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RESEARCH

Response of Broad-Spectrum and Target-Specific Seed Treatments and Seeding Rate on Soybean Seed Yield, Profitability, and Economic Risk

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ABSTRACT

Seed-applied fungicides and insecticides have become common components in modern soybean [*Glycine max* (L.) Merr.] production for their broad-spectrum activity. However, adding a target-specific seed treatment (fluopyram) to these seed treatment packages in light of increased costs and declining grain sale prices has not been evaluated. Reducing seeding rates (SRs) is possibly one avenue to maximize the economic benefit of seed treatments. Three seed treatments and six SRs were evaluated to determine yield, profitability, and economic risk benefits across 26 environments. Seed treatment effects on plant stand and yield were environment specific. Commercial base (CB) and CB plus fluopyram (ILeVO) seed treatments increased plant stand over the untreated control (UTC) and across all environments, the addition of fluopyram in ILeVO increased yield by 2.8% over CB. In environments where sudden death syndrome (SDS) symptoms were present, yield response of ILeVO over CB was 5.3 and 6.1%. The CB treatment, and more so, ILeVO, lowered farmer risk (>70%) and increased profit (9–78 US$ ha^{-1}) at currently recommended and reduced SRs regardless of grain sale prices. The lowest risk and largest average profit increase always occurred at the economically optimal SR (EOSR), which decreased with the grain sale price and differed between seed treatments by as much as 17,000 seed ha^{-1}. This study reinforces the profit and economic risk benefits of broad spectrum and target specific seed treatments across diverse environments. These benefits may be amplified by targeting fields with a history of early-season insect and disease pressure.

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Abbreviations: CB, commercial base; EOSR, economically optimal seeding rate; ILeVO, commercial base plus fluopyram; RCBD, randomized complete block design; SDS, sudden death syndrome; SP, seed price; SR, seeding rate; UTC, untreated control.

Seed-applied fungicides and insecticides have become a common component in modern soybean production systems for protection against various seedling diseases and insects. Munkvold (2009) reported that only 8 and 30% of soybean seed in the United States was treated in 1996 and 2008, respectively. Since 2008, seed treatment use has more than doubled to >75% in 2015 according to seed industry personnel. The drastic surge in soybean seed treatment use over the past 15 yr is most likely a result of four underlying factors. First, farmers within the Midwest are planting earlier into cooler and wetter soil, which slows seedling emergence and gives the seed greater exposure to early-season root rooting pathogens and insects (Conley and Santini, 2007). Second, soybean seed costs have nearly doubled in the past decade to ~US$50 unit^{-1} (140,000 seeds) and now represent 36% of the total annual variable operating expenses worth protecting

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(USDA–Economic Research Service, 2016). Third, soybean commodity prices climbed to historic highs between 2007 and 2013 (USDA–National Agricultural Statistics Service [NASS], 2016), providing farmers with more revenue to invest in various inputs including seed treatments. Fourth, the decision to use a seed treatment based on traditional integrated pest management strategies is difficult because field-scale insect and disease levels are largely unknown and unquantifiable before planting when seed treatment choices are made. Additionally, growing conditions vary within a single field (Sawchik and Mallarino, 2008) as a result of weather, soil type, and topography, resulting in varying levels of disease and insect pressure, while seed treatment use is a whole-field decision.

Overlaying the four aforementioned factors are multiple studies reporting economically significant yield gains from seed treatment use across a broad range of environments (Cox and Cherney, 2011; Esker and Conley, 2012; Gaspar et al., 2015a,b; Vossenkemper et al., 2015). Specifically, the use of a combination fungicide plus insecticide seed treatment has provided more consistent yield gains across different SRs (Gaspar et al., 2015a) and dissimilar environments and cultivars (Esker and Conley, 2012; Gaspar et al., 2015b), whereas fungicide-only seed treatments have provided smaller and less-consistent yield responses (Bradley, 2008; Gaspar et al., 2015b; Poag et al., 2005; Schulz and Thelen, 2008).

Currently, a majority of soybean seed treatments packages contain multiple active ingredients, providing broad-spectrum control of many early-season pathogens, such as *Pythium* spp., *Phytophthora* spp., *Fusarium* spp., and *Rhizoctonia* spp., and insects such as wireworms (*Melanotus* spp.) and seed corn maggots [*Delia platura* (Meigen)], which can severely decrease plant stand. However, until the introduction of fluopyram (ILeVO; Bayer CropScience AG), control of SDS, caused by *Fusarium virguliforme,* was mainly sought through breeding resistance and cultural practices such as delayed planting. Unfortunately, breeding for genetic resistance has been difficult, and while delayed planting has been shown to reduce foliar disease development, the yield loss as a result of delayed planting is significant, thereby reducing farmer profit (Kandel et al., 2016b; Marburger et al., 2016). A yield loss of 21.2 kg ha^{-1} d^{-1} from delaying planting past the first week in May has been reported in Wisconsin (Gaspar and Conley, 2015). Therefore, ILeVO may provide farmers the opportunity to control SDS in early planted soybeans. Kandel et al. (2016a) found that fluopyram decreased the SDS foliar disease index in five of 12 experiments and improved yield in three of 12 experiments by an average of 11%. Thus, the frequency of disease development and a yield response was low, but the magnitude of positive yield responses was large. These responses were also dependent on baseline disease levels suggesting that the economic value of ILeVO may only be realized in field-specific situations and not as a broad-spectrum use product (Kandel et al., 2016a).

Unfortunately, since 2013, soybean commodity prices have decreased by ~45% (USDA–NASS, 2016), putting increased pressure on management practices (SR) and inputs (seed treatment) to be cost-effective, meaning they at least break even or increase profit (Marra et al., 2003). Previous studies in the upper Midwest have shown SRs as low as 185,300 and 276,000 seed ha^{-1} represent the most economically optimum rate (De Bruin and Pedersen, 2008; Gaspar et al., 2015a), while in Kentucky, SRs as low as 171,000 seed ha^{-1} produced 95% of maximum yield (Lee et al., 2008). Furthermore, the combination of reduced SRs and fungicide plus insecticide seed treatment has been shown to increase farmer profit and reduce economic risk (Gaspar et al., 2015a). However, most fungicide plus insecticide seed treatment packages have a broad spectrum of control, whereas, ILeVO mainly targets a single seedling disease (SDS). Ultimately, farmers want products that provide a consistent return on investment across multiple environments (fields and years) especially for seed treatments where whole-field use is required but disease and insect levels are difficult to quantify. Therefore, in this study, we extended the prior research of Gaspar et al. (2015a) and Kandel et al. (2016a) to quantify the yield, profit, and economic risk benefits of a broad-spectrum fungicide plus insecticide plus nematistat seed treatment only, and in combination with a pathogen-specific seed treatment (fluopyram), across various SRs within current soybean production economic realities.

