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Evaluation of input-intensive soybean management systems and the effect of lactofen application on soybean physiology

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EVALUATION OF INPUT-INTENSIVE SOYBEAN MANAGEMENT SYSTEMS AND THE EFFECT OF LACTOFEN APPLICATION ON SOYBEAN PHYSIOLOGY

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture, Food, and Environment
at the University of Kentucky

By
John Mark Orlowski

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Director: Dr. Chad Lee, Professor of Agronomy

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ABSTRACT OF DISSERTATION

2015

In an effort to maximize yields, many soybean growers have begun moving to intensive, input-based soybean management systems. However, limited reliable information exists about the effect of these inputs on soybean yield. The purpose of this study was to evaluate the effect of individual inputs and combinations of inputs as part of high-yield management systems on soybean seed yield and to determine the effect of one of these inputs, lactofen, on soybean physiology. Small plot studies were established in nine states across the Midwest. A number of commercially available soybean inputs were evaluated individually and in combination to determine their effect on soybean yield and quality. Lactofen and comparison treatments were applied to soybeans at multiple growth stages and yield and yield components were determined. When examined across environments, input-intensive combination treatments increased soybean yields from 3.9 to 8.1 %. However, break-even economic analysis indicated that the combination (SOYA) treatments evaluated had 0% probability of breaking across a wide range of yield levels and soybean prices, due to the high input costs. The foliar insecticide showed the highest probability of breaking even across a range of yield levels and crop prices (40% to 99%). Yield increases and breakeven probabilities were generally greatest in the northern states (Minnesota, Wisconsin, Michigan) and similar in the central and southern states. Lactofen application did not kill the apical meristem and had minimal effect on yield components compared to untreated soybeans at any growth stage. Meristem removal increased node m^{-2} in some environments, but did not increase pods m^{-2} and seeds m^{-2} or seed yield.

KEYWORDS: Soybean, High-yield management, break-even, meristem, lactofen

John Mark Orlowski

9 May 2015

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CHAPTER I: Introduction and Literature Review

The United States is the largest producer of soybean (*Glycine max* L. Merr.) in the world, accounting for 33% of world production (USDA-ERS, 2014b). Soybean is the second most important cash crop in the United States covering 30.8 million hectares in 2012 with a total production of 3.7 million metric tons for a total economic impact of 40.2 billion US dollars (USDA NASS, 2013). The main production areas in the US are the Midwest where soybean is grown in rotation with corn (*Zea mays* L.) and the Mississippi Delta, where soybean is primarily grown in rotation with rice (USDA-ERS, 2014b).

In the calendar year 2001, the average price received by soybean growers in the Midwest was \$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 a kilogram of soybean jumped to \$0.42 kg^{-1} (Schnitkey, 2013). This dramatic increase in soybean prices spurred a widespread interest in maximizing soybean yield to capitalize on the increased profitability of producing soybean.

University extension programs generally recommend limited inputs for soybean production. These inputs are generally restricted to untreated soybean seed, enough phosphorous and potassium fertilizer to ensure sufficiency, inoculation with *Bradyrhizobium japonicum* on certain fields, and a herbicide program to control weeds. The use of other soybean inputs such as seed applied and foliar applied insecticides and fungicides is only recommended in cases where the disease or insect pest population was determined through crop scouting to be above the economic injury level, the pest population where the economic damage caused by the pest is equal to the cost of controlling the pest (Stern et al. 1959).

Despite university recommendations, soybean producers seeking to maximize yield to take advantage of elevated soybean prices generally looked toward increasing the number of inputs used as part of their soybean management system. Many growers transitioned from a conservative management program that relied on the principles of integrated pest management to a more aggressive approach where inputs are applied to the crop regardless of known crop need. Agricultural companies began producing novel products designed to increase soybean yield through a number of mechanisms. Companies also began promoting use of existing products for non-traditional uses. For example, a number of chemical companies began promoting the use of seed applied and foliar fungicides and insecticides for general "plant health" benefits that would purportedly lead to higher yield. Often soybean producers would combine a number of inputs and management practices into what this dissertation will refer to as "high-yield" management systems.

Seed Treatments

Early planting is one management strategy that has been shown in some recent studies to increase yields in the Midwest (DeBruin and Pedersen, 2008; Robinson et al., 2009). Planting soybeans in late April or Early May has been shown to increase both pod plant^{-1} and seed plant^{-1} (Pedersen and Lauer, 2004) and seeds m^{-2} (DeBruin and Pedersen, 2008) when compared to later planting dates in May and June. Earlier planting allows soybean to achieve canopy closure before the critical period of yield determination or shift the critical period into part of the growing where more solar radiation is available. These results support earlier findings that show a yield penalty for soybeans planted after late May to early June in the Midwest, Upper South and Lower South (Egli and Cornelius, 2009).

Despite the yield benefit of early soybean planting, there are a number of risks associated with the practice. Early planting exposes soybean seeds to cool wet soil conditions that are conducive to infection from soil borne pathogens such as *Pythium* spp. (Dorrance et al. 2004), *Phytophthora sojae* (Dorrance et al., 2009), and *Rhizoctonia solani* (Murillo-Williams and Pedersen, 2008). One strategy to overcome this problem is the treatment of soybean seed with fungicides and insecticides. Results of previous research have produced mixed results in regards to the benefits of soybean seed treatment. One study in the northeast US found no differences in stand establishment and seed yield between soybeans planted with untreated seed and two insecticide/fungicide seed treatments (Cox et al. 2008). Bradley (2001) found that metalaxyl increased soybean stands in one year of a two year study but yield was not affected in either growing season. A study in Illinois evaluated six fungicidal seed treatments and their interactions with different herbicide programs and found that seed treatments did not increase soybean seed yield in any environment (Bierman et al., 2005).

Another study in the northeast US found a modest yield increase (~4%) for soybean planted with an insecticide/fungicide seed treatment (Cox and Cherney, 2011). This study found that seeding rates could be reduced when using seed treatment. However, the economic benefit of the reduced seeding rate was negligible due the added cost of the seed treatment. Schulz and Thelen (2008) found that seed applied metalaxyl and fludioxonil increased soybean yield in 3 of 16 site-years but decreased yield in 2 of 16 site-years. Esker and Conley (2012) found that the yield and economic benefits of seed treatment varied greatly by variety and year but could be a cost-effective management practice at high commodity prices.

Limited peer reviewed research exists concerning any benefits of seed applied insecticides on soybean yield (Cox and Cherney, 2011). Soybean are rarely affected by soil borne insect pests. However, the class of insecticides applied to soybean seed, the neonicotinoids, are absorbed by the developing soybean plant and can provide systemic residual control of early season foliar insect pests. McCornak and Ragsdale (2006) showed that seed applied thiamethoxam (Syngenta Crop Protection, Greensboro, NC), a neonicotinoid insecticide, can provide up to 50 days of residual control of soybean insect pests such as soybean aphid and bean leaf beetle. A study in Nebraska investigated control of soybean aphid with two seed applied neonicotinoid insecticides, imidacloprid and thiamethoxam. Thiamethoxam held soybean aphid populations below economic threshold levels but imidacloprid did not due to higher levels of thiamethoxam in leaf tissue (Magalhaes et al., 2009). Another study in South Dakota found that neither seed applied thiamethoxam nor imidacloprid affected populations of soybean aphid, and did not increase soybean yield (Seagraves and Lundgren, 2012).

While soil-borne diseases and insects can be problematic, the most damaging soil born pathogen limiting soybean yield is the soybean cyst nematode (SCN) (Delheimer et al., 2010). Soybean cyst nematode has been shown to reduce yield by 15% yield loss without causing visible foliar injury symptoms in the soybean plant (Wang et al., 2003).

Soybean cyst nematode is an endoparasitic obligate pathogen which infects soybean roots. While the primary management strategies for SCN are crop rotation and genetic resistance, agri-chemical companies are now providing seed treatment products designed to protect young soybean from SCN infestation. One such product is called Votivo (Bayer Crop Science, Monheim, Germany). Votivo is a bacterial (*Bacillus firmus* I-1582) seed applied inoculant that competes with plant parasitic nematodes in the rhizosphere around the plant roots (Wilson and Jackson, 2013). While some studies (ie. Gaspar et al., 2014) have included Votivo as part of a larger seed treatment study, peer reviewed research of the effects of Votivo application are limited.

Inoculation

Soybean inoculants are another input that have recently been added to seed treatment packages in an attempt to increase soybean yield. Soybean seeds are composed of around 42% protein by dry weight (Wilson, 2004). In order to produce seeds with this high protein content, developing soybean have a large nitrogen (N) requirement for maximum yield. Soybean acquire N through uptake of plant available N in the soil and via biological N fixation through a symbiosis with a soil borne bacterium, *Bradyrhizobia japonicum* (Patterson and LaRue, 1983). The N supplied via biological nitrogen fixation is estimated to be between 49% and 67% of the N required by the soybean plant (Hunt et al. 1985). Large populations of *B. japonicum* are needed to ensure adequate nodulation and N supply to the plant (Berg et al. 1988). Fields that have never been planted to soybean require inoculation of the soybean seed with the rhizobia to ensure adequate populations of *B. japonicum*. However, after a field has been planted to soybean, subsequent soybean crops usually do not require inoculation because adequate native populations of *B. japonicum* exist in the soil (Nelson et al., 1978).

Although inoculation of soybean is not usually recommended for soybean production in the Midwest, growers seeking to maximize soybean yield have considered adding inoculants as part of their management programs despite extensive field history of soybean production. Research from across the Midwest has repeatedly failed to show yield advantages for inoculating soybean where there has been a history of soybean production (Nelson et al., 1978; Ham et al., 1971). However, a study in in the Upper Midwest found that inoculants increased soybean seed yield in six of 14 site-years in fields that had recently had soybean in rotation (Shulz and Thelen, 2008). Another study conducted between 2000 and 2008 across the Midwest, tested 51 different inoculant products in 73 environments and found that inoculation had no effect on soybean yield in fields that had a history of soybean production (De Bruin et al., 2010). Other studies in the Midwest also failed to find yield increases for inoculation (Furseth et al., 2011; Furseth et al, 2012).

Despite the lack of responses to soybean inoculation, inoculant manufacturers have created products that contain additional compounds designed to improve the efficacy of the inoculant. An example of this is an inoculant product called Optimize (Novozymes BioAg, Franklinton, NC). Optimize combines a *B. japonicum* inoculant as well as with lipochitooligosaccharides (LCO). Lipochitooligosaccharides are a group of compounds that are produced by rhizobia that mediate recognition between the bacteria and the soybean plant and initiate the organogenesis process in soybean plants that leads to the formation of root nodules (Cullimore et al., 2001). Since LCO molecules stimulate nodulation applying LCO molecules as a soybean seed treatment along with an inoculant could theoretically increase nodulation, potentially leading to higher soybean yield. While no peer-reviewed field studies have been conducted to evaluate any yield benefits associated with LCO application in laboratory studies LCO application increased seed germination and plant growth in legumes (Souleimanov et al., 2002, Prithiviraj et al., 2003). Although in nature LCO molecules are involved only in root nodulation LCO molecules applied to legume foliage can cause plant responses, such as increased disease resistance, photosynthesis, and sugar production (Almaraz et al., 2007; Duzan et al., 2005).

Soybean Branching and Lactofen Application

An important soybean yield component is pod number per area (pods m^{-2}). Studies have shown that changes in crop growth rate and light interception during reproductive growth primarily affect pods m^{-2} (Board et al., 1992; Board and Tan, 1995). Soybean pods are produced on both mainstem and branches that originate from mainstem nodes (Board, 1987). The branching behavior of soybean is genetically controlled (Nelson, 1996) but is also highly influenced by environmental factors such as soil moisture (Frederick et al., 2001) and agronomic factors such as row spacing (Carpenter and Board, 1997; Norsworthy and Shipe, 2005). Soybean grown at low populations can often yield similarly to soybean grown at higher populations because of increased branch development in the low-population soybean (Herbert and Litchfield, 1982; Leuschen and Hicks, 1997, Carpenter and Board, 1997). Studies have shown that mainstem seed yield is relatively stable across environments. (Frederick et al., 2001; Norsworthy and Shipe, 2005). Yield reductions in soybean from stress during reproductive growth were primarily due to decreased branch seed yield plant^{-1} (Board et al., 1990; Linkemer et al., 1998; Frederick et al., 2001).

Since total soybean seed yield is heavily dependent on seed yield produced on branches, increasing soybean branch number, or pods and seeds per branch, could result in increased total seed yield. A typical soybean plant has a single mainstem, with branches arising from the cotyledonary node (Fehr et al., 1977) and unifoliate node (Acock and Acock, 1987). The growth of the axillary branches is regulated by hormones produced in the apical meristem on the main soybean stem (Ali and Fletcher, 1970). Growth of axillary buds is inhibited by the production and translocation of indole-acetic acid (IAA) in the apical meristem. If the apical meristem is removed, lateral buds in soybean are released from inhibition and other plant hormones (primarily cytokinins and gibberellins) interact with lateral buds to increase cell division and internode elongation leading to branch development (Ali and Fletcher, 1970; Ali and Fletcher, 1971).

One strategy that has been suggested to remove apical dominance is to kill the apical meristem via the application of herbicides to early-vegetative soybean. Weidenhamer et al. (1989) observed apical meristem death after application of the synthetic auxin herbicide dicamba. A more recent study found that applying dicamba at rates above 2.3 g ha^{-1} resulted in apical meristem death (Robinson et al., 2013). Other synthetic auxin herbicides such as aminopyralid, picloram, clopyralid, and aminocyclopyrachlor have been shown to kill the soybean apical meristem (Solomon and Bradley, 2014). While synthetic auxins can effectively kill the apical meristem, thereby removing apical dominance, these herbicides are not labeled for use in soybean and often lead to yield decreases due to severe soybean injury.

A class of herbicides that is registered for use in soybean are the protoporphyrinogen oxidase (PPO) inhibitors. These herbicides are used primarily post-emergence to control broadleaf weeds in soybean and other crops. Protoporphyrinogen oxidase inhibitors such as acifluorfen, fomesafen, and lactofen cause bronzing and necrosis on the foliage of susceptible species (Graham, 2005). These symptoms can also be observed on the foliage of tolerant crops such as soybean (Kapusta et al., 1986; Wichert and Talbert, 1993). The injury to soybean caused by PPO herbicides varies depending on the soybean growth stage. Kapusta et al. (1986) found that acifluorfen caused more visible injury to soybean at the V3 growth stage compared to the V5 growth stage. In other studies, soybean injury was greater when either acifluorfen (Hart et al., 1997; Young et al., 2003) or lactofen (Wichert and Talbert, 1993) was applied to earlier growth stages compared to later growth stages. Nelson et al. (2002a) found that tank mixtures containing lactofen applied to soybean at V5 injured the soybean and delayed development.

While the PPO herbicides are known to cause soybean injury, their effect on soybean yield is inconsistent. Nelson et al. (2002a) herbicide mixes that included lactofen decreased yield when compared to untreated soybean. Young et al. (2003) found that application of acifluorfen reduced soybean yield compared to untreated/weed-free plots but only by 1.5%. There was no yield decrease with lactofen application in other studies (Kapusta et al., 1986; Wichert and Talbert, 1993).

Lactofen has also been shown to have anti-fungal activity (Dann et al. 1999; Nelson et al., 2002; Sango et al., 2001). The application of lactofen induced the accumulation of large amounts of isoflavones in soybean tissue (Nelson et al., 2002b;

Landini et al., 2002). The cell death caused by lactofen leads to the up-regulation of isoflavone synthase genes (Graham, 2005). Two of the isoflavones produced, daidzen and genistein, assist in the development of soybean fungal defense mechanisms (Graham and Graham, 1999). Lactofen also increases the soybean tissue's ability to accumulate fungal defense compounds (Landini et al., 2002). Furthermore, Graham (2005) found that the application of lactofen induced the expression of pathogenesis related protein genes.

