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RESEARCH

# High-Input Management Systems Effect on Soybean Seed Yield, Yield Components, and Economic Break-Even Probabilities

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## ABSTRACT

Elevated soybean [*Glycine max* (L.) Merr.] prices have spurred interest in maximizing soybean seed yield and has led growers to increase the number of inputs in their production systems. However, little information exists about the effects of high-input management on soybean yield and profitability. The purpose of this study was to investigate the effects of individual inputs, as well as combinations of inputs marketed to protect or increase soybean seed yield, yield components, and economic break-even probabilities. Studies were established in nine states and three soybean growing regions (North, Central, and South) between 2012 and 2014. In each site-year both individual inputs and combination high-input (SOYA) management systems were tested. When averaged between 2012 and 2014, regional results showed no seed yield responses in the South region, but multiple inputs affected seed yield in the North region. In general, the combination SOYA inputs resulted in the greatest yield increases (up to 12%) compared to standard management, but Bayesian economic analysis indicated SOYA had low break-even probabilities. Foliar insecticide had the greatest break-even probabilities across all environments, although insect pressure was generally low across all site-years. Soybean producers in North region are likely to realize a greater response from increased inputs, but producers across all regions should carefully evaluate adding inputs to their soybean management systems and ensure that they continue to follow the principles of integrated pest management.

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**Abbreviations:** IPM, integrated pest-management; LCO, lipo-chitooligosaccharide; SOYA, high-input management system consisting of a seed treatment fungicide, insecticide, inoculant, lipo-chitooligosaccharide, nitrogen fertilizer, foliar lipo-chitooligosaccharide, foliar fertilizer, antioxidant, foliar fungicide, and foliar insecticide; SP, standard practice (current university recommendations for fertilizer and herbicide programs).

In calendar year 2001, the average price received by soybean growers in the Midwest was US\$0.16 kg$^{-1}$ (USDA-NASS, 2002). In the same year, the break-even price for producing soybean in Illinois was approximately \$0.15 kg$^{-1}$ depending on factors such as cash rent rates (Schnitkey, 2013). In calendar year 2008, the break-even price for soybean nearly doubled to \$0.30 kg$^{-1}$. However, the price received by farmers for soybean jumped to \$0.42 kg$^{-1}$. This dramatic increase in soybean prices spurred a

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widespread interest in maximizing soybean yield to capitalize on the increased profitability of producing soybean.

University Extension programs generally recommend minimal external inputs in a soybean production system beyond fertilizer, weed control, and an integrated pest management program (Conley and Smith, 2015). The use of other soybean inputs such as seed-applied and foliar-applied insecticides and fungicides are only recommended in cases where the disease or insect pest population was determined to be at a critical treatment threshold (Ragsdale et al., 2007). However, despite Extension recommendations, soybean producers seeking to maximize yield to take advantage of elevated soybean prices have looked toward increasing the number of inputs used as part of their soybean management system.

One input that has been widely adopted by soybean producers is the use of seed-applied fungicides and insecticides. Research from across the United States has generally failed to show consistent benefits from soybean seed treatment. Cox et al. (2008) found no differences in stand establishment and seed yield between untreated soybean seed and two insecticide/fungicide seed treatments, while Bradley et al. (2001) found that seed-applied metalaxyl increased soybean stands in 1 yr of a 2 yr study but seed yield was not affected in either growing season. Similarly, Bierman et al. (2006) evaluated six fungicidal seed treatments and their interactions with different herbicide programs but failed to observe a seed yield increase for seed treatment in any environment. On the other hand, some studies have reported seed yield increases associated with soybean seed treatments. Schulz and Thelen (2008) found that seed-applied metalaxyl and fludioxonil increased soybean seed yield in 3 of 16 site-years but decreased seed yield in 2 of 16 site-years. Similarly, Gaspar et al. (2014) found that fungicide+insecticide and fungicide+insecticide+nematicide seed treatments consistently increased plant stands and seed yield over untreated seed, and Esker and Conley (2012) concluded that the seed yield and economic benefits of seed treatment varied greatly by cultivar and year but could be a cost-effective management practice at high commodity prices.

In addition to seed treatments, growers seeking to maximize soybean seed yield have considered adding inoculants as part of high-yield management programs. DeBruin et al. (2010) evaluated 51 inoculant products at 73 locations across five states (Indiana, Iowa, Minnesota, Nebraska, and Wisconsin) between 2000 and 2008 and found that inoculation had no effect on soybean seed yield in fields that had a history of soybean production. Other research from Mid-western soybean-producing areas has failed to show yield advantages for inoculation where there has been a history of soybean production (Ham et al., 1971; Nelson et al., 1978; Furseth et al., 2011; Furseth et al., 2012). However, Schulz and Thelen (2008) found that inoculants increased soybean seed yield in 6 of 14 site-years in fields that had recently had soybean in rotation. Furthermore, Marburger et al. (2016b) found that soybean seed treated with an inoculant (Optimize) yielded 0.13 Mg ha$^{-1}$ (4%) more than the untreated control and crop rotation and tillage practice did not interact ($P > 0.05$) with inoculant use to influence seed yield.

Along with seed treatments and inoculants, growers have also included inputs designed to affect soybean growth during the growing season. One such input is the herbicide lactofen {2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate}. It has been suggested that lactofen applied at early vegetative growth kills the apical meristem, leading to increased branch node development and subsequently increased seed yield. Early studies examining lactofen for weed control purposes failed to observe seed yield increases for early season lactofen application (Kapusta et al., 1986; Harris et al., 1991; Wichert and Talbert, 1993), while more recent work has shown that lactofen does not affect soybean branching or seed yield (Gregg et al., 2015; Mangialardi et al., 2016; Orlowski et al., 2016).

Although soybean is a leguminous crop and, therefore, able to obtain N via symbiosis with *Bradyrhizobium japonicum*, soybean is also able to take up N from the soil. However, some commercial agronomists have recommended additional N fertilizer for high-yield soybean management. The effects of N fertilization on soybean yield have been mixed. Welch et al. (1973) found that N fertilizer either decreased or had no effect on soybean seed yield. Similarly, Gutierrez-Boem et al. (2004) found that two rates of N applied at growth stages R3 and R5 (Fehr and Caviness, 1977) had no effect on soybean seed yield. In contrast, (Sorensen and Penas, 1978) found that pre-plant N fertilization increased seed yield in 9 of the 13 study locations. Similarly, Ray et al. (2006) reported seed yield increases of 7.7% for non-irrigated soybean and 15.5% for irrigated soybean when N was applied at soybean emergence (Ray et al., 2006) and Salvagiotti et al. (2009) found N fertilization increased soybean seed yield by an average of 228 kg ha$^{-1}$ over unfertilized soybean when yield levels were >4849 kg ha$^{-1}$.

Like N fertilization, foliar fertilization of soybean is a practice that has been considered to increase soybean yield. Foliar fertilizers have been shown to increase seed yield when a specific nutrient was known to be limiting (Randall et al., 1975; Nelson et al., 2005; Ross et al., 2006). However, multiple studies have failed to show widespread and consistent yield increases for foliar fertilizers in soybean not exhibiting visible deficiency symptoms. Haq and Mallarino (2000) summarized the effects of 27 early season N–P–K foliar fertilizations trials. Yield increases from foliar fertilization occurred in only 6 out of the 27 trials with an average seed yield increase of 0.4 Mg ha$^{-1}$.

However, the authors concluded that the observed yield increases seldom covered application costs.

The prophylactic use of foliar-applied fungicides and insecticides has also been considered by growers seeking to maximize soybean seed yield. However, yield responses to foliar fungicides have been inconsistent. Swoboda and Pedersen (2009) found no differences in pods $m^{-2}$, seeds $m^{-2}$, seeds $pod^{-1}$, and seed yield from application of foliar fungicides in a low-disease environment in Iowa. Similarly, Dorrance et al. (2010) observed soybean yield increases at only 6 out of 28 locations from fungicide application and Hanna et al. (2008) found that fungicide application did not affect soybean seed yield across a number of studies in Indiana. However, Henry et al. (2011) found that R4 application of foliar fungicide increased soybean seed yield by 3%, primarily through a 3% increase in seed mass.

Similar to foliar fungicides, foliar insecticides are effective at protecting soybean yield when insect pests are present. However, some studies have reported increased seed yield for soybean treated with foliar insecticides in the absence of insect pest pressure. Dorrance et al. (2010) found that foliar insecticide application increased soybean seed yield in two out of five locations in the absence of threshold level insect pests. Similarly, Henry et al. (2011) found that an application of a foliar insecticide increased soybean seed yield by 5% across three locations in Indiana in the absence of threshold levels of insect pests.

While previous research has reported on the effects of individual inputs on soybean yield, few studies have investigated the combination of multiple inputs to identify potential synergies between inputs as part of high-yield management systems. Recent research by Bluck et al. (2015) found little yield response from the incorporation of multiple inputs into a soybean management system and concluded that high-yield management had little potential to increase soybean seed yield in the absence of disease and nutrient deficiencies. In contrast, Marburger et al. (2016a) found that high-input management systems, similar to the ones investigated in this study, increased soybean yield between 3.5 and 5.5% compared to standard management systems across multiple cultivars at each study locations. However, despite observed yield increases, the authors concluded that grower return on investment would be negative at recent commodity prices. This study builds on the work of Marburger et al. (2016a) by evaluating the individual inputs as well as multiple high-input systems in order to identify specific inputs that may be driving the yield increase due to high-input management.

This study was conducted across 60 site-years over three growing seasons and therefore generated a very large dataset for analysis. A large dataset such as this one allows multiple avenues for analysis at multiple spatial scale ranging from individual site-years to national analysis across multiple soybean-producing regions. The objectives of this study were to (i) determine the effect of high-input management systems and their individual input components on soybean seed yield and primary yield components and (ii) use the agronomic data to determine the economic break-even probabilities for individual inputs as well as high-input soybean management systems on a regional (North, Central, South) and national scale.

## MATERIALS AND METHODS

Field trials were established in 2012, 2013, and 2014 in nine states (Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, and Wisconsin). At least two study locations were established in each state each year of the study, resulting in 60 total site-years (Fig. 1). All study locations chosen had a recent history of producing high soybean yields. In the fall of the preceding year or in the spring prior to planting, soil tests were taken at each study location to determine soil nutrient status (Table 1). Study locations were chosen that were considered to have adequate soil fertility to support a high-yielding soybean crop. If necessary, inorganic fertilizers were applied to correct any nutrient deficiencies at rates recommended by soil test information. Study locations were managed by cooperating researchers at the major land-grant universities in the participating states. The majority of locations were planted in May in all years of the study. Plot size and row spacing (Table 1) varied according to equipment availability; however, all plots were planted at 432,000 seed $ha^{-1}$. The soybean cultivars used at each location were selected from commercially available glyphosate [N-(phosphonomethyl) glycine] resistant, Asgrow (Monsanto Company, St. Louis, MO) brand soybean cultivars. All cultivars chosen were of the appropriate relative maturity for the geographic area where the study sites were located. Where possible, the same cultivar was used in all 3 yr at a particular location, however, yearly changes in seed availability resulted in varietal changes at some locations.