MATERIALS AND METHODS

Field Experiment

Field trials were conducted in Wisconsin during 2015 and 2016 but just during 2016 in Iowa, Indiana, Michigan, and Ontario, Canada (Table 1). Wisconsin field trials were established at 10 locations for a total of 20 environments (location × year). These trials were organized in a randomized complete block design (RCBD) with four replications using a factorial treatment arrangement of two varieties, three seed treatments, and six SRs. The single trials located in Michigan and Indiana were a RCBD in a split-plot arrangement with four replicates. In Michigan, the whole-plot factor was two different varieties and the subplots were factorial of three seed treatments and six SRs. In Indiana, the whole-plot factor was six different SRs and the subplots were three different seed treatments, utilizing one variety for the whole trial. Iowa and Ontario trials were conducted at two locations each and organized in a RCBD with four replications in a factorial arrangement of one variety, three seed treatments, and six SRs.

All trials used glyphosate [*N*-(phosphomethyl) glycine]-resistant soybean varieties. In 2015, the two varieties seeded in Wisconsin trials were RS224NR2 and RS213NR2 (Renk Seed Co.), which had SDS scores of 5 and 7, respectively. A score of 1 is susceptible to SDS and 9 is resistant. Wisconsin trials in 2016 contained RS213NR2, again, and AG2136 (Monsanto

Table 1. Environment description of the trials throughout Wisconsin, Iowa, Indiana, Michigan, and Ontario during 2015 and 2016.

Year	Location	Latitude and longitude	Planting date	Soil type†‡	Clay§	OM¶	pH¶	P¶	K¶	Precipitation#
					g kg^{-1}	g kg^{-1}		Bray-1	Bray-1	mm
2015	Arlington, WI	43°18′8″ N, 89°20′8″ W	30 April	Plano SiL	225	36	7.0	60	273	112 (18)
	East Troy, WI	42°46′9″ N, 88°27′57″ W	7 May	Sebewa SiL	130	61	6.8	49	129	94 (0)
	East Troy, WI	42°46′9″ N, 88°27′57″ W	7 May	Matherton SiL	160	61	6.8	49	129	94 (0)
	Platteville, WI	42°32′57″ N, 90°26′18″ W	13 May	Fayette SiL	280	29	6.9	39	141	112 (5)
	Fond du Lac, WI	43°43′34″ N, 88°34′18″W	5 May	Pella SiL	310	49	6.7	15	127	102 (20)
	Galesville, WI	44°4′27″ N, 91°19′58″W	1 May	Downs SiL	280	37	5.9	15	120	142 (46)
	Hancock, WI	44°7′10″ N, 89°32′7″W	1 May	Plainfield S	0	17	6.0	126	51	142 (48)
	Chippewa Falls, WI	44°57′0″ N, 91°21′1″W	1 May	Sattre L	205	15	6.7	27	113	137 (48)
	Marshfield, WI	44°38′29″ N, 90°7′59″ W	13 May	Withee SiL	215	33	7.0	32	154	127 (33)
	Seymour, WI	44°31′25″ N, 88°19′46″ W	4 May	Solona SiL	190	23	7.0	14	142	86 (13)
2016	Arlington, WI	43°18′8″ N, 89°20′8″ W	3 May	Plano SiL	225	34	7.0	53	191	57 (−34)
	East Troy, WI	42°46′9″ N, 88°27′57″ W	9 May	Sebewa SiL	130	50	6.3	75	323	60 (−26)
	East Troy, WI	42°46′9″ N, 88°27′57″ W	9 May	Matherton SiL	160	84	7.6	5	130	60 (−26)
	Platteville, WI	42°32′57″ N, 90°26′18″ W	6 May	Fayette SiL	280	31	7.0	49	186	110 (4)
	Fond du Lac, WI	43°43′34″ N, 88°34′18″ W	4 May	Pella SiL	310	39	6.9	19	106	91 (8)
	Galesville, WI	44°4′27″ N, 91°19′58″ W	4 May	Downs SiL	280	34	6.2	19	178	105 (16)
	Hancock, WI	44°7′10″ N, 89°32′7″ W	2 May	Plainfield S	0	7	5.9	54	40	90 (0)
	Chippewa Falls, WI	44°57′0″ N, 91°21′1″ W	4 May	Sattre L	205	11	6.6	40	147	97 (9)
	Marshfield, WI	44°38′29″ N, 90°7′59″ W	5 May	Withee SiL	215	34	6.8	27	126	53 (−28)
	Seymour, WI	44°31′25″ N, 88°19′46″ W	3 May	Solona SiL	190	25	7.4	18	103	85 (11)
	Ames, IA	42°3′35″ N, 93°37′3″ W	6 May	Coland CL	260	41	7.25	118	213	90 (−26)
	Roland, IA	42°8′30″ N, 93°37′3″ W	6 May	Nicollet CL	250	27	5.2	91	165	90 (−26)
	Wanatah, IN	41°27′20″ N, 86°56′33″ W	24 May	Sebewa L	230	30	6.6	35	158	94 (−5)
	Decatur, MI	42°7′36″ N, 86°1′24″ W	9 May	Spinks LS	150	24	7.8	136	106	85 (−14)
	Highgate, ON	42°31′59″ N, 81°49′8″ W	31 May	Watford LS	70	30	7.1	53	176	38 (−40)
	West Lorne, ON	42°35′46″ N, 81°38′36″ W	30 May	Walsing S	20	18	6.7	28	155	44 (−34)

† Soil type from web soil survey. Plano: fine-silty, mixed, superactive, mesic Typic Argiudolls; Sebewa: fine-loamy, mixed, superactive, mesic Typic Argiaquolls; Matherton: fine-loamy, mixed, superactive, mesic Udollic Endoaqualfs; Fayette: fine-silty, mixed, superactive, mesic Typic Hapludalfs; Pella: fine-silty, mixed, superactive, mesic Typic Endoaquolls; Downs: fine-silty, mixed, superactive, mesic Mollic Hapludalfs; Plainfield: mixed, mesic Typic Udipsamments; Sattre: fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Mollic Hapludalfs; Withee: fine-loamy, mixed, superactive, frigid Aquic Glossudalfs; Solona: coarse-loamy, mixed, superactive, frigid Aquic Argiudolls; Coland: fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls; Nicollet: fine-loamy, mixed, superactive, mesic Aquic Hapludolls; Spinks: sandy, mixed, mesic Lamellic Hapludalfs; Watford: Brunisolic gray brown Luvisol; Walsing: fine sand, Gleyed Bruniosolic gray brown Luvisol.

‡ CL, clay loam; L, loam; LS, loamy sand; S, sand; SiL, silt loam.

§ Average clay basis for this soil type.

¶ OM, organic matter. pH, P, and K values are a composite of individual sites each year.

Precipitation within the month of May. Deviation from the 30-yr average is reported in parentheses. The Hancock, WI, Decatur, MI, Wanatah, IN, and Ames, IA, locations received supplemental irrigation in season when appropriate.

Table 2. Soybean seed treatment component information.

