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Comparing High- and Low-Input Management on Soybean Yield and Profitability in Michigan

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Abstract

Increased commodity prices, commercial marketing, and convenience have encouraged soybean [*Glycine max* (L.) Merr.] producers to adopt high-input management systems for maximum grain yield regardless of soil or plant tissue nutrient concentrations, soil physical properties, or disease pressure. A three site-year trial was established in Michigan to investigate soybean grain yield and profitability in response to commonly recommended inputs, including poultry litter (PL), potassium thiosulfate (KTS), foliar micronutrient, and fungicide applications across intensive (i.e., high-input) and traditional (i.e., low-input) management systems. Across all site-years, intensive management did not significantly increase soybean grain yield compared with traditional management. No single input applied significantly increased grain yield as suggested by an absence of visible nutrient deficiencies and minimal foliage disease in either growing season. In addition, traditional management significantly increased producer economic net return by an average of $203/acre. Potassium thiosulfate significantly decreased net return in one of three site-years while PL significantly decreased net return in all three site-years due to a lack of positive yield response and high individual input costs. Data suggest limited potential for intensive management systems to increase soybean grain yield and profitability without the presence of yield-limiting factors (e.g., disease pressure and nutrient deficiencies). Practitioners should consider site-specific soil properties and the likelihood of a grain yield response prior to broad-scale implementation of soil fertility and plant nutrition programs.

Utilizing Multiple Inputs to Improve Soybean Production

Since 2007, soybean commodity prices increased 21% compared with a 1% decrease for corn (*Zea mays* L.) (USDA-NASS, 2017). During this same time, soybean yield and total acres planted in Michigan increased by 8 and 28%, respectively (USDA-NASS, 2017). Increased prices paid and commercial marketing have encouraged soybean producers to adopt high-input management in which a greater number of agronomic inputs are applied to maximize yield and profitability (Gregg et al., 2015; Marburger et al., 2016; Orlowski et al., 2016). Additionally, increased adoption of intensive soybean systems combined with the introduction of new genetics have some individuals questioning older (>20 years) university nutrient recommendations (Vitosh et al., 1995; Fulford and Culman, 2018). However, many of the inputs being applied contain limited,

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Core Ideas

- Both profitability and grain yield should be considered prior to adopting intensive management systems.
- No single input positively impacted economic net return.
- Traditional management increased economic net return on average $203/acre.
- In lieu of broad-scale implementation, practitioners should consider soil physical and chemical properties and the likelihood of grain yield response before determining specific input applications.

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Abbreviations: IPM, integrated pest management; KTS, potassium thiosulfate; PL, poultry litter; R1, beginning bloom; R3, beginning pod development; SOM, soil organic matter; Zn, zinc.

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

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
9.35	US gallon per acre, gal/acre	liters per hectare, L/ha
0.304	foot, ft	meter, m
67.19	60-lb bushel per acre, bu/acre	kg/ha

unbiased information validating the proposed benefits (Marburger et al., 2016).

Poultry litter has generated recent interest due to purported soil quality and ensuing grain yield benefits compared with inorganic nitrogen (N), phosphorus (P), and potassium (K) fertilization (Adeli et al., 2005; Watts and Torbert, 2011). Adeli et al. (2005) observed 8–10% yield increases from at-plant PL applications compared with inorganic fertilizers due to added availability of secondary and micronutrients. Direct manure application to soybean can enhance plant biomass, nutrient uptake, nutritional status, and grain P, K, secondary, and micronutrient concentrations (Adeli et al., 2005; Slaton et al., 2013). In addition, continuous applications of poultry litter (PL) may increase concentrations of soil macro- and micronutrients, soil organic matter (SOM), and soil cation exchange capacity and decrease risk from soybean cyst nematode (Wood et al., 2008; Morant et al., 1997; Adeli et al., 2005; Watts et al., 2010).