Studies were established as an incomplete factorial experiment, arranged in a randomized complete block design with four replications at all locations. Inputs consisted of several commercially available inputs marketed to protect or increase soybean yield as well as a control that was managed according to each university's best management practices and considered to be the standard practice (SP) for the area where the study site was located. The SP did not include any of the products tested in the other study treatments at any location. All inputs were applied at rates and application volumes recommended by the product label. Three separate seed treatment inputs were included in the study (Table 2). One was a fungicide only seed treatment composed of pyraclostrobin applied at 0.031 mg a.i. per seed, metalaxyl applied at 0.049 mg a.i. per seed and fluxapyroxad at 0.0161 mg a.i. per seed. Another was a fungicide+insecticide seed treatment that included pyraclostrobin, metalaxyl, and fluxapyroxad at the aforementioned rates with imidacloprid (*N*-{1-[(6-Chloro-3-pyridyl)methyl]-4,5-dihydroimidazol-2-yl}nitramide) at 0.2336 mg a.i. per seed, clothianidin [1-(2-Chloro-1,3-thiazol-5-ylmethyl)-3-methyl-2-nitroguanidine] at 0.13 mg a.i. per seed and *Bacillus firmus* at 0.026 mg a.i. per seed. The Max seed treatment had the same products as the insecticide+fungicide seed treatment but also

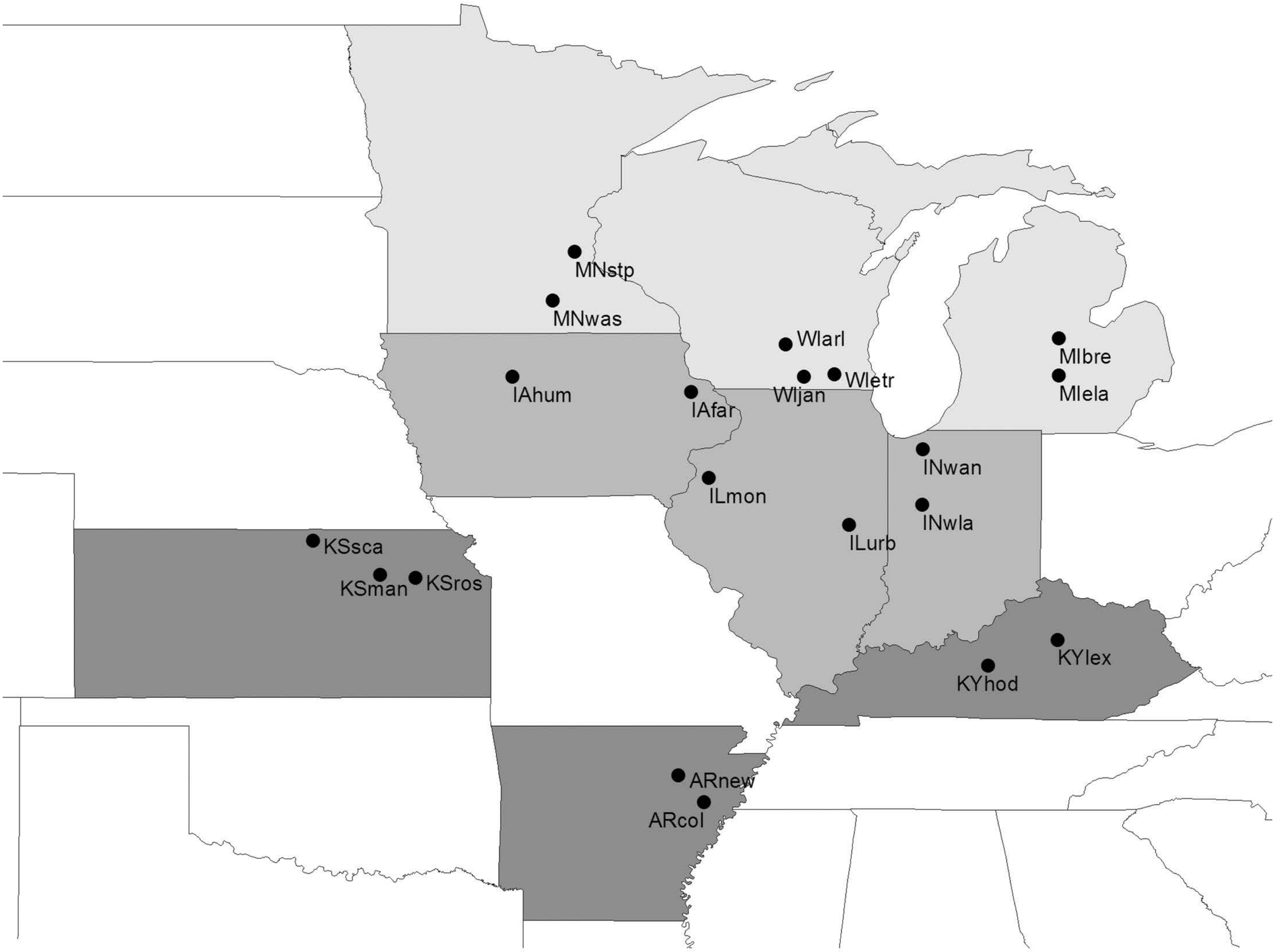


Fig. 1. Study locations across nine states between 2012 and 2014. States shaded dark gray are considered the South region, while states shaded medium gray are considered the Central region, and states shaded light gray are considered the North region.

included *B. japonicum* and lipo-chitooligosaccharide (LCO) at an application rate of 1.83 mL per kg seed and included a foliar applied LCO at a rate of 292 mL ha$^{-1}$. All seed treatment inputs were applied to untreated seed at the University of Minnesota using a rotary drum seed-treater and shipped to cooperating scientists prior to planting.

Nitrogen fertilizer was broadcast directly on the soil surface at V4 but was not incorporated. The fertilizer mix included urea (46–0–0) applied at 84 kg ha$^{-1}$ and polymer coated urea (44–0–0) at 84 kg ha$^{-1}$. Lactofen herbicide (Defoliant) was applied at V4 at 240 g a.i. ha$^{-1}$ with 1% volume volume$^{-1}$ of crop oil concentrate added as an adjuvant to the spay mix. Foliar fertilizer (11–8–5–0.1–0.05–0.04–0.02–0.00025–0.00025%N–$P_2O_5$–$K_20$–Fe–Mn–Zn–B–Co–Mo) was applied at R1 at 4676 mL ha$^{-1}$. N,N′–diformyl urea (Bio-Forge) was applied at R3 at 1169 mL ha$^{-1}$.

The foliar fungicide, pyraclostrobin {carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl] methoxy-, methyl ester}, was applied at 108 g a.i. ha$^{-1}$ at R3 in 2012 while a combination product (Priaxor) containing pyraclostrobin at 194 g a.i. ha$^{-1}$ and fluxapyroxad {3-(difluoromethyl)-1-methyl-N-[2-(3′,4′,5′-trifluorophenyl)phenyl]pyrazole-4-carboxamide} at 97 g a.i. ha$^{-1}$ were applied at R3 in 2013 and 2014. The foliar insecticide, lambda cyhalothrin [3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyano(3-phenoxyphenyl) methyl cyclopropanecarboxylate], was applied at 35 g a.i. ha$^{-1}$ at R3 in 2012 while in 2013 and 2014 a combination product (Endigo) containing lambda cyhalothrin at 31 g a.i. ha$^{-1}$ and thiamethoxam{3-[(2-Chloro-1,3-thiazol-5-yl)methyl]-5-methyl-*N*-nitro-1,3,5-oxadiazinan-4-imine} at 41 g a.i. ha$^{-1}$ at R3 was used. The foliar fungicide+insecticide was a tank mix of the fungicide and insecticides at the aforementioned rates and timing.

Individual products were combined as part of high-yield management systems and are referred to here as SOYA. SOYA included the Max seed treatment, N, foliar fertilizer, N,N′-diformyl urea, foliar fungicide, and foliar insecticide at the rates and timings previously described. Four variations of SOYA were also included in this study. SOYA+D included the defoliant at the rate and timing described above. SOYA-N included all components of SOYA except N fertilizer. SOYA-FF was SOYA without the foliar fungicide and SOYA-FF+FI was SOYA without the foliar fungicide and foliar insecticide components (Table 2).

Insects and diseases were scouted weekly at all locations. Disease and insect ratings were conducted for each plot at the

Table 1. Location, soil fertility and classification, cropping and tillage history, and planting and harvest dates during 2012 to 2014.

| Location† | Year | Coordinates | Soil Series‡ | Previous crop | Tillage system§ | Soil fertility pH¶ | P# | K# | OM†† | SCN | Row spacing | Planting date | Harvest date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | mg kg$^{-1}$ | mg kg$^{-1}$ | g kg$^{-1}$ | Eggs 100$^{-1}$ cm$^3$ soil | cm | | |
| ARcol | 2012‡‡ | 35°7′51″ N, 90°48′41″ W | D | Rice | CT | 7.1 | 23 | 118 | – | 0 | 38 | 23 May | 22 Oct. |
| | 2013 | | | Soybean | | 7.4 | 46 | 94 | – | 500 | | 15 May | 5 Oct. |
| | 2014 | | | | | 7.2 | 43 | 94 | – | 0 | | 24 May | 18 Oct. |
| ARnew | 2012‡‡ | 35°36′43″ N, 91°15′44″ W | CA | Fallow | CT | 6.5 | 126 | 252 | – | 0 | 38 | 17 May | 22 Oct. |
| | 2013 | | | Soybean | | 6.4 | 121 | 144 | – | 0 | | 10 June | 23 Oct. |
| | 2014 | | | Rice | | 6.0 | 54 | 112 | – | 0 | | 27 May | 22 Oct. |
| IAfar | 2012 | 42°15′56″ N, 91°1′28″ W | KCF | Corn | CT | 6.9 | 15 | 116 | 26 | 4 | 38 | 9 May | 27 Sept. |
| | 2013 | | | | | 6.7 | 60 | 180 | 31 | 0 | | 16 May | 25 Oct. |
| | 2014 | | | | | 7.0 | 16 | 169 | 26 | 75 | | 7 May | 7 Oct. |
| IAhum | 2012 | 42°43′25″ N, 94°13′17″ W | CNW | Corn | CT | – | 55 | 183 | – | – | 76 | 17 May | 25 Sept. |
| | 2013 | | | | | 6.0 | 44 | 142 | 44 | – | | 8 June | 9 Oct. |
| | 2014 | | | | | 6.8 | 55 | 183 | 56 | 8132 | | 20 May | – |
| ILmon | 2012 | 40°55′12″ N, 90°43′12″ W | M | Corn | CT | 6.6 | 9 | 125 | – | 0 | 76 | 11 May | 8 Oct. |
| | 2013 | | | | | 6.2 | 29 | 189 | 55 | 300 | | 24 May | 7 Oct. |
| | 2014 | | | | | 6.2 | 20 | 152 | 51 | 0 | | 22 May | 7 Oct. |
| ILurb | 2012 | 40°4′48″ N, 88°13′12″ W | DR | Corn | CT | 5.9 | 21 | 116 | – | 0 | 76 | 9 May | 12 Oct. |
| | 2013 | | | | | 5.3 | 53 | 172 | 33 | 500 | | 19 May | 12 Oct. |
| | 2014 | | | | | 6.3 | 53 | 165 | 38 | 4 | | 19 May | 21 Oct. |
| INwan | 2012 | 41°25′47″ N, 86°53′55″ W | S | Corn | CT | 6.3 | 53 | 178 | 40 | 0 | 38 | 15 May | 9 Oct. |
| | 2013 | | | | | 6.2 | 31 | 116 | 26 | – | | 8 May | 1 Oct. |
| | 2014 | | | | | 6.5 | 49 | 129 | 31 | 30 | | 26 May | 29 Oct. |
| INwla | 2012 | 40°26′31″ N, 86°54′45″ W | CL | Corn | CT | 6.2 | 24 | 147 | 35 | 90 | 38 | 17 May | 17 Oct. |
| | 2013 | | | | | 6.7 | 16 | 117 | 31 | – | | 14 May | 8 Oct. |
| | 2014 | | | | | 6.5 | 17 | 89 | 38 | 0 | | 27 May | 24 Oct. |
| KSman | 2012 | 39°11′25″ N, 96°35′13″ W | K | Sorghum | NT | 7.3 | 19 | 211 | 26 | 0 | 76 | 7 May | 11 Oct. |
| | 2013 | | | | MT | 7.5 | 33 | 286 | 35 | 0 | | 13 June | 21 Oct. |
| | 2014 | | | Soybean | NT | 6.8 | 26 | 170 | 30 | 0 | | 14 May | 30 Oct. |
| KSros | 2012‡‡ | 39°8′12″ N, 95°57′5″ W | B | Corn | MT | 6.2 | 21 | 180 | 17 | 130 | 25 | 4 May | 8 Oct. |
| | 2013‡‡ | | E | | | 7.4 | 13 | 204 | 14 | 100 | 38 | 22 May | 7 Oct. |
| | 2014‡‡ | | KI | | | 7.0 | 44 | 312 | 19 | 40 | | 15 May | 7 Oct. |
| KSsca | 2012‡‡ | 39°47′44″ N, 97°47′2″ W | C | Corn | MT | 6.9 | 8 | 295 | 15 | 0 | 25 | 9 May | 10 Oct. |
| | 2013‡‡ | | | | | 6.4 | 5 | 387 | 19 | 0 | 38 | 3 June | 18 Oct. |
| | 2014‡‡ | | | | | 6.6 | 14 | 444 | 31 | 0 | | 13 May | 16 Oct. |
| KYhod | 2012 | 37°34′16″ N, 85°44′19″ W | NL | Corn | CT | 6.7 | 345 | 594 | 22 | 0 | 38 | 11 May | 16 Oct. |
| | 2013 | | | | | 6.9 | 315 | 638 | 21 | 0 | | 29 May | 11 Nov. |
| | 2014 | | | | | 6.7 | 321 | 603 | 22 | 0 | | 4 June | 14 Nov. |