While the anti-fungal activity of lactofen has been demonstrated under laboratory conditions, inconsistent benefits of lactofen application for disease control have seen under field conditions. Dann et al. (1999) found that, when white mold [*Sclerotinia sclerotiorum* (Lib.) deBarry] incidence was high, lactofen reduced disease severity 40% to 60%. However, when white mold incidence was moderate to low, lactofen application decreased yield by 10%. This yield decrease was attributed to foliar injury from lactofen.

Nitrogen

While soybean is a leguminous crop and, therefore, able to obtain N via symbiosis with *B. japonicum*, soybean are also able to take up N from the soil. Salvagiotti et al. (2008) concluded that 50-60% of soybean N is acquired through biological N fixation, with the remainder of N being acquired via through uptake by the plant. The importance of soil N suggests that increasing the soil available N by applying N fertilizer would potentially increase soybean yield. However, numerous studies have shown that, as N fertilization rate increases, biological N fixation decreases (Salvigiotti et al., 2008).

The effects of N fertilization on soybean yield have been mixed. A study in Illinois investigated the effect of different levels of residual N from the preceding corn crop as well as different rates of N from both organic and inorganic sources (Welch et al., 1973). Nitrogen, whether applied to the previous corn crop or directly to the soybean crop, had no effect on soybean seed yield. Nitrogen application, during flowering and pod filling did not affect yield while pre-plant N injured soybean and decreased yield. In contrast, another study in Nebraska found that N applied pre-plant increased yield at 9 out of the 13 sites investigated (Sorensen and Penas, 1978). Yield increases ranged from 0.83 kg seed per kg N applied to 2.5 kg seed per kg N applied (Sorensen and Penas, 1978). Another study in Kansas evaluated the effects of residual soil N and the effect of pre-plant N fertilization. The researchers observed yield increases for N applied to the soybean crop when the When residual soil NO_3^- - N was below 190 kg ha^{-1}, N fertilization increased soybean yield. However, if residual soil NO_3^- - N was above 190 kg ha^{-1} N fertilization decreased soybean yield due to the inhibition of biological N fixation (Stone et al., 1985).

More recent studies have also shown mixed results with soybean N fertilization. A study Argentina found that two rates of N applied at growth stages R3 and R5 did not affect soybean seed yield (Gutierrez-Boem et al., 2004). A study on clay soils in Mississippi yield increases of 7.7% for non-irrigated soybean and 15.5% for irrigated soybean were found when N was applied at soybean emergence. The yield increases were due to an increase in seeds m^{-2} (Ray et al., 2006). A study conducted on silt-loam soils in Arkansas found yield increases of 15 to 25% for soybean grown under drought conditions and yield increases of 12 to 15% for well-watered soybean. In the second year of the study, yield increases of 9% were observed from N fertilization for both the well-watered and drought grown soybean (Purcell et al., 2004). Salvagiotti et al. (2009) also found that soybean N fertilization increased seed yield by an average of 228 kg ha^{-1} over unfertilized soybean when yield levels were greater than 4849 kg ha^{-1}.

Foliar Fertilizer

Nitrogen fertilization studies have largely investigated the effects of soil applied N ton soybean yield. However, N and other mineral nutrients can also be applied to the soybean crop through the leaf, via foliar fertilization. Foliar fertilization of soybean is a practice that has been examined numerous times over the past 50 years and the results have been inconsistent and appear to be influenced by soil fertility levels. Foliar fertilization has been shown to increase soybean yield when a certain mineral nutrient was known to be limiting. For example, foliar applied boron increased soybean yield by 4% and 10% in Arkansas where visible boron deficiency symptoms were evident (Ross et al., 2006). In the same study, soybean at a late-planted, no-till location exhibited dramatic boron deficiency symptoms and the application of foliar boron increased yield between 111% and 130%. However, yield increases of only 5% and 14% were observed after foliar boron application where there were no visible boron deficiency symptoms (Ross et al., 2006). Similarly, in a study conducted at two locations in Wisconsin, with low soil manganese levels, manganese applied to soybean foliage at initial bloom and early pod set (R1 and R3) stages increased yield over an control in two growing seasons (Randall et al., 1975).

A study on clay pan soils in Missouri with low to medium soil test K levels found foliar K application increased yield under no-till conditions (Nelson et al., 2005). When averaged across application timings, foliar K fertilization increased yield between 20% and 35% in one year of the study and between 47% and 66% in the second, drier, year of the study (Nelson et al., 2005). While foliar K fertilization increased soybean yield compared to unfertilized soybean, pre-plant K application always increased yield more than foliar K application. A similar study observed a 2% yield increase for foliar applied K at one location in Missouri (Nelson et al., 2010).

While foliar fertilization increase soybean yield by correcting known nutrient deficiencies, some studies have shown that foliar fertilizers can increase yield, even without apparent nutrient deficiencies. A study in Iowa found that certain foliar applications of N, P, K, and S increased yield when applied during the seed filling period (R5-R7). Garcia and Hanway (1976) hypothesized that nutrient uptake from the soil was not adequate to supply the needs of the plant and the foliar nutrients overcame this deficiency, even in the absence of visual symptoms. While yield increases of 27% to 31% were observed for certain ratios of N,P,K and S, no yield effect was found at some location. Although the foliar fertilizer was applied during seed fill (R5-R7), the yield increases were due to an increase in harvestable seed number, not seed size, as would be expected. Poole et al. (1983) conducted a study in Minnesota with a number of the same treatments as Garcia and Hanway (1976) but added micronutrients and a foliar fungicide to the mixture. Foliar fertilization increased yield in only one of nine site-years. The inclusion of the foliar fungicide and micronutrients also did not affect yield (Poole et al., 1983). Another study in Georgia examined the effects of applying N, P, and K, both individually and in combination, on soybean seed yield. No treatments increased yield and multiple treatments decreased yield due to physical damage from the fertilizer sprays (Parker and Boswell, 1980).

A study in Iowa summarized the effects of 27 early season N-P-K foliar fertilizations trials. Yield increases from foliar fertilization occurred in only six out of the 27 trials with an average yield increase of 0.4 Mg ha^{-1}. At the remainder of the study locations, yield was either decreased or unchanged compared to an unfertilized. The authors concluded that early-season foliar fertilization of soybean will seldom result in yield increases that cover application costs (Haq and Mallarino, 2000). An earlier study by the same authors found that foliar fertilization with N-P-K at early vegetative growth stages increased yield in only 7 out of 48 environments and that yield increases rarely covered application costs (Haq and Mallarino, 1998). Similarly, another study in Iowa found that foliar N-P-K fertilizers with sulfur and micronutrients increased yield in only two of 26 small trials and yield increases would not cover application costs (Mallarino et al., 2001).

Foliar Fungicide

The goal of foliar fertilization is to increase the nutrient status of the soybean crop in order to provide adequate plant nutrients for increased yield. Another strategy to increase yield is the application of foliar fungicides to protect soybean plants from diseases and for potential plant health benefits. Foliar soybean diseases are not generally considered a production obstacle in much of the north central U.S. soybean producing region. Yet, the soybean acreage treated with foliar fungicide increased from about 113,000 ha in 2002 to 3.3 million ha in 2012 (USDA-ERS, 2014a). The increase in fungicide use was largely due to soybean rust. Soybean rust is caused by the fungus *Phakospora pachyrhizi* and has been shown to cause yield losses over 60% in South America (Yorinori et al., 2005) and up to 100% in Africa (Caldwell and McLaren, 2004). When introduced to the United States in 2004, soybean rust was expected to be a major production issue across the entire US soybean producing area. In response, chemical manufacturers increased soybean fungicide production to satisfy the anticipated demand for foliar fungicides to control the disease. As expected, soybean rust became an annual problem in southern soybean growing regions but failed to spread to the major soybean production region in the Midwest, resulting in an excess of soybean fungicides. While foliar fungal diseases such as Septoria brown spot and Cercospora leaf spot, have the ability to reduce soybean yield, foliar pathogens, that can be controlled with fungicide application, rarely cause yield losses in the upper Midwest (Wrather and Koenning, 2006). To reduce fungicide stocks, agricultural chemical companies began marketing fungicides for yield enhancing benefits in both corn and soybean (Wise and Mueller, 2011).

The fungicide class primarily marketed for yield enhancing benefits in soybean is the strobilurins. Strobilurin fungicides prevent fungal spore germination and are active against a wide range of pathogens (Grossman and Retzlaff, 1997). The use of strobilurin fungicides, even in the absence of disease pressure, is being promoted by claiming a number of “plant health” effects, including “stay green” where the fungicide increases photosynthesis and delayed senescence (Grossman et al., 1999). For example, the application of pyraclostrobin was shown to delay soybean maturity but the effect varied with cultivar (Mahoney et al., 2015).

Soybean yield responses to foliar fungicides have been inconsistent. Dorrance et al. (2010) observed soybean yield increases at 6 out of 28 locations from a strobilurin fungicide but concluded that the economic threshold for fungicide application varied due to yearly fluctuations in soybean prices. In another study, the effect of two fungicides, tebuconzole and pyraclostrobin, on soybean yield and yield components in a low disease pressure environment was examined. There were no differences in pod m^{-2}, seeds m^{-2}, seeds pod^{-1} and seed yield between any treatments and the control and the authors concluded that foliar fungicides should only be applied for disease management in soybean (Swoboda and Pedersen, 2009). Another study in Indiana found that fungicide application did not affect soybean seed yield (Hanna et al., 2008). A study in Missouri examined the effect of a strobilurin fungicide with soil-applied and foliar fertilizers on soybean yield. The strobilurin fungicide applied at R4 increased soybean seed yield between 6% and 16% at one location but did not affect soybean seed yield at the other location (Nelson et al., 2010). Another study in Indiana found that R4 application of pyraclostrobin increased soybean seed yield by 3%, primarily through a 3% increase in seed mass (Henry et al., 2011). In Ontario, pyraclostrobin increased soybean seed yield by 4% but was generally not profitable due to the cost of fungicide application (Mahoney et al., 2015).

Foliar Insecticide

Foliar insecticide can also protect soybeans from pests during critical periods of yield formation. The soybean area treated with a foliar insecticides increased from 1.6 million ha in 2002 to 5.4 million ha in 2012 (USDA ERS, 2014). The two major economically important soybean insect pests in the Midwest are the bean leaf beetle (*Cerotoma trifurcata*) and the soybean aphid (*Aphis glycines*). These pests can reduce soybean yield by feeding directly on the plant and by transmitting several viruses that affect soybean (Johnson et al., 2008). The predominant classes of insecticides used in soybeans are the pyrethroids and the neonicotinoids and both effectively controlling bean leaf beetles and soybean aphids. As a consequence, foliar insecticide application is the primary management strategy for both pests (Ragsdale et al., 2004, Johnson et al., 2009).

The decision to treat a soybean crop with a foliar insecticide to control an insect pest is based on two values; the economic injury level (EIL) and the economic threshold (ET). The EIL is the lowest pest population density that will cause economic damage and the ET is the pest population where a control action needs to be initiated in order to prevent a pest population from reaching the EIL (Stern et al., 1959). A study that included locations in Iowa, Michigan, Minnesota, Nebraska, North Dakota and Wisconsin found that peak soybean aphid densities occurred between full flower (R3) and full pod (R5) and that the average EIL was 674 aphids plant^{-1}(Ragsdale et al., 2007). The ET value, when averaged across control costs, soybean prices, and yield levels was determined to be 273 aphids plant^{-1}. This value is largely similar to the treatment threshold of 250 aphids plant^{-1} recommended by most university extension programs in the upper Midwest (NCSRP, 2006). A study in Ohio found that the application of an insecticide increased soybean yield over untreated plants in eight out of nine locations where soybean aphid levels were above threshold levels (Dorrance et al., 2010). Johnson et al. (2009) found that both prophylactic and Integrated Pest Management (IPM) based applications of foliar insecticides for control of soybean aphid, increased soybean yield in three Midwestern states but the IPM management strategy gave the greatest probability of recouping treatment costs at all soybean prices.

A study in Iowa investigating the timing of foliar insecticide application for control of bean leaf beetle found that two early season applications of lambda-cyhalothrin increased yield by 16% and an early season application, coupled with a mid-season application (R2), increased soybean seed yield by 18% (Krell et al.,2004). While bean leaf beetle and soybean aphid can be problematic in the same growing season, Johnson et al. (2008) found that foliar insecticides targeted for control of bean leaf beetle did not prevent soybean aphid populations from reaching threshold levels due to the different timings of peak populations for the two species.

While soybean aphid and bean leaf beetle are the primary insect pests in the Midwest, stinkbugs are the major soybean pest in the southern U.S. The brown stink bug *Euschistus servus* (Say), the green stink bug (*Chinovia hilare* Say), and the southern green stink bug (*Nezara viridula* L.) are the most problematic species (Musser et al., 2011). The treatment threshold is one stinkbug per foot of row in Arkansas and Kentucky and both pyrethroid and organophosphate insecticides are registered for control of these species (Johnson, 2015; Lorenz et al., 1998). A study in Louisiana over five years found that pyrethroids, organophosphates and neonicotinoids provided 94%, 90% and 78% control, respectively, of southern green stinkbugs (Temple et al. 2013). Pyrethroids caused between 13% (lambda cyhalothrin) and 79% (bifethrin) mortality in nymphal stage stinkbugs when egg masses were treated (Brown et al., 2012).

While insecticides are effective at protecting or increasing soybean yield when insect pests are present, some studies have reported yield increases for soybean treated with foliar insecticides in the absence of insect pests. A study in Ohio found that the application of a foliar insecticide, lambda cyhalothrin, increased soybean yield in two out of five locations where aphids were not present (Dorrance et al., 2010). Another study found that an application of lambda cyhalothrin at R4 increased soybean seed number (seeds m^{-2}) by 5% resulting in a seed yield increase of 5% when averaged across three locations in Indiana although no above-threshold insect pests were observed at any location (Henry et al., 2011).

N,N'-diformyl urea

Products such as foliar fungicides and foliar insecticides increase soybean yield by controlling pests known to limit soybean yield potential. While these products have well established mechanisms of action and agronomic effects, novel products are available that claim to increase soybean yield via unknown or unproven mechanisms. One example is N,N'-diformyl urea marketed as Bio-Forge (Stoller USA, Houston, TX). The application of N,N' -diformyl urea up-regulated anti-oxidant pathways in the plant, including the thioredoxin reductase pathway and dihydroascorbate reductase pathway(Stoller, 2011). The assumed subsequent increase in anti-oxidants can help mitigate cell damage within the plant caused by stresses such as drought. The activity of these genes prevents the over-production of the plant hormone, ethylene, which can lead to cell death (Liptay, 2015).

There are no peer-reviewed, manuscripts detailing the effects of N,N' -diformyl urea on soybean yield. However, university extension reports outlining the results of studies that include N,N' -diformyl urea are available. N,N' -diformyl urea applied as a seed treatment followed by a foliar application of N,N' -diformyl urea at growth stage V4 increased soybean yield by 3% and income by \$22.23 ha^{-1} in Michigan (Staton, 2013). A study in Ohio compared N,N' -diformyl urea applied as a seed treatment, at R1 and at R5 on both glyphosate tolerant and non-genetically modified soybean (Yost et al., 2009). When used as a seed treatment, N,N' -diformyl urea decreased soybean yield by 18% on glyphosate-tolerant soybean and by 13% on non-genetically modified soybean and resulted in decreased plant populations at harvest. Yields with foliar applications of N,N' -diformyl urea were similar to that of the control. However, this study was conducted under ideal environmental conditions, which may have limited the efficacy of products like N,N' -diformyl urea that help plants deal with environmental stress (Yost, et al., 2009).

Objective

Limited peer-reviewed, independent research has been published on the potential yield effects of a number of soybean production inputs and combining these inputs as part of input-intensive, high- yield management systems. Moreover, inconsistent results have been documented in the research that has been published. The research is often done only in one state or geographic region and rarely includes economic analysis to quantify the profitability of different management strategies. The purpose of this study was to determine the effect of a number of soybean inputs and management strategies on soybean yield and quality and to determine the economic consequences of incorporating various inputs into soybean management systems. Another objective of this study was to determine the effect of early season lactofen application on soybean morphology, physiology, and agronomic performance.