Increased grain yields, more frequent weather volatility, and decreased atmospheric sulfur (S) deposition have driven producers to consider in-season soybean K and S applications (Dick et al., 2008; Kaiser and Kim, 2013). In-season potassium thiosulfate (KTS) applications give producers the flexibility to address both K and S deficiencies in a single application. In-season K applications can provide additional K during peak soybean uptake (Bender et al., 2015; Gaspar et al., 2017) and minimize potential yield-limiting K deficiencies caused by variable soil properties, management practices, and environmental conditions (Nelson et al., 2005). However, positive results from in-season K applications often depend on soil test K levels and environmental conditions (Haq and Mallarino, 2000; Nelson et al., 2005). Soybean response to S is often site-specific, depending on SOM, crop rotation, and S mineralization (Kaiser and Kim, 2013). Under conditions with sufficient S tissue concentrations, Bluck et al. (2015) did not observe a positive soybean yield response to S fertilization across 10 Ohio locations. Kaiser and Kim (2013) observed a positive soybean grain yield response to S when SOM was < 2%. Previous trials have concluded that consideration of all potential S sources (i.e., SOM, residual soil S, S-deposition, and fertilizer S) is critical when determining soybean S requirements (Kaiser and Kim, 2013; Thurgood, 2014).

Suggested low micronutrient availability due to more intensive cropping systems, greater nutrient removal, and increased purity of synthetic fertilizers have producers utilizing foliar micronutrient applications (Dewal and Pareek, 2004; Alloway, 2008). However, yield increases are seldom observed (Bluck et al., 2015; Enderson et al., 2015; Mallarino et al., 2017). In Ohio, Bluck et al. (2015) observed a significant yield increase from Mn application due to reduced plant availability on a dry, coarse-textured soil. Enderson et al. (2015) and Sutradhar et al. (2017) concluded foliar- or soil-applied boron (B), manganese (Mn), and zinc (Zn) individually and in combination did not significantly increase yield across 54 locations. Mallarino et al. (2017) summarized 88–99 field trials from Iowa, Kansas, and Minnesota and observed only one significant yield response to Mn application and no significant responses to applied Zn and B.

Despite below-threshold levels of disease, growers are increasingly adopting prophylactic fungicide applications to increase soybean yield (Swoboda and Pedersen, 2009; Henry et al., 2011; Mourtzinis et al., 2016). Strobilurin-based fungicides have displayed effectiveness against varying types of fungi and plant physiological enhancements (e.g., increased leaf greenness, water use efficiency) in the absence of disease (Grossmann and Retzlaff, 1999; Bartlett et al., 2002). However, positive yield responses were inconsistent. Henry et al. (2011) and Orlowski et al. (2016) observed soybean yield increases of 3.5 and 4.6% from pyraclostrobin applications, respectively, in the absence of disease. In contrast, Swoboda and Pedersen (2009), Gregg et al. (2015), and Ng et al. (2018) found no differences in soybean grain yield from fungicide applications within an environment lacking disease pressure.

Until recently, few studies have examined soybean response to specific inputs applied across various management systems (Bluck et al., 2015; Marburger et al., 2016; Orlowski et al., 2016). Driven by industry promotion, perceived nutrient deficiencies, potential plant health benefits, and convenience of adoption, Michigan soybean producers often utilize applications of PL, KTS, foliar micronutrients, and fungicide regardless of soil and tissue nutrient concentrations or disease pressure. The objective of this trial was to investigate soybean grain yield and economic net return in response to PL, KTS, micronutrient, and fungicide applications across intensive (i.e., high-input) and traditional (i.e., low-input) production systems.

Locations and Site Descriptions

Trials were initiated at the Saginaw Valley Research and Extension Center near Richville, MI (43°23′57.3″N, 83°41′49.7″W) on Tappan-Londo loam soil (fine-loamy, mixed, active, calcareous, mesic Typic Enduaquolls) in 2016 and at Richville

Table 1. Soil descriptions, chemical properties, and mean nutrient concentrations (0–8 inches) obtained prior to soybean planting, Richville and Lansing, MI, 2016–2017.