*Cont'd.*

**Table 1. Continued.**

| Location† | Year | Coordinates | Soil Series‡ | Previous crop | Tillage system§ | Soil fertility pH¶ | P# | K# | OM†† | SCN | Row spacing | Planting date | Harvest date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | —— mg kg$^{-1}$ —— | | g kg$^{-1}$ | Eggs 100$^{-1}$ cm$^{3}$ soil | cm | | |
| KYlex | 2012‡‡ | 38°1′47″ N, 84°29′41″ W | L | Corn | NT | 6.6 | 305 | 261 | 24 | 0 | 38 | 10 May | 19 Oct. |
| | 2013 | | | | | 6.6 | 335 | 441 | 25 | 0 | | 16 May | 21 Oct. |
| | 2014 | | | | | 6.6 | 356 | 241 | 24 | 0 | | 28 May | 27 Oct. |
| MIbre | 2012 | 43°24′30″ N, 84°28′35″ W | P | Corn | CT | 6.0 | 51 | 141 | – | 0 | 38 | 21 May | 3 Nov. |
| | 2013 | | | | | 6.2 | 55 | 220 | – | 0 | | 9 May | 25 Oct. |
| | 2014 | | | Soybean | | 6.1 | 49 | 193 | – | 0 | | 25 May | 23 Oct. |
| MIela | 2012 | 42°44′25″ N, 84°28′54″ W | A | Corn | CT | 6.7 | 52 | 178 | – | 0 | 38 | 21 May | 6 Nov. |
| | 2013 | | | | | 6.6 | 126 | 385 | – | – | | 9 May | 30 Oct. |
| | 2014 | | | | | 7.2 | 20 | 91 | – | 0 | | 22 May | 7 Nov. |
| MNstp | 2012 | 44°57′16″ N, 93°6′51″ W | W | Corn | CT | 5.7 | 112 | 124 | 39 | 25 | 76 | 10 May | 5 Oct. |
| | 2013 | | | | | 6.1 | 124 | 191 | 38 | 0 | | 7 May | 26 Oct. |
| | 2014 | | | | | 6.0 | 67 | 90 | 39 | 25 | | 6 May | 20 Oct. |
| MNwas | 2012 | 44°4′44″ N, 93°30′23″ W | N | Corn | CT | 6.2 | 68 | 259 | 46 | 13 | 76 | 11 May | 2 Oct. |
| | 2013 | | | | | 6.2 | 16 | 107 | 65 | 0 | | 16 May | 24 Oct. |
| | 2014 | | | | | 6.0 | 44 | 163 | 59 | 13 | | 29 May | – |
| WIarl | 2012 | 43°12′6″ N, 89°12′19″ W | PL | Corn | CT | 6.4 | 27 | 135 | 29 | 200 | 38 | 11 May | 12 Oct. |
| | 2013 | | | | | 6.9 | 51 | 153 | 33 | 11,850 | | 7 May | 3 Oct. |
| | 2014 | | | | | 6.4 | 33 | 159 | 33 | 525 | | 6 May | 27 Oct. |
| WIjan | 2012 | 42°26′0″ N, 89°0′41″ W | PL | Corn | CT | 7.0 | 41 | 107 | 35 | 147 | 38 | 10 May | 2 Oct. |
| | 2013 | | | | | 6.3 | 44 | 109 | 33 | 0 | | 16 May | 14 Oct. |
| WIetr | 2014 | 42°45′58″ N, 88°28′55″ W | M | Corn | CT | 6.1 | 88 | 207 | 39 | 250 | 38 | 19 May | 21 Oct. |

† ARcol, Colt, AR; ARnew, Newport, AR; IAfar, Farley, IA; IAhum, Humboldt, IA; ILmon, Monmouth, IL; ILurb, Urbana, IL; INwan, Wanatah, IN; INwla, West Lafayette, IN; KSman, Manhattan, KS; KSros, Rossville, KS; KSsca, Scandia, KS; KYhod, Hodgenville, KY; KYlex, Lexington, KY; MIbre, Breckenridge, MI; MIela, East Lansing, MI; MNstp, St. Paul, MN; MNwas, Waseca, MN; WIarl, Arlington, WI; WIjan, Janesville, WI; WIetr, East Troy, WI.

‡ Source: USDA web soil survey. Dexter silt loam (D): fine-silty, mixed, active, thermic Ultic Hapludalf; Calloway silt loam (CA): fine-silty, mixed, active, thermic Aquic Fraglossudalf; Kenyon Loam/Clyde-Floyd Loam (KCF): fine-loamy, mixed, superactive, mesic Typic Hapludoll, fine-loamy, mixed, superactive, mesic Typic Endoaquoll, fine-loamy, mixed, superactive, mesic Aquic Pachic Hapludoll; Clarion loam/Nicollet loam/Webster clay loam (CNW): fine-loamy, mixed, superactive, mesic Typic Hapludoll, fine-loamy, mixed, superactive, mesic Aquic Hapludoll, fine-loamy, mixed, superactive, mesic Typic Endoaquoll; Muscatine silty clay loam (M): fine-silty, mixed, superactive, mesic Aquic Hapludolls; Drummer silty clay loam (DR): fine-silty, mixed, superactive, mesic Typic Endoaquoll; Sebewa loam (S): fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiaquoll; Chalmer silty clay loam (CL): fine-silty, mixed, superactive, mesic Typic Endoaquoll; Kahola silt loam (K): fine-silty, mixed, mesic Cumulic Hapludoll; Bismarckgrove-Kimo complex (B): fine-silty, mixed, superactive, mesic Fluventic Hapludoll; Eudora silt loam (E): coarse-silty, mixed, superactive, mesic Fluventic Hapludoll; Kimo silty clay loam (KI): clayey over loamy, smectitic, mesic Fluvaquentic Hapludoll; Crete silt loam (C): fine, smectic, mesic Pachic Udertic Arguistoll; Nolin silt loam (NL): fine-silty, mixed, active, mesic Dystric Fluventic Eutrudepts; Loradale silt loam (L): fine, mixed, active, mesic Typic Argiudoll; Parkhill loam (P): fine-loamy, mixed, semiactive, nonacid, mesic Mollic Epiaquept; Aubbeenaubbee-Capac sandy loam (A): fine-loamy, mixed, active, mesic Aeric Epiaqualf, fine-loamy, mixed active, mesic Aquic Glossudalf; Waukegan silt loam (W): fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls; Nicollet clay loam (N): fine-loamy, mixed, superactive, mesic Aquic Hapludoll; Plano silt loam (PL): fine-silty, mixed, superactive, mesic Typic Argiudoll; Matherton sandy loam (M): fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Udollic Endoaqualf.

§ CT, conventional tillage; MT, mulch tillage; NT, no-tillage.

¶ Sikora buffer method.

# Mehlich-3 extraction.

†† Loss of ignition test.

‡‡ Irrigated location.

Table 2. Component products, active ingredients, rates, and timings for experiments in 2012, 2013, and 2014.

| | | | | | Seed treatment | | | Single product | | | | | | | Combination | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product† | Active ingredient | Rate | Timing | SP‡ | F ST | F+IST | Max ST | D | N | F | N-N’ urea | FF | FI | FF+FI | SOYA | SOYA+ D | SOYA- N | SOYA- FF | SOYA- FF+FI |
| | | mL kg seed $^{-1}$ | | | | | | | | | | | | | | | | | |
| Acceleron F | pyraclostrobin +metalaxyl+fluxapyroxad | 1.04 | Seed | – | + | + | + | – | – | – | – | – | – | – | + | + | + | + | + |
| Acceleron I | imidacloprid | 2.60 | Seed | – | – | + | + | – | – | – | – | – | – | – | + | + | + | + | + |
| Poncho/Votivo | Clothiaidin + *Bacillus firmus* | 0.64 | Seed | – | – | + | + | – | – | – | – | – | – | – | + | + | + | + | + |
| Optimize | *Bradyrhizobium japonicum* + LCO | 1.83 | Seed | – | – | – | + | – | – | – | – | – | – | – | + | + | + | + | + |
| | | kg ha$^{-1}$ | | | | | | | | | | | | | | | | | |
| Urea§ | 46–0–0%N–$P_2O_5$–$K_20$ | 84 | V4 | – | – | – | – | – | + | – | – | – | – | – | + | + | – | + | + |
| ESN | 44–0–0%N–$P_2O_5$–$K_20$ | 84 | V4 | – | – | – | – | – | + | – | – | – | – | – | + | + | – | + | + |
| | | mL ha$^{-1}$ | | | | | | | | | | | | | | | | | |
| Cobra ¶ | lactofen | 877 | V4 | – | – | – | – | + | – | – | – | – | – | – | – | + | – | – | – |
| Ratchet | LCO | 292 | V4-V6 | – | – | – | + | – | – | – | – | – | – | – | + | + | + | + | + |
| Task Force II | 11–8-5–0.1–0.05–0.040.02–0.00025–0.00025%N–$P_2O_5$–$K_20$–Fe–Mn–Zn–B–Co–Mo | 4676 | R1 | – | – | – | – | – | – | + | – | – | – | – | + | + | + | + | + |
| Bio-Forge | N,N′-diformyl urea | 1169 | R3 | – | – | – | – | – | – | – | + | – | – | – | + | + | + | + | + |
| Headline | pyraclostrobin | 438 | R3 | – | – | – | – | – | – | – | – | + | – | + | + | + | + | – | – |
| Priaxor | pyraclostrobin + fluxapyroxad | 585 | R3 | – | – | – | – | – | – | – | – | + | – | + | + | + | + | – | – |
| Warrior II | lambda- cyhalothrin | 140 | R3 | – | – | – | – | – | – | – | – | – | + | + | + | + | + | + | – |
| Endigo | lambda- cyhalothrin +thiamethoxam | 292 | R3 | – | – | – | – | – | – | – | – | – | + | + | + | + | + | + | – |