Seed treatment code†	Seed treatment trade name	Active ingredient‡	Application rate
			mg a.i. seed^{-1}
UTC	na	–	–
Commercial base (CB)	EverGol Energy +	prothioconazole (F)	0.0083
		penflufen (F)	0.0041
		metalaxyl (F)	0.0066
	Allegiance FL +	metalaxyl (F)	0.02
	Poncho/VOTiVO	clothianidin (I)	0.1074
		Bacillus firmus (N)	0.0218
CB plus fluopyram (ILeVO)	EverGol Energy +	prothioconazole (F)	0.0083
		penflufen (F)	0.0041
		metalaxyl (F)	0.0066
	Allegiance FL +	metalaxyl (F)	0.02
	Poncho/VOTiVO +	clothianidin (I)	0.1074
		Bacillus firmus (N)	0.0218
	ILeVO	fluopyram (F)	0.15

† Seed treatment code represents the unique combination of active ingredients. The letters were used for coding each seed treatment.

‡ F: fungicide; I: insecticide; N: nematistat.

Company,), which had a SDS score of 5. Iowa trials contained AG2136 and the Michigan trial contained RS213NR2 and AG2636 (Monsanto Company), which had an SDS score of 5. The trial in Indiana and two trials in Ontario also used the variety AG2636.

The six SRs employed for all trials were 98,800; 148,200; 197,600; 247,000; 296,400; and 345800 seed ha^{-1}. The three seed treatment combinations followed product labels concerning application rates and methods. The specific rates and components of the three seed treatments (UTC, CB, ILeVO) are described in detail in Table 2 and consist of a UTC, a CB (fungicide plus insecticide plus nematistat) seed treatment, and the ILeVO seed treatment (CB plus the fungicidal a.i., fluopyram; Bayer CropScience AG). Sudden death syndrome caused by *F. virguliforme* is the main pathogen targeted by fluopyram, while the other fungicidal components target a wide range of other pathogens including *Pythium, Phytophthora, Fusarium,* and *Rhizoctonia.*

Planting occurred during the first 2 wk of May in both years for all trials except for the Wanatah, IN, and Ontario locations in 2016. (Table 1). Plots in Wisconsin were seeded in six 38-cm rows at a length of 6.4 m. Michigan and Iowa plots were seeded in four 76-cm rows at a length of 5.3 m, while Indiana plots were seeded in four 38-cm rows at a length of 9.1 m. Ontario plots were seeded in eight 38-cm rows at a length of 4.9 m. Furthermore, at the Ames, IA, and Wanatah, IN, locations, the soils were artificially infected with *F. virguliforme* following methods described by de Farias Neto et al. (2006). The inoculum was produced by colonizing sorghum grain with *F. virguliforme* isolates and then placing the sorghum in furrow with the seed at planting. The middle four (Wisconsin, Ontario), middle two (Iowa, Michigan), and all four (Indiana) rows of each plot were harvested at maturity with a plot combine to determine yield. Yield was computed by adjusting moisture to 130 g kg^{-1}. Early-season plant stands (V2) were collected by counting the number of plants in 1.5 m or the entire row length of the center four or two rows depending on plot configuration.

Soil samples were taken from each location and analyzed for percentage clay, organic matter, soil pH, and macronutrients at each state's respective University soil and plant analysis laboratories (Table 1). Fertility and in-season pest control followed each state's University recommendations for best management practices.

Statistical Analysis

Because of the differences between each state's experimental designs, ANOVA was performed and the results are presented by state. Statistical analysis was performed using PROC MIXED in SAS (SAS Institute, 2010). For each data set, multi-environment or single-environment (year × location) analysis was used to examine the effects of soybean seed treatments and SRs on early-season plant stand and seed yield (Littell et al., 2006). For Wisconsin, SR, seed treatment, environment, and all two-way and three-way interactions were treated as fixed effects, while variety, variety × environment, replicate within environment, and the overall error term were treated as random effects (Littell et al., 2006). Omitted Wisconsin locations include the 2015 Marshfield location because of flooding, the 2015 East Troy location because of excessive white mold (*Sclerotinia sclerotiorum*) infection, and the 2016 East Troy location because of severe drought. For Iowa, SR, seed treatment, environment, and all two-way and three-way interactions were treated as fixed effects, while replicate within environment and the overall error term were treated as random effects (Littell et al., 2006). For Indiana, SR, seed treatment, and the two-way interaction were treated as fixed effects, while replicate, replicate × SR, and the overall error term were treated as random effects (Littell et al., 2006). For Michigan, SR, seed treatment, and the two-way interaction were treated as fixed effects, while replicate, variety, replicate × variety, and the overall error term were treated as random effects (Littell et al., 2006). For Ontario, SR, seed treatment, environment, and all two-way and three-way interactions were treated as fixed effects, while replicate within environment and the overall error term were treated as random effects (Littell et al., 2006). The varieties selected in the various trials are representative of adapted varieties used in each geographical region. Each environment in Iowa, Indiana, Michigan, and Ontario developed foliar SDS symptomology, whereas only a portion of the Wisconsin environments displayed symptomology. Therefore, a data subset was created from the 20 Wisconsin environments. This data subset, denoted WI-SDS, only included the seven Wisconsin environments that developed foliar SDS symptomology and was analyzed the same way as the complete Wisconsin data set (20 environments), denoted WI-complete to determine the effect of seed treatment across all environments (WI-complete) compared with only visually confirmed SDS positive environments (WI-SDS).

Within each of the six ANOVAs, the level of significance was 5%, and means comparisons were conducted according to Fischer's protected LSD test. Boxplots and residual plots were evaluated to confirm variance assumptions (Oehlert, 2000). The Kenward–Rogers method was used to calculate degrees of freedom (Littell et al., 2006).

Combining the Wisconsin, Iowa, Indiana, and Ontario data sets, which contain 17, two, one, and one environments, respectively, yield was modeled separately for the three different

Table 3. Components of the economic risk analysis including seed prices, model parameters, grain sale prices, economically optimal seeding rates, and preset seeding rates.

Seed treatment	Seed price†	Estimated parameters‡		Economically optimal seeding rate¶ Grain sale price§ (US$ kg^{-1})			Preset seeding rates¶
		Y_{max}	β	0.29	0.40	0.51	
	US$ seed^{-1}			seed ha^{-1}			
Untreated control	0.00036	5084	1.5×10^{-5}	272,557	293,431	309,242	(345,800)#
							296,400
							247,000
							197,600
							148,200
							98,800
Commercial base (CB)	0.00044	5211	1.6×10^{-5}	256,164	276,620	292,112	345,800
							296,400
							247,000
							197,600
							148,200
							98,800
CB plus fluopyram (ILeVO)	0.00054	5361	1.5×10^{-5}	255,010	276,519	292,809	345,800
							296,400
							247,000
							197,600
							148,200
							98,800

† Based on a combination price of one soybean seed unit (140,000 seeds for $50) and a seed treatment of untreated control ($0 unit^{-1}), CB ($12 unit^{-1}), or ILeVO ($25 unit^{-1}).