Site	Year	Soil description	Soil test†							
			P	K	S	B	Mn	Zn	pH	OM
			ppm							%
Richville	2016	Tappan-Londo Loam	48	182	8	1.6	44	6	7.1	3.0
	2017	Tappan-Londo Loam	30	191	7	1.7	40	5.8	7.7	2.8
Lansing	2017	Capac Loam	39	117	7	0.6	34	2.9	6.5	3.2

†P phosphorus (Bray–P1); K potassium (ammonium acetate extractable K); Zn zinc (0.1 M HCl); Mn, manganese (0.1 M HCl); B, boron (hot-water extraction).

and the South Campus Field Research Farm in Lansing, MI (42°42′37.0″N, 84°28′14.6″W) on a Capac loam soil (fine-loamy, mixed, active, mesic Aquic Glossudalfs) in 2017. Fields were non-irrigated, previously cropped to corn, and cultivated prior to planting. Pre-plant soil samples were taken at an 8-inch depth and analyzed for soil chemical properties (Table 1).

Experimental Procedures for Input Evaluation

Trials were arranged in a randomized complete block design with four replications and utilized an omission treatment design (Table 2). Omission treatment designs utilize two treatment controls, one containing all applied inputs (i.e., intensive treatment) and another containing no applied inputs (i.e., traditional treatment) (Bluck et al., 2015; Ruffo et al., 2015; Quinn and Steinke, 2019). To evaluate treatment effects, inputs are individually removed from the intensive system and compared only to the intensive treatment while inputs individually added to the traditional system are compared only to the traditional treatment (Bluck et al., 2015; Ruffo et al., 2015; Quinn and Steinke, 2019).

Individual six-row plots measured 15 × 40 ft (30-inch row spacing). Plots were planted with a Monosem planter (Monosem Inc., Edwardsville, KS) on 9 May 2016 at Richville and on 28 Apr. 2017 and 12 May 2017 at Richville and Lansing, respectively. Soybean cultivar 'Asgrow 2433' (Monsanto Co., St. Louis, MO) was seeded across site-years to a population of 140,000 seeds/acre. Poultry litter (4–3–2 N–P–K) was broadcast and incorporated prior to planting at a rate of 1 ton/acre. Potassium thiosulfate fertilizer (0–0–25–17 N–P–K–S) was surface-banded at R1 at a rate of 3 gal/acre. Foliar Zn, Mn, and B (Max-In Ultra ZMB, 4% Zn [EDTA], 3% Mn [EDTA], 0.1% B [boric acid]; Winfield United LLC., St. Paul, MN) and fungicide (Stratego YLD; prothioconazole and trifloxystrobin; Bayer CropScience Research Triangle Park, NC) were applied at R1 (64 oz/acre) and R3 (4.7 oz/acre), respectively, utilizing a backpack sprayer calibrated to a volume of 15 gal/acre.

Leaf nutrient analysis was collected from the uppermost, fully developed trifoliate of 20 plants per plot. Mean monthly temperature and total cumulative precipitation were recorded throughout the growing season and obtained from Enviro-weather (http://www.agweather.geo.msu.edu/mawn/, Michigan State University, East Lansing, MI). Grain yield was harvested from the center 5 ft of each plot using a small-plot combine (Almaco, Nevada, IA) on 11 Oct. 2016 at Richville and 2 Oct. 2017 at Richville and Lansing and adjusted to 13.5% moisture. Economic net returns were calculated by subtracting total treatment cost from gross revenue (soybean cash price estimates of $9.34/bu in 2016 and $8.76 and $8.82/bu in 2017 for Richville and Lansing, respectively, × grain yield) (Table 3). Harvest cash price estimates were obtained from local grain elevators.

Statistical Analysis

Results were determined significantly different between years ($P \leq 0.10$) and analyzed separately. Replication was considered a random factor with all other factors considered fixed. Data analysis was performed in SAS Version 9.4 (SAS Institute, 2012) using the GLIMMIX procedure at $\alpha = 0.10$. Single degree-of-freedom contrasts were used to assess differences between treatment means. Factors removed from the intensive management system are contrasted only to the intensive treatment containing all inputs, and factors added

Table 2. Overview of omission trial design, treatment names, and inputs applied, 2016–2017.