† Acceleron (Monsanto Co., St. Louis, MO); Poncho/Votivo (Bayer Crop Science, Research Triangle Park, NC); Optimize (Novozymes, Brookfield, WI); ESN [environmentally smart nitrogen (polymer-coated urea)] (Agrium, Calgary, Alberta, Canada); Ratchet (Novozymes, Brookfield, WI); Cobra (Valent USA Corp., Walnut Creek, CA); Task Force 2 (Loveland Products, Inc., Greeley, CO); Bio-Forge (Stoller USA, Inc., Houston, TX); Headline (BASF Corp., Florham Park, NJ) used in 2012; Priaxor (BASF Corp., Florham Park, NJ) used in 2013–2014; Warrior II (Syngenta Crop Protection, LLC, Greensboro, NC) used in 2012; Endigo (Syngenta Crop Protection, LLC, Greensboro, NC) used in 2013–2014.

‡ SP, standard practice; FST, fungicide seed treatment; F+I ST, fungicide + insecticide seed treatment; D, defoliant; F, foliar fertilizer; FF, foliar fungicide; FI foliar insecticide; LCO; lipo-chitooligosaccharide.

§Treated with Agrotain [N-(n-butyl) thiophosphoric triamide] (Koch Agronomic Services, LLC, Wichita, KS) at 3.1 mL kg urea$^{-1}$.

¶ Tank mixed with 1% v/v crop oil concentrate.

**Table 3. Additional marginal costs for inputs over the standard practice for experiments in 2012, 2013, and 2014.**

| Input† | Additional cost, $ ha$^{-1}$‡ | |
|---|---|---|
| | 2012 | 2013, 2014 |
| Fungicide ST | 21.61 | 21.61 |
| Fungicide+Insecticide ST | 52.49 | 52.49 |
| Max ST | 59.90 | 59.90 |
| Defoliant | 44.73 | 44.73 |
| Nitrogen | 109.22 | 109.22 |
| Foliar fertilizer | 46.93 | 46.93 |
| N,N'-diformyl urea | 51.38 | 51.38 |
| Foliar Fungicide | 63.92 | 96.08 |
| Foliar Insecticide | 29.66 | 34.06 |
| Foliar Fungicide+Insecticide | 73.83 | 110.38 |
| SOYA | 341.26 | 377.81 |
| SOYA+D | 385.99 | 422.54 |
| SOYA-N | 232.03 | 268.59 |
| SOYA-FF | 277.33 | 281.73 |
| SOYA-FF and FI | 267.43 | 267.43 |

† ST, seed treatment; D, defoliant; F, foliar fertilizer; FF, foliar fungicide; FI, foliar insecticide; SOYA, combination high-yield management.

‡ Costs differ between 2012 and 2013, 2014 due to the use of different input products.

R3 and R5 growth stages. Plots were harvested at R8 and grain weight and maturity were recorded for each plot. Grain weight was adjusted to a moisture content of 130 g kg$^{-1}$. During harvest, a ~500 g seed sample was collected from each plot and used to determine seed mass. Final stands counts were determined prior to plot harvest. Rainfall and temperature data was collected from the federal or state managed weather station nearest to the study location.

The data were analyzed within regions and on a national level. Regions were largely defined by latitude and length of growing season. The North region consisted of all locations in Michigan, Minnesota, and Wisconsin. The Central region consisted of all locations in Illinois, Indiana, and Iowa; and the South region consisted of all study locations in Arkansas, Kansas, and Kentucky. When analyzed across regions and nationally, input was the only fixed effect while year, location(year), and replication(location × year) and the overall error term were considered random effects. Input means were separated using Fisher's protected LSD at a critical value of $P \leq 0.05$.

To perform an economic analysis, the marginal cost of each input above the SP was calculated (Table 3). The costs for each input were obtained from publicly available sources and industry representatives. Application costs were included for some inputs. It was assumed that the seed manufacturer would apply soybean seed treatments and the grower would not incur application cost. It was also assumed that lactofen could be applied to the soybean crop in a tank mix with a standard post-emergence herbicide application at V4 so no additional application costs would be incurred by the soybean producer. It was assumed that urea and polymer coated urea application would be applied with a ground driven fertilizer spreader and would therefore incur additional application costs. Stand reduction at this stage is negligible and would not result in a yield penalty for application (Hanna et al., 2008). Application costs were incurred for foliar fertilizer at R1 because no late herbicide applications were required in our weed management programs and herbicides have been shown to reduce efficacy when tank-mixed with foliar fertilizers (Bernards et al., 2005; Scroggs et al., 2009). Foliar applications were assumed to be applied with a ground driven sprayer with a large spray boom resulting in negligible yield loss (Hanna et al., 2008). The inputs designated for application at R3 (foliar insecticide, foliar fungicide, N,N′-diformyl urea) would also incur application costs. For management that required multiple R3 inputs, it was assumed that the inputs were tank-mixed and would therefore only incur a single application cost.

Bayesian economic analysis was used to quantify the probability that revenue generated from yield increases associated with the use of additional inputs in a high-yield soybean management system would cover the costs associated with the use of the inputs (i.e., break-even analysis). The methods used for this analysis were similar to those used by Esker and Conley (2012), DeBruin et al. (2010), Johnson et al. (2009), and Munkvold et al. (2001). Least square means estimates were obtained from the ANOVA's for each environment (site × year combination ($n$ = 60). For this analysis, input was considered a fixed effect and replication was considered a random effect. Relative yield change (RYC) values were used to construct models to determine the effect of inputs across all environments, within the North, Central, and South regions. For these analyses, environment and input were considered fixed effects while the error term was considered a random effect.

Break-even analysis was conducted at three yield levels (3.0, 4.0, and 5.0 Mg ha$^{-1}$) and three grain prices ($0.33 kg$^{-1}$, $0.44 kg$^{-1}$, and $0.55 kg$^{-1}$) (Table 4). Relative yield changes necessary to cover the costs of each input were determined by dividing the cost of the input by each combination of yield level and grain price. Individual %RYC for each input were subtracted from the minimum yield gain and then divided by the appropriate standard error to generate a $t$ value. The SAS PROBT function (SAS Institute, Cary, NC) was used to estimate a one-tail probability, which in this case represents the probability of breaking-even for a particular input.

## RESULTS

Temperature and precipitation patterns differed between locations and years (Table 4). In general, the 2012 growing season was very dry across most study locations. Study locations in Illinois, Kentucky, Iowa, Indiana, and Wisconsin had monthly rainfall totals well below 30-yr averages while study locations in Minnesota received near normal rainfall amounts. Irrigation at locations in Arkansas and Kansas helped compensate for reduced rainfall, but both states experienced above average temperatures throughout the entire growing season. The 2013 growing season provided very favorable growing conditions at most study locations. Climatic conditions during the 2014 growing season were more variable than the 2013 growing season. While planting was delayed at a number of locations due to above-average spring rainfall, study locations received adequate rainfall and temperatures that resulted in high yields at all locations.

Table 4. Average monthly air temperature (temp.) (°C) and accumulated precipitation (precip.) (mm) from 1 May to 30 September for all study locations in 2012, 2013, and 2014. Values in parentheses represent the deviation from the 30 yr average.

