; BASF Corporation) applied at 3 fl oz/acre (219.3 mL/ha). Starter fertilizers included nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) listed as (N- P_2O_5– K_2O) and other nutrients specified outside the parentheses. These included (6–24–6), (6–24–6) 1% S, (10–20–5) 1% S 0.43% Zn, (9–18–9), and (19–17–0) (Table 2). Most locations included one combination of a fungicide and starter fertilizer; while some locations include both fluxapyroxad + pyraclostrobin + starter fertilizer and pyraclostrobin + starter fertilizer (Table 3).

Treatments were arranged in a randomized complete block design with four replicates. Plant population and plant height were assessed at around 14 and 28 days after seeding and reported as assessment date (AD) AD1 and AD2, respectively. Actual dates are listed in Table 1. Seedling root rot data were collected at the Arkansas and Ontario sites,

Table 3. Treatments including fungicide, fertilizers, and fungicide + fertilizer combinations used in Arkansas, Indiana, Iowa, Mississippi, and Ontario, Canada in 2014 and 2015.

Year	Location	Fungicide†	Fertilizer‡	Fertilizer + fungicide
2014	Newport, AR	Headline	6–24–6	6–24–6 + Priaxor
	Ames, IA	Priaxor, Headline	6–24–6- 1% Su	6–24–6- 1% Su + Headline
	Lafayette, IN	Priaxor, Headline	19–17–0	19–17–0 + Priaxor
	Stoneville, MS	Priaxor, Headline	10–20–5- 1% Su 0.43% Zn	10–20–5- 1% Su 0.43% Zn + Priaxor
	Rodney, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline
	Rodney, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline
	Ridgetown, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline
	Ridgetown, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline
2015	Altheimer, AR	Priaxor, Headline	6–24–6	6–24–6 + Priaxor
	Ames, IA	Priaxor, Headline	6–24–6- 1% Su	6–24–6- 1% Su + Priaxor
	Nashua, IA	Priaxor, Headline	9–18–9	9–18–9 + Priaxor
	Stoneville, MS	Priaxor, Headline	10–20–5- 1% Su 0.43% Zn	10–20–5- 1%Su 0.43% Zn + Headline
	Ridgetown, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline
	Rodney, ON	Priaxor, Headline	6–24–6	6–24–6 + Priaxor, 6–24–6 + Headline

† Fungicides used included 14.3% fluxapyroxad (0.043 lb/acre) + 28.6% pyraclostrobin (0.087 lb/acre) (Priaxor BASF, Research Triangle Park, NC) at 4 fl oz/acre (292.4 ml/ha), and 23.6% pyraclostrobin (0.049 lb/acre) (Headline EC, BASF) at 3 fl oz/acre (219.3 mL/ha).

‡ Fertilizers are listed as percentage of weight (N) – (P_2O_5) – (K_2O) with other elements listed such as sulfur and zinc.

but no significant observations were observed (data not shown). Population was determined by counting the number of plants within 3.3 to 17.4 ft (1 to 5.25 m) in each plot and converted to plants/acre (Table 4). Plant height (inches) was measured from the soil to the growing point on 5 plants per plot. Soybean yield was harvested from the two middle rows of each plot in Arkansas, Iowa, Indiana, and Mississippi and the four middle rows of from each plot in Ontario, converted to 13% moisture, and reported in bu/acre.

Analysis of Variance

Because the main objective of this study was to examine the effect of in-furrow fungicide applications with and without starter fertilizer on soybean growth and yield across multiple environments, individual products were not compared across trials. Rather, treatments were grouped as: i) NTC, ii) fungicide alone, iii) starter fertilizer, and iv) a combination of fungicide and starter fertilizer. Analysis of variance was performed for plant population, plant heights, grain moisture, and grain yield using the PROC GLIMMIX procedure in SAS (SAS Inst. Inc., Cary, NC). Each site-year was analyzed separately because fungicide and starter fertilizer products varied across locations and to determine if response differences were related to location or region. Fisher's protected LSD was used to separate treatment means at $\alpha = 0.10$. Treatment LS means were obtained using the LSMEANS statement in SAS. Plant population and plant heights at AD1 and AD2 were analyzed separately for each trial. An ANOVA was performed for each trial separately considering treatments as a fixed and replication as random factors.