CHAPTER II: Materials and Methods

National High-Yield Study

Field Experiments

Field trials were established in between 2012 and 2014 in nine states in the major soybean growing areas of the United States. At least two study locations were established in each state (Table 2.1) each year of the study resulting in 60 environments. Study locations were managed by cooperating researchers at the major land-grant universities in the participating states and all locations had high soybean yield potential. The soybean varieties used at each location were selected from commercially available cultivars. All varieties were glyphosate [N-(phosphonomethyl) glycine] resistant, Asgrow® brand soybean (Monsanto Company, St. Louis, MO) and represented maturity groups appropriate for the geographic area where the study sites were located. Where possible, the same variety was used in all three years at a particular location. However, yearly changes in seed availability resulted in varietal changes at some locations.

A randomized complete block design with four replications (blocks) was used at all locations. Treatments consisted of a number of commercially available inputs reported to have the ability to increase soybean yield (Table 2.2). Three seed treatment products were included in the study. 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 at 0.2336 mg a.i. per seed, clothianidin 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 included *B. japonicum* and lipo-chitooligosaccharide (LCO) at an application rate of 1.83 mL per kg seed. This treatment included a foliar applied LCO (Ratchet) at a rate of 292 mL ha^{-1}.

Nitrogen fertilizer was applied at V4 (Table 2.2). The fertilizer mix included urea (46-0-0 %N-P_20_5-K_20) applied at 84 kg ha^{-1} and polymer coated urea (44-0-0 %N-P_20_5-K_20) at 84 kg ha^{-1}). The defoliant was lactofen herbicide applied at V4 at 240 g ai ha^{-1}. Foliar fertilizer (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) was applied at R1 at 4676 mL ha^{-1}. N,N’–diformyl urea (Bio-Forge) was applied at R3 at 1169 ml ha^{-1} in all three years of the study.

For the foliar fungicide treatment, pyraclostrobin 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 at 97 g a.i. ha^{-1} were applied at R3 in 2013 and 2014. For the foliar insecticide treatment in 2012 lambda cyhalothrin 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 at 41 g a.i. ha^{-1} at R3 was used. The foliar fungicide + insecticide treatment was a tank mix of the fungicide and insecticide treatments (Table 2.2).

Individual products were combined as part of high-yield management systems and are referred to in this dissertation as SOYA treatments. The SOYA treatment included the Max seed treatment, nitrogen, foliar fertilizer, N,N’ – diformyl urea, foliar fungicide, and foliar insecticide at the rates and timings describes earlier (Table 2.2). Four variations of the SOYA treatment were also included in this study. The SOYA+ D treatment included the defoliant at the rate and timing described above. The SOYA-N treatment included all components of SOYA except nitrogen fertilizer. The SOYA- FF was the SOYA without the foliar fungicide and the SOYA- FF + FI was SOYA without the foliar fungicide and foliar insecticide.

Seed treatment products were applied to untreated soybean seed at the University of Minnesota Soybean Extension Laboratory and then shipped to cooperating researchers. Granular nitrogen products (urea and polymer-coated urea) were applied to the soil surface. Foliar applied products were applied with a backpack sprayer at a spray volume recommended on the product label.

The majority of locations were planted in May in all years of the study. Scandia, KS (2013), and Hodgenville, KY (2014) were seeded in June. Newport, AR (2013) and Manhattan, KS (2013) had poor stand establishment requiring these locations to be replanted in June. The Minnesota Lake-Drained and Minnesota Lake-Undrained locations in 2013 as well as the Waseca, MN location in 2014 were abandoned due to flooding. Plot size varied according to equipment availability at the universities managing each study location; however, all plots were planted at 432,000 seed ha^{-1}. Early plant densities were determined at the second node stage (V2, Fehr and Caviness, 1977) by counting all plants in a 1.52 m^2 area. The area where the early plant densities were determined was marked and final plant densities were determined for the same area prior to harvest. Plots were harvested at R8 and grain weight and maturity were recorded for each plot. Grain weight was converted to kg ha^{-1} and 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. The seed sample was also used to determine protein and oil concentration with near infrared spectroscopy (NIR). For analysis, all protein and oil concentrations were adjusted to a seed moisture content of 130 g kg^{-1}.

Statistical Analysis

Data from each environment was subjected to analysis of variance using a random effects mixed model using PROC MIXED in SAS 9.3 (SAS Institute, Cary, North Carolina). For each environment, management (treatment) was considered a fixed effect while replication was considered a random effect. Model significance was assessed at $P \leq 0.05$. In the environments where treatment effects were significant, Fishers Protected LSD was used to compare treatment means at a critical value of $P \leq 0.05$. For most dependent variables, management treatments were compared to the control treatment which represented management according to university extension guidelines and was considered the standard strategy.

The data were also analyzed across all environments and within regions. 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. The South region consisted of all locations in Arkansas, Kansas, and Kentucky. When analyzed across region, year and replication nested within location were considered random variables while management was the only fixed effect. When analyzed across all environments, year, location, and replication were considered random variables, while management was the only fixed effect. Treatment means were separated using Fishers- Protected LSD at a critical value of $P \leq 0.05$.

Economic Analysis

To perform an economic analysis, the marginal cost of each treatment above the standard management (control) was calculated (Table 2.3). The costs for each input were obtained from publicly available sources and from 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 that the V4 defoliant treatment (lactofen) could be applied to the soybean crop in a tank mix with a standard post-emergence herbicide application so no additional application costs would be incurred by the soybean producer. Applying the urea and polymer coated urea that are part of the nitrogen fertilization (N) treatment would incur additional application costs. It was assumed that urea and polymer coated urea application would be applied with a ground driven fertilizer spreader. Population reduction at this stage was considered to be negligible and would not result in a yield penalty for application. Application costs were included for the foliar fertilizer treatment at R1 because no other standard management practices would be carried out at this growth stage. Foliar applications were assumed to be applied with a ground driven sprayer with a large spray boom resulting in negligible yield loss. The inputs designated for application at R3 (insecticide, fungicide, N,N' -diformyl urea) would also incur application costs. For treatments containing multiple R3 inputs (the foliar fungicide + foliar insecticide and the SOYA treatments), it was assumed that the R3 treatments could be tank mixed and incur a single application cost.

Bayesian Economic Analysis

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 (ie. break-even analysis). The methods used for this analysis were similar to those used by Esker and Conley (2010), De Bruin et al. (2010), Johnson et al. (2009), and Munkvold et al. (2001). Least square means (LS means) estimates were obtained from the ANOVA's for each environment (site-year combination n=60). For this analysis, treatment was considered a fixed effect and replication was considered a random effect. Relative yield changes (%RYC) values were used to construct models to determine the effect of management across all environments, within regions (North, Central, South), and within individual environments. For these analyses, environment and management were considered fixed effects while the error term was considered a random effect.

Break-even analysis was conducted at three yield levels (3.0 Mg ha^{-1}, 4.0 Mg ha^{-1}, 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 minimum yield gains (%) necessary to cover the costs of each treatment were determined by dividing the cost of the treatment by each combination of yield level and grain price. Individual %RYC for each treatment 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, 2012) was used to estimate a one-tail probability which in this case represents the probability of breaking-even for a particular treatment.

Lactofen Study

Field Experiments

Field studies were established during 2013 and 2014 at two locations in Kentucky. One site was located at the Spindletop Research Farm in Lexington, KY (38.12 N, 84.49124W). The soil type at this location was a Loradale silt loam (Fine, mixed, active, mesic Typic Argiudoll). The other site was located on a private farm near Hodgenville, KY (37.567839,-85.82642) on an Elk silt loam soil (Fine-silty, mixed, active, mesic Ultic Hapludalfs). The preceding crop was corn (*Zea mays* L.) at both locations in both years. Planting occurred in mid-May in 2013 and late-May to early June in 2014 (Table 2.4). All plots were seeded in 0.38m row spacing and at a seeding rate 432,000 seeds ha^{-1}. A glyphosate [N-(phosphomethyl) glycine] resistant soybean variety, AG 4130 (Monsanto Co, St. Louis MO) was planted in 2013. Due to seed availability issues, a similar variety, AG 4135, was planted in 2014. Plots were maintained weed-free for the entire growing season with the use of pre-emergence and post-emergence herbicides.

The trials were arranged in a randomized complete block design with four replications. Treatments consisted of a control, lactofen (2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate) applied at a rate of 240 g ai ha^{-1} and fomesafen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide) applied at 600 g ai ha^{-1} acre. The herbicide treatments were applied using a CO_2 backpack sprayer calibrated to deliver a spray volume of 187 L ha^{-1} at a pressure of 0.2 MPa and an application speed of 4.8 km hr^{-1}. Crop oil concentrate (COC) was also added to the spray mix at a rate of 1.87 L ha^{-1} COC (1% volume/volume ratio) as a spray adjuvant. This study also included a defoliation treatment, where the leaves of each plant in the plot were physically removed with hand clippers, and a meristem removal treatment where the apical meristem of each plant in the plot was manually removed by pinching between the thumb and forefinger. Each treatment was performed at V1, V2, V3, and V4 growth stages in both years; however, the V3 treatments in Hodgenville in 2013 were not applied due to excessive rainfall preventing access to the plots (Table 2.5).

Plant densities were determined at the V2 and again at the R8 growth stages by counting the total number of plants in a 1.5 m^2 (four 0.38m rows 1 meter long) area in each plot. Light interception and canopy NDVI measurements were taken throughout the growing season. Canopy light interception was determined using the digital imagery method described by Purcell (2004). Canopy images were analyzed with Sigma Scan Pro 5.0 (Systat Inc, Richmond, CA) using a macro that automated the analysis process for a large number of images (Karcher and Richardson, 2005). The software was used to quantify the fraction of green pixels to total pixels in an image which was assumed to have a one to one relationship with the percentage of light intercepted by the soybean canopy (Edwards et al., 2005). Normalized Difference Vegetative Index (NDVI) measurements were taken using a Crop Circle Handheld Sensor (Holland Scientific, Lincoln Nebraska). The sensor was passed over the entire length of one outside harvest row in each plot and measured NDVI every 0.5 seconds.

Prior to harvesting, one meter of outside harvest row was clipped at ground level and the branches separated from the mainstem for each plant in the sample. Nodes and pods were counted and then the pods were threshed and the number of seeds in each sample determined using an Electronic Seed Counter (Old Mill Co., Savage, MD) for both the mainstem and branch samples. Pod, node, and seed numbers for each branch and mainstem sample were divided by the harvested area to determine nodes m^{-2}, pods m^{-2}, and seeds m^{-2}. Seed mass was determined for each sample by dividing the dry weight of each seed sample by the total seed number. The four middle rows of each plot were harvested with a Wintersteiger Delta plot combine (Wintersteiger AG, Reid Austria) and the yield and moisture recorded with a HarvestMaster System (Juniper Systems, Logan Utah). Soybean yield was adjusted to a moisture content of 130 g kg^{-1}.

Statistical Analysis

Statistical analysis was performed using the PROC MIXED function in the SAS 9.3 statistical package (SAS Institute, 2014). The Shapiro-Wilk statistic indicated normality for all data. The Bartlett test indicated that the variances for most measurements were not similar across years or locations, so each environment (year x location interface) was analyzed separately. The main effects of stress, timing and the stress x timing interaction were considered fixed effects while replication (block) was considered a random effect in the ANOVA for each environment. Fishers protected LSD was used to separate means, if significant, at a critical level of $P \leq 0.05$.

Table 2.1. Location, soil classification, cropping and tillage history, soil fertility, varieties and planting dates for experiments during 2012-2014.

Location	Year	Coordinates	Soil series‡	Previous Crop	Tillage system§	Soil fertility				Variety	Planting date
						pH¶	P#	K#	OM		
							—mg kg^{-1}—		g kg^{-1}		
Colt, AR	2012‡‡	35°13’N, 90°81’W	D	soybean	CT	7.1	23	118	--	AG4730	23-May
	2013			soybean		7.4	46	94	--	AG4730	15-May
	2014			rice		--	--	--	--	AG4730	24-May
Newport, AR	2012‡‡	35°61’N, 91°26’W	Ca	soybean	CT	6.5	126	128	--	AG4730	17-May
	2013			soybean		6.4	121	144	--	AG4730	10-Jun
	2014			rice		--	--	--	--	AG4730	27-May
Farley, IA	2012	42°44’N, 91°01’W	KCF	corn	CT	6.9	15	116	2.6	AG2731	9-May
	2013					6.7	60	180	3.1	AG2731	16-May
	2014					7	16	169	2.6	AG2731	7-May
Humboldt, IA	2012	42°72’N, 94°22’W	CNW	corn	CT	--	--	--	--	AG2430	17-May
	2014					6.8	55	183	5.6	AG2431	20-May
Monmouth, IL	2012	40°92’N, 90°72’W	M	corn	CT	6.4	52	255	--	AG3131	11-May
	2013					5.8	25	183	5.2	AG3030	24-May
	2014					6.3	23	197	5	AG3030	22-May
Urbana, IL	2012	40°08’N, 88°22’W	Dr	corn	CT	5.8	37	112	--	AG3431	9-May
	2013					5.7	64	158	4.8	AG3431	19-May
	2014					6.3	56	142	4.1	AG3431	19-May
Wanatah, IN	2012	41°43’N, 86°90’W	S	corn	CT	6.3	61	189	2.1	AG3131	15-May
	2013					6.5	54	110	2.5	AG3030	8-May
	2014					--	--	--	--	AG3030	26-May
West Lafayette, IN	2012	41°42’N, 86°89’W	CL	corn	CT	6.2	44	165	4.1	AG3431	17-May
	2013					6.7	51	145	3.3	AG3431	14-May
	2014					--	--	--	--	AG3431	27-May

Table 2.1. Location, soil classification, cropping and tillage history, soil fertility, varieties and planting dates for experiments during 2012-2014.

Manhattan, KS	2012	39°19’N, 96°59’W	K	corn	NT	7.3	19	211	2.6	AG4130	7-May
	2013					7.5	31	304	3.6	AG4130	17-May
	2014					6.8	26	170	3	AG4033	12-May
Rossville, KS	2012‡‡	39°14’N, 95°95’W	B	corn	CT	6.8	23	174	1.7	AG4130	4-May
	2013‡‡		E			7.3	13	140	1.1	AG4130	22-May
	2014‡‡		EB			7	44	312	1.9	AG4033	15-May
Scandia, KS	2012‡‡	39°80’N, 97°78’W	C	sorghum	CT	6.9	8	295	1.5	AG3431	9-May
	2013‡‡			sorghum		6.4	5	387	1.9	AG3431	3-Jun
	2014‡‡			soybean		6.3	12	432	3.3	AG3431	13-May
Hodgenville, KY	2012	37°57’N, 85°74’W	Nol	corn	CT	6	186	157	--	AG4130	11-May
	2013					6.3	167	153	--	AG4130	29-May
	2014					--	--	--	--	AG4033	4-Jun
Lexington, KY	2012‡‡	38°03’N, 84°49’W	L	corn	NT	6	186	157	--	AG3803	25-Jun
	2013					6.3	167	153	--	AG4130	16-May
	2014					--	--	--	--	AG4033	28-May
Breckenridge, MI	2012	43°41’N, 84°48’W	P	corn	CT	6.9	51	141	--	AG2731	21-May
	2013					6.2	55	220	--	AG2431	9-May
	2014					--	--	--	--	AG2431	25-May
East Lansing, MI	2012	42°74’N, 84°48’W	A	corn	CT	6.7	52	178	--	AG2731	21-May
	2013					6.6	126	385	--	AG2731	9-May
	2014					--	--	--	--	AG2731	22-May
Minnesota Lake, MN-Drained	2012	43°85’N, 93°73’W	NM	corn	CT	5.9	16	180	--	AG2430	14-May
	2014					6.2	28	154	5.9	AG2431	23-May
Minnesota Lake, MN-Un-drained	2012			corn		5.8	15	175	--	AG2430	14-May
	2014					6.2	28	154	5.9	AG2431	6-May

Table 2.1. Location, soil classification, cropping and tillage history, soil fertility, varieties and planting dates for experiments during 2012-2014.