‡ Parameters are estimated using Eq. [1] and substituted into Eq. [2] to randomly draw partial profit ($ ha^{-1}). Y_{max} is the estimated, asymptotic yield maximum, and β is the responsiveness of yield (kg ha^{-1}) as seeding rate increases for each seed treatment.

§ The three grain sale prices were used throughout the analysis to determine the economically optimal seeding rate and economic risk for each seed treatment and seeding rate combination.

¶ Both economically optimal seeding rate and preset seeding rates are used in Eq. [2] as the seeding rate for each seed treatment.

Untreated seed at 345,800 seed ha^{-1} is the base case for comparison in the economic risk analysis.

seed treatments using a negative exponential equation to quantify the relationship between SR and yield (Gaspar et al., 2015a):

$$\text{Yield} = Y_{max}(1 \quad e^{-\beta \text{SR}}) \qquad [1]$$

The Michigan data set and the West Lorne, ON, environment were not included in this model because of their considerably higher CV values (28 and 47%) compared with the other data sets.

The nonlinear least squares function in RStudio (RStudio, 2012) was used to estimate the parameters Y_{max} and β to determine the response of yield (kg ha^{-1}) to SR (seed ha^{-1}) for each seed treatment (Table 3). In Eq. [1], Y_{max} is the estimated asymptotic yield maximum, and β determines the responsiveness of yield as SR changes. Therefore, a smaller β indicates that a higher SR is needed to reach maximum yield for any given seed treatment.

Economic Risk Analysis

An economic risk analysis was conducted according to a three-step process described in detail by Gaspar et al. (2015a). This methodology uses Monte Carlo simulation to account for the variation in the model parameter estimates in Eq. [1] (Y_{max} and β) and ultimately the uncertainty of each SR, including an EOSR, and seed treatment increasing profit across various environments compared with a predetermined base case of untreated seed at 345,800 seed ha^{-1}. The result is a Monte Carlo estimate of the break-even probability for each seed treatment at each SR, that is, the probability that a treatment combination (SR + seed treatment) will generate increased profit over the base case. Furthermore, this method quantifies the upside potential and downside economic risk for each treatment combination by estimating the average response of just positive outcomes and just negative outcomes separately in addition to the average profit of all outcomes, positive or negative.

Three grain sale prices and three seed prices (SPs), based on the cost of seed treatment (Table 3), were used in addition to Eq. [1–3] to perform the profit and economic risk analysis. Partial profit (US$ ha^{-1}) calculated using Eq. [2] is revenue minus costs, or the product of the soybean grain sale price (GSP, US$ kg^{-1}) and yield as defined by Eq. [1], minus the product of the SP (US$ unit^{-1}) and the chosen SR (seed ha^{-1}):

$$\text{Partial profit} = \text{GSP}\left[Y_{max}\left(1 - e^{-\beta \text{SR}}\right)\right] - (\text{SP} \times \text{SR}) \qquad [2]$$

Partial profit only includes costs associated with seed and seed treatment and not other production costs such as land rent, as that does not affect the economics of SR or seed treatment decisions. Equation [3] is the result of taking the first derivative of Eq. [2] with respect to the SR (seed ha^{-1}) and produces the EOSR (seed ha^{-1}) for a given SP (US$ unit^{-1}), depending on the seed treatment, and soybean GSP (US$ kg^{-1}) and is displayed in Table 3

Table 4. Analysis of variance for early-season (V2) soybean plant stand for the Wisconsin–complete (WI-C), WI–sudden death syndrome (WI-SDS), Iowa, Indiana, Michigan, and Ontario data sets.

Source	WI-C†	WI-SDS†	Iowa	Indiana	Michigan	Ontario
	$P > F$‡					
Environment (E)	<0.0001	0.0007	0.0199	na§	na	0.0036
Seed treatment (ST)	<0.0001	0.0257	0.0371	0.1374	<0.0001	<0.0001
Seeding rate (SR)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
E × ST	<0.0001	<0.0001	0.5634	na	na	<0.0001
E × SR	<0.0001	0.0565	0.1174	na	na	0.1761
ST × SR	0.4471	0.9927	0.6220	0.1669	0.3985	0.1295
E × ST × SR	0.8312	0.2433	0.3789	na	na	0.7009

† WI-C data set contains 20 environments, while the WI-SDS data set contains only Wisconsin environments where foliar sudden death syndrome symptoms developed.

‡ Probability of a larger *F*-value by chance among environment, seed treatment, seeding rate, and their interactions.

§ na, not available because of a single environment in that data set.

$$\mathrm{EOSR} = \ln\left(\frac{\mathrm{SP}}{\mathrm{GSP}\times\beta\times Y_{\max}}\right)\times\frac{-1}{\beta} \qquad [3]$$

RESULTS AND DISCUSSION

Growing conditions were diverse amongst the environments because of differences in soil type and weather conditions. Most Wisconsin locations during 2015 experienced slightly greater than normal precipitation during May, with precipitation being adequate for the whole growing season (Table 1). During 2016, Wisconsin experienced an abnormally cold and wet period from 9 May through 17 May, which was after all trials had been seeded, providing seedlings prolonged exposure to various pathogens and insects. After this period, temperature returned to normal throughout the remainder of the growing season except for late July, when temperatures exceeded normal. For Indiana, May was abnormally cool, but the remainder of the growing season experienced above average temperatures. The Michigan location experienced near average precipitation during the month of May (Table 1); however, the majority of May precipitation fell in a single event immediately after planting. This resulted in reduced stands at the Michigan location, but thereafter, growing conditions were favorable. Early-season growing conditions at the Iowa locations were below average in precipitation (Table 1). The remainder of the growing season had above-average temperature with multiple precipitation events in August. In both of the Ontario trials, substantially less precipitation occurred during May, which continued through the rest of the growing season accompanied with above-average temperatures (Table 1). Particularly, the West Lorne location experienced greater drought conditions than Highgate. Overall, during 2015 in Wisconsin and 2016 across all locations, near optimal growing conditions prevailed, leading to record soybean yields in 2015 and then again in 2016 (USDA–NASS, 2016).

Plant Stand

Seed treatment affected early-season plant stands in each data set except for Indiana, whereas SR affected plant stand in all data sets (Table 4). Excluding Indiana, both ILeVO and CB increased stands over the UTC (Table 5). Increases in early-season plant stand from a fungicide plus insecticide seed treatment compared with UTC has been frequently documented (Gaspar and Conley, 2015; Gaspar et al., 2015a,b; Cox and Cherney, 2011). However, the addition of fluopyram, which is the component that differentiates the ILeVO treatment from CB, resulted in numerically lower plant stands than CB across all data sets and was significant in the WI-complete and Ontario data sets (Table 5). The difference between ILeVO and CB was <9000 plants ha^{-1} across all data sets and <15,000 plants ha^{-1} between CB and the UTC (excluding Michigan). Ultimately, the effect of seed treatment on early-season plant stands is field and year specific as evident by the interaction between environment and seed treatment in three of four data sets (Table 4). Yet, farmers may consider slightly increasing their SR when including fluopyram in their seed treatment or planting untreated seed to obtain similar stands as a fungicide plus insecticide seed treatment.