| | | May | | June | | July | | Aug. | | Sept. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location† | Year | Air temp. | Precip. | Air temp. | Precip. | Air temp. | Precip. | Air temp. | Precip. | Air temp. | Precip. |
| | | °C | mm | °C | mm | °C | mm | °C | mm | °C | mm |
| ARcol | 2012‡ | 24.3 (+3.1) | 51 (–91) | 26.1 (+0.3) | 55 (–20) | 30.1 (+3.0) | 39 (–52) | 27.6 (+1.2) | 56 (–18) | 23.7 (+1.3) | 128 (+65) |
| | 2013 | 20.6 (–0.6) | 209 (+67) | 25.9 (+0.1) | 50 (–25) | 25.6 (–1.5) | 118 (+27) | 25.9 (–0.5) | 74 (+0) | 24.5 (+2.1) | 74 (+11) |
| | 2014 | 21.7 (+0.5) | 188 (+46) | 24.6 (–2.5) | 431 (+356) | 24.6 (–2.5) | 54 (–37) | 26.8 (+0.4) | 30 (–44) | 23.6 (+1.2) | 20 (–43) |
| ARnew | 2012‡ | 24.4 (+3.3) | 86 (–45) | 24.8 (–0.9) | 41 (–45) | 28.7 (+1.1) | 56 (–41) | 25.8 (–1.3) | 56 (–12) | 21.9 (–0.8) | 175 (+96) |
| | 2013 | 19.2 (–1.9) | 242 (+111) | 25.2 (–0.5) | 57 (–29) | 25.0 (–2.6) | 86 (–11) | 24.8 (–2.3) | 115 (+47) | 23.4 (+0.7) | 40 (–39) |
| | 2014 | 19.9 (–1.2) | 128 (–3) | 24.4 (–1.3) | 204 (+118) | 24.0 (–3.6) | 100 (+3) | 26.3 (–0.8) | 21 (–47) | 21.9 (–0.8) | 22 (–57) |
| IAfar | 2012 | 17.3 (+2.5) | 83 (–24) | 21.2 (+1.0) | 36 (–74) | 25.7 (+3.4) | 12 (–109) | 20.9 (–0.3) | 102 (–5) | 15.6 (–1.0) | 30 (–56) |
| | 2013 | 15.0 (+0.2) | 179 (+72) | 19.8 (–0.4) | 92 (–18) | 21.3 (–1.0) | 64 (–57) | 21.3 (+0.1) | 76 (–31) | 18.0 (+1.4) | 60 (–26) |
| | 2014 | 15.2 (+0.4) | 70 (–37) | 20.9 (+0.7) | 319 (+209) | 19.6 (–2.7) | 53 (–68) | 21.2 (+0.0) | 79 (–28) | 15.8 (–0.8) | 54 (–32) |
| IAhum | 2012 | 18.2 (+2.5) | 71 (–41) | 22.2 (+1.4) | 66 (–74) | 26.2 (+3.3) | 28 (–93) | 21.6 (+0.2) | 22 (–79) | 17.1 (+0.4) | 77 (+3) |
| | 2013 | 14.5 (–1.2) | 191 (+79) | 20.3 (–0.5) | 134 (–6) | 22.9 (+0.0) | 26 (–95) | 20.9 (–0.5) | 33 (–68) | 19.1 (+2.4) | 20 (–54) |
| | 2014 | 15.6 (–0.1) | 89 (–23) | 21.3 (+0.5) | 263 (+123) | 20.3 (–2.6) | 61 (–60) | 21.6 (+0.2) | 92 (–9) | 16.5 (–0.2) | 124 (+50) |
| ILmon | 2012 | 18.8 (+1.7) | 85 (–32) | 21.8 (–0.3) | 143 (+31) | 26.4 (+2.4) | 25 (–79) | 22.8 (–0.2) | 81 (–17) | 17.9 (–0.9) | 145 (+53) |
| | 2013 | 17.1 (+0.0) | 299 (+182) | 21.7 (–0.4) | 96 (–16) | 22.1 (–1.9) | 52 (–52) | 22.4 (–0.6) | 1 (–97) | 19.7 (+0.9) | 52 (–40) |
| | 2014 | 16.7 (–0.4) | 83 (–34) | 22.3 (+0.2) | 181 (+69) | 20.7 (–3.3) | 108 (+4) | 22.8 (–0.2) | 134 (+36) | 17.4 (–1.4) | 154 (+62) |
| ILurb | 2012 | 20.2 (+3.2) | 79 (–44) | 22.4 (+0.1) | 58 (–60) | 27.9 (+3.9) | 15 (–100) | 23.4 (+0.3) | 141 (+47) | 18.2 (–0.9) | 145 (+67) |
| | 2013 | 17.9 (+0.8) | 95 (–28) | 21.8 (–0.5) | 159 (+51) | 22.5 (–1.5) | 90 (–25) | 22.8 (–0.3) | 9 (–85) | 20.9 (+1.8) | 17 (–61) |
| | 2014 | 17.7 (+0.6) | 111 (–12) | 22.8 (+0.5) | 209 (+101) | 21.0 (–3.0) | 221 (+106) | 23.0 (–0.1) | 39 (–55) | 18.1 (–1.0) | 87 (+9) |
| INwan | 2012 | 18.4 (+3.5) | 62 (–35) | 21.2 (+0.6) | 89 (–16) | 14.4 (–7.9) | 155 (+45) | 20.2 (–1.0) | 89 (–21) | 15.9 (–1.3) | 45 (–39) |
| | 2013 | 15.7 (+0.8) | 89 (–8) | 19.6 (–1.0) | 242 (+137) | 22.5 (+0.2) | 62 (–48) | 19.7 (–1.5) | 112 (+2) | 17.6 (+0.4) | 78 (–6) |
| | 2014 | 15.3 (+0.4) | 95 (–2) | 21.6 (+1.0) | 248 (+143) | 23.0 (+0.7) | 87 (–23) | 21.2 (+0.0) | 265 (+155) | 17.0 (–0.2) | 84 (+0) |
| INwla | 2012 | 19.9 (+3.5) | 88 (–32) | 22.3 (+0.7) | 42 (–64) | 26.6 (+3.5) | 27 (–77) | 21.8 (–0.2) | 198 (+109) | 17.3 (–1.0) | 104 (+34) |
| | 2013 | 18.4 (+2.0) | 95 (–25) | 21.8 (+0.2) | 124 (+18) | 22.1 (–1.0) | 70 (–34) | 21.4 (–0.6) | 48 (–41) | 19.0 (+0.7) | 90 (+20) |
| | 2014 | 17.0 (+0.6) | 124 (+4) | 22.7 (+1.1) | 148 (+42) | 20.1 (–3.0) | 95 (–9) | 21.9 (–0.1) | 211 (+122) | 16.8 (–1.5) | 143 (+73) |
| KSman | 2012 | 21.4 (+3.0) | 34 (–94) | 25.2 (+1.4) | 105 (–41) | 30.0 (+3.4) | 18 (–105) | 24.4 (–1.4) | 109 (+4) | 19.6 (–0.9) | 72 (–15) |
| | 2013 | 17.6 (–0.8) | 102 (–25) | 23.7 (+0.0) | 96 (–50) | 24.9 (–1.7) | 107 (–6) | 24.9 (–0.9) | 83 (–22) | 22.7 (+2.2) | 146 (+59) |
| | 2014 | 18.4 (+0.0) | 55 (–72) | 23.3 (–0.4) | 245 (+99) | 24.1 (–2.5) | 17 (–106) | 26.1 (+0.3) | 82 (–23) | 19.7 (–0.8) | 52 (–35) |
| KSros | 2012‡ | 21.9 (+3.5) | 61 (–65) | 26.1 (+2.6) | 115 (–15) | 30.2 (+4.0) | 30 (–76) | 24.8 (–0.5) | 36 (–76) | 19.9 (–0.3) | 12 (–89) |
| | 2013‡ | 18.1 (–0.3) | 147 (+21) | 24.3 (+0.8) | 62 (–68) | 25.8 (–0.4) | 59 (–47) | 25.2 (–0.1) | 71 (–41) | 22.7 (+2.5) | 251 (+150) |
| | 2014‡ | 19.9 (+1.5) | 58 (–68) | 24.4 (+0.9) | 140 (+10) | 24.9 (–1.3) | 44 (–62) | 26.9 (+1.6) | 42 (–70) | 20.6 (+0.4) | 123 (+22) |
| KSsca | 2012‡ | 20.4 (+3.1) | 3 (–99) | 24.7 (+1.9) | 116 (+17) | 28.6 (+2.7) | 75 (–24) | 23.3 (–1.6) | 59 (–19) | 18.7 (–1.1) | 30 (–39) |
| | 2013‡ | 16.8 (–0.5) | 96 (–6) | 22.9 (+0.1) | 43 (–56) | 24.4 (–1.5) | 111 (+12) | 24.6 (–0.3) | 133 (+55) | 21.9 (+2.1) | 40 (–29) |
| | 2014‡ | 17.2 (–0.1) | 11 (–91) | 23.2 (+0.4) | 131 (+32) | 23.8 (–2.1) | 36 (–63) | 24.8 (–0.1) | 112 (+34) | 18.6 (–1.2) | 73 (+4) |
| KYhod | 2012 | 20.9 (+2.2) | 134 (–14) | 22.8 (+0.1) | 9 (–91) | 26.7 (+2.1) | 201 (+91) | 24.0 (–0.1) | 71 (–6) | 20.6 (+0.0) | 101 (+8) |
| | 2013 | 18.9 (+0.2) | 163 (+15) | 22.6 (–0.1) | 203 (+103) | 22.8 (–1.8) | 226 (+116) | 23.2 (–0.9) | 179 (+102) | 21.1 (+0.5) | 104 (+11) |
| | 2014 | 18.8 (+0.1) | 179 (+31) | 22.7 (+0.0) | 36 (–64) | 23.2 (–1.4) | 95 (–15) | 23.3 (–0.8) | 168 (+91) | 20.7 (+0.1) | 13 (–80) |
| KYlex | 2012‡ | 20.4 (+2.5) | 91 (–44) | 22.4 (–0.3) | 41 (+73) | 26.9 (+0.6) | 203 (+85) | 23.4 (–0.7) | 55 (–28) | 19.2 (–0.9) | 138 (+61) |
| | 2013 | 19.0 (+1.1) | 144 (+9) | 23.2 (+0.5) | 192 (+78) | 23.6 (–2.7) | 231 (+113) | 23.8 (–0.3) | 131 (+48) | 20.9 (+0.8) | 41 (–36) |
| | 2014 | 19.2 (+1.3) | 138 (+3) | 23.8 (+1.1) | 142 (+28) | 22.9 (–3.4) | 82 (–36) | 24.4 (+0.3) | 243 (+160) | 20.8 (+0.7) | 110 (+33) |
| MIbre | 2012 | 15.8 (+1.9) | 55 (–33) | 19.8 (+0.5) | 63 (–26) | 23.9 (+2.2) | 177 (+106) | 20.0 (–0.4) | 130 (+41) | 16.0 (+0.0) | 29 (–56) |
| | 2013 | 15.3 (+1.4) | 120 (+32) | 18.9 (–0.4) | 74 (–15) | 21.3 (–0.4) | 22 (–49) | 19.9 (–0.5) | 86 (–3) | 16.1 (+0.1) | 26 (–59) |
| | 2014 | 13.7 (–0.2) | 84 (–4) | 19.8 (+0.5) | 61 (–28) | 18.8 (–2.9) | 167 (+96) | 19.5 (–0.9) | 65 (–24) | 15.8 (–0.2) | 91 (+6) |
| MIela | 2012 | 17.0 (+3.0) | 58 (–29) | 21.0 (+1.6) | 48 (–40) | 25.4 (+3.7) | 44 (–31) | 21.2 (+0.6) | 98 (+15) | 16.6 (+0.3) | 73 (–11) |
| | 2013 | 16.4 (+2.4) | 100 (+13) | 19.7 (+0.3) | 213 (+125) | 22.0 (+0.3) | 44 (–31) | 20.7 (+0.1) | 121 (+38) | 16.5 (+0.2) | 25 (–59) |
| | 2014 | 14.7 (+0.7) | 108 (+21) | 20.5 (+1.1) | 163 (+75) | 19.5 (–2.2) | 123 (+48) | 20.8 (+0.2) | 121 (+38) | 16.1 (–0.2) | 65 (–19) |
| MNstp | 2012 | 17.6 (+2.5) | 237 (+150) | 22.4 (+2.0) | 91 (–18) | 26.8 (+3.5) | 124 (+20) | 22.2 (+0.4) | 35 (–73) | 17.7 (+1.0) | 8 (–69) |
| | 2013 | 14.6 (–0.5) | 158 (+71) | 20.5 (+0.1) | 131 (+22) | 23.9 (+0.6) | 89 (–15) | 23.7 (+1.9) | 53 (–55) | 19.6 (+2.9) | 34 (–43) |
| | 2014 | 14.8 (–0.3) | 116 (+29) | 20.8 (+0.4) | 289 (+180) | 21.9 (–1.4) | 58 (–46) | 22.9 (+1.1) | 74 (–34) | 17.1 (+0.4) | 23 (–54) |
| MNwas | 2012 | 17.1 (+2.5) | 146 (+46) | 21.0 (+0.9) | 108 (–12) | 24.3 (+2.2) | 53 (–61) | 20.3 (–0.5) | 37 (–78) | 15.4 (–0.7) | 24 (–69) |
| | 2013 | 13.0 (–1.6) | 164 (+64) | 19.6 (–0.5) | 169 (+49) | 22.1 (+0.0) | 134 (+20) | 20.9 (+0.1) | 53 (–62) | 17.9 (+1.8) | 49 (–44) |
| | 2014 | 13.7 (–0.9) | 73 (–27) | 20.2 (+0.1) | 328 (+208) | 20.1 (–2.0) | 30 (–84) | 21.5 (+0.7) | 81 (–34) | 16.0 (–0.1) | 59 (–34) |

*Cont'd.*

Table 4. Continued.