St. Paul, MN	2012‡‡	44°95’N, 93°11’W	W	corn	CT	5.7	104	125	--	AG2430	10-May
	2013‡‡					6.2	114	170	3.8	AG2431	7-May
	2014‡‡					6	67	90	3.9	AG2431	29-May
Waseca, MN	2012	44°08’N, 93°51’W	N	corn	CT	6.4	82	279	--	AG2731	11-May
	2013					6.8	23	111	6.7	AG2431	16-May
Arlington, WI	2012	43°21’N, 89°21’W	Pl	corn	CT	6.4	27	135	2.9	AG2731	11-May
	2013					6.9	51	153	3.3	AG2731	7-May
	2014					6.4	33	159	3.3	AG2731	6-May
Jamesville, WI	2012	42°43’N, 89°01’W		corn	CT	7	41	107	3.5	AG2731	10-May
	2013					6.3	44	109	3.3	AG2731	16-May
	2014					6.1	88	207	3.9	AG2731	19-May

‡ Source: USDA web soil survey. Dexter silt loam (D): fine-silty, mixed, active, thermic Ultic Hapludalfs; Calloway silt loam (CA): fine-silty, mixed, active, thermic Aquic Fraglossudalfs; Kenyon Loam/Clyde-Floyd Loam (KCF): fine-loamy, mixed, superactive, mesic Typic Hapludolls, fine-loamy, mixed, superactive, mesic Typic Endoaquolls, fine-loamy, mixed, superactive, mesic Aquic Pachic Hapludolls; Clarion loam/Nicollet loam/Webster clay loam (CNW): fine-loamy, mixed, superactive, mesic Typic Hapludolls, fine-loamy, mixed, superactive, mesic Aquic Hapludolls, fine-loamy, mixed, superactive, mesic Typic Endoaquolls; Muscatine silty clay loam (M): fine-silty, mixed, superactive, mesic Aquic Hapludolls; Drummer silty clay loam (DR): fine-silty, mixed, superactive, mesic Typic Endoaquolls; Sebewa loam (S): fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiaquolls; Chalmer silty clay loam (CL): fine-silty, mixed, superactive, mesic Typic Endoaquolls; Kahola silt loam (K): fine-silty, mixed, mesic Cumulic Hapludolls; Bismarckgrove-Kimo complex (B): fine-silty, mixed, superactive, mesic Fluventic Hapludolls; Eudora silt loam (E): coarse-silty, mixed, superactive, mesic Fluventic Hapludolls; Eudora-Bismarckgrove silt loams (EB): coarse-silty to fine-silty, mixed, superactive, mesic Fluventic Hapludolls; Crete silt loam (C): fine, smectic, mesic Pachic Udertic Arguistolls; Nolin silt loam (NL): fine-silty, mixed, active, mesic Dystric Fluventic Eutrudepts; Loradale silt loam (L): fine, mixed, active, mesic Typic Argiudolls; Parkhill loam (P): fine-loamy, mixed, semiactive, nonacid, mesic Mollic Epiaquepts; Aubbeenaubbee-Capac sandy loam (A): fine-loamy, mixed, active, mesic Aeric Epiaqualfs, fine-loamy, mixed active, mesic Aquic Glossudalfs; 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 Hapludolls; Plano silt loam (PL): fine-silty, mixed, superactive, mesic Typic Argiudolls; Matherton sandy loam (M): fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Udollic Endoaqualfs.

Table 2.2. Component products, active ingredients, rates and timings for experiments across the Midwest and Mid-South between 2012 and 2014.

					Seed Treatment			Single Product							Combination				
Product†	**Active Ingredient**	**Rate**	**Timing**	**C¥**	**F ST**	**F+I ST**	**Max ST**	**D**	**N**	**F**	**N-N' urea**	**FF**	**FI**	**FF +FI**	**SOYA**	**SOYA + D**	**SOYA-N**	**SOYA-FF**	**SOYA-FF and 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* + LCOǂ	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.

¶ 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

ǂ LCO; lipo-chitooligosaccharide; ¥ C, control ; F ST, fungicide seed treatment; F+I ST, fungicide + insecticide seed treatment; D, defoliant; N, nitrogen; F, foliar fertilizer; FF, foliar fungicide; FI foliar insecticide

‡‡ Irrigated location.

Table 2.3. Additional marginal costs for each management treatment over the control for experiments between 2012 and 2014.

Treatmentǂ	Additional cost (\$ ha^{-1})	
	2012	2013, 2014†
F ST	21.61	21.61
F+I ST	52.49	52.49
Max ST	59.90	59.90
D	44.73	44.73
N	109.22	109.22
Foliar Fertilizer	46.93	46.93
N-N'-diformyl urea	51.38	51.38
FF	63.92	96.08
FI	29.66	34.06
FF +FI	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

† costs differ between 2012 and 2013, 2014 due to the use of different input products

ǂ LCO; lipo-chitooligosaccharide; ¥ C, control ; F ST, fungicide seed treatment; F+I ST, fungicide + insecticide seed treatment; D, defoliant; N, nitrogen; F, foliar fertilizer; FF, foliar fungicide; FI foliar insecticide

Table 2.4. Variety, planting date, tillage, seeding rate, and row width of soybeans planted in Lexington and Hodgenville, Kentucky for the 2013 and 2014 growing seasons.

	2013		2014	
	Lexington	**Hodgenville**	**Lexington**	**Hodgenville**
Variety	AG 4130 †	AG 4130	AG 4135	AG 4135
Planting Date	16 May	28 May	20 May	4 June
Tillage	No-till	Conventional- till	No-till	Conventional- till
Seeding Rate	432,000 seeds ha^{-1}	432,000 seeds ha^{-1}	432,000 seeds ha^{-1}	432,000 seeds ha^{-1}
Row width	0.38m	0.38m	0.38m	0.38m

† Asgrow brand soybeans, Monsanto Company, St. Louis, MO

Table 2.5. Treatment application timings and date of application for studies conducted in Lexington and Hodgenville, Kentucky for the 2013 and 2014 growing seasons.

	2013		**2014**	
Growth Stage	**Lexington**	**Hodgenville**	**Lexington**	**Hodgenville**
V1	5 June	18 June	9 June	18 June
V2	12 June	21 June	13 June	24 June
V3	17 June	n/a	19 June	29 June
V4	20 June	28 June	23 June	3 July

CHAPTER III: Results and Discussion

National High-Yield Study

Climatic conditions

Temperature and precipitation patterns differed between locations and years (Tables 3.1 and 3.2). In general, the 2012 growing season was very dry across a large area of the Midwest and Mid-South. Study locations in Illinois, Kentucky, Iowa, Indiana, Illinois and Wisconsin had monthly rainfall totals well below 30-year 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.

Plant Stands

While certain management treatments increased soybean stands at 12 out of 60 environments at V2 growth stage and nine environments at R8, the responses are difficult to explain (data not shown). For example, at the Wanatah, IN location in 2012, the lactofen and foliar insecticide treatments had greater V2 stands than the control. However, neither lactofen nor the foliar insecticide had been applied at V2. By R8, the stands were similar to the control. At the Minnesota Lake, MN- Drained location in 2012, the SOYA-FF, SOYA-F+I, N,N' -diformyl urea, and lactofen treatments increased V2 plant stands compared to the control. But, stand counts taken at the V2 stage occurred before any of the in-season foliar treatments were applied. As a result, treatment difference at this stage due to management could only have come from the inclusion of a seed treatment. Of the 16 management treatments included in this study, half included a seed treatment. While the SOYA treatments included the Max seed treatment, which could explain increased V2 plant stands, the other treatments that included the maximum seed treatment did not have increased stands. In addition, the R8 stands were similar across treatments and did not respond to management. Similar inconsistent results were observed for Hodgenville, KY and East Lansing, MI in 2013 and Humboldt, IA, Scandia, KS, St. Paul, MN, and Janesville, WI in 2014.

While in a number of environments the stand data were inconclusive, there were environments where meaningful conclusions can be drawn. For Janesville, WI in 2012, all treatments that included the Max seed treatment (except SOYA + D) increased V2 plant stands relative to the control, the fungicide only, and the fungicide + insecticide seed treatments. The soybean inoculant and LCO promoter components of the Max seed treatment were likely responsible for the increased V2 plant stands. A previous study did not find increased stands from seed inoculation (Cox and Cherney, 2014).

At East Lansing, MI in 2014, all treatments that contained the Max seed treatment, as well as the fungicide + insecticide seed treatment, increased V2 stands compared to the control. The only seed treatment that did not increase stands was the fungicide seed treatment, indicating that the insecticide component was largely responsible for increased stands. In a study in Wisconsin, Gaspar et al. (2014) found increased plant stands for a seed treatment that contained both a fungicide and insecticide when compared to untreated seed and a fungicide only seed treatment. Another study in Wisconsin observed a 3% increase in stands for a fungicide + insecticide seed treatment compared to untreated seed but no difference for a seed treatment that contained only a fungicide (Esker and Conley, 2012).

Fungicide and fungicide+insecticide seed treatments increased stands at Minnesota Lake, MN- Undrained, a poorly drained location, in 2014. The fungicide and fungicide + insecticide seed treatments did not affect V2 soybean stands at Minnesota Lake, MN-Drained, which is a tile-drained site very near the Minnesota Lake, MN-Undrained site. High levels of rainfall in June 2014 at these locations resulted in highly saturated field conditions (Table 1). Perhaps these wet conditions in June favored disease development in the undrained site and the fungicide seed treatments provided protection against diseases. Seed treatments increased stands primarily in North study locations where soybean are often planted under cool and wet spring conditions. While seed treatments increased stands at some locations, all studies were seeded at 432,000 plants ha^{-1}, which likely resulted in stands adequate to achieve maximum yields (De Bruin and Pedersen, 2008).

Yield by Environment Interaction

Yield responses varied by environment and were inconsistent. When compared with the control, additional inputs increased yield in 22 (37%) of the 60 environments (Table 3.3). The majority of environments where yield responses were observed (14) were in the northern part of the U.S. (Minnesota, Wisconsin, Michigan) with three in the Central states (Indiana, Illinois, Iowa) and five in the south (Kansas, Kentucky, Arkansas). Where management increased yield, grand mean yield ranged from 2.43 Mg ha^{-1} (Rossville, KS, 2013) to 5.71 Mg ha^{-1} (Janesville, WI, 2014). Yield increases ranged from 0.2 to over 1.1 Mg ha^{-1} and relative yield increased ranged from ~4% to over 30% in some environments (Table 3.3).

While seed treatments affected stands at in a number of environments, their effect on yield was limited. The fungicide only seed treatment did not increase yield in any environment, while the fungicide + insecticide seed treatment increased yield at only one location. The Max seed treatment increased yield in only two environments (Minnesota Lake, MN-Undrained in 2012 and MNLKD) but was a component of the SOYA treatments where yield increases were observed across a number of environments (Table 3.3).

Yield responses to early-season inputs, which included the nitrogen and defoliant treatments, were observed in more environments than seed treatments. The defoliant (lactofen) increased soybean yield in only one environment (Table 3.3). Soybean yield did not respond to foliar fertilizer in any environment, similar to a study in Georgia that also found no yield response to foliar fertilization (Parker and Boswell, 1980). However, two studies in Iowa found yield responses to foliar fertilization in 6 out of 27 environments and 7 out of 48 environments (Haq and Mallarino, 1998; Haq and Mallarino, 2000). Nitrogen increased soybean seed yield in five of the 60 environments (8%), less than the response observed by Sorensen and Penas (1978) which observed a response to N in nine out of 13 environments (69%) but more than other research studies that observed no response to N fertilization (Welch et al., 1973; Gutierrez-Boem et al., 2004). Recent research suggests that yield responses to N are more likely in environments that are capable of producing 4.5 Mg ha^{-1} (Salvagiotti et al., 2009). Of the five locations showing a positive response to N fertilization, only St. Paul, MN in 2013 and East Lansing, MI had average yield near 4.5 Mg ha^{-1} (4.54 and 4.31 Mg ha^{-1}, respectively) and eight other environments that yielded above 4.5 Mg ha^{-1} did not respond to N fertilization. This suggests that while N fertilization may increase yield in some environments but is not a necessity for high-yield soybean.

Yield responses to soybean inputs applied during reproductive growth were more numerous and consistent within environments. Of the three input treatments applied during reproductive growth, N,N’ -diformyl urea increased soybean yield in only one environment, while the foliar fungicide increased soybean yield in three out of 60 environments with an average yield increase of 12.6%. Low disease pressure was reported across all environments which likely limited the utility of foliar fungicide for increasing soybean yield (Swoboda and Pedersen, 2008). Foliar insecticide applied at R3 increased yield over standard management in 6 out of 60 total environments (10%) with an average yield increase of 17.6%. When foliar fungicide and insecticide were applied together, yield responses were observed in 13 out of the 60 total environments (22%) with an average yield increase of 17.6% (Table 3.3). Insect pest pressure was low in most environments. Soybean aphids were reported in some northern environments, although aphid populations failed to reach threshold levels. Although insect and disease pressure were low across most environments, a recent study in the Midwest reported yield increases for both a foliar fungicide and foliar insecticide in the absence of significant pest pressure (Henry at al., 2011)

The SOYA combination treatment proved to be the most consistent treatment for increasing yield (18 out of 60 environments). Increases ranged from 0.29 Mg ha^{-1} to 1.1 Mg ha^{-1} with an average response of 0.61 Mg ha^{-1}. Of the 18 environments where a yield response was observed for the SOYA treatment, only seven responded to the SOYA +D treatment (Table 3.3). This indicates that the addition of the defoliant to the SOYA program may have eliminated the yield increases expected from the SOYA treatment. Six of the 18 environments where the SOYA treatment increased yield, the SOYA-N treatment did not increase yield. This indicates that nitrogen fertilization may have a management component driving the yield responses to the SOYA treatment in these environments.

The multiple components in the SOYA treatment can lead to complex interactions between inputs, often leading to inconsistent results. For example, the only "single product" treatment that increased soybean seed yield in Janesville, WI in 2014 was the foliar fungicide + foliar insecticide treatment (0.54 Mg ha^{-1}). This yield increase was similar to the yield increase observed from the SOYA treatment (0.64 Mg ha^{-1}) suggesting that the foliar fungicide and foliar insecticide were the inputs responsible for the SOYA yield increase. However, the SOYA treatment without the foliar fungicide and foliar insecticide (SOYA-FF +FI) also increased soybean yield by 0.52 Mg ha^{-1}.

Yield by Region

The large number of environments and complex input interactions makes discerning trends difficult for factors such as yield, seed number (seeds m^{-2}), and seed mass and yield components. In order to draw more meaningful conclusions about seed yield and yield component responses to management, data were analyzed across all environments and grouped into geographic regions for further analysis. Seed yield, seed number, and seed mass in the South region of this study, which includes study locations in the states of Arkansas, Kentucky, and Kansas, did not respond to management (Tables 3.4 and 3.5). Disease and insect pressure were low for South environments over the three years of this study. In years with higher disease and insect pressure, yield differences for treatments containing foliar fungicide and/or foliar insecticide would be expected.

In the Central region of this study, which included all study locations in Illinois, Indiana, and Iowa, management increased seed yield and seed mass but not seed number (Table 3.4). The complete SOYA treatment was the only treatment in this region which increased yield compared to the control (4.04 vs 4.25 Mg ha^{-1}) (Table 3.6). The SOYA treatment is a combination of inputs applied early in the growing season and during reproductive growth. The inputs applied early in the growing season, during vegetative or early reproductive growth, would be expected to affect seed number, as seed number is determined earlier in the growing season (R1-R4) than seed mass (R5-R6) (Egli and Yu, 1991). Three components of the SOYA treatment, N,N' -diformyl urea, the foliar fungicide and the foliar insecticide were applied at the R3, the beginning of pod development. The N,N' -diformyl urea treatment did not increase seed mass compared to the control, while both the foliar fungicide and foliar insecticide treatments did (168 and167 mg seed^{-1} vs. 163 mg seed^{-1}, respectively) (Table 3.6). This suggests that either the foliar fungicide and/or the foliar insecticide were the component of the SOYA treatment that resulted in increased seed mass and yield. While the R1-R4 stage is considered the critical stage for seed number determination (Egli and Yu, 1991), the foliar fungicide and foliar insecticides used have residual activity and could provide control of disease and insect pests until R5 and R6, when seed mass is determined. Furthermore, the SOYA treatment without the foliar fungicide and foliar insecticide (SOYA-FF+ FI) did not increase seed mass or yield compared to the control, thus providing more evidence that the foliar fungicide and/or the foliar insecticide are responsible for these responses. The SOYA-FF treatment, which included the foliar insecticide but not the foliar fungicide, increased seed mass compared to the control (166 vs. 163 mg seed^{-1}) (Table 3.6), indicating that the foliar insecticide may have been more important than the foliar fungicide. However, the lack of a SOYA treatment that included the foliar fungicide but not the foliar insecticide and lack of adequate information on insect pest and disease levels at these locations limits the conclusions that can be drawn. It appears that pest pressure during seed filling is important to yield determination in these environments.