Treatment Effects on Plant Population and Plant Height

The main effect of treatment was significant for plant population at AD1 in 3 of 10 trials; Ames, IA in 2014, Arkansas in 2015, and Ridgetown, Ontario in 2015 (Table 4). However, the trend was inconsistent across the trials. Fungicide alone and starter fertilizer alone increased plant population by 14.2 and 22.2% compared to the NTC, respectively in Ames, Iowa in 2014 ($P = 0.02$). In contrast, in Arkansas in 2015, starter fertilizer reduced plant population by 20.3% ($P = 0.04$) when compared to NTC. Fungicide alone and combined with a starter fertilizer reduced plant stands by 9.3% at Ridgetown, ON in 2015 ($P = 0.08$). Plant population was also reduced ($P = 0.006$) by 19.1% at AD2 with a starter fertilizer in 2015 in Arkansas (Table 4).

Plant height at AD1 was significantly affected by treatment at two locations ($P < 0.10$) (Table 5). At the second planting in Ridgetown, Ontario in 2014, the starter fertilizer and fungicide combination increased plant height by 10.0% compared to the NTC ($P = 0.02$). In Arkansas in 2015, plant height was reduced at AD1 ($P = 0.04$), and the NTC had 9.1, 20.0, and 14.3% taller plants compared to the fungicide, starter fertilizer, and fungicide and starter fertilizer combination, respectively. At this same trial, the NTC had 17.3% taller plants compared to the starter fertilizer at AD2 ($P = 0.09$) (Table 5). This reduction in plant height observed in the Arkansas trial differs from a previous report that showed increased plant height with starter fertilizer in soybean (Ham et al., 1973). This reduction in height, as well as the reduction in plant stand may have been due to seedlings injured by salt in starter fertilizers (Clapp and Small, 1970; Randall and Hoeft, 1988; Rehm and Lamb, 2010).

Table 4. Plant population per acre at assessment date (AD) 1 and 2 from field trials conducted in 2014 and 2015 in Arkansas, Iowa, Indiana, Mississippi, and Ontario, Canada. Plant populations were measured from a range of row lengths of 3.3 to 17.4 feet and converted to plants per acre.

	Plant population AD1 (in thousands)													
	2014								2015					
Trt†	AR1‡	IN	IA1	MS	RDONM	RDONJ	RTONM	RTONJ	AR2	IA1	IA2	MS	RTON	RDON
NTC	. §	.	91.4 b¶	73.0	97.8	133.1	158.8	188.9	136.5 a	77.8	.	.	158.8a	140.7
Fung#	.	.	104.4 a	71.0	106.4	132.9	162.7	181.1	134.3 a	78.1	.	.	144.1b	142.8
SF††	.	.	111.7 a	64.8	101.2	143.1	164.7	180.7	108.8 b	78.9	.	.	158.6a	132.0
Fung + SF‡‡	.	.	85.6 b	64.0	106.8	143.1	160.1	174.4	125.1 ab	70.9	.	.	144.1b	140.8
P-value	.	.	0.02	0.35	0.42	0.49	0.83	0.55	0.04	0.63	.	.	0.08	0.87
	Plant population AD2 (in thousands)													
	2014								2015					
NTC	122.9	103.0	91.4	70.1	110.2	152.1	166.5	181.9	137.0 ab	.	.	.	147.8	174.0
Fung	130.2	97.4	118.5	67.7	118.5	158.9	168.4	186.7	142.5 a	.	.		146.1	170.6
SF	120.7	99.8	113.1	65.1	108.0	157.9	167.7	190.0	110.9 c	.	.	.	150.9	168.9
Fung + SF	128.3	99.5	116.0	65.1	114.7	162.0	163.9	181.4	126.2 b	.	.	.	142.2	164.9
P-value	0.49	0.89	0.13	0.86	0.25	0.72	0.85	0.82	0.006	.	.	.	0.67	0.75

† Trt = Treatment, NTC = Non-treated control.

‡ In 2014, experiments were conducted at locations Newport, AR (AR1); Lafayette, IN (IN); Ames, IA (IA1); Stoneville, MS (MS); Rodney, ON; and Ridgetown, ON. Trials were planted on two dates at Rodney on 30 May 2014 (RDONM) and on 5 June 2014 (RDONJ) and at Ridgetown on 23 May 2014 (RTONM) and on 23 June 2014 (RTONJ). In 2015, experiments were conducted in Altheimer, AR (AR2); Ames and Nashua, IA (IA1 and IA2); Stoneville, MS (MS); Rodney, ON (RDON); and Ridgetown, ON (RTON).

§ Missing data points within the table are noted with ".".

¶ Means were separated by Fisher's protected least significant difference (LSD). Means followed by the same letter within a column do not differ significantly at $\alpha = 0.10$.