Treatment	Treatment name	Agronomic input applied			
		PL†	KTS‡	Micro§	Fungicide¶
1	Intensive (I) #	Yes	Yes	Yes	Yes
2	I- PL	No	Yes	Yes	Yes
3	I- KTS	Yes	No	Yes	Yes
4	I- Micro	Yes	Yes	No	Yes
5	I- Fungicide	Yes	Yes	Yes	No
6	Traditional (T)††	No	No	No	No
7	T + PL	Yes	No	No	No
8	T + KTS	No	Yes	No	No
9	T + Micro	No	No	Yes	No
10	T + Fungicide	No	No	No	Yes

† Poultry Litter (PL) pre-plant incorporated at a rate of 1 ton/acre.

‡ Potassium thiosulfate (KTS) surface-banded at a rate of 3 gal/acre at R1.

§ Foliar micronutrients (micro) containing Zn, Mn, and B applied at a rate of 64 oz/acre at R1.

¶ Prothioconazole + trifloxystrobin fungicide applied at a rate of 4.7 oz/acre at R3.

Intensive treatment containing all agronomic inputs.

†† Traditional treatment containing no fertilizer or additional inputs (i.e., check).

Table 3. Product and application cost values utilized for economic net return analysis, 2016–2017.

Cost type	Input	2016	2017
		—— $/ac ——	
Product†	Poultry litter (PL)	144.00	134.00
	Potassium thiosulfate (KTS)	14.00	14.00
	Foliar micronutrient (Micro)	14.00	12.75
	Fungicide	17.25	17.11
Application	PL broadcast application	7.50	7.00
	KTS surface-band application	14.00	14.00
	Micro foliar spray application	7.50	7.00
	Fungicide foliar spray application	7.50	7.00

† Product and application costs obtained from local agriculture retailers in 2016 and 2017.

to the traditional management system are contrasted only to the traditional treatment containing no inputs.

Intensive vs. Traditional Management Systems

No significant yield differences were observed between the intensive and traditional treatments (Table 4). Individual site-years experienced below-average rainfall, minimal foliar disease, and ≥ 2.8% SOM; thus, the capacity to supply sufficient nutrients. Environmental conditions contributed to nonsignificant input responses since adverse conditions (e.g., disease pressure and nutrient deficiencies) warranting specific input applications were not present. Results are supported by research from Ohio, Kentucky, and Wisconsin, which also observed inconsistent and nonsignificant soybean yield increases from multiple input applications without the presence of adverse environmental conditions (Bluck et al., 2015; Gregg et al., 2015; Mourtzinis et al., 2016).

Table 4. Soybean grain yield for Richville and Lansing, MI, 2016–2017. Mean grain yield of intensive and traditional control treatments displayed. All other treatments represent change in grain yield from respective intensive or traditional control treatment utilizing single degree-of-freedom contrasts.

Treatment†	2016 Richville	2017 Richville	2017 Lansing
	—— bu/acre ——		
Intensive (I)‡	64.2	55.5	58.3
I- PL¶	+3.7	–4.7	–6.8
I- KTS	+4.2	–3.1	–4.3
I- Micro	+0.6	–2.4	–1.6
I- Fungicide	+1.6	+1.7	–0.7
Traditional (T)§	66.4	53.3	53.5
T + PL#	–3.7	–0.0	+2.1
T + KTS	–2.9	+1.1	–1.8
T + Micro	–0.1	+2.1	–1.1
T + Fungicide	+0.7	+4.0	–0.9
I vs. T††	ns‡‡	ns	ns

† Poultry litter (PL); potassium thiosulfate (KTS); foliar-applied Zn, Mn, and B (micro); and prothioconazole + trifloxystrobin fungicide.

‡ Intensive treatment containing all agronomic inputs.

§ Traditional treatment containing no fertilizer or additional inputs (i.e., check).

¶ Values in I – input rows indicate a yield (bu/ac) change from respective intensive (I) treatment.

Values in T + input rows indicate a yield (bu/ac) change from respective traditional (T) treatment.

†† Comparison between the intensive and traditional treatment utilizing single degree-of-freedom contrasts.

‡‡ Nonsignificant a = 0.10 using single degree-of-freedom contrasts.