Seed yield, seed number, and seed mass all were increased with additional inputs North region of this study, which included the states of Michigan, Minnesota and Wisconsin (Tables 3.4 and 3.7). The Max seed treatment increased seed yield (4.27 vs 4.11 Mg ha^{-1}) and seed mass (169 vs. 164 mg seed^{-1}) but not seed number when compared to the control. The mechanism by which a seed treatment affected seed mass but not seed number is unclear. The Max seed treatment contains a *Bradyrhizobia* *japonicum* inoculant with an LCO promoter which has been shown to increase soybean nodulation (Xie et al., 1995). Perhaps the seed treatment products improved nodulation which lead to increased N availability during seed fill, resulting in increased seed mass (Table 3.7). The seed yield increase observed for the N fertilization treatment over the control supports this hypothesis, except that the yield increase observed with the N fertilization treatment resulted from an increase in seed number (2582 vs. 2515 seeds m^{-2}), not seed mass.

Foliar fungicide application did not affect seed number but did increase seed mass and seed yield. In contrast, the foliar insecticide and foliar fungicide + foliar insecticide treatments increased both seed number and seed mass and also increased seed yield when compared to the control. Interestingly, all SOYA treatments had greater seed number than the control except the SOYA-N treatment indicating that N fertilization may increase seed number in northern environments. The SOYA-FF+FI had increased seed yield compared to the control (4.37 vs. 4.11 Mg ha^{-1}) but yield was less than the SOYA treatment (4.37 vs. 4.60 Mg ha^{-1}) and foliar fungicide +insecticide treatment (4.37 vs. 4.57 Mg ha^{-1}). The Max seed treatment and N fertilizer components of the SOYA treatment likely increased seed yield over the control, while the inclusion of the foliar fungicide and foliar insecticide increased seed yield even further (Table 3.7).

Disease pressure was reported to be low across all northern environments. A number of environments reported soybean aphid pressure indicating that the foliar insecticide may be more important for yield increases in the North region. Increased seed mass resulted in yield increases for treatments containing both the foliar fungicide and foliar insecticide. These increases were likely due to residual control of insects and diseases during seed filling (R5-R6).

When analyzed across all environments, the foliar fungicide, foliar insecticide, foliar insecticide + fungicide, and all SOYA treatments increased seed yield compared to the control (Table 3.8). Only two treatments, SOYA and SOYA-FF, increased seed number compared to the control (2629 and 2620 seeds m^{-2} vs. 2560 seeds m^{-2}, respectively). All treatments that increased yield over the control also increased seed mass compared to the control. While much of the responses observed to management are likely driven by North region, it appears that protecting soybean during reproductive development is the most effective way to increase soybean seed yield.

Bayesian Break-even Analysis

While yield responses were observed for a number of treatments in multiple environments and within regions, treatment costs must also be considered to help inform grower decision making. When the data was analyzed across all environments, relative yield changes (RYC) for management treatments ranged from -1.79% to 8.08%. Responses were generally positive with only two treatments showing decreased yield compared to standard management (Table 3.9).

The fungicide only seed treatment slightly decreased yield (- 0.03%) which resulted in low break-even probabilities across all yield levels and soybean sale prices. The fungicide and insecticide seed treatment increased yield by 0.55% but, because of the substantially increases costs of adding insecticides to the seed treatment package, achieved lower break-even probabilities compared to the fungicide only seed treatment.

The Max seed treatment, which included the fungicides, insecticides, as well as an inoculant and LCO promoter, increased yield across all environments by 2.15% and was only slightly more expensive than the fungicide and insecticide seed treatment, leading to greater break-even probabilities. However, the only break-even probability ≥ 50% was at a yield level on 5.0 Mg ha^{-1} and a high soybean price of \$0.55 kg^{-1} (Table 3.9).

The foliar fertilizer resulted in a small yield increase (1.17%) across environments but only low break-even probabilities across yield levels and soybean sale prices (Table 8). A similar situation occurred with N,N' -diformyl urea . The N,N' -diformyl urea treatment resulted in a small 0.39% yield increase which was not enough to cover the costs of application resulting in very low break-even probabilities. The N fertilizer treatment resulted in a slightly larger yield increase of 2.15% but due to the high costs of N fertilization, breaking even was not possible at any yield level or soybean sale price. The use of the defoliant, lactofen, decreased yield by 1.79% resulting in no scenarios with any chance of breaking even.

The foliar fungicide treatment increased yield by 2.45% over standard management when analyzed across environments. While yield were increased, foliar fungicides are expensive, resulting in very low break-even probabilities. Compared to foliar fungicides, foliar insecticides are relatively inexpensive and resulted in a greater yield increase of 3.19%. The only break-even probability below 50% was at the lowest yield level of 3.0 Mg ha^{-1} and the lowest soybean sale price of 0.33 \$ kg^{-1}. Break-even probabilities were greater than 90% for a number of yield level and soybean sale price combinations. The foliar fungicide +insecticide treatment increased yield by 5.56%. Break-even probabilities for this treatment are low at the 3.0 Mg ha^{-1} yield level and 0.33

\$ kg^{-1} soybean sale prices. However, at higher yield level and soybean sale price combinations, break-even probabilities increase substantially. The largest relative yield changes were observed with the SOYA treatments. However, break-even probabilities were 0% for all yield levels and soybean sale prices. The high per acre costs of the SOYA treatments prevented these treatments from being cost-effective despite the observed yield increases.

In general, regional treatment response trends were similar to the responses observed across environment but the magnitude of the responses varied by region. In the South region, yield responses to seed treatments and early season inputs such as N fertilization and foliar fertilizer were small or negative leading to very low break-even probabilities across all yield levels and soybean sale prices (Table 3.10). The foliar fungicide increased yield by only 1.19% in the South region resulting in low break-even probabilities. The foliar insecticide increased yield by only 1.93% but due to the low chemical cost had relatively high break-even probabilities compared to other treatments. The foliar fungicide with the foliar insecticide increased yield by 4.31% but the only break-even scenario >50% was at the highest yield level and highest soybean sale price. The SOYA treatments had the highest relative yield changes but no chance of breaking even due to high input and application cost.

The responses in the Central region were very similar to the responses in the South region (Table 3.11). Seed treatments and early season products had only marginal or negative relative yield changes and very low break-even probabilities. Yield response to the foliar insecticide was less than in the South region (1.70% vs. 1.93%) but still had the greatest break-even probabilities in the Central region. Also, similar to the South region, combining the foliar insecticide with the fungicide led to a greater yield response than with either product alone. However, primarily due to the cost of the fungicide break-even probabilities remained low. The SOYA treatments again had the greatest relative yield increases but due to high input and application costs had 0% break-even probabilities across all yield levels and soybean sale prices.

Responses to management treatments were much greater in the North region as compared to the South and Central regions (Table 3.12). Unlike the other regions, the fungicide only seed treatment increased yield by 2.49%, resulting in break-even probabilities > 60% at all yield level and soybean sale price combinations. The relative yield change was greater for the fungicide and insecticide seed treatment (3.08%) but break-even probabilities were lower due to the higher costs of including the insecticide component. The Max seed treatment increased yield by 4.68% and had >50% break-even probabilities at all except the lowest yield level and lowest soybean seed sale price. Unlike the other regions, soybean in the North region responded to foliar fertilization, with a relative yield change of 3.7% resulting in break-even probabilities >50% at all but the lowest yield level and lowest soybean sale price. The defoliant exhibited a marginal yield increase but low break-even probabilities. Nitrogen (N) fertilization increased yield by 4.68% had <50% break-even probabilities at all but the highest yield level and highest soybean sale price due to high fertilizer and application costs. N,N’ -diformyl urea increased yield by 2.92% resulting in >50% break-even probabilities at higher yield levels and soybean sale prices. The foliar fungicide increased yield by 4.97% and had >50% break-even probabilities at higher yield levels and soybean sale prices. The foliar insecticide increased yield by 5.71% resulting in very high (95-99%) break-even probabilities at all yield levels and soybean sale prices. When the foliar insecticide and fungicide were combined, yield was increased by 8.09% resulting in high break-even probabilities at high soybean sale prices and yield levels. Again, the SOYA treatments had the greatest yield increases but break-even probabilities remained low due to the high costs of the treatments.

When examined across all environments, the inputs and management systems investigated in this study generally increased yield but rarely were the observed yield increases enough to cover input and application costs. The majority of the study locations in the South and Central states had limited responses to inputs besides the foliar insecticide. In these areas, the response to the foliar insecticide was small (< 2%) but the low cost of the insecticide resulted in high break-even probabilities. The use of the defoliant, lactofen, decreased yield in most environments and would not be recommended as an input for soybean production.

Responses to inputs were greatest in northern environments. This result was not unexpected as soybean grown in northern latitudes have a shorter growing season and lower growing season temperatures, which limits the crops ability to accumulate leaf area and heat units necessary for yield production. Products like foliar fungicides and foliar insecticides can help protect this limited leaf area appear to be a useful management strategy for high yield soybean management in northern environments. While large responses were observed for the use of the foliar insecticide and foliar fungicide in the Northern environment, it should be noted that threshold level disease and insects were not usually observed at the study locations. Growers should still base fungicide and insecticide applications on scouting and IPM principles. However, this research suggests that growers should pay close attention to insect and disease levels in their fields during reproductive growth stages and be ready to apply fungicides and insecticides if significant pest levels are observed.

Lactofen Study

Climatic Conditions

While monthly temperature patterns were very consistent between growing seasons, precipitation patterns differed markedly (Table 3.13). Somewhat wet conditions in May 2013 did not delay planting and allowed for excellent emergence and early season growth at both locations. In 2013, both locations received substantial amounts of precipitation through the end of August resulting in very high yield especially at the Lexington location (5.56 Mg ha^{-1}). While conditions became dry in September (35-62 mm), high levels of soil moisture were available to the crop and no drought stress was observed at either location. May of 2014 was slightly drier; however, the timing of the rainfall events delayed planting at both locations. The Lexington location experienced dry conditions in July (68 mm) but substantial amounts of rainfall during flowering and pod development in August (164 mm) allowed for very high yield (5.29 Mg ha^{-1}) . The Hodgenville location experienced rather dry conditions in June and July. However, the study at this location was planted on very deep soils and also received substantial rainfall in August (135 mm) resulting in exceptional yield (5.95 Mg ha^{-1}) (Table 24).

Plant Stands

The favorable planting conditions resulted in limited early season (V2) stand responses; however, a number of stand responses at full maturity (R8) were observed. Plant stands at V2 did not respond to the main effects of stress or timing in any environment but a significant stress x timing interaction was observed at the Hodgenville location in 2013 (Table 3.14). The leaf removal treatment at V4 had greater stands than fomesafen treated plants at V1 and V2 (78.5 vs 66.1 and 65.8 plants m^{-2} respectively) and also greater stands than the meristem removal treatment at V1 (78.5 vs. 66.0 plants m^{-2}) and the leaf removal treatment at V2 (78.5 vs 64.0 plants m^{-2}). Stand densities at R8 also responded to a stress x timing interaction (Table 3.14). Stand densities for the leaf removal treatment at V4 were greater than all stress treatments at V1. The leaf removal treatment at V4 also had greater stand densities than the leaf removal treatment at V2 (74.0 vs 56.8 plants m^{-2}). While these results are statistically significant, the stand variability is likely not due to treatment effects. The plots were seeded at this location in 2013 with a grain drill. Seeding with grain drills generally results in more variable stands than seeding with a row crop planter, which may explain the differences in stand establishment at this location (Bertram and Pedersen, 2004). Plant stands did not respond to the main effects of timing or stress and there was no interaction for the Lexington location in 2013 (Table 3.15).

Plant stands at R8 responded to stress at the Lexington location in 2014 (Table 3.17). In this case the meristem removal treatment decreased stands compared to both the control (42.3 vs. 47.9 plants m^{-2}) and all other stress treatments (~15% lower). Plant densities at R8 also responded to the main effect of stress at the Hodgenville location in

2014 (Table 3.16). Similar to the Lexington location in 2014, the meristem removal treatment decreased soybean stands at R8 stand densities compared the other stress treatments (~9% lower). There are two main hypotheses to explain the reduced stand densities observed for the meristem removal treatment. One theory is that the physical damage to the plant caused by the removal of the meristem resulted in the death of some plants in the plot leading to decreased R8 stands. A number of studies have shown stand reductions for soybean that are damaged during early vegetative growth from environmental factors such as hail (Kalton et al., 1949, Weber 1955). However, if plant damage was the cause of the reduced stands for the meristem removal treatment, then decreased stand densities at R8 would be expected for other stress treatments, particularly the leaf removal treatment. Another explanation for the reduction in R8 stands for the meristem removal treatment is increased branching observed on plants where the meristem was removed. The increase in branch development could increase early season shading, resulting in loss of plants over the course of the growing season.

Plant Height

Similar to the responses observed with plant stands, the main effect of timing did not affect soybean height in any environment and there were no timing x stress interactions. However, the main effect of stress affected plant heights in two of the four environments. At the Lexington location in 2013, the meristem removal and leaf removal treatments decreased plant heights compared to the control (91.2 and 91.3 vs. 95.3 cm, respectively) (Table 3.15). At the Hodgenville location in 2014, the meristem removal decreased plant heights compared to the control (91.8 vs. 99.4 cm) (Table 3.16). While statistically significant differences were observed, these differences were likely not agronomically significant.

Light Interception

Differences in light interception were observed for the main effect of stress in all four environments. At the Hodgenville location in 2013, light interception was measured only twice before all stress treatments reached > 95% light interception (Fig. 3.1). On the 21 June sampling date, the leaf removal treatment intercepted less light than the control (11% vs 17%). The 13 July sampling date coincided with the date of first flower (R1) and the beginning of reproductive growth. Similar to the Lexington location in 2013, both the lactofen treatment (84% vs 94%) and leaf removal treatments (70% vs. 94%) intercepted less light than the control. All treatments achieved canopy closure (>95% light interception) by 22 July.

At the Lexington location in 2013, differences in light interception for stress treatments were not observed until late June (Fig. 3.2). The lactofen treatment and leaf removal treatment intercepted less light between 14 June and 19 July compared to the control. On the 25 June sampling date, untreated plants intercepted 56% of the available light while lactofen treated plants were intercepted 28% and leaf removal plants intercepted 21% of available light. Similarly, on the 3 July sampling date, untreated soybean intercepted 85% of the available light while lactofen treated plants intercepted 64% of available light and leaf removal plants intercepted 52% of available light. The meristem removal and fomesafen treatments had similar levels of light interception to the control throughout the growing season. At the beginning of reproductive growth (R1), the lactofen and leaf removal treatments still lagged behind the control and other stress treatments, however, all stress treatments achieved >95% light interception by 19 July.

Early in the 2014 growing season (25 June) at the Hodgenville location, the leaf removal treatment intercepted less light than the control (32% vs. 39%) (Fig. 3.3). On 2 July the lactofen (66% vs. 87%) and leaf removal treatments (54% vs 87%) intercepted less light than the control. The lactofen treated plants eventually intercepted a similar amount of light as the untreated plants on 10 July but the leaf removal treatment caused less light to be intercepted than the control (80% vs 90%). Interestingly, all stress treatments achieved canopy closure (> 95% light interception) before the onset of reproductive growth, with the exception of the control which only achieved a maximum of 90% light interception throughout the growing season.