Fungicide (Fung) applied in-furrow were 14.3% fluxapyroxad (0.043 lb/acre) + 28.6% pyraclostrobin (0.087 lb/acre) (Priaxor, BASF, Research Triangle Park, NC), at 4 fl oz/acre (292.4 ml/ha), and 23.6% pyraclostrobin (0.049 lb/acre) (Headline EC, BASF) at 3 fl oz/acre (219.3 ml/ha). These treatments were combined for analysis.

†† Starter fertilizers (SF) varied at locations and are listed individually in Table 2.

‡‡ Fungicide and starter fertilizer (Fung + SF) treatments varied at locations and are listed individually in Table 3.

Treatment Effects on Grain Yield and Moisture

Analysis of variance for individual trials showed that the effect of treatment significantly affected yield in Arkansas in 2014 only ($P = 0.05$); the starter fertilizer plus fungicide treatment resulted in greater yield than any other treatment (Table 6). Grain moisture at harvest decreased at the second planting in Ridgetown, Ontario in 2014 with fungicide by 0.3% ($P = 0.099$) when compared to the NTC and the starter fertilizer plus fungicide treatment (Table 6).

Quantitative Synthesis of Treatment Effects on Grain Yield Based on Meta-analysis

Analysis of variance for individual trials showed inconsistent results across the trials with treatments increasing plant population in some trials, but reducing populations in other trials, and in many trials, analysis of variance showed no treatment effect. Treatment effect was statistically significant for yield only in Arkansas in 2014 ($P = 0.04$) even though the starter fertilizer plus fungicide treatment resulted in numerically greater yield than NTC also in other site-years (Table 6). Meta-analysis is statistically more powerful than that of an individual study to detect treatment effect (the probability of rejecting null hypothesis when alternative hypothesis is true) (Madden and Paul, 2011). A multivariate random effect model meta-analysis was performed to synthesize the overall yield differences between the NTC, fungicide, and starter fertilizer treatments (Madden and Paul, 2011; Piepho et al., 2012). Meta-analysis was performed using a standard factorial ANOVA approach in PROC GLIMMIX. In the model, treatment was considered as a fixed effect factor and study and study-treatment interaction were considered as random effect factors. Treatments including the NTC least squares means (LS-means) summaries from each study were used in the meta-analysis. Multivariate meta-analysis provides similar results to the popular baseline contrast-based approach of meta-analysis (Piepho et al., 2012). The LSMEANS statement was used in the model to estimate the treatment LS means, contrast estimates, and standard errors associated with the means. Treatment effect size was calculated as the difference in mean for each treatment compared to NTC ($D = X_{treatment} - X_{NTC}$). Upper and lower limits of 95% confidence interval of the means were calculated as follows: $CI95\%$ (effect) = $effect \pm 1.96 \times SE_{effect}$.

Yield response, the mean difference, in individual studies ranged between −9.0 to 4.2 bu/acre (−605.3 to 282.2 kg/ha) of fungicide, –11.4 to 4.3 bu/acre (–766.0 to 288.9 kg/ha) of starter

Table 5. Plant heights (inches) at assessment date (AD) 1 and 2 were measured to determine the effects of fungicide, starter fertilizer, and a combination of fungicide and starter fertilizer on plant growth at experiments conducted in Arkansas, Indiana, Iowa, Mississippi, and Ontario, Canada in 2014 and 2015.

	Plant height AD1													
	2014								2015					
Trt†	AR1‡	IN	IA1	MS	RDONM	RDOMJ	RTONM	RTONJ	AR2	IA1	IA2	MS	RDON	RTON
	inches													
NTC	5.0	. §	6.5	.	2.0	1.9	2.3	3.0 b¶	2.4 a	3.4	.	.	1.6	1.5
Fung#	5.1	.	6.3	.	1.9	1.8	2.3	3.0 b	2.2 b	3.2	.	.	1.7	1.5
SF††	5.0	.	6.7	.	1.9	2.0	2.2	3.1 b	2.0 b	3.6	.	.	1.6	1.6
Fung + SF‡‡	5.2	.	6.3	.	1.9	2.0	2.3	3.3 a	2.1 b	3.4	.	.	1.5	1.6
P-value	0.50	.	0.94	.	0.34	0.16	0.94	0.02	0.04	0.52	.	.	0.76	0.46
	Plant height AD2													
	2014								2015					
	inches													
NTC	11.2	6.9	16.1	.	5.3	4.0	4.2	7.4	5.4 a	.	.	.	3.4	3.5
Fung	12.2	6.4	15.7	.	5.1	4.1	4.4	8.0	5.2 a	.	.	.	3.3	3.3
SF	12.3	6.3	17.6	.	5.3	4.5	4.3	7.5	4.6 b	.	.	.	3.7	3.5
Fung + SF	11.9	7.2	16.2	.	5.2	3.9	4.2	8.2	5.0 ab	.	.	.	3.3	3.3
P-value	0.16	0.30	0.66	.	0.65	0.20	0.65	0.41	0.09	.	.	.	0.43	0.24

† Trt = Treatment, NTC = Non-treated control.