| Location† | Year | May Air temp. | May Precip. | June Air temp. | June Precip. | July Air temp. | July Precip. | Aug. Air temp. | Aug. Precip. | Sept. Air temp. | Sept. Precip. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | mm | °C | mm | °C | mm | °C | mm | °C | mm |
| WIarl | 2012 | 15.0 (+0.9) | 75 (–18) | 19.8 (+0.4) | 7 (–111) | 24.3 (+2.7) | 56 (–46) | 19.4 (–1.0) | 73 (–24) | 14.3 (–1.8) | 26 (–65) |
| | 2013 | 13.3 (–0.8) | 153 (+60) | 17.9 (–1.5) | 191 (+73) | 20.4 (–1.2) | 76 (–26) | 19.2 (–1.2) | 45 (–52) | 15.5 (–0.6) | 75 (–16) |
| | 2014 | 12.6 (–1.5) | 71 (–22) | 19.2 (–0.2) | 237 (+119) | 18.1 (–3.5) | 48 (–54) | 19.4 (–1.0) | 94 (–3) | 15.4 (–0.7) | 45 (–46) |
| WIjan | 2012 | 17.5 (+2.2) | 50 (–48) | 21.6 (+1.4) | 14 (–87) | 26.6 (+3.7) | 81 (–23) | 21.5 (+0.1) | 76 (–18) | 16.3 (–0.5) | 60 (–26) |
| | 2013 | 15.9 (+0.6) | 84 (–14) | 19.9 (–0.3) | 242 (+141) | 22.1 (–0.8) | 46 (–58) | 20.7 (–0.7) | 36 (–58) | 17.9 (+1.1) | 50 (–36) |
| WIetr | 2014 | 13.3 (+0.0) | 75 (–16) | 20.4 (+1.5) | 125 (+28) | 19.9 (–1.5) | 72 (–14) | 20.4 (–0.2) | 71 (–28) | 15.5 (–0.5) | 68 (–15) |

† ARcol, Colt, AR; ARnew, Newport, AR; IAfar, Farley, IA; IAhum, Humboldt, IA; ILmon, Monmouth, IL; ILurb, Urbana, IL; INwan, Wanatah, IN; INwla, West Lafayette, IN; KSman, Manhattan, KS; KSros, Rossville, KS; KSsca, Scandia, KS; KYhod, Hodgenville, KY; KYlex, Lexington, KY; MIbre, Breckenridge, MI; MIela, East Lansing, MI; MNstp, St. Paul, MN; MNwas, Waseca, MN; WIarl, Arlington, WI; WIjan, Janesville, WI; WIetr, East Troy, WI.

‡ Location received supplemental irrigation.

Table 5. Model significance for the ANOVA for the main effect of input on seed yield, seed number, seed mass, and final stands for the South, Central, and North regions averaged across environments for studies in 2012, 2013, and 2014.

| Region | Seed yield | Seed number | Seed mass | Final stands |
|---|---|---|---|---|
| South | NS† | NS | NS | NS |
| Central | ** | NS | *** | NS |
| North | *** | *** | *** | ** |
| All | *** | *** | *** | NS |

** Significant at the $P < 0.01$ probability level.

*** Significant at the $P < 0.001$ probability level.

† NS, no significant differences at $P \leq 0.05$.

When analyzed across site-years within the South region, seed yield, seed number, seed mass, and final stands did not respond to inputs (Table 5). Seed yield averaged 4.15 Mg ha$^{-1}$ across all inputs in this region (Table 6).

In the Central region of this study, which included all study locations in Illinois, Indiana, and Iowa, inputs affected seed yield and seed mass but not seed number or final stands (Table 5). The defoliant decreased seed yield by 4.7% compared to the SP (3.85 vs. 4.04 Mg ha$^{-1}$), while SOYA increased seed yield by 4.9% compared to the SP (4.04 vs. 4.25 Mg ha$^{-1}$) (Table 6). SOYA also increased seed mass by 3.0% compared to the SP (168.3 vs. 163.4 mg seed$^{-1}$). While seed yield was unaffected, the foliar fungicide, foliar insecticide, and foliar fungicide+insecticide increased seed mass compared to the SP (167.8, 166.7, and 168.5 vs. 163.4 mg seed$^{-1}$, respectively). Similarly, SOYA-FF and SOYA+D both increased seed mass by 1.6% compared to the SP (166.1 and 166.1 vs. 163.4 mg seed$^{-1}$, respectively).

Seed yield, seed number, seed mass, and final stands responded to inputs in the North region of this study, which included the states of Michigan, Minnesota, and Wisconsin (Table 5). The Max seed treatment increased seed yield by 3.9% (4.27 vs. 4.11 Mg ha$^{-1}$) and seed mass by 2.6% (168.8 vs. 164.4 mg seed$^{-1}$) but not seed number when compared to the SP (Table 6). Nitrogen increased seed yield and seed number by 3.9% (4.27 vs. 4.11 Mg ha$^{-1}$) and 2.6% (2581 vs. 2515 seeds m$^{-2}$) compared to the SP, respectively. Foliar fungicide increased seed yield by 4.6% (4.30 vs. 4.11 Mg ha$^{-1}$) and seed mass by 3.5% (170.1 vs. 164.4 mg seed$^{-1}$) when compared to the SP. Similarly, foliar insecticide (4.40 Mg ha$^{-1}$) and foliar fungicide+insecticide (4.57 Mg ha$^{-1}$) increased seed yield by 7.1 and 11.1%, respectively, when compared to the SP (4.11 Mg ha$^{-1}$). Foliar insecticide and foliar fungicide+insecticide also increased seed number (2596 and 2646 vs. 2515 seeds m$^{-2}$, respectively) and seed mass (170.7 and 174.2 vs. 164.4 mg seed$^{-1}$, respectively) when compared to the SP. All SOYA combinations increased seed yield compared to the SP. However, while SOYA-FF+FI increased seed yield by 6.3% compared to the SP (4.37 vs. 4.11 Mg ha$^{-1}$), seed yield of SOYA-FF+FI was less than SOYA (4.37 vs. 4.60 Mg ha$^{-1}$) and foliar fungicide+insecticide (4.37 vs. 4.57 Mg ha$^{-1}$). Interestingly, all inputs except the foliar insecticide and foliar fungicide+insecticide increased final soybean stands compared to the SP (Table 6).

When data were analyzed across all environments, inputs affected seed yield, seed number, and seed mass but not final stands (Table 5). Foliar fungicide, foliar insecticide, foliar fungicide+insecticide, and all SOYA combinations increased seed yield compared to the SP (Table 7). All inputs that increased seed yield over the SP also increased seed mass compared to the SP. Only SOYA and SOYA-FF increased seed number compared to the SP (2629 and 2620 seeds m$^{-2}$ vs. 2560 seeds m$^{-2}$, respectively).

While seed yield increases were observed for a number of inputs both nationally and within regions, input costs must also be considered to help inform grower decision making. When the data were analyzed across all environments, relative yield changes for inputs ranged from –2.5% to 7.4% (Table 8). Seed treatment inputs had low break-even probabilities. The fungicide and fungicide+insecticide seed treatments had break-even probabilities well below 50% at all yield levels and soybean sale prices. The Max seed treatment had greatest break-even probability (48%) only at the highest yield level (5.0 Mg ha$^{-1}$) and soybean sale price (\$0.55 kg$^{-1}$) (Table 8). The defoliant had ≤1% break-even probabilities across all yield levels due to negative yield

**Table 6. Yield, seed number, seed mass and final stand values for input treatments across environments in the South (Arkansas, Kansas, Kentucky), Central (Illinois, Indiana, Iowa), and North (Michigan, Minnesota, Wisconsin) averaged across 2012 to 2014.**

| | South | | | | Central | | | | North | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment† | Yield | Seed number | Seed mass | Final stands | Yield | Seed number | Seed mass | Final stands | Yield | Seed number | Seed mass | Final stands |
| | Mg ha$^{-1}$ | seeds m$^{-2}$ | mg seed$^{-1}$ | plants ha$^{-1}$ | Mg ha$^{-1}$ | seeds m$^{-2}$ | mg seed$^{-1}$ | plants ha$^{-1}$ | Mg ha$^{-1}$ | seeds m$^{-2}$ | mg seed$^{-1}$ | plants ha$^{-1}$ |
| Standard practice | 4.11 | 2633 | 154.4 | 277,544 | 4.04 | 2445 | 163.4 | 333,525 | 4.11 | 2515 | 164.4 | 320,961 |
| Fung ST | 4.05 | 2595 | 154.9 | 295,008 | 4.02 | 2438 | 165.3 | 332,643 | 4.15 | 2504 | 167.0 | 333,022 |
| Fung. + Insect. ST | 4.07 | 2635 | 153.0 | 280,364 | 4.06 | 2454 | 164.0 | 335,257 | 4.18 | 2533 | 166.5 | 343,507 |
| Max ST | 4.16 | 2683 | 154.6 | 283,310 | 4.02 | 2429 | 164.6 | 329,649 | 4.27 | 2564 | 168.8 | 348,688 |
| Foliar fertilizer | 4.12 | 2638 | 155.2 | 293,027 | 4.01 | 2428 | 165.4 | 327,500 | 4.21 | 2568 | 165.0 | 331,845 |
| Defoliant | 4.16 | 2673 | 156.1 | 287,796 | 3.85 | 2368 | 161.6 | 322,021 | 3.94 | 2449 | 162.6 | 335,040 |
| Nitrogen | 4.11 | 2655 | 154.2 | 278,624 | 4.09 | 2492 | 163.6 | 323,833 | 4.27 | 2581 | 166.6 | 330,792 |
| N,N'-diformyl urea | 4.13 | 2670 | 155.0 | 287,769 | 4.03 | 2416 | 164.7 | 334,451 | 4.15 | 2507 | 166.9 | 332,209 |
| Foliar fungicide | 4.13 | 2606 | 157.7 | 283,556 | 4.14 | 2457 | 167.8 | 327,602 | 4.30 | 2548 | 170.1 | 327,355 |
| Foliar insecticide | 4.05 | 2639 | 154.6 | 277,925 | 4.10 | 2457 | 166.7 | 328,697 | 4.40 | 2596 | 170.7 | 328,295 |
| Foliar F+I | 4.11 | 2617 | 156.4 | 286,241 | 4.18 | 2479 | 168.5 | 326,008 | 4.57 | 2646 | 174.2 | 325,384 |
| SOYA | 4.29 | 2737 | 157.1 | 284,245 | 4.25 | 2519 | 168.3 | 325,711 | 4.60 | 2625 | 176.5 | 334,619 |
| SOYA+D | 4.26 | 2708 | 157.0 | 280,303 | 4.17 | 2492 | 166.1 | 333,140 | 4.42 | 2581 | 172.0 | 348,204 |
| SOYA-N | 4.23 | 2662 | 157.8 | 285,595 | 4.18 | 2474 | 165.9 | 335,706 | 4.48 | 2567 | 175.8 | 347,491 |
| SOYA-FF | 4.25 | 2689 | 156.6 | 276,489 | 4.15 | 2485 | 166.1 | 336,402 | 4.55 | 2646 | 174.0 | 352,778 |
| SOYA-FF+FI | 4.17 | 2671 | 155.8 | 280,403 | 4.15 | 2514 | 165.6 | 327,818 | 4.37 | 2580 | 170.2 | 348,896 |
| LSD‡ | NS§ | NS | NS | NS | 0.15 | NS | 2.6 | NS | 0.13 | 64 | 3.4 | 7,116 |

† ST, seed treatment; SOYA, combination high-yield treatment; D, defoliant; FF foliar fungicide; FI, foliar insecticide.