The Lexington location in 2014 had somewhat different pattern of light interception than the other environments (Fig. 3.4). Dry conditions toward the end of June and the beginning of July appear to have triggered the soybean to flower early. Similar to the other environments, the lactofen and leaf removal soybean intercepted less light than the control prior to flowering (R1). However, unlike the other environments, differences in light interception between treatments persisted for a number of days after R1. Dry conditions (Table 3.13) during the month of July delayed canopy closure for all stress treatments. On the 18 July sampling date, only the meristem removal treatment achieved 95% light interception which was greater than the control (87%) (Fig. 3.4).

NDVI

In most cases, the NDVI results were very similar to the light interception results in all environments. NDVI values have been correlated to a number of agronomic factors such as leaf area index (LAI), plant biomass, and chlorophyll content. Higher NDVI values indicate increased levels of plant "greenness" and are more desirable than lower NDVI values. At the Hodgenville location in 2013, NDVI values were lower for the leaf removal treatment compared to the control treatment (0.47 vs. 0.59) at the 28 June sampling date and the 12 July sampling date (Figure 3.5). NDVI values were similar between the control and lactofen treated plants at the 28 June sampling date but the lactofen treatment had decreased NDVI values at the 12 July sampling date (0.75 vs 0.83). The leaf removal NDVI treatment values were also lower than the control at the 12 July sampling date (0.67 vs. 0.83).

Both the lactofen and leaf removal treatment had lower NDVI values than the control at three sampling dates for Lexington in 2013 (Figure 3.6). On the 25 June sampling date, the control had an NDVI value of 0.64 while the lactofen treatment had an average NDVI value of 0.50 and the leaf removal treatment a value of 0.40. At the 3 July sampling date, the control had an average NDVI value of 0.81 while the lactofen treatment had a NDVI value of 0.68 and the leaf removal treatment a value of 0.62. This trend continued to the 15 July sampling date. Both the lactofen treatment (0.80 vs 0.87) and the leaf removal treatment (0.76 vs. 0.87) had significantly lower NDVI values than the control. The meristem removal and fomesafen treatments had similar NDVI values as the control at all sampling dates and all treatments reached maximum NDVI by the 5 August sampling date.

At the Hodgenville location in 2014, the NDVI responses to the main effect of stress differed from the light interception responses observed at this location (Figure 3.7). On the 2 July sampling date, both the lactofen and leaf removal had lower light interception values than the control but the lactofen treatment intercepted more light than the leaf removal treatment (66% vs. 54%). While the light interception values differed, the lactofen and leaf removal treatments had identical 0.50 NDVI values. At the 10 July sampling date, only the leaf removal treatment had lower NDVI values than the control (0.75 vs. 0.83). Similar to the light interception data, all stress treatments achieved maximum NDVI values by the 15 July sampling date which was also the date of first flower (R1).

The NDVI responses had greater separation between treatments than the light interception data at the Lexington location in 2014 (Figure 3.8). On the 25 June sampling date, the lactofen and leaf removal treatments had lower NDVI values than the control, which is similar to the trend observed in the light interception data. However, the fomesafen and meristem removal treatments had greater NDVI values than the control (0.47 and 0.45 vs. 0.39 respectively). On the 3 July sampling date, the only stress treatment that had lower NDVI values than the control was the leaf removal treatment (0.61 vs. 0.72). On the 9 July sampling date, the meristem removal and fomesafen treatments had greater NDVI values than the control (0.79 and 0.80 vs. 0.73 respectively). All treatments achieved maximum NDVI by 2 August (Fig. 8). It is not surprising that NDVI values for the leaf removal and lactofen treatments resulted in lower measured NDVI values. Both treatments resulted in decreased green-leaf area which resulted in reduced NDVI values compared to other stress treatments.

Yield and yield components

All environments

The stress treatments applied to the early vegetative soybean produced visual effects on the soybean plants. The fomesafen treatment caused slight discoloration and bronzing of the soybean tissue and the visual injury symptoms usually persisted for only 3-4 days. The lactofen treatment caused more damage compared to the fomesafen treatment. Severe bronzing and necrosis occurred on of all soybean tissues that came in contact with lactofen occurred. While exposed tissues were heavily damaged, new leaf tissue was unaffected and lactofen treated soybean were indistinguishable from untreated soybean 2 to 3 weeks after application. The soybean in the leaf removal treatment appeared to be lighter in color than untreated soybean (as evidenced by lower NDVI values) and were easily distinguishable from other plots for a number of weeks, although the canopy development eventually recovered toward the middle of the growing season.

Removal of the apical meristem halted growth of the main soybean stem and resulted in the development of 3 to 6 long lateral branches. For the majority of the growing season, the meristem removal treatment plots appeared shorter than the other plots and were bushier than untreated soybean plants. After the meristem was removed, the only mainstem nodes remaining were the mainstem nodes present at the time of removal. All pods and seeds were produced on branch nodes with no pod or seed production observed on the residual mainstem nodes.

Hodgenville 2013

At the Hodgenville location in 2013, there were differences between treatments in node number, pod number, and seed number for both the mainstem and branches (Table 3.18). The meristem removal treatment had reduced mainstem node numbers compared to the control (24 vs. 564 nodes m^{-2}) but compensated for this by exhibiting increased branch node number (802 vs 93 nodes m^{-2}). The lactofen treatment had increased mainstem node number compared to the control and leaf removal treatments (690 vs. 564 and 583 nodes m^{-2}, respectively). While there were differences in both mainstem and branch node number between treatments, there were no differences in total nodes m^{-2}.

The lactofen treatment had increased mainstem pod number (1294 vs. 1020 pods m^{-2}), but had similar branch pod number compared to the control (Table 3.18). The fomesafen and leaf removal treatments had similar mainstem and branch pod numbers as the control. No mainstem pods were produced by the soybean in the meristem removal treatment resulting in increased branch pod number compared to the other treatments. While there were differences in both mainstem and branch pod numbers, total pod numbers were similar across treatments.

The seed number response was similar to the pod number responses (Table 3.18). The lactofen treatment had higher mainstem seeds than the control (3215 vs 2586 seeds m^{-2}), while the fomesafen and leaf removal treatments had similar seed number to the control. It is not clear why the lactofen treatment would show increased pod and seed numbers as light interception lagged behind the control at the beginning of reproductive growth (R1)(Fig. 3.1). The meristem removal treatment soybean set all pods and seeds on lateral branches, resulting in greatly increased soybean branch seed numbers compared to the other treatments (3334 vs. 347 seeds m^{-2}). There were no differences in total seed number between stress treatments. Differences in mainstem seed mass between treatments were due to the lack of mainstem seed production for the meristem removal treatment, all other treatments had similar mainstem seed mass. No differences in average seed mass were observed between treatments. While yield components varied for both the mainstem and branch portions of the soybean plant, total yield components remained largely similar across treatments.

Seed yield did not show a response to timing or stress and there was no timing x stress interaction, likely due to the lack of differences in total yield components between treatments. Seed yield in this environment averaged 3.81 Mg ha^{-1} across all early-season stresses and timings (Table 3.14). Given that canopy closure was not achieved by R1 for the leaf removal and lactofen treatments, it is surprising that there were no differences in soybean yield and yield components at this location. Given the productivity of this environment and ideal growing conditions, it is likely that both the lactofen and leaf removal treatments reached canopy closure shortly after R1. However, the lack of yield differences may also suggest that canopy closure is not necessary until later in reproductive growth for maximum soybean yield (Schou et al., 1978).

Lexington 2013

The soybean at the Lexington location in 2013 had decreased mainstem node, pod, and seed numbers for the meristem removal treatment compared to the other stress treatments but compensated with greater branch node, pod, and seed numbers (Table 3.19). No differences in total pod, node, and seed numbers were observed and there were no differences between locations in average seed mass. Despite the lack of differences in total node, pod, and seed number and average seed mass, there were yield differences between the stress treatments. The yield of lactofen and fomesafen treatments was similar to the yield of the control (Table 3.15). The yield of the leaf removal treatment was decreased by 12 % as compared to the control (4.83 vs. 5.43 Mg ha^{-1}). Yield of the meristem removal treatment were reduced by 9% as compared to the control (4.93 vs. 5.43 Mg ha^{-1}). Similar to the other environments, the leaf removal and lactofen treatments failed to reach canopy closure (>95% light interception) by R1, which research has shown to be necessary for yield maximization (Johnson 1987; Tanner and Hume, 1978). The lack of canopy closure at R1 would suggest that yield differences would be due to differences in seed number. However, it appears that the leaf removal treatment reached canopy closure shortly after R1 (Fig. 3.2) and there were no differences in seed number between stress treatments (Table 3.19). The lactofen treatment also did not decrease yield compared to the control. The leaf removal treatment had a 9% decrease in average seed mass compared to the control, which was found to be statistically different when a single degree of freedom contrast was performed between the treatments (p= 0.03). A yield difference due to decreased seed mass could not be due directly to light interception as canopy closure was obtained well before the onset of seed filling (R5) (Fig. 2). Studies have suggested that a critical leaf area index (LAI) must be achieved before the onset of reproductive growth in order to maximize yield. The critical LAI value for soybean is usually considered to be between 3.5 and 4.0 (Jeffers and Shibles, 1969). The physical damage to the soybean plant from the lactofen application and leaf removal could have reduced soybean leaf area below a critical level resulting in decreased seed yield for these treatments. These results would also seem to support the work of Edwards et al. (2005) who suggested cumulative intercepted photosynthetically active radiation (CIPAR) was more important to yield determination than simple attainment of canopy closure. Early-season leaf removal could reduce CIPAR, potentially resulting in decreased soybean seed mass and decreased seed yield.

The yield decrease observed for the meristem removal treatment is more difficult to explain. Light interception was similar to untreated plants throughout the growing season (Fig. 3.2) and there were no differences in total seed number or average seed mass. One possible explanation for the decreased seed yield for the meristem removal treatment is increased harvest loss. Soybean branches are more fragile than the mainstem, making them more likely to break-off the mainstem especially with pods attached. The soybean at this location were harvested late due to a wet fall, which exposed the standing plants to a number of weeks of harsh fall weather conditions. Physical damage to the standing plants caused by the combine harvester may have caused brittle branches to break off and remain in the field instead of being threshed in the combine. The whole plants harvested for yield component analysis were harvested right at R8 and would not have been subject to the fall weather.

Hodgenville 2014

At the Hodgenville location in 2014, the meristem removal treatment had decreased mainstem nodes and increased branch nodes compared to the other stress treatments (Table 3.20). However, unlike other environments, the meristem removal increased total node number compared to the other stress treatments (820 vs. 692 nodes m^{-2}). The fomesafen treatment had increased mainstem pod number compared to the lactofen and leaf removal treatments (1224 pod m^{-2} vs. 2615 and 2547 pods m^{-2}, respectively). The control, lactofen, and fomesafen treatments had more total pods than the leaf removal treatment (1306 vs. 1121 pods m^{-2}). While the meristem removal treatment had greater node number; pod numbers were decreased compared to all other treatments (1256 vs 735 pods m^{-2}). The fomesafen treatment also had increased mainstem seed numbers compared to the other stress treatments. While there were differences in total node and pod numbers, there were no significant differences in in total seed number between stress treatments. The leaf removal treatment had decreased mainstem seed mass compared to the other treatments (except the meristem removal treatment) (140 vs 160 mg seed^{-1}) but there were no differences in average seed mass between treatments (Table 3.20).

Yield responded to the main effect of stress but not to the main effect of timing and there was no timing x stress interaction (Table 3.16). The only treatment that yielded similarly to the control was the fomesafen treatment. Lactofen treatment decreased yield by 8% (5.78 vs 6.25 Mg ha^{-1}), while the leaf removal treatment reduced yield by 6% compared to the control (5.91 vs. 6.25 Mg ha^{-1}). The meristem removal treatment decreased yield by 7% compared to the control (5.82 vs. 6.25 Mg ha^{-1}). The lactofen and leaf removal treatments had decreased early season light interception compared to untreated soybean; however, in this environment all treatments, except the control, reached canopy closure (>95% light interception) by R1 (Fig. 3.3). Similar to the Lexington location in 2013, the damage caused by the lactofen and leaf removal may have reduced soybean LAI below a critical level, resulting in decreased yield compared to untreated soybean (Jeffers and Shibles, 1966). Also similar to Lexington in 2013, the Hodgenville location in 2014 was harvested very late due to wet fall conditions, resulting in the potential yield loss due to mechanical harvesting.

Lexington 2014

Similar to the other environments, the meristem removal treatment increased branch node number and decreased mainstem node number compared to the other treatments (Table 3.21). Like the Hodgenville location in 2014, the meristem removal treatment resulted greater total node number than the control, lactofen, and fomesafen treatments (965 vs. 779 nodes m^{-2}). Interestingly, the leaf removal treatment increased mainstem nodes compared to the other treatments. The fomesafen treatment had slightly increased mainstem pod number compared to the leaf removal treatment (1104 vs 1008 pods m^{-2}) but total pod numbers were similar across treatments. Total seed number was similar across treatments as well. Differences between treatments were observed for mainstem, branch, and average seed mass. The control and fomesafen treatments had increased mainstem seed mass compared to the leaf removal treatment (172 and 172 mg seed^{-1} vs. 161 mg seed^{-1}, respectively). The control and fomesafen treatment also increased branch seed mass compared to the lactofen treatment, leaf removal, and meristem removal treatments. The control had greater average seed mass than the lactofen, leaf removal, and meristem removal treatments (182 mg seed^{-1} vs. 177, 173 and 173 mg seed^{-1} respectively) (Table 3.21). Despite the differences in seed mass, this location did not show a seed yield response to the main effects of timing or stress and there was not a timing x stress interaction (Table 3.17).

Seed quality

Soybean seed quality at the Hodgenville location in 2013 did not respond to either main effect of timing or stress and there was no timing x stress for either protein or oil content (Table 3.22). Seed quality at the Lexington location in 2013 responded to the main effect of stress for both protein and oil. The leaf removal and meristem removal treatments had increased seed protein levels compared to the control (388.6 and 370.5 g kg^{-1} vs. 364.5 g kg^{-1}, respectively). While these treatments had increased seed protein, they also decreased seed oil content compared to the control (185.0 and 186.6 g kg^{-1} vs. 189.1 g kg^{-1} respectively (Table 3.23). A similar situation occurred at the Hodgenville location in 2014. Both the leaf removal and meristem removal treatments had increased seed protein levels compared to the control (366.0 and 368.1 g kg^{-1} vs. 364.0 g kg^{-1}, respectively). In this environment, the lactofen treatment also had increased protein compared to the control (366.0 vs. 364.0 g kg^{-1}). The lactofen, leaf removal, and meristem removal also decreased seed oil content (187.6, 188.3 and 186.9 g kg^{-1} vs. 191.0 g kg^{-1}, respectively) (Table 3.24). In contrast, at the Lexington location in 2014, the lactofen, leaf removal and meristem removal treatments had decreased seed protein content compared to the control (379.9 g kg^{-1} vs. 376.9, 375.1 and 376.7 g kg^{-1}, respectively). The only treatment that decreased seed oil content was the meristem removal treatment (189.2 vs. 186.2 g kg^{-1}) (Table 3.25).

Table 3.1. Average monthly air temperature for studies across the Midwest and Mid-South between 2012 and 2014.