Seed Yield

Seed treatment affected soybean seed yield in four of the six data sets (Table 6), and the yield response to each seed treatment differed among these four data sets (Table 7). In the WI-SDS and Iowa data sets, ILeVO yielded more than both CB and the UTC. The Michigan data set showed ILeVO and CB yield similarly but were both greater than the UTC, whereas the WI-complete data set showed ILeVO yielding the greatest (5007 kg ha^{-1}) followed by CB (4906 kg ha^{-1}) and then the UTC (4758 kg ha^{-1}). The ILeVO treatment exhibited greater yields than CB in three data sets (WI-complete, WI-SDS, and Iowa) signifying that the addition of fluopyram to ILeVO was responsible for the yield increase. Kandel et al. (2016a) also demonstrated yield increases from fluopyram; however, the response was dependent on SDS disease levels. A similar

Table 5. Main effect means for early-season plant stand for the Wisconsin–complete (WI-C), WI–sudden death syndrome (WI-SDS), Iowa, Indiana, Michigan, and Ontario data sets for the three seed treatments and six seeding rates.

Source	Early-season (V2) plant stand					
	WI-C	WI-SDS	Iowa	Indiana	Michigan	Ontario
	plant ha^{-1}					
Seed treatment						
Commercial base plus fluopyram (ILeVO)	193,260b†	196,797a	193,712a	204,427a	143,868a	163,099b
Commercial base (CB)	197,138a	200,616a	194,295a	209,626a	147,019a	171,309a
Untreated control	182,595c	189,652b	182,684b	201,918a	107,927b	156,067c
LSD(0.05)†	2949	4708	9947	7771	12,508	5844
Seeding rate (seed ha^{-1})						
345,800	288,701a	291,853a	282,701a	323,498a	222,461a	258,056a
296,400	250,890b	255,731b	246,210b	280,819b	189,004b	218,437b
247,000	211,842c	218,252c	213,304c	225,946c	157,957c	179,154c
197,600	171,559d	176,267d	182,281d	182,192d	111,948d	143,682d
148,200	132,333e	137,275e	128,396e	134,850e	76,545e	108,715e
98,800	90,666f	94,752f	88,495f	84,639f	39,708f	72,905f
LSD(0.05)†	4172	6657	14,069	10,992	17,690	8262

† Values followed by the same letter within each column are not significantly different at $P \leq 0.05$ for seed treatment and seeding rate within each state. In addition, LSD value follows each group.

Table 6. Analysis of variance for soybean seed yield for the Wisconsin–complete (WI-C), WI–sudden death syndrome (WI-SDS), Iowa, Indiana, Michigan, and Ontario data sets.

Source	WI-C†	WI-SDS†	Iowa	Indiana	Michigan	Ontario
	$P > F$‡					
Environment (E)	<0.0001	<0.0001	0.0092	na§	na	0.4359
Seed treatment (ST)	<0.0001	<0.0001	0.0010	0.1613	<0.0001	0.3181
Seeding rate (SR)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
E × ST	<0.0001	<0.0001	0.6100	na	na	0.1324
E × SR	<0.0001	<0.0001	0.7733	na	na	0.6949
ST × SR	0.3119	0.9018	0.2076	0.1019	0.9056	0.5917
E × ST × SR	0.1243	0.4493	0.4152	na	na	0.3565

† WI-C data set contains 17 environments, while the WI-SDS data set contains only Wisconsin environments with visual sudden death syndrome symptoms.

‡ Probability of a larger *F*-value by chance among environment, seed treatment, seeding rate, and their interactions.

§ na, not available because of a single environment in that data set.

Table 7. Main effect means for soybean seed yield for the Wisconsin–complete (WI-C), WI–sudden death syndrome (WI-SDS), Iowa, Indiana, Michigan, and Ontario data sets for the three seed treatments and six seeding rates.

Source	Seed yield					
	WI-C	WI-SDS	Iowa	Indiana	Michigan	Ontario
	kg ha^{-1}					
Seed treatment						
Commercial base plus fluopyram (ILeVO)	5007a†	5107a	4060a	6295a	3946a	3886a
Commercial base (CB)	4906b	4852b	3826b	6161a	4034a	3718a
Untreated control	4758c	4799b	3899b	6067a	3470b	3564a
LSD(0.05)†	44	77	124	232	270	420
Seeding rate (seed ha^{-1})						
345,800	5322a	5336a	4161a	7074a	4617a	4483a
296,400	5195b	5121b	4161a	6960a	4470a	4141ab
247,000	5081c	5087b	3966b	6631ab	4409a	3913abc
197,600	4913d	4933c	3926b	6275bc	3765b	3604bc
148,200	4658e	4745d	3725c	5732c	3208c	3530c
98,800	4181f	4302e	3631c	4369d	2416d	2671d
LSD(0.05)†	63	99	176	684	382	595

† Values followed by the same letter within each column are not significantly different at $P \leq 0.05$ for seed treatment and seeding rate within each state. In addition, LSD values follow each group.

effect was observed in the current study when comparing the yield response between ILeVO and CB in the WI-complete and WI-SDS data sets. The WI-complete data set, which included environments with and without foliar SDS disease symptomology, averaged only a 2.1% (101 kg ha^{-1}) yield increase. By comparison, the WI-SDS data set, which contained only environments with foliar SDS disease symptomology, averaged a 5.3% yield increase (255 kg ha^{-1}) (Table 7). In agreement, the Iowa data set, which also developed foliar SDS symptomology, showed a 6.1% (234 kg ha^{-1}) yield increase of ILeVO over CB. At the Michigan location, a large yield response for CB compared with the UTC was observed, but no yield difference between ILeVO and CB was detected (Table 7). This response is not surprising in light of the precipitation event that occurred immediately after planting and likely contributed to the plant stand reduction of the UTC by ~40,000 seed ha^{-1} compared with both ILeVO and CB (Table 5). Also, early-season environmental conditions in Ontario likely contributed to the lack of a yield response to both CB and ILeVO compared with the UTC (Table 7). Both trials in Ontario experienced dry and warm early-season growing condition, which are not conducive for fungal infection, particularly *F. virguliforme*. No significant yield response to CB or ILeVO was observed in Indiana. Both Indiana and Ontario displayed similar numerical differences between the three seed treatments as the WI-complete data set; however, greater variability (CV > 18%) in the Indiana and Ontario data sets compared with Wisconsin and Iowa made mean separation difficult at $P = 0.05$ (Table 7). The varying responses between data sets, in addition to seed treatment interacting with environment in both the WI-complete and WI-SDS data set, suggests that the yield response to fluopyram was environment specific regardless of foliar SDS symptomology. The lack of a trend between yield response and foliar SDS disease development may partially be due to the root rot infection of *F. virguliforme,* which can cause yield loss without foliar disease development occurring. Yet, farmers should prioritize fields with a history of SDS for application of fluopyram in combination with a commercial base fungicide plus insecticide seed treatment to maximize the yield response.