Impact of Input Application on Economic Net Return

The traditional treatment was significantly more profitable (+$203/acre) across all three site-years (Table 5). Potassium thiosulfate significantly decreased net return in one of three site-years while PL significantly decreased net return across all site-years. Decreased net return was due to the lack of positive yield response to input application and input costs. Poultry litter had the greatest cost of all the applied inputs and was, on average, eight times greater than the next expensive input (i.e., fungicide).

Profitability increases from individual or multiple input applications to soybean were not observed (Table 5). Without adverse conditions and/or nutrient deficiencies to drive input responses, producer profitability decreased and exposed the economic risks of prophylactic soybean input applications. Economic results are supported by recent soybean studies totaling 117 site-years, suggesting that at current commodity prices, a high-input soybean system (e.g., seed treatments, foliar fungicides, foliar insecticides, and foliar fertilizers) results in a 0% chance to break even financially without significant pest pressure or nutrient deficiencies (Marburger et al., 2016; Orlowski et al., 2016).

Soybean Response to Poultry Litter

Poultry litter did not impact grain yield within either management system (Table 4). Due to soybean N_2 fixation, benefits from PL applications typically occur from nutrient additions other than N (Watts and Torbert, 2011; Slaton et al., 2013). Soil P and K concentrations were above critical in all site-years (Warncke et al., 2009) (Table 1). Results correspond to Swoish (2016) who did not observe a significant yield benefit to PL on Michigan soils sufficient in P and K. Watts and Torbert (2011) observed significant soybean yield increases from PL on a sandy loam soil due to the addition of micronutrients. In the current study, low soil Zn and B was observed in 2 of 3 and 1 of 3 site-years, respectively (Table 1) (Vitosh et al., 1995; Warncke et al., 2009). However, no tissue nutrient deficiencies were observed (Table 6) (Vitosh et al., 1995; Warncke et al., 2009).

Table 5. Soybean net economic return for Richville and Lansing, MI, 2016–2017. Mean net return of intensive and traditional control treatments displayed. All other treatments represent change in net return from respective intensive or traditional control treatment utilizing single degree-of-freedom contrasts.

Treatment†	2016 Richville	2017 Richville	2017 Lansing
	US$/acre		
Intensive (I)‡	374.11	273.32	301.57
I- PL¶	+185.59*	+100.05*	+81.02*
I- KTS	+66.99*	+0.63	–9.49
I- Micro	+26.64	–1.48	+5.85
I- Fungicide	+39.93	+39.00	+17.71
Traditional (T)§	619.71	466.47	471.60
T + PL#	–186.29*	–141.22*	–122.87*
T + KTS	–54.62*	–18.80	–43.83
T + Micro	–22.68	–1.57	–29.18
T + Fungicide	–17.98	+10.93	–31.78
I vs. T††	*	*	*

* Significantly different at a = 0.10 using single degree-of-freedom contrasts.

† Poultry litter (PL); potassium thiosulfate (KTS); foliar-applied Zn, Mn, and B (micro); and prothioconazole + trifloxystrobin fungicide.

‡ Intensive treatment containing all agronomic inputs.

§ Traditional treatment containing no fertilizer or additional inputs (i.e., check).

¶ Values in I – input rows indicate a net return (US$/acre) change from respective intensive (I) treatment.

Values in T + input rows indicate a net return (US$/acre) change from respective traditional (T) treatment.

†† Comparison between the intensive and traditional treatment utilizing single degree-of-freedom contrasts.

Results suggest limited soybean benefit from PL application on soils with sufficient nutrient concentrations. Previous literature has shown PL to increase SOM levels, cation exchange capacity, C and N mineralization, and soil respiration (Watts et al., 2010; Swoish, 2016), suggesting further research may be needed to understand the potential effects of PL application on longer-term nutrient mineralization rates and the soil microbiome.