Location	Year	April	May	June	July	Aug.	Sept.	Oct.
					°C			
Colt, AR	2012	18.7	24.3	26.1	30.1	27.6	23.7	15.9
	2013	15.0	20.6	25.9	25.6	25.9	24.5	17.3
	2014	16.2	21.7	26.5	24.6	26.8	23.6	18.7
	30 yr.	16.1	21.2	25.8	27.1	26.4	22.4	16.9
Newport, AR	2012	17.8	24.4	24.8	28.7	25.8	21.9	14.4
	2013	13.8	19.2	25.2	25.0	24.8	23.4	15.7
	2014	14.8	19.9	24.4	24.0	26.3	21.9	17.1
	30 yr.	16.1	21.1	25.7	27.6	27.1	22.7	16.5
Farley, IA	2012	9.4	17.3	21.2	25.7	20.9	15.6	8.7
	2013	6.9	15.0	19.8	21.3	21.3	18.0	9.6
	2014	7.8	15.2	20.9	19.6	21.2	15.8	9.3
	30 yr.	9.0	14.8	20.2	22.3	21.2	16.6	10.1
Humboldt, IA	2012	10.6	18.2	22.2	26.2	21.6	17.1	8.8
	2013	5.2	14.5	20.3	22.9	20.9	19.1	10.1
	2014	8.1	15.6	21.3	20.3	21.6	16.5	10.3
	30 yr.	8.9	15.7	20.8	22.9	21.4	16.7	10.1
Monmouth, IL	2012	12.5	18.8	21.8	26.4	22.8	17.9	11.2
	2013	8.7	17.1	21.7	22.1	22.4	19.7	11.7
	2014	10.2	16.7	22.3	20.7	22.8	17.4	11.4
	30 yr.	11.6	17.1	22.1	24.0	23.0	18.8	12.5
Urbana, IL	2012	12.3	20.2	22.4	27.9	23.4	18.2	10.7
	2013	10.1	17.9	21.8	22.5	22.8	20.9	12.6
	2014	11.5	17.7	22.8	21.0	23.0	18.1	12.1
	30 yr.	11.2	17.1	22.3	24.0	23.1	19.1	12.4
Wanatah, IN	2012	9.1	18.4	21.2	14.4	20.2	15.9	9.3
	2013	6.9	15.7	19.6	22.5	19.7	17.6	10.6
	2014	8.1	15.3	21.6	23.0	21.2	17.0	10.8
	30 yr.	9.1	14.9	20.6	22.3	21.2	17.2	10.7
West Lafayette, IN	2012	11.3	19.9	22.3	26.6	21.8	17.3	10.4
	2013	10.0	18.4	21.8	22.1	21.4	19.0	12.0
	2014	10.7	17.0	22.7	20.1	21.9	16.8	10.9
	30 yr.	10.4	16.4	21.6	23.1	22.0	18.3	11.8
Manhattan, KS	2012	15.3	21.4	25.1	30.0	24.4	19.6	12.6
	2013	9.2	17.6	23.7	24.9	24.9	22.7	12.9
	2014	12.1	18.4	23.3	24.1	26.1	19.7	14.7
	30 yr.	12.9	18.4	23.7	26.6	25.8	20.5	13.9
Rossville, KS	2012	15.8	21.9	26.1	30.2	24.8	19.9	13.2
	2013	10.3	18.1	24.3	25.8	25.2	22.7	13.4
	2014	12.8	19.9	24.4	24.9	26.9	20.6	15.1

Table 3.1. Average monthly air temperature for studies across the Midwest and Mid-South between 2012 and 2014.

	30 yr.	12.8	18.4	23.5	26.2	25.3	20.2	13.7
Scandia, KS	2012	14.2	20.4	24.7	28.6	23.3	18.7	11.1
	2013	7.7	16.8	22.9	24.4	24.6	21.9	12.0
	2014	10.7	17.2	23.2	23.8	24.8	18.6	13.4
	30 yr.	11.6	17.3	22.8	25.9	24.9	19.8	12.9
Hodgenville, KY	2012	14.4	20.9	22.8	26.7	24.0	20.6	14.0
	2013	13.7	18.9	22.6	8.4	23.2	21.1	14.2
	2014	14.4	18.8	22.7	23.2	23.3	20.7	15.4
	30 yr.	13.8	18.7	22.7	24.6	24.1	20.6	14.6
Lexington, KY	2012	14.6	20.4	22.4	26.9	23.4	19.2	12.4
	2013	13.3	19.0	23.2	23.6	23.8	20.9	14.2
	2014	13.3	19.2	23.8	22.9	24.4	20.8	14.7
	30 yr.	12.9	17.9	22.7	26.3	24.1	20.1	13.9
Breckenridge, MI	2012	7.4	15.8	19.8	23.9	20.0	16.0	9.7
	2013	5.1	15.3	18.9	21.3	19.9	16.1	10.3
	2014	6.7	13.7	19.8	18.8	19.5	15.8	9.8
	30 yr.	7.6	13.9	19.3	21.7	20.4	16.0	9.5
East Lansing, MI	2012	8.3	17.0	21.0	25.4	21.2	16.6	10.1
	2013	6.8	16.4	19.7	22.0	20.7	16.5	11.1
	2014	8.3	14.7	20.5	19.5	20.8	16.1	9.8
	30 yr.	8.1	14.0	19.4	21.7	20.6	16.3	9.9
Minnesota Lake, MN Drained and Undrained	2012	9.3	17.7	21.5	25.3	21.1	16.3	8.0
	2013	4.1	13.9	20.2	22.3	21.5	18.7	9.1
	2014	6.5	14.1	20.6	20.1	21.7	16.6	8.9
	30 yr.	7.7	14.3	20.1	22.4	20.9	16.4	9.3
St. Paul, MN	2012	10.0	17.6	22.4	26.8	22.2	17.7	8.6
	2013	5.0	14.6	20.5	23.9	23.7	19.6	9.5
	2014	5.9	14.8	20.8	21.9	22.9	17.1	9.6
	30 yr.	8.6	15.1	20.4	23.3	21.8	16.7	9.5
Waseca, MN	2012	8.7	17.1	21.0	24.3	20.3	15.4	7.4
	2013	3.6	13.0	19.6	22.1	20.9	17.9	8.6
	2014	5.8	13.7	20.2	20.1	21.5	16.0	8.8
	30 yr.	7.7	14.6	20.1	22.1	20.8	16.1	8.9
Arlington, WI	2012	6.4	15.0	19.8	24.3	19.4	14.3	6.8
	2013	4.1	13.3	17.9	20.4	19.2	15.5	7.9
	2014	4.9	12.6	19.2	18.1	19.4	15.4	8.9
	30 yr.	7.8	14.1	19.4	21.6	20.4	16.1	9.5
Janesville, WI	2012	8.7	17.5	21.6	26.6	21.5	16.3	9.2
	2013	6.8	15.9	19.9	22.1	20.7	17.9	9.6
	2014	7.7	15.3	21.1	20.1	21.8	16.3	9.8
	30 yr.	8.9	15.3	20.2	22.9	21.4	16.8	11.0

Table 3.2. Total monthly precipitation in mm for studies across the Midwest and Mid-South between 2012 and 2014.

		April	May	June	July	Aug.	Sept.	Oct.
					mm			
Colt, AR	2012	26	51	55	39	56	128	100
	2013	182	209	50	118	74	74	53
	2014	36	188	431	54	30	20	126
	30 yr.	135	142	75	91	74	63	103
Newport, AR	2012	45	86	41	56	56	175	109
	2013	109	242	57	86	115	40	129
	2014	175	128	204	100	21	22	107
	30 yr.	128	131	86	97	68	79	103
Farley, IA	2012	58	83	36	12	102	30	67
	2013	217	179	92	64	76	60	46
	2014	152	70	319	53	79	54	77
	30 yr.	94	107	110	121	107	86	67
Humboldt, IA	2012	128	71	66	28	22	77	77
	2013	167	191	134	26	33	20	52
	2014	114	89	263	61	92	124	48
	30 yr.	89	112	140	121	101	74	58
Monmouth, IL	2012	49	85	143	25	81	145	91
	2013	215	299	96	52	1	52	64
	2014	109	83	181	108	134	154	120
	30 yr.	98	117	112	104	98	92	76
Urbana, IL	2012	59	79	58	15	141	145	139
	2013	179	95	159	90	9	17	91
	2014	100	111	209	221	39	87	126
	30 yr.	94	123	108	115	94	78	83
Wanatah, IN	2012	47	62	89	155	89	45	96
	2013	168	89	242	62	112	78	136
	2014	71	95	248	87	265	84	97
	30 yr.	85	97	105	110	110	84	89
West Lafayette, IN	2012	44	88	42	27	198	104	114
	2013	230	95	124	70	48	90	53
	2014	101	124	148	95	211	143	150
	30 yr.	93	120	106	104	89	70	77
Manhattan, KA	2012	54	34	105	18	109	72	16
	2013	89	102	96	107	83	146	133
	2014	145	55	245	17	82	52	69
	30 yr.	81	127	146	113	105	87	68
Rossville, KS	2012	73	61	115	30	36	12	33
	2013	65	147	62	59	71	251	101
	2014	82	58	140	44	42	123	45

Table 3.2. Total monthly precipitation in mm for studies across the Midwest and Mid-South between 2012 and 2014.

	30 yr.	89	126	130	106	112	101	71
Scandia, KS	2012	155	3	116	75	59	30	36
	2013	73	96	43	111	133	40	38
	2014	45	11	131	36	112	73	74
	30 yr.	67	102	99	99	78	69	52
Hodgenville, KY	2012	51	134	9	201	71	101	101
	2013	132	163	203	226	179	104	86
	2014	142	179	36	95	168	13	180
	30 yr.	96	148	100	110	77	93	91
Lexington, KY	2012	58	91	41	203	55	138	33
	2013	124	144	192	231	131	41	158
	2014	152	138	142	82	243	110	114
	30 yr.	98	135	114	118	83	77	81
Breckenridge, MI	2012	50	55	63	177	130	29	115
	2013	229	120	74	22	86	26	73
	2014	104	84	61	167	65	91	66
	30 yr.	81	88	89	71	89	85	72
East Lansing, MI	2012	65	58	48	44	98	73	113
	2013	200	100	213	44	121	25	90
	2014	35	108	163	123	121	65	90
	30 yr.	77	87	88	75	83	84	66
Minnesota Lake, MN Drained and Undrained	2012	89	131	106	42	53	23	35
	2013	73	184	320	163	79	33	79
	2014	175	42	222	26	124	84	33
	30 yr.	76	98	122	117	116	87	56
St. Paul, MN	2012	77	237	91	124	35	8	33
	2013	133	158	131	89	53	34	76
	2014	159	116	289	58	74	23	44
	30 yr.	68	87	109	104	108	77	60
Waseca, MN	2012	78	146	108	53	37	24	35
	2013	157	164	169	134	53	49	90
	2014	141	73	328	30	81	59	35
	30 yr.	82	100	120	114	115	93	66
Arlington, WI	2012	78	75	7	56	73	26	101
	2013	138	153	191	76	45	75	39
	2014	164	71	237	48	94	45	70
	30 yr.	86	93	118	102	97	91	62
Janesville, WI	2012	67	50	14	81	76	60	101
	2013	241	84	242	46	36	50	54
	2014	80	120	139	52	116	55	85
	30 yr.	81	98	101	104	94	86	85

Table 3.3. Yield responses to management treatments for environments where management increased yield compared to the control for experiments conducted between 2012 and 2014.

Environment	Region	Control Yield	F ST†	F+I ST	Max ST	D	N	F	N-N' urea	FF	FI	FF +FI	SOYA	SOYA+ D	SOYA- N	SOYA- FF	SOYA- FF and FI
		Mg ha^{-1}									% increase over control						
12MNLKD	North	2.96									30.9a	30.1ab	29.7ab	17.5b	27.9ab	35.4a	
12MNLKU	North	3.06			16.5c						23.3ab	20.8b	28.4ab	29.9ab	33.3a	32.6a	
12MNWAS	North	3.36					14.8a		14.6a			21.6a		19.1a		16.7a	
12WIARL	North	4.20											10.2a		10.9a		
13MIBRE	North	3.69					5.8a				5.7a		7.7a	6.4a	3.9a	7.6a	6.5a
13MIELA	North	4.39										11.3a	12.4a			13.5a	13.4a
13MNSTP	North	4.54					9.5a			9.8a			11.2				
13MNWAS	North	4.75									16.4a	20.2a	12.7a		16.8a	12.2a	
13WIJAN	North	5.09									13.4a	15a	10.4a		12.3a	14.8a	11.8a
14MIBRE	North	3.04								10.5a		15.9a	16.2a		23.4a		12.5a
14WIJAN	North	5.52										9.7a	11.6a			7.8a	9.3a
14MIELA	North	4.31					7.4a					9.4a	7.4a	7.8a	10.3a		7.9a
14MNLKD	North	3.73		13.6de	16.7cde					17.5cde	15.7cde	31.3a	29.2ab	23.9abcd	24.2abcd	21.3bcd	14.8cde
14MNLKU	North	4.03										18.9a	19.3a	23.3a	21.3a	19.9a	
13ILMON	Central	4.01					12.5a					13.6a				12.1a	13a
14INWAN	Central	3.57											23.5a				
14INWLA	Central	4.19										11.6a	8.6a				
13KSROS	South	1.85											41.2a	60.0a	46.0a	57.1a	
13KSSCA	South	3.97				23.5a											
14ARCOL	South	4.91											12.4a		14.1a	14.5a	
14KYHOD	South	4.19											9.7a				
14KYLEX	South	3.30													16.8a		

† F ST, fungicide seed treatment; F+I ST, fungicide + insecticide seed treatment; D, defoliant; N, nitrogen; F, foliar fertilizer; FF, foliar fungicide; FI, foliar insecticide

Table 3.4. P-values associated with ANOVA models for yield, seed number, and seed mass for the South, Central, and North regions averaged across environments for studies conducted in the Midwest and Mid-South between 2012 and 2014.

Region	Yield	Seed number	Seed mass
		P-value	
South	0.22	0.79	0.07
Central	0.0019	0.18	0.0003
North	<0.0001	<0.0001	<0.0001
All	<0.0001	<0.0001	<0.0001

Table 3.5. Yield, seed number, and seed mass values for management treatments across environments in the South region (Arkansas, Kansas, Kentucky) between 2012 and 2014.

	South		
Treatment	Yield	Seed number	Seed mass
	Mg ha^{-1}	seeds m^{-2}	mg seed^{-1}
UTC	4.11	2633	154.4
Bio-forge	4.13	2670	155.0
Fung ST	4.05	2595	154.9
Fung and Inst. ST	4.07	2635	153.0
Max ST	4.16	2683	154.6
Foliar Fertilizer	4.12	2638	155.2
Defoliant	4.16	2673	156.1
Foliar Fungicide	4.13	2606	157.7
Foliar Insecticide	4.05	2639	154.6
Foliar F+I	4.11	2617	156.4
Nitrogen	4.11	2655	154.2
SOYA	4.29	2737	157.1
SOYA +D	4.26	2708	157.0
SOYA - N	4.23	2662	157.8
SOYA - FF	4.25	2689	156.6
SOYA - FF+FI	4.17	2671	155.8
LSD	NS	NS	NS

Table 3.6. Yield, seed number, and seed mass values for management treatments across environments in the Central region (Indiana, Illinois, Iowa) between 2012 and 2014.

Central			
Treatment	Yield	Seed number	Seed mass
	Mg ha^{-1}	seeds m^{-2}	mg seed^{-1}
UTC	4.04	2445	163.4
Bio-forge	4.03	2416	164.7
Fung ST	4.02	2438	165.3
Fung and Inst. ST	4.06	2454	164.0
Max ST	4.02	2429	164.6
Foliar Fertilizer	4.01	2428	165.4
Defoliant	3.85	2368	161.6
Foliar Fungicide	4.14	2457	167.8
Foliar Insecticide	4.10	2457	166.7
Foliar F+I	4.18	2479	168.5
Nitrogen	4.09	2492	163.6
SOYA	4.25	2519	168.3
SOYA +D	4.17	2492	166.1
SOYA - N	4.18	2474	165.9
SOYA - FF	4.15	2485	166.1
SOYA - FF+FI	4.15	2514	165.6
LSD	0.15	NS	2.6

Table 3.7. Yield, seed number, and seed mass values for management treatments across environments in the northern region (Michigan, Minnesota, Wisconsin) between 2012 and 2014.

	North		
Treatment	Yield	Seed number	Seed mass
	Mg ha^{-1}	seeds m^{-2}	mg seed^{-1}
UTC	4.11	2515	164.4
Bio-forge	4.15	2507	166.9
Fung ST	4.15	2504	167.0
Fung and Inst. ST	4.18	2533	166.5
Max ST	4.27	2564	168.8
Foliar Fertilizer	4.21	2568	165.0
Defoliant	3.94	2449	162.6
Foliar Fungicide	4.30	2548	170.1
Foliar Insecticide	4.40	2596	170.7
Foliar F+I	4.57	2646	174.2
Nitrogen	4.27	2581	166.6
SOYA	4.60	2625	176.5
SOYA +D	4.42	2581	172.0
SOYA - N	4.48	2567	175.8
SOYA - FF	4.55	2646	174.0
SOYA - FF+FI	4.37	2580	170.2
LSD	0.13	64	3.4

Table 3.8. Yield, seed number, and seed mass values for management treatments across all environments between 2012 and 2014.