‡ LSD, least significant difference for management.

§ NS, not significant ($P \leq 0.05$).

**Table 7. Yield, seed number, and seed mass values for inputs across all environments averaged across 2012 to 2014.**

| | All environments | | | |
|---|---|---|---|---|
| Input† | Yield | Seed no. | Seed mass | Final stands |
| | Mg ha$^{-1}$ | seeds m$^{-2}$ | mg seed$^{-1}$ | plants ha$^{-1}$ |
| Standard practice | 4.08 | 2559 | 160.1 | 307,437 |
| Fungicide ST | 4.07 | 2526 | 161.8 | 317,703 |
| Fungicide+Insecticide ST | 4.10 | 2550 | 160.7 | 317,211 |
| Max ST | 4.15 | 2575 | 161.9 | 318,228 |
| Foliar fertilizer | 4.11 | 2564 | 161.3 | 314,940 |
| Defoliant | 3.98 | 2509 | 159.9 | 312,644 |
| Nitrogen | 4.15 | 2586 | 161.2 | 308,559 |
| N,N'-diformyl urea | 4.10 | 2548 | 161.5 | 314,779 |
| Foliar fungicide | 4.18 | 2549 | 164.8 | 310,128 |
| Foliar insecticide | 4.19 | 2573 | 163.5 | 308,895 |
| Foliar fungicide+Insecticide | 4.28 | 2588 | 166.0 | 309,950 |
| SOYA | 4.38 | 2629 | 167.0 | 312,507 |
| SOYA+D | 4.28 | 2603 | 164.7 | 318,093 |
| SOYA-N | 4.29 | 2583 | 165.9 | 320,281 |
| SOYA-FF | 4.31 | 2620 | 164.9 | 319,271 |
| SOYA-FF+FI | 4.23 | 2595 | 163.4 | 316,768 |
| LSD‡ | 0.10 | 54 | 1.8 | NS§ |

† ST, seed treatment; D, defoliant; N, nitrogen; FF foliar fungicide; FI, foliar insecticide; SOYA, combination high-yield management Blob no. 89.

‡ LSD, least significant difference for management.

§ NS, not significant ($P \leq 0.05$).

responses as well as treatment costs. Break-even probabilities for the foliar fertilizer and N were similarly limited across all yield levels and soybean sale prices (Table 8).

Of the late-season (R3) inputs, the foliar insecticide had the greatest break-even probabilities across all yield levels and soybean sale prices. Break-even probabilities for the foliar insecticide were >50% at all except the lowest yield level and soybean sale price with break-even probability >90% at the 5.0 Mg ha$^{-1}$ and \$0.55 kg$^{-1}$ soybean sale price (Table 8). Despite similar %RYC values as the foliar insecticide (2.5 vs. 2.7%, respectively) the foliar fungicide has much lower break-even probabilities due to greater input costs (Table 3.) The combination of the foliar fungicide and foliar insecticide resulted in greater RYC than either input alone (4.9%) (Table 8). However, break-even probabilities were decreased compared to the foliar insecticide, although at the 5.0 kg ha$^{-1}$ yield level and \$0.55 kg$^{-1}$ yield level the break-even probability for the foliar fungicide+insecticide was 85%. The N,N'-diformyl had low break-even probabilities across all yield levels and soybean sale prices. The SOYA treatments resulted in the largest RYC values. However, break-even probabilities were 0% for all yield levels and soybean sale prices, due to very high input costs (Table 8).

In the South region break-even probabilities were <50% for all seed treatment inputs across all yield levels and soybean sale prices (Table 9). Similar to national trends, the foliar fertilizer and N had relatively low break-even probabilities (<50%). In contrast, break-even probabilities were

**Table 8. Relative yield change and break-even probabilities for inputs compared to the standard practice at multiple yield levels and soybean sale prices across all environments between 2012 and 2014.**

| | | Yield level, Mg ha$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.0 | | | 4.0 | | | 5.0 | | |
| | | Soybean sale price, $ kg$^{-1}$ | | | | | | | | |
| Input† | RYC‡ | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 |
| | % | % probability of break-even | | | | | | | | |
| Fungicide ST | −0.2 | 5 | 11 | 17 | 11 | 18 | 24 | 17 | 24 | 29 |
| Fungicide+Insecticide ST | 0.5 | 0 | 0 | 1 | 0 | 2 | 5 | 1 | 5 | 10 |
| Max ST | 1.7 | 0 | 2 | 11 | 2 | 15 | 31 | 11 | 31 | 48 |
| Foliar fertilizer | 0.7 | 0 | 2 | 6 | 2 | 8 | 17 | 6 | 17 | 27 |
| Defoliant | −2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Nitrogen | 1.7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 7 |
| N,N'-diformyl urea | 0.5 | 0 | 0 | 2 | 0 | 3 | 8 | 2 | 8 | 15 |
| Foliar fungicide | 2.5 | 0 | 0 | 0 | 0 | 1 | 5 | 0 | 5 | 17 |
| Foliar insecticide | 2.7 | 37 | 64 | 78 | 64 | 81 | 88 | 78 | 88 | 93 |
| Foliar fungicide+Insecticide | 4.9 | 0 | 1 | 13 | 1 | 21 | 59 | 13 | 59 | 85 |
| SOYA | 7.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA+D | 4.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-N | 5.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-FF | 5.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-FF+FI | 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

† ST, seed treatment; FF, foliar fungicide; FI, foliar insecticide; D, defoliant; SOYA, combination high-yield management.

‡ RYC, relative yield change vs. standard practice.

**Table 9. Relative yield change and break-even probabilities for inputs compared to the standard practice at multiple yield levels and soybean sale prices for studies across the South region (Kansas, Kentucky, Arkansas) between 2012 and 2014.**

| | | Yield level, Mg ha$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.0 | | | 4.0 | | | 5.0 | | |
| | | Soybean sale price, $ kg$^{-1}$ | | | | | | | | |
| Input† | RYC‡ | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 |
| | % | % probability of break-even | | | | | | | | |
| Fungicide ST | −1.5 | 13 | 18 | 21 | 18 | 22 | 25 | 21 | 25 | 27 |
| Fungicide+Insecticide ST | −1.0 | 2 | 7 | 11 | 7 | 13 | 18 | 11 | 18 | 23 |
| Max ST | 1.2 | 7 | 17 | 27 | 17 | 30 | 39 | 27 | 39 | 47 |
| Foliar Fertilizer | 0.2 | 9 | 19 | 27 | 19 | 29 | 36 | 27 | 36 | 42 |
| Defoliant | 1.2 | 31 | 47 | 57 | 47 | 60 | 67 | 57 | 67 | 72 |
| Nitrogen | 0.0 | 0 | 0 | 2 | 0 | 2 | 6 | 2 | 6 | 12 |
| N,N'-diformyl urea | −0.5 | 4 | 9 | 15 | 9 | 17 | 23 | 15 | 23 | 28 |
| Foliar fungicide | 0.5 | 0 | 0 | 2 | 0 | 3 | 6 | 2 | 6 | 11 |
| Foliar insecticide | −1.5 | 8 | 13 | 18 | 13 | 19 | 23 | 18 | 23 | 27 |
| Foliar Fungicide+Insecticide | 0.0 | 0 | 0 | 1 | 0 | 1 | 4 | 1 | 4 | 8 |
| SOYA | 4.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA+D | 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-N | 2.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| SOYA-FF | 3.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| SOYA-FF+FI | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

† ST, seed treatment; FF, foliar fungicide; FI, foliar insecticide; D, defoliant; SOYA, combination high-yield management.

‡ RYC, relative yield change vs. standard practice.

>50% at most yield levels for the defoliant in the South region. Also in contrast to the national data, break-even probabilities were limited for the foliar insecticide with a maximum break-even probability of only 27%. However, similar to the national data the SOYA treatments had the highest %RYC values but had 0% break-even probabilities at most yield levels and soybean sale prices.

Similar to the South region, in the Central region the seed treatments and early-season inputs (defoliant, N, foliar fertilizer) had <50% break-even probabilities across all yield levels and soybean sale prices (Table 10). Unlike the South region, the foliar insecticide had the greatest break-even probabilities, with a maximum break-even probability (69%) achieved at the 5.0 Mg ha$^{-1}$ yield level

Table 10. Relative yield change and break-even probabilities for inputs compared to the standard practice at multiple yield levels and soybean sale prices for studies across the Central region (Illinois, Indiana, Iowa) between 2012 and 2014.

| | | Yield level, Mg ha$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.0 | | | 4.0 | | | 5.0 | | |
| | | Soybean sale price, \$ kg$^{-1}$ | | | | | | | | |
| Input† | RYC‡ | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 |
| | % | % probability of break-even | | | | | | | | |
| Fungicide ST | −0.5 | 9 | 16 | 21 | 16 | 23 | 28 | 21 | 28 | 32 |
| Fungicide+Insecticide ST | 0.5 | 0 | 1 | 2 | 1 | 3 | 6 | 2 | 6 | 10 |
| Max ST | −0.5 | 0 | 0 | 1 | 0 | 1 | 2 | 1 | 2 | 5 |
| Foliar Fertilizer | −0.7 | 0 | 1 | 2 | 1 | 3 | 5 | 2 | 5 | 9 |
| Defoliant | −4.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nitrogen | 1.2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 6 |
| N,N’-diformyl urea | −0.2 | 0 | 1 | 2 | 1 | 3 | 7 | 2 | 7 | 11 |
| Foliar Fungicide | 2.5 | 0 | 0 | 2 | 0 | 4 | 13 | 2 | 13 | 28 |
| Foliar Insecticide | 1.5 | 19 | 37 | 49 | 37 | 53 | 62 | 49 | 62 | 69 |
| Foliar Fungicide+Insecticide | 3.5 | 0 | 0 | 3 | 0 | 6 | 22 | 3 | 22 | 43 |
| SOYA | 5.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA+D | 3.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-N | 3.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-FF | 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-FF+FI | 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

† ST, seed treatment; FF, foliar fungicide; FI, foliar insecticide; D, defoliant; SOYA, combination high-yield management.

‡ RYC, relative yield change vs. standard practice.