Soybean Response to Potassium Thiosulfate

Application of KTS did not significantly impact yield within either management system. (Table 4). Soil test data indicated soil K concentrations were above critical across site-years, indicating no expected K response (Warncke et al., 2009) (Table 1). Michigan fertilizer guidelines suggest 1.7 to 2.5% K within the uppermost trifoliate at R1 (Vitosh et al., 1995). Soybean R1 trifoliate samples collected prior to K fertilization were within the recommended sufficiency range in all site-years (Table 6). Results suggest growers should not expect a response to in-season K fertilization when soil and tissue K concentrations exceed critical thresholds (Vitosh et al., 1995; Warncke et al., 2009; Clover and Mallarino, 2013; Stammer and Mallarino, 2018). Even on soils deficient in K, previous research determined in-season liquid K applications often did not supply enough total K (<16 lb/acre) to result in a yield increase, thus suggesting that growers should not replace preplant broadcast K applications based on soil test values with in-season K applications (Nelson et al., 2005; Nelson et al., 2010).

Table 6. Mean soybean uppermost trifoliate K, S, B, Mn, and Zn concentrations taken prior to fertilization at the R1 growth stage, Richville and Lansing, MI, 2016–2017.

Site	Year	Tissue nutrient concentration K	S	B	Mn	Zn
		%		ppm		
Richville	2016	2.6	0.3	45.0	44.8	48.3
	2017	1.8	0.4	41.3	43.8	30.0
Lansing	2017	2.1	0.3	40.3	58.0	36.3

Although soil test S concentrations are presented (Table 1), sufficiency ranges for soil test S are not recommended in Michigan (Vitosh et al., 1995; Warncke et al., 2009). Soil S sufficiency concentrations are difficult to assess due to soil SO_4–S variability (Hitsuda et al., 2004; Kaiser and Kim, 2013; Franzen, 2015). Tissue S and SOM levels are better predictors of soybean S response rather than soil S (Hitsuda et al., 2008; Kaiser and Kim, 2013). Michigan fertilizer guidelines recommend 0.2- 0.4% S within the uppermost trifoliate at R1 (Vitosh et al., 1995). All R1 trifoliate samples collected prior to fertilization were within the recommended S sufficiency range (Table 6), likely influencing the nonsignificant response. Bluck et al. (2015) did not observe a significant soybean yield response to S application in Ohio where R1 tissue analysis was within the current recommended S sufficiency range (0.2–0.4%). Sandy soils with low SOM (< 2.0%) are more likely to incur S deficiencies (Barker et al., 2005; Warncke et al., 2009; Kaiser and Kim, 2013). Soil OM content was 3.0% at Richville in 2016 and 2.8 and 3.2% at Richville and Lansing, respectively, in 2017, thus suggesting adequate S was available for soybean growth across site-years (Table 1).

Soybean Response to Foliar Zn, Mn, and B

Foliar applications of Zn, Mn, and B did not significantly impact grain yield in any site-year (Table 4). Nonsignificant responses were consistent with R1 tissue samples taken prior to fertilization, which exhibited sufficient Zn (>21 ppm), Mn (>21 ppm), and B (>21 ppm) in all site-years (Vitosh et al., 1995) (Table 6). In contrast, pre-plant soil test data indicated low B (<0.7 ppm) in one site-year and low Zn (i.e., deficiency defined utilizing function [(5.0 × pH) – (0.4 × soil test Zn ppm)] – 32) in two site-years (Warncke et al., 2009) (Table 1). However, no visual deficiency symptoms were observed. Due to infrequent micronutrient deficiencies in Midwestern U.S. soils, developing soil and tissue test interpretations is difficult

(Enderson et al., 2015; Sutradhar et al., 2017; Mallarino et al., 2017). Research by Enderson et al. (2015) and Sutradhar et al. (2017) was unsuccessful in developing sufficiency ranges for soybean micronutrient concentrations as no responses to micronutrient fertilization occurred across 77 locations.

University recommendations define crop sensitivities to low micronutrient availability and designate soybean response to Zn and B fertilization at low soil and/or tissue concentrations as unlikely (Vitosh et al., 1994; Warncke et al., 2009; Mallarino et al., 2017). In support, Mallarino et al. (2017) summarized 99 soybean Zn trials and 88 soybean B trials from Minnesota, Iowa, and Kansas in which no soybean yield responses were observed from Zn and B fertilization at soil levels as low as 0.3 and 0.2 ppm in Zn and B, respectively, and tissue levels as low as 16 and 22 ppm in Zn and B, respectively (Enderson et al., 2015; Sutradhar et al., 2017). In contrast, soybeans are highly sensitive to yield loss at low Mn concentrations (Vitosh et al., 1994; Warncke et al., 2009; Mallarino et al., 2017). Manganese soil concentrations were sufficient in all site-years (Table 1) (i.e., deficiency defined utilizing function {[(6.2 × pH) – (0.35 × soil test Mn ppm)] – 36}, and tissue concentrations exceeded ≥ 21 ppm (Table 6) (Warncke et al., 2009). Soil and plant diagnostic results indicated supplemental Mn was not required and supported the nonsignificant yield response to foliar Mn.