‡ In 2014, experiments were conducted at locations Newport, AR (AR1); Lafayette, IN (IN); Ames, IA (IA1); Stoneville, MS (MS); Rodney, ON; and Ridgetown, ON. Trials were planted on two dates at Rodney on 30 May 2014 (RDONM) and on 5 June 2014 (RDONJ) and at Ridgetown on 23 May 2014 (RTONM) and on 23 June 2014 (RTONJ). In 2015, experiments were conducted in Altheimer, AR (AR2); Ames and Nashua, IA (IA1 and IA2); Stoneville, MS (MS); Rodney, ON (RDON); and Ridgetown, ON (RTON).

§ Missing data points within the table are noted with ".".

¶ Means were separated by Fisher's protected least significant difference (LSD). Means followed by the same letter within a column do not differ significantly at $\alpha = 0.10$.

Fungicide (Fung) applied in-furrow were 14.3% fluxapyroxad (0.043 lb/acre) + 28.6% pyraclostrobin (0.087 lb/acre) (Priaxor, BASF, Research Triangle Park, NC), at 4 fl oz/acre (292.4 ml/ha), and 23.6% pyraclostrobin (0.049 lb/acre) (Headline EC, BASF) at 3 fl oz/acre (219.3 ml/ha). These treatments were combined for analysis.

†† Starter fertilizers (SF) varied at locations and are listed individually in Table 2.

‡‡ Fungicide and starter fertilizer (Fung + SF) treatments varied at locations and are listed individually in Table 3.

fertilizer, and −5.3 to 9.5 bu/acre (–356.1 to 638.3 kg/ha) of the fungicide and starter fertilizer combination (Table 6). Overall, the fungicide plus starter fertilizer combination yielded 1.6 bu/acre (108 kg/ha) greater compared to the NTC which was significantly different than zero ($P = 0.02$) (Table 7). The response to fungicide and starter fertilizer, mean yield difference between fungicide alone and NTC and starter fertilizer alone and NTC, were not different from zero based on standard normal test statistics, Z, in meta-analysis (Table 7).

Although there was an early season treatment response to plant height in one trial due to fungicide and starter fertilizer treatments, early season growth responses did not directly translate into yield responses, and in some cases, treatment had a negative effect on plant population and plant height. The ANOVA showed a yield response to the fungicide + starter fertilizer treatment at Arkansas in 2014, however, there was no response to starter fertilizer or fungicide alone. A meta-analysis showed a significant yield response to fungicide and starter fertilizer combinations. However, the inconsistency in results observed among years and locations, supported previous research that shows the use of these products does not always translate into yield increases (Ham et al., 1973; Rehm and Lamb, 2010). We did see a reduction in plant stand at one location, which is similar to others that saw that placing products with a high salt content near the seed at planting increases the risk for seedling injury and reduced seedling emergence (Clapp and Small, 1970; Randall and Hoeft, 1988). These risks may outweigh potential benefits reported from use of in-furrow products, and the costs of applying fungicide and fertilizer in-furrow will likely be greater than the economic response achieved. Fungicide and starter fertilizers have been promoted for use in cool and wet soils, however, only 3 of our 14 site-years were planted in conditions that would be considered early or cool, which may have limited treatment responses. Also, seed in 3 of 14 site-years was treated with seed treatment packages containing fungicides, which may have provided control of pathogens, limiting any response to in-furrow fungicide. Seedling disease was not present in all locations where it was recorded, which also may explain no response to in-furrow fungicide. Soil tests were mostly in ranges with low chances of responses to additional fertilizer and we did not see responses to starter fertilizer alone, as expected with mostly optimum to high nutrient levels. In-furrow fungicide applications may be more beneficial on fields with known seedling disease issues, rather than prophylactically treating all soybean fields, however, further research

Table 6. Grain yield (bu/acre) and grain moisture (%) at harvest at experiments carried out in the states of Arkansas, Indiana, Iowa, Mississippi, and Ontario, Canada in 2014 and 2015.