Table 11. Relative yield change and break-even probabilities for inputs compared to the standard practice at multiple yield levels and soybean sale prices for studies across the northern region (Michigan, Minnesota, Wisconsin) between 2012 and 2014.

| | | Yield level, Mg ha$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.0 | | | 4.0 | | | 5.0 | | |
| | | Soybean sale price, \$ kg$^{-1}$ | | | | | | | | |
| Input† | RYC‡ | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 | 0.33 | 0.44 | 0.55 |
| | % | % probability of break-even | | | | | | | | |
| Fungicide ST | 1.0 | 27 | 39 | 46 | 39 | 48 | 54 | 46 | 54 | 59 |
| Fungicide+Insecticide ST | 1.7 | 1 | 5 | 13 | 5 | 15 | 25 | 13 | 25 | 36 |
| Max ST | 3.9 | 18 | 50 | 71 | 50 | 76 | 87 | 71 | 87 | 93 |
| Foliar fertilizer | 2.4 | 5 | 17 | 30 | 17 | 34 | 47 | 30 | 47 | 57 |
| Defoliant | −4.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nitrogen | 3.9 | 0 | 0 | 5 | 0 | 9 | 27 | 5 | 27 | 50 |
| N,N’-diformyl urea | 1.0 | 1 | 7 | 15 | 7 | 18 | 29 | 15 | 29 | 39 |
| Foliar fungicide | 4.6 | 0 | 3 | 16 | 3 | 23 | 47 | 16 | 47 | 67 |
| Foliar insecticide | 7.1 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| Foliar fungicide+Insecticide | 11.2 | 64 | 98 | 99 | 98 | 99 | 99 | 99 | 99 | 99 |
| SOYA | 11.9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 36 |
| SOYA+D | 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOYA-N | 9.0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 12 | 63 |
| SOYA-FF | 10.7 | 0 | 0 | 0 | 0 | 1 | 31 | 0 | 31 | 86 |
| SOYA-FF+FI | 6.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

† ST, seed treatment; FF, foliar fungicide; FI, foliar insecticide; D, defoliant; SOYA, combination high-yield management.

‡ RYC, relative yield change vs. standard practice.

and 0.55 kg$^{-1}$ soybean sale price. The SOYA treatments had a 0% break-even probability across all yield levels and soybean sale prices.

Responses to inputs were much greater in the North region as compared to the South and Central regions (Table 11). The fungicide seed treatment had break-even probabilities >50% at all multiple yield levels and soybean sale prices, while the Max seed treatment had ≥50% break-even probabilities at all but the lowest yield level and soybean sale price. Foliar fertilizer had greater break-even probabilities than the South and Central regions, although it achieved >50% break-even probability only at the highest yield level (5.0 Mg ha$^{-1}$) and soybean sale price (\$0.55 kg$^{-1}$). In contrast to the South region, break-even probabilities for the defoliant were 0% at all yield levels and soybean sale prices, while the foliar insecticide had 99% break-even probabilities at all yield levels and soybean sale prices. Foliar fungicide achieved break-even probability >50% only at 5.0 Mg ha$^{-1}$ and \$0.55 kg$^{-1}$. However, when the foliar fungicide was combined with the foliar insecticide (foliar fungicide+insecticide) RYC increased to 11.2% resulting in 98 to 99% break-even probabilities at all but the lowest yield level and soybean sale price. SOYA had similar RYC to the foliar fungicide+insecticide, however, break-even probabilities were low due to greater input costs (Table 3). Similar to the other regions, all SOYA treatments had low break-even probabilities, except SOYA-N (63%) and SOYA-FF (86%) which had >50% break-even probabilities at the 5.0 Mg ha$^{-1}$ and \$0.55 kg$^{-1}$ soybean sale price.

## DISCUSSION

This study is one of the first studies to evaluate a number of individual soybean inputs as well as multiple high-input management systems across the major soybean producing regions in the United States. The majority of yield increases observed both for individual inputs and high-input systems were in the North region, with little response to inputs in the Central and South regions. The high-input SOYA systems resulted in the increases in seed yield, but had low break-even probabilities across a wide range of soybean sale prices and yield levels. These results support the findings on a companion study, (Marburger et al., 2016a) that was conducted concurrently with this study and compared the SOYA and SOYA-FF input system to the SP across multiple cultivars at similar regional and national scales. In contrast to the lack of yield response observed in this study, Marburger et al. (2016a) found that SOYA increased seed yield by 4.3% and SOYA-FF increased seed yield by 2.5% compared to the SP in the South region (Table 6). In the Central region, Marburger et al. (2016a) found that both SOYA and SOYA-FF treatments increased yield compared to the SP by 6.2 and 5.1%, respectively. The yield increase observed by Marburger et al. (2016a) for SOYA in the Central region was slightly greater than the one observed in this study (6.2 vs. 4.9%), while in this study no yield increase was observed for SOYA-FF. In the North region Marburger et al. (2016a) found that SOYA increased seed yield by 7.4%, while SOYA-FF increased seed yield by 5.3% compared to the SP. However, unlike in the South and Central Regions, SOYA increased seed yield by 2.0% over SOYA-FF. Seed yield increases observed in the North region of this study were greater than those observed by Marburger et al. (2016a), as SOYA increased yield by 11.9% and SOYA-FF increased yield by 10.7%. However, there were no differences in seed yield between SOYA and SOYA-FF in this study. While this study and Marburger et al. (2016a) were conducted in the same environments, the data presented by Marburger et al. (2016a) was combined across multiple ($n$ = 6) cultivars in each site-year, which likely affected seed yield responses to the SOYA and SOYA-FF treatments.

On a national scale, Marburger et al. (2016a) observed a maturity group × cultivar interaction. Yield increases for SOYA over the SP ranged from 4.6 to 7.0% while yield increases for SOYA-FF ranged from 2.4 to 5.6%, depending on maturity group. These results are largely similar to the results observed in this study with SOYA increasing yield by 7.3% and SOYA-FF increasing yield 5.6%, compared to the SP. Despite increased seed yield, Marburger et al. (2016a) concluded that both SOYA and SOYA-FF would both result in a negative return on investment (ROI) for soybean producers who utilized these high-input management systems.

Soybean producers interested in maximizing yield would be better served to identify specific inputs that give them the best chance of increasing soybean profitability. Although responses were observed in individual site-years, when averaged across environments seed yield responses were not observed for any inputs in the South region. This is surprising since pest pressure is generally considered to be greater in southern environments compared to more northern environments. However, disease and insect ratings across the South region indicated both insect and disease pressure was minimal in all study environments (data not shown). In growing seasons with much higher pest pressure, yield responses to inputs such as seed treatments, foliar fungicides, and foliar insecticides could likely be expected.

In the Central region, which encompasses the majority of the soybean land areas in the United States, only SOYA increased seed yield over the standard practice. However, Bayesian analysis indicated that SOYA had limited chance of breaking even due to high input costs. While they did not significantly increase seed yield, the foliar fungicide, foliar insecticide, foliar fungicide+insecticide and two other SOYA variations increased seed mass compared to standard practices. Numerous previous studies have shown that yield increases are often the result of increased seed number (seeds m$^{-2}$) (DeBruin and Pedersen, 2008; Gaspar and Conley, 2015), but few studies have reported yield increases due to increased seed mass. Seed number (R1–R5) (Egli and Yu, 1991; Board and Tan, 1995) is determined prior to seed mass (R5–R6), so inputs such as foliar fungicide and/or foliar insecticide applied at R3 (beginning of pod development) would be expected to affect seed number and not seed mass. The same trend was observed and markedly more pronounced in the North region, with inputs containing the foliar fungicide and/or the foliar insecticide increased seed yield over the SP and also had greater seed mass compared to the SP.

To affect seed mass the foliar fungicide and/or foliar insecticide must have either suppressed disease and/or insect populations at R3, or provided residual control of soybean pests until the R5–R6 growth stages. Furthermore, in the North region SOYA without the foliar fungicide and foliar insecticide (SOYA-FF+FI) had lower seed mass and seed yield than the foliar fungicide+insecticide, SOYA and SOYA-N, indicating that the foliar fungicide and foliar insecticides increased yield through an increase in seed mass. It appears that pest pressure during seed filling (R5–R6) is important to seed yield determination in these environments.

While large responses were observed for the use of the foliar insecticide in the North region, it is important to note that threshold level insect populations (soybean aphid [*Aphis glycines*]) were observed in only 5 out of 18 site-years in the North region. Researchers at all other North region site-years reported very low levels of insect pests. The yield increases observed with the foliar insecticide, both in the presence and absence of threshold levels populations, as well as the high break-even probabilities would seem to suggest that soybean growers in the North region should always apply a foliar insecticide, regardless of insect pest pressure. However, a foliar insecticide application at suboptimal insect thresholds would be highly inadvisable. Insects have been shown to develop resistance to various insecticides due to the repeated used of a single chemical or mode of action (Elzen and Hardee, 2003; Ragsdale et al., 2007; Bielza, 2008). The prophylactic application of foliar insecticides would greatly increase selection pressure in favor of resistant individuals and populations, potentially leading to widespread insecticide resistance. Instead of considering planned insecticide applications regardless of pest pressure, soybean producers should closely monitor insect populations through scouting and only apply insecticides once pest populations reach threshold levels as part of integrated pest management (IPM) systems (Johnson et al., 2009). By continuing to practice IPM, soybean producers across the country will help to ensure that insecticides (as well as fungicides and other crop protection inputs) are still efficacious when threshold level pest populations do threaten a soybean crop.

On the other hand, the results of this study indicate that foliar insecticides, and to some extent foliar fungicides, are increasing soybean yields in the North region (Michigan, Minnesota, Wisconsin) even in the absence of threshold level insect pests. However, the reason for the observed yield response to these products is unclear. Perhaps, threshold levels for treatment of insects were too high for soybean in this study or yield was affected by the combined effects of multiple low-level pests. Alternatively, previous studies have reported that a certain class of foliar fungicides (i.e., strobilurins) can cause changes in plant physiology such as increased chlorophyll content, increased photosynthetic rates, and delayed senescence (Grossmann and Retzlaff, 1997; Grossmann et al., 1999). Perhaps foliar insecticides result in similar changes under certain environmental conditions. Further research needs to be conducted to elucidate the mechanisms for yield increases observed for foliar insecticides observed in this study.

While positive yield responses were observed for inputs such as the foliar fungicide and foliar insecticide, there were inputs where no yield increases were observed at either the regional or national scale. For example, foliar fertilizer did not affect yield in any region or nationally. This finding supports the findings of numerous previous studies that also failed to observe increased seed yield with the use of a foliar fertilizer (Parker and Boswell, 1980; Haq and Mallarino, 2000; Mallarino et al., 2001). Similarly, this study did not observe increased seed yield with the defoliant. These findings support recent studies which also did not observe increased seed yield with defoliant use (Gregg et al., 2015; Orlowski et al., 2016; Mangialardi et al., 2016). Finally, increased seed yield was not observed for N,N'-diformyl. A lack of seed yield response to N,N'-diformyl was also reported by Gregg et al. (2015).

## CONCLUSIONS

Due largely to increased commodity prices in recent years, many soybean producers have considered switching to high-input management systems in place of recommended management systems based on the principles of IPM, despite the lack of un-biased information about the effects of such systems on soybean yield. The purpose of this study was to examine several high-input soybean management systems as well as the individual inputs that were components of these systems on a regional and national scale. Yield response to high-input management systems appeared to vary by region, with no responses observed when averaged across environments in the South region (Arkansas, Kansas, Kentucky) and extensive yield increases observed in the North region (Michigan, Minnesota, Wisconsin). On the national level, all of the high-input systems increased yield compared to standard practices; however, break-even analysis indicated that these systems presented soybean producers with no (0%) opportunity to break-even financially from adopting these systems across a wide range of yield levels and soybean sale prices. While the high-input systems held little promise for increasing producer profitability, the data revealed that foliar insecticide applied at R3 resulted in significant break-even probabilities. This response was driven by a robust response to the foliar insecticide in the North region, despite threshold levels of insect pests. Additional research is needed to determine the reason for the foliar insecticide responses observed in this study to ensure both the maximization of soybean producer profitability as well as the continued utilization of IPM in soybean production systems.

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