Growers should consider the likelihood of soybean responding to micronutrient applications (high, moderate, and low for Mn, Zn, and B, respectively) when choosing to apply a foliar micronutrient application (Vitosh et al., 1994; Warncke et al., 2009). Due to difficulties with predicting crop micronutrient deficiencies, growers should utilize multiple diagnostic tools and techniques in combination with understanding soil physical and chemical properties and site-specific environmental conditions before adopting a micronutrient spray program (Moraghan and Mascagni, 1991; Vitosh et al., 1994; Alloway, 2008; Warncke et al., 2009; Mallarino et al., 2017).

Soybean Response to Fungicide

Fungicide did not significantly impact yield in any site-year (Table 4). Minimal disease pressure occurred due to dry weather conditions and low relative humidity. Growing season (May– Sept.) rainfall averaged 30 and 35% below the 30-year mean at Richville in 2016 and at both locations in 2017, respectively, likely reducing pathogen risks (i.e., Septoria brown spot [*Septoria glycines*] and Sclerotinia stem rot [*Sclerotinia sclerotium*]) (Cruz et al., 2010; Fall et al., 2018). In addition, soybeans were planted in 30-inch rows, which increases air movement and reduces humid microclimates, which both encourage pathogen development (Grau and Radke, 1984; Boland and Hall, 1988). Fungicide applications may provide greater benefits in narrow-row (≤15 inch) soybean systems, which experience greater canopy density and humidity levels (Mahoney et al., 2015). The observed lack of soybean response to fungicide is supported by several publications that failed to realize benefits from fungicide applications during below-threshold levels of disease (Swoboda and Pedersen, 2009; Nelson et al., 2010; Gregg et al., 2015; Ng et al., 2018).

Although previous trials observed soybean physiological and yield enhancements following strobilurin fungicide applications (Grossmann and Retzlaff, 1999; Bartlett et al., 2002; Mahoney et al., 2015; Orlowski et al., 2016; Mourtzinis et al., 2017), results were inconsistent across trials (Swoboda and Pedersen, 2009; Nelson et al., 2010; Gregg et al., 2015; Mourtzinis et al., 2016). Due to inconsistent plant health benefits and the greater risk for strobilurin resistance development (Henry et al., 2011), growers should be cautious when prophylactically applying fungicides and should consider utilizing university recommended IPM resources to justify fungicide applications (Henry et al., 2011; Mahoney et al., 2015; Marburger et al., 2016; Mourtzinis et al., 2016).

Implications for Soybean Producers

Application of PL, KTS, foliar micronutrients, and fungicide did not significantly increase soybean grain yield or producer profitability. A traditional management system was significantly more profitable than the intensive management system. Due to a lack of yield increases in this trial and high input costs, KTS and PL significantly decreased net returns in one and three site-years, respectively. Soybean plants did not express foliar nutrient deficiencies or pathogen infection during 2016 and 2017. Within the environments evaluated, a prophylactic approach to soybean management was seldom economical. Results support the use of university recommended IPM programs that stress the justification of input applications to optimize both grain yield and profitability. Soybean producers should consider management systems that utilize various techniques (i.e., crop scouting, disease prediction models, varietal selection, soil properties, and nutrient recommendations) to evaluate in-season needs and justify input applications rather than relying on prophylactic input applications as insurance against yield-limiting factors. Although efforts to create intensive management systems that universally fit across crop production continue, soil physical and chemical property information and the likelihood of a grain yield response should be considered prior to development and broad-scale implementation of cost-effective nutrient management programs.

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