Seeding rate affected soybean seed yield in all six data sets (Table 6). In both Wisconsin data sets, greater yield was observed for each increasingly higher SR through 345,800 seed ha^{-1} (Table 7). This is slightly higher than past reports in Wisconsin, where Gaspar et al. (2015a) indicated maximum yields were attained with SRs approaching 296,400 seed ha^{-1}. The Iowa data set agreed with Gaspar et al. (2015a), attaining similar yields at SRs as low as 296,400 seed ha^{-1}, which is in line with previous findings in Iowa from De Bruin and Pedersen (2008) who showed 95% of maximum yield was reached with SRs between 199,000 and 345,800 seed ha^{-1}. The remaining data sets (Indiana, Michigan, and Ontario) showed similar yields could be obtained with SRs from 345,800 down to 247,000 seed ha^{-1}. While this does agree with Lee et al. (2008), the limited environments should be considered when interpreting the response of yield to SR in these three data sets.

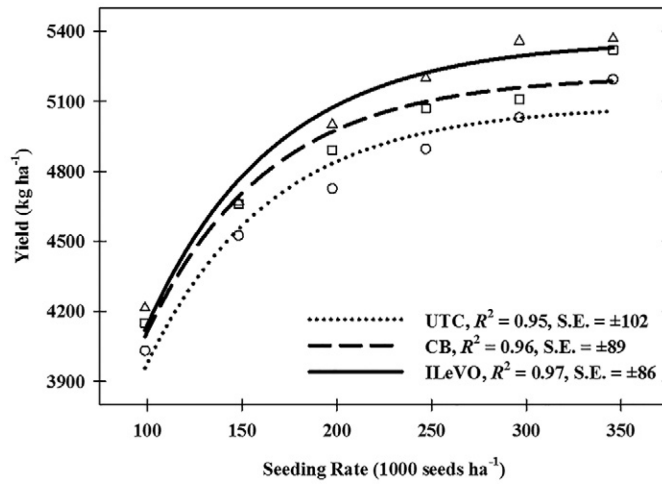

Fig. 1. Yield (kg ha^{-1}) modeled with a negative exponential model (Eq. [1]) for the untreated control (UTC; square), commercial base (CB; circle), and CB plus fluopyram seed treatment (ILeVO; triangle) across all seeding rates and environments. Shapes represent treatment means. Coefficients for the estimated model parameters for each seed treatment are listed in Table 3.

A wide range in yield and environmental conditions (Table 1) was achieved by pooling data over locations and years to capture the uncertainty of seed treatments producing positive yield gains in different environments, which is considered important by Bradley (2008) and Schulz and Thelen (2008). For that reason, the soybean yield response to SR was modeled for the three separate seed treatments (Fig. 1). Across all SRs, CB and ILeVO displayed a consistent yield advantage over the UTC. In comparison, the yield benefit of ILeVO over CB increased as SR increased, which was evident in the larger yield response of ILeVO at 345,000 seed ha^{-1} vs. 98,800 seed ha^{-1} (Fig. 1). This likely is due to the reduced plant stands associated with ILeVO vs. CB (Table 5), which at lower populations likely has a larger effect on yield than higher populations because of the plants' compensatory ability. Overall, a consistent comparison can be made at the modeled yield max (Y_{max} in the model), where CB and ILeVO increased yield over the UTC by 2.8 and 5.6%, respectively.

Farmer Return

Partial profit (US$ ha^{-1}) was affected by both seed treatment and SR for the three different grain sale prices of 0.29, 0.40, or 0.51 US$ kg^{-1} (Fig. 2). Both CB and ILeVO increased profit compared with the UTC regardless of the grain sale price and SR. In contrast, SRs greater than ~175,000 seed ha^{-1} were required before ILeVO displayed greater partial profit than CB (Fig. 2). While partial profits were reduced for the lowest grain sale price (US$0.29 kg^{-1}), CB (US$9 ha^{-1}) and to a greater extent, ILeVO (US$18 ha^{-1}) still resulted in greater partial profit than the UTC at the highest SR (345,800 seed ha^{-1}). Notably, the EOSR, or the SR corresponding to the highest point on the partial profit curves (Fig. 2), was always <345,800 seed ha^{-1} for each seed treatment and grain sale price (Table 2). When the grain sale price increased, the EOSR for each seed treatment also increased. Between grain sale prices of 0.29 and 0.51 US$ kg^{-1}, the EOSR for each seed treatment increased by 13 to 15% (Table 2), which is similar to the 12% increase reported by Gaspar et al. (2015a). The EOSRs for CB and ILeVO were nearly identical for each grain sale price, while the UTC EOSR was ~17,000 seed ha^{-1} greater than both CB and ILeVO for each grain sale price (Table 2). Cox and Cherney (2011) and Gaspar et al. (2015a) both reported a considerably greater separation (50,000 seed ha^{-1}) between the EOSR for a thiamethoxam-containing seed treatment than the UTC. Nevertheless, a similar conclusion to Gaspar et al. (2015a) was found, in which lower than currently recommended SRs (345,800 seed ha^{-1}) may increase farmer return especially at lower grain sale prices (US$0.29 kg^{-1}) and when a fungicide plus insecticide seed treatment is used. Moreover, the addition of fluopyram to a fungicide plus insecticide seed treatment (ILeVO) could further increase profit not because of cost savings from a lower SR, but rather increased yield, which more than covered the additional cost of fluopyram.

Economic Risk and Break-Even Probability

The Gaspar et al. (2015a), method of assessing economic risk was used to quantify a break-even probability over the base case (UTC at 345,800 seed ha^{-1}) and the results are displayed in Tables 8, 9, and 10 for soybean grain sale prices of 0.29, 0.40, and 0.51 US$ kg^{-1}, respectively. For example, in Table 8, ILeVO at 345,800 seed ha^{-1} had a 0.87 (87% chance) probability of increasing profit over the base case and for all simulated outcomes (all environments) increased profit by an average of US$18 ha^{-1}. In addition, an average US$22 ha^{-1} increase was observed for the positive simulated outcomes and an average US$8 ha^{-1} loss for the negative simulated outcomes. The positive outcomes column represents responsive environments (upside potential), while the negative outcomes column represents nonresponsive environments (downside risk) (Table 8–10). Approximately 50% of the environments used in this analysis developed foliar SDS symptomology.