	Yield														
	All	2014								2015					
Trt†	Yield	AR1‡	IN	IA1	MS	RDONM	RDONJ	RTONM	RTONJ	AR2	IA1	IA2	MS	RDON	RTON
	bu/acre														
NTC	53.9	34.2 b§	54.2	64.5	40.1	47.9	36.1	64.3	59.8	21.1	70.8	64.1	51.8	47.8	80.1
Fung¶	53.7	36.2 b	55.5	64.6	39.2	44.3	38.2	61.6	61.4	25.3	73.5	65.2	48.4	49.4	71.1
SF#	53.6	35.7 b	56.0	63.1	37.6	50.2	37.5	63.7	59.7	22.5	75.1	63.2	51.2	47.3	68.8
Fung + SF††	55. 1	40.1 a	53.8	66.4	37.7	47.3	34.8	64.3	61.4	30.6	74.7	65.0	54.0	50.7	74.8
P-value	0.34	0.04	0.74	0.58	0.88	0.38	0.41	0.21	0.62	0.40	0.21	0.42	0.28	0.94	0.42
	Grain Moisture														
	All	2014								2015					
	%														
NTC	12.7	. ‡‡	13.9	14.7	.	13.3	13.5	14.2	13.70 a	.	10.9 ab	11.6	12.6	12.1	12.1
Fung	12.7	.	13.8	14.4	.	13.4	13.6	14.1	13.38 b	.	11.0 a	11.7	12.3	12.3	12.2
SF	12.7	.	13.8	14.6	.	13.1	13.8	13.9	13.43 ab	.	10.8 b	11.8	12.4	12.2	12.0
Fung + SF	12.7	.	13.8	14.8	.	13.4	13.6	14.0	13.65 a	.	10.9 ab	11.7	12.6	12.3	12.0
P-value	0.37	.	0.70	0.23	.	0.38	0.28	0.42	0.099	.	0.06	0.76	0.69	0.46	0.36

† Trt = Treatment, NTC = Non-treated control.

‡ In 2014, experiments were conducted at locations Newport, AR (AR1); Lafayette, IN (IN); Ames, IA (IA1); Stoneville, MS (MS); Rodney, ON; and Ridgetown, ON. Trials were planted on two dates at Rodney on 30 May 2014 (RDONM) and on 5 June 2014 (RDONJ) and at Ridgetown on 23 May 2014 (RTONM) and on 23 June 2014 (RTONJ). In 2015, experiments were conducted in Altheimer, AR (AR2); Ames and Nashua, IA (IA1 and IA2); Stoneville, MS (MS); Rodney, ON (RDON); and Ridgetown, ON (RTON).

§ Means were separated by Fisher's protected least significant difference (LSD). Means followed by the same letter within a column do not differ significantly at $\alpha = 0.10$.

¶ Fungicide (Fung) applied in-furrow were 14.3% fluxapyroxad (0.043 lb/acre) + 28.6% pyraclostrobin (0.087 lb/acre) (Priaxor, BASF, Research Triangle Park, NC), at 4 fl oz/acre (292.4 ml/ha), and 23.6% pyraclostrobin (0.049 lb/acre) (Headline EC, BASF) at 3 fl oz/acre (219.3 ml/ha). These treatments were combined for analysis.

Starter fertilizers (SF) varied at locations and are listed individually in Table 2.

†† Fungicide and starter fertilizer (Fung + SF) treatments varied at locations and are listed individually in Table 3.

‡‡ Missing data points within the table are noted with ".".

Table 7. Effect sizes the yield differences of treatments compared to the non-treated control and corresponding statistics recorded in the experiments carried out in the states of Arkansas, Indiana, Iowa, Mississippi, and Ontario, Canada in 2014 and 2015.

	Effect size†						
Treatment	K‡	D	se D	CI_L	CI_U	*P* value	NTC mean§
							bu/acre
Fungicide	14	0.4	0.65	-0.9623	1.6636	0.5921	52.2
Starter fertilizer	14	0.3	0.65	-0.9706	1.6554	0.6008	52.2
Fungicide + starter fertilizer	14	1.6	0.65	0.2377	2.8637	0.0218	52.2

† Effect size (D) was computed as the difference in mean for each treatment relative to control ($D = X_{treatment} - X_{NTC}$), se (D) = standard error of the mean difference, 95% confidence interval (CI) lower and upper limits of the mean difference was computed as CI95% (effect) = effect ± 1.96 × SE_{effect}.

‡ K = total number of studies used in the analysis.

§ Least square means of the NTC for yield as estimated by meta-analysis.

targeting fields is required to understand when and where in-furrow fungicides may benefit soybean production.

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