At a grain sale price of US$0.29 kg^{-1} (Table 8), a SR reduction to 296,000 seed ha^{-1} provided substantial risk benefits (0.99), but profit was only increased US$9 ha^{-1}, on average. In comparison, the same SR reduction for CB maintained similar risk benefits (0.93) but also provided a much larger average profit increase (US$22 ha^{-1}) with limited downside potential (−US$7 ha^{-1}) only 7% of the time. Gaspar et al. (2015a) found similar break-even

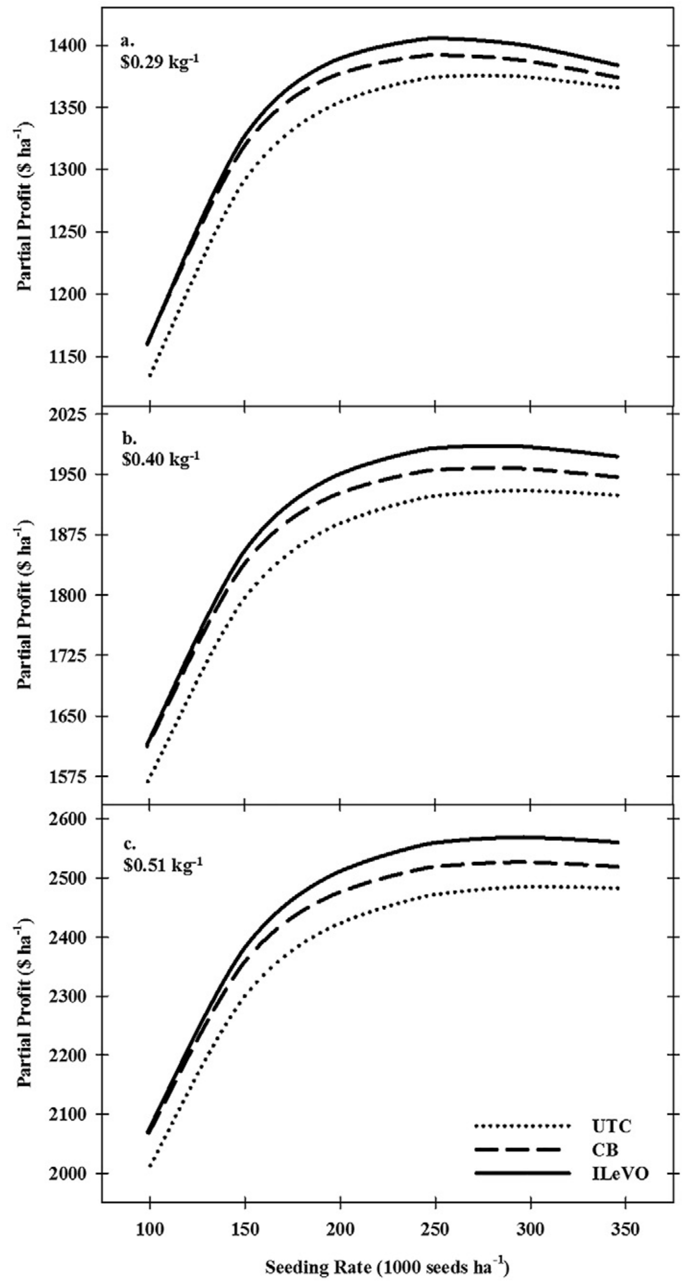

Fig. 2. Partial profit (US$ h^{-1}) of the untreated control (UTC; dotted), commercial base (CB; dashed), and CB plus fluopyram (ILeVO; solid) seed treatments across all seeding rates and environments for grain sale prices of (a) $0.29 kg^{-1}, (b) $0.40 kg^{-1}, and (c) $0.51 kg^{-1}.

probabilities for CruiserMaxx (a.i. thiamethoxam, mefanoxam, and fludioxynil), a fungicide plus insecticide seed treatment, and slightly higher average profit increases at a grain sale price of US$0.33 kg^{-1}. Furthermore, ILeVO, or the addition of fluopyram to CB at 296,400 seed ha^{-1}, improved upon the risk benefits of CB to an almost identical level as UTC (0.98) and provided considerably greater average profit increases for all outcomes (US$34 ha^{-1}) and positive outcomes (US$35 ha^{-1}) (Table 8). Not only were the benefits of CB and ILeVO present at slightly reduced SRs (296,400 seed ha^{-1}) but also across a wide range of

Table 8. Resulting break-even probabilities and average profit increases from the economic risk analysis for each seed treatment by seeding rate combination at a grain sale price of $0.29 kg⁻¹.

Treatment combination†		Break-even prob-ability§	Avg. profit increase over the base case‡		
Seed treatment	Seeding rate		Positive outcomes	All outcomes	Negative outcomes
	seed ha⁻¹			US$ ha⁻¹	
Untreated control (UTC)	296,400	0.99	9	9	na
	247,000	0.97	8	8	–2
	197,600	0.04	3	–13	–14
	148,200	0.00	na¶	–78	–78
	98,900	0.00	na	–236	–236
Commercial base (CB)	345,800	0.70	16	9	–10
	296,400	0.93	24	22	–7
	247,000	0.97	27	26	–6
	197,600	0.76	15	10	–8
	148,200	0.01	4	–50	–51
	98,900	0.00	na	–206	–206
CB plus fluopyram (ILeVO)	345,800	0.87	22	18	–8
	296,400	0.98	35	34	–6
	247,000	0.99	40	39	–5
	197,600	0.95	23	22	–6
	148,200	0.01	7	–43	–43
	98,900	0.00	na	–206	–206
UTC	EOSR#	0.99	10	10	–1
CB	EOSR	0.97	28	27	–6
ILeVO	EOSR	0.99	40	40	–6

† Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.

‡ Base case is untreated control at 345,800 seed ha⁻¹.

§ Break-even probability is the probability that a treatment combination will at least provide the same profit (US$ ha⁻¹) as the base case.

¶ na, no outcome found.

EOSR, economically optimal seeding rate.

Table 9. Resulting break-even probabilities and average profit increases from the economic risk analysis for each seed treatment by seeding rate combination at a grain sale price of $0.40 kg⁻¹.

Treatment combination†		Break-even prob-ability‡	Avg. profit increase over the base case§		
Seed treatment	Seeding rate		Positive outcomes	All outcomes	Negative outcomes
	seed ha⁻¹			US$ ha⁻¹	
Untreated control (UTC)	296,400	0.99	6	6	–1
	247,000	0.38	3	–2	–5
	197,600	0.00	na¶	–38	–38
	148,200	0.00	na	–134	–134
	98,900	0.00	na	–358	–358
Commercial base (CB)	345,800	0.85	29	23	–11
	296,400	0.95	36	33	–9
	247,000	0.94	33	31	–8
	197,600	0.50	15	0	–15
	148,200	0.00	na	–91	–91
	98,900	0.00	na	–313	–313
CB plus fluopyram (ILeVO)	345,800	0.98	49	48	–9
	296,400	0.99	61	60	–8
	247,000	0.99	58	58	–8
	197,600	0.90	27	23	–9
	148,200	0.00	8	–76	–76
	98,900	0.00	na	–310	–310
UTC	EOSR#	0.99	6	6	–1
CB	EOSR	0.96	36	34	–9
ILeVO	EOSR	0.99	62	62	–7

† Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.

‡ Break-even probability is the probability that a treatment combination will at least provide the same profit (US$ ha⁻¹) as the base case.

§ Base case is untreated control at 345,800 seed ha⁻¹.

¶ na, no outcome found.

EOSR, economically optimal seeding rate.

SRs from 197,600 to 345,800 seed ha^{-1}. The opposite was true for the UTC, in which SRs below 247,000 seed ha^{-1} and approaching 197,600 seed ha^{-1} were very risky (<0.04) and resulted in profit loss for all outcomes. Ultimately, at a grain sale price of US$0.29 kg^{-1}, the EOSR for each seed treatment provided its respective greatest break-even probability and largest average profit increase. Across all SRs and seed treatments, however, the lowest risk (0.99) and largest average profit increase for all outcomes (US$40 ha^{-1}) was ILeVO at its EOSR (255,000 seed ha^{-1}).

When the grain sale price increased from 0.29 kg^{-1} to 0.40 (Table 9) and 0.51 US$ kg^{-1} (Table 10), reducing the SR below 296,400 seed ha^{-1} for the UTC decreased the break-even probabilities well below 0.50, resulting in profit losses across all outcomes of increasing magnitude as the SR was lowered further. In contrast, CB was able to maintain high break-even probabilities and profit margins down to 247,000 seed ha^{-1}, while ILeVO did so down to 197,600 seed ha^{-1} for both the 0.40 and 0.51 US$ kg^{-1} grain sale prices. This highlights a key finding that as grain sales prices increase so should SRs to reduce economic risk and maximize profit, especially for untreated seed, whereas CB and ILeVO treated seed still maintained higher break-even probabilities and profit margins at reduced SRs. Yet, SR adjustments were still warranted with these seed treatments to maximize profit and reduce risk as grain sale prices changed. For instance, CB at 197,600 seed ha^{-1} with a grain sale price of US$0.29 kg^{-1} had its break-even probability decrease from 0.76 to 0.50 and 0.34 for grain sale prices of 0.40 and 0.51 US$ kg^{-1}, respectively. The average profit increase for all outcomes also declined in a stepwise fashion (10, 0, −10 US$ ha^{-1}) (Table 8–10). Like the lowest grain sale price (US$0.29 kg^{-1}), simply adjusting the SR for CB and ILeVO to the highest SR (345,800 seed ha^{-1}) at higher grain sale prices did not maximize the average profit increase across all outcomes nor did it provide the greatest risk benefit (Table 9, 10). This was achieved only at the EOSR for both CB and ILeVO, which was ~277,000 and 292,500 seed ha^{-1} for the 0.40 and 0.51 US$ kg^{-1} grain sale prices, respectively (Table 3).

Table 10. Resulting break-even probabilities and average profit increases from the economic risk analysis for each seed treatment by seeding rate combination at a grain sale price of \$0.51 kg^{-1}.

Treatment combination†		Break-even prob-ability‡	Avg. profit increase over the base case§		
Seed treatment	Seeding rate		Positive outcomes	All outcomes	Negative outcomes
	seed ha^{-1}		———	US\$ ha^{-1}	———
Untreated control (UTC)	296,400	0.83	3	2	−2
	247,000	0.03	2	−12	−13
	197,600	0.00	na¶	−63	−63
	148,200	0.00	na	−190	−190
	98,900	0.00	na	−480	−480
Commercial base (CB)	345,800	0.91	42	37	−13
	296,400	0.95	47	44	−11
	247,000	0.92	39	35	−11
	197,600	0.34	16	−10	−23
	148,200	0.00	na	−132	−132
	98,900	0.00	na	−419	−419
CB plus fluopyram (ILeVO)	345,800	0.98	78	78	−10
	296,400	0.99	87	87	−7
	247,000	0.98	76	76	−9
	197,600	0.85	32	25	−12
	148,200	0.01	14	−108	−108
	98,900	0.00	na	−414	−414
UTC	EOSR#	0.94	3	3	−1
CB	EOSR	0.96	47	45	−11
ILeVO	EOSR	0.99	87	87	−7

† Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.

‡ Break-even probability is the probability that a treatment combination will at least provide the same profit (US\$ ha^{-1}) as the base case.

§ Base case is untreated control at 345,800 seed ha^{-1}.

¶ na, no outcome found.

EOSR, economically optimal seeding rate.

Regardless of the grain sale price (Table 9–10), CB and, to a greater extent, ILeVO were able to considerably lower risk and increase profit across a wide range of SRs (197,000–345,800 seed ha^{-1}), unlike the UTC, where reducing the SR to 296,400 seed ha^{-1} only provided risk benefits but not substantial profit increases. Looking across all grain sale prices (Table 8–10) and holding the SR at currently recommended levels (345,800 seed ha^{-1}), CB reduced risk and significantly increased profit across all outcomes compared with the UTC, similar to the benefits of CruiserMaxx seed treatment that were documented by Gaspar et al. (2015a). The addition of fluopyram to CB, which created ILeVO, further enhanced the risk benefits and profit increases over those of CB at 345,800 seed ha^{-1}. The lowest risk and greatest average profit increase for all outcomes was always achieved by ILeVO at its EOSR when compared with any other SR × seed treatment combination for each grain sale price (Table 4–6). Nonetheless, both CB and ILeVO at their EOSR provided nearly identical break-even probabilities (0.96–0.99) but with greater average profit increases occurring for ILeVO compared with CB at each grain sale price. Therefore, even at lower grain sale prices, clear economic risk benefits were associated with CB and ILeVO with greater profit increases for ILeVO compared with CB.

CONCLUSIONS

This study built on the work reported by Gaspar et al. (2015a) to determine if a target-specific seed treatment (fluopyram) could be an economically viable option for farmers. Kandel et al. (2016a) found that ILeVO could increase soybean yield but noted yield responses were related to SDS disease levels. Our study confirmed these findings in that the yield response to seed treatment was environment specific, and across all environments, the modeled yield response to fluopyram was 2.8% compared with 5.3 and 6.1% when foliar SDS symptomology was present. In addition, profit and economic risk benefits were substantial for CB and, to a greater extent, ILeVO (CB + fluopyram), compared with the UTC when considering all associated costs. The CB and ILeVO treatments were able to decrease risk and substantially increase profit across a wide range of SRs, whereas the UTC increased risk when SRs moved below 296,400 seed ha^{-1} for the 0.40 and 0.51 US\$ kg^{-1} grain sale prices and average profit increases were always minimal or negative (<US\$9 ha^{-1}). At current seed and seed treatment costs, CB and ILeVO at 345,800 seed ha^{-1} reduced economic risk (>0.70) and increased average profit (9–78 US\$ ha^{-1}) across an array of realistic environments and grain sale prices (0.29–0.51 US\$ kg^{-1}). However, to realize the lowest risk and highest average profit increase with CB or ILeVO, farmers should consider lowering their SR to the EOSR (255,000–293,000 seed ha^{-1}) according to their expected grain sale price and particularly target fields with a history of SDS and risk of damage from early-season insects and pathogens to maximize the return.

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