	All environments		
Treatment	Yield	Seed number	Seed mass
	Mg ha^{-1}	seeds m^{-2}	mg seed^{-1}
UTC	4.08	2559	160.1
Bio-forge	4.10	2548	161.5
Fung ST	4.07	2526	161.8
Fung and Inst. ST	4.10	2550	160.7
Max ST	4.15	2575	161.9
Foliar Fertilizer	4.11	2564	161.3
Defoliant	3.98	2509	159.9
Foliar Fungicide	4.18	2549	164.8
Foliar Insecticide	4.19	2573	163.5
Foliar F+I	4.28	2588	166.0
Nitrogen	4.15	2586	161.2
SOYA	4.38	2629	167.0
SOYA +	4.28	2603	164.7
SOYA - N	4.29	2583	165.9
SOYA - FF	4.31	2620	164.9
SOYA - FF+FI	4.23	2595	163.4
LSD	0.1	54	1.8

Table 3.9. Relative yield change and break-even probabilities for management treatments compared to the control at multiple yield levels and soybean sale prices for studies across the Midwest and Mid-South between 2012 and 2014.

		Yield level (Mg ha^{-1})								
		3.0			4.0			5.0		
		Soybean sale price ($ kg^{-1})								
Treatment †	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	-0.03	1	3	6	3	7	12	6	12	17
F+I ST	0.55	0	0	0	0	0	2	0	2	6
Max ST	2.15	0	0	5	0	8	26	5	26	50
Foliar fertilizer	1.17	0	0	3	0	4	14	3	14	27
Defoliant	-1.79	0	0	0	0	0	0	0	0	0
Nitrogen	2.15	0	0	0	0	0	0	0	0	2
N-N' diformyl urea	0.39	0	0	0	0	0	1	0	1	4
Foliar fungicide	2.45	0	0	0	0	0	1	0	1	12
Foliar insecticide	3.19	40	77	91	77	93	97	91	97	99
FF+FI	5.56	0	0	11	0	23	76	11	76	97
SOYA	8.08	0	0	0	0	0	0	0	0	0
SOYA + D	5.88	0	0	0	0	0	0	0	0	0
SOYA-N	6.02	0	0	0	0	0	0	0	0	0
SOYA- FF	6.65	0	0	0	0	0	0	0	0	0
SOYA-FF+FI	3.92	0	0	0	0	0	0	0	0	0

† ST, seed treatment; F, fungicide; I, insecticide FF, foliar fungicide; FI, foliar insecticide; D, defoliant; N, nitrogen

¶ RYC, relative yield change vs. control

Table 3.10. Relative yield change and break-even probabilities for management treatments compared to the control 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})								
Treatment †	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	-1.29	1	2	3	2	3	5	3	5	6
F+I ST	-0.70	0	0	0	0	0	1	0	1	3
Max ST	0.90	0	0	2	0	3	9	2	9	18
Foliar fertilizer	-0.08	0	0	2	0	2	5	2	5	10
Defoliant	-3.04	0	0	0	0	0	0	0	0	0
Nitrogen	0.90	0	0	0	0	0	0	0	0	1
N-N' diformyl urea	-0.86	0	0	0	0	0	1	0	1	2
Foliar fungicide	1.19	0	0	0	0	0	1	0	1	5
Foliar insecticide	1.93	14	32	47	32	51	62	47	62	70
FF+FI	4.31	0	0	4	0	8	31	4	31	60
SOYA	6.83	0	0	0	0	0	0	0	0	0
SOYA + D	4.63	0	0	0	0	0	0	0	0	0
SOYA-N	4.77	0	0	0	0	0	0	0	0	0
SOYA- FF	5.40	0	0	0	0	0	0	0	0	0
SOYA-FF+FI	2.67	0	0	0	0	0	0	0	0	0

† ST, seed treatment; F, fungicide; I, insecticide FF, foliar fungicide; FI, foliar insecticide; D, defoliant; N, nitrogen

¶ RYC, relative yield change vs. control

Table 3.11. Relative yield change and break-even probabilities for management treatments compared to the control 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})								
Treatment †	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	-1.52	0	1	2	1	2	3	2	3	5
F+I ST	-0.93	0	0	0	0	0	1	0	1	2
Max ST	0.67	0	0	2	0	2	7	2	7	14
Foliar fertilizer	-0.31	0	0	1	0	2	4	1	4	7
Defoliant	-3.27	0	0	0	0	0	0	0	0	0
Nitrogen	0.67	0	0	0	0	0	0	0	0	1
N-N' diformyl urea	-1.09	0	0	0	0	0	1	0	1	2
Foliar fungicide	0.96	0	0	0	0	0	1	0	1	3
Foliar insecticide	1.70	11	27	40	27	44	55	40	55	64
FF+FI	4.08	0	0	3	0	6	26	3	26	53
SOYA	6.60	0	0	0	0	0	0	0	0	0
SOYA + D	4.40	0	0	0	0	0	0	0	0	0
SOYA-N	4.53	0	0	0	0	0	0	0	0	0
SOYA- FF	5.17	0	0	0	0	0	0	0	0	0
SOYA-FF+FI	2.43	0	0	0	0	0	0	0	0	0

† ST, seed treatment; F, fungicide; I, insecticide FF, foliar fungicide; FI, foliar insecticide; D, defoliant; N, nitrogen

¶ RYC, relative yield change vs. control

Table 3.12. Relative yield change and break-even probabilities for management treatments compared to the control 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})								
Treatment †	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	2.49	60	74	81	74	83	87	81	87	90
F+I ST	3.08	6	26	48	26	54	70	48	70	81
Max ST	4.68	17	55	79	55	83	93	79	93	97
Foliar fertilizer	3.70	23	55	74	55	78	88	74	88	93
Defoliant	0.74	0	3	8	3	10	17	8	17	26
Nitrogen	4.68	0	1	8	1	14	43	8	43	71
N-N' diformyl urea	2.92	5	25	45	25	51	67	45	67	78
Foliar fungicide	4.97	0	5	28	5	38	68	28	68	87
Foliar insecticide	5.71	95	99	99	99	99	99	99	99	99
FF+FI	8.09	2	44	86	44	92	99	86	99	99
SOYA	10.61	0	0	0	0	0	0	0	0	1
SOYA + D	8.41	0	0	0	0	0	0	0	0	0
SOYA-N	8.54	0	0	0	0	0	0	0	0	20
SOYA- FF	9.18	0	0	0	0	0	1	0	1	24
SOYA-FF+FI	6.44	0	0	0	0	0	0	0	0	1

† ST, seed treatment; F, fungicide; I, insecticide FF, foliar fungicide; FI, foliar insecticide; D, defoliant; N, nitrogen

¶ RYC, relative yield change vs. control

Table 3.13. Monthly average temperature and precipitation for Lexington and Hodgenville, Kentucky for the 2013 and 2014 growing seasons.

	Lexington		Hodgenville	
Year/month	**Precip.**	**Temp.**	**Precip.**	**Temp.**
	mm	° C	mm	° C
2013				
May	143	18.1	152	18.7
June	166	22.4	121	22.3
July	233	22.9	147	22.8
August	181	23.1	103	23.2
September	36	20.3	62	20.7
October	102	13.8	86	14.2
Total	861	20.1	671	20.3
2014				
May	108	18.4	124	19.2
June	116	22.9	86	23.2
July	68	22.3	78	22.2
August	164	23.3	135	23.7
September	89	19.9	17	20.2
October	116	13.3	114	14.1
Total	661	20.1	554	20.4

Table 3.14. Plant stands at the second node stage (V2), plant stands at maturity (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Hodgenville, Kentucky in 2013.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
Plant stands-V2			plants m^{-2}			
V1	77.2	71.7	66.1	69.0	66.0	70.0
V2	73.8	68.8	65.8	64.3	75.8	69.7
V3	-	-	-	-	-	-
V4	69.2	62.3	73.5	78.5	64.0	69.5
Avg.	73.4	67.6	68.4	70.6	68.6	
LSD¶	11.5					
Plant stands-R8						
V1	61.7	60.7	61.7	59.8	61.0	60.9
V2	67.5	68.3	63.5	56.8	68.0	64.8
V3	-	-	-	-	-	-
V4	67.4	55.8	67.0	74.0	57.0	64.2
Avg.	65.5	61.6	64.1	63.5	62.0	
LSD	11.7					
Plant height			cm			
V1	98.7	99.6	98.6	94.5	93.8	97.0
V2	99.0	99.5	100.3	89.5	98.8	97.4
V3	-	-	-	-	-	-
V4	94.5	103.0	100.8	100.5	94.3	98.6
Avg.	97.4	100.7	99.9	94.8	95.6	
LSD	NS†					
Seed Yield			Mg ha^{-1}			
V1	3.77	3.71.	3.88	3.55	3.98	3.78
V2	3.87	3.93	4.01	3.61	4.06	3.89
V3	-	-	-	-	-	-
V4	3.83	3.87	3.72	3.67	3.79	3.78
Avg.	3.82	3.83	3.87	3.61	3.95	
LSD	NS					

Significance (P values)	Plant Stands-V2	Plant Stands-R8	Plant height	Seed Yield
Stress	0.49	0.79	0.07	0.08
Timing	0.98	0.31	0.69	0.35
Timing x Stress	0.03	0.03	0.26	0.89

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.15. Plant stands at the second node stage (V2), plant stands at maturity (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Lexington, Kentucky in 2013.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
<u>Plant stands-V2</u>			plants m^{-2}			
V1	63.2	47.3	51.0	53.3	46.8	52.3
V2	37.8	50.5	45.8	53.3	51.8	47.8
V3	60.3	38.5	42.8	53.0	51.8	49.3
V4	57.8	59.8	48.5	49.5	65.0	55.5
Avg.	54.0	49.0	47.0	52.3	53.8	
LSD¶	NS†					
<u>Plant stands-R8</u>						
V1	50.8	42.0	37.8	44.3	35.5	42.1
V2	30.8	40.8	38.3	46.3	42.3	39.7
V3	43.5	36.0	32.5	42.3	39.0	38.7
V4	40.8	40.8	44.3	36.3	51.0	42.6
Avg.	41.4	39.9	38.2	42.3	41.9	
LSD	NS					
<u>Plant height</u>			cm			
V1	97.3	91.8	90.8	90.5	93.3	92.7
V2	91.5	96.3	96.0	93.3	92.3	93.8
V3	96.5	93.5	91.5	92.5	87.8	92.4
V4	95.8	90.8	93.3	88.8	91.5	92.0
Avg.	95.3	93.1	92.9	91.3	91.2	
LSD	2.6					
<u>Seed yield</u>			Mg ha^{-1}			
V1	5.57	5.21	5.59	4.82	4.70	5.18
V2	5.21	5.06	5.25	5.19	4.97	5.14
V3	5.41	5.03	5.03	4.89	5.02	5.08
V4	5.52	5.56	5.35	4.42	5.03	5.18
Avg.	5.43	5.21	5.31	4.83	4.93	
LSD	0.4					

	<u>Plant Stands-V2</u>	<u>Plant Stands-R8</u>	<u>Plant height</u>	<u>Seed Yield</u>
Significance (P values)				
Stress	0.54	0.83	0.02	0.02
Timing	0.32	0.63	0.42	0.94
Timing x Stress	0.34	0.33	0.06	0.66

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.16. Plant stands at the second node stage (V2), plant stands at maturity (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Hodgenville, Kentucky in 2014.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
Plant stands-V2			plants m^{-2}			
V1	51.9	56.0	54.0	56.8	56.3	54.9
V2	54.5	54.3	54.0	52.0	51.1	53.2
V3	55.6	54.8	54.3	54.5	55.4	54.9
V4	54.8	53.8	51.3	55.8	52.0	53.5
Avg.	54.2	54.7	53.4	54.8	53.7	
LSD¶	NS†					
Plant stands-R8						
V1	58.8	58.0	56.0	56.0	51.3	56.0
V2	55.9	54.8	56.3	55.0	51.6	54.7
V3	57.1	59.3	54.3	58.5	52.4	56.3
V4	56.3	52.5	53.4	55.5	50.8	53.7
Avg.	57.0	56.1	55.0	56.3	51.5	
LSD	3.0					
Plant height			cm			
V1	98.3	101.0	97.8	106.5	94.3	99.6
V2	102.0	102.3	99.8	98.5	94.7	99.4
V3	97.8	95.8	103.8	101.8	91.8	98.2
V4	99.5	103.5	98.7	96.8	86.5	97.0
Avg.	99.4	100.6	100.0	100.9	91.8	
LSD	3.8					
Seed yield			Mg ha^{-1}			
V1	6.47	5.95	6.21	5.94	6.13	6.14
V2	6.12	5.58	6.00	6.10	5.58	5.88
V3	6.17	5.64	6.15	6.02	5.62	5.99
V4	6.23	5.94	5.79	5.57	5.95	5.83
Avg.	6.25	5.78	6.04	5.91	5.82	
LSD	0.29					

Significance (P values)	Plant Stands-V2	Plant Stands-R8	Plant height	Seed Yield
Stress	0.76	0.0038	<0.0001	0.02
Timing	0.27	0.19	0.41	0.09
Timing x Stress	0.61	0.90	0.09	0.66

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.17. Plant stands at the second node stage (V2), plant stands at maturity (R8), plant height, and seed yield values for early-season stress treatments at four timings for a study in Lexington, Kentucky in 2014.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
<u>Plant stands-V2</u>			plants m^{-2}			
V1	48.7	48.8	47.5	47.8	45.8	47.7
V2	50.7	47.5	46.5	50.8	48.3	48.8
V3	51.8	49.8	46.3	50.8	45.5	48.8
V4	47.0	47.8	50.5	50.3	47.5	48.6
Avg.	49.6	48.4	47.7	49.9	46.8	
LSD¶	NS†					
<u>Plant stands-R8</u>						
V1	48.3	52.8	50.0	47.3	39.0	47.5
V2	47.0	48.0	49.0	50.3	41.8	47.2
V3	48.9	49.8	46.5	49.5	42.3	47.4
V4	47.5	49.3	50.5	49.8	46.0	48.6
Avg.	47.9	49.9	49.0	49.2	42.3	
LSD	4.0					
<u>Plant height</u>			cm			
V1	75.3	79.0	73.3	76.8	71.5	75.2
V2	74.6	78.5	73.0	103.8	72.3	80.4
V3	72.4	80.8	76.0	77.3	69.8	75.2
V4	74.8	79.0	75.3	76.8	70.3	75.2
Avg.	74.3	79.3	74.4	83.6	70.9	
LSD	NS					
<u>Seed yield</u>			Mg ha^{-1}			
V1	5.08	5.37	5.26	5.15	5.70	5.31
V2	5.23	5.37	5.21	5.35	5.19	5.27
V3	4.86	5.27	5.55	5.17	5.31	5.23
V4	5.23	5.49	5.33	5.15	5.52	5.37
Avg.	5.11	5.37	5.33	5.24	5.43	
LSD	NS					

Significance (P values)	<u>Plant Stands-V2</u>	<u>Plant Stands-R8</u>	<u>Plant height</u>	<u>Seed Yield</u>
Stress	0.42	0.001	0.07	0.12
Timing	0.90	0.84	0.54	0.55
Timing x Stress	0.94	0.88	0.57	0.35

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.18. Mainstem and branch node number, pod number, seed number, and seed mass for soybean exposed to early-season stress treatments, averaged across four timings for a study in Hodgenville, Kentucky in 2013.

	Stress					
Yield components	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	LSD¶
nodes			m^{-2}			
Mainstem	564	690	595	583	24	107
Branch	66	121	82	105	802	82
Total	697	810	701	688	825	NS†
pods						
Mainstem	1020	1294	1031	1012	0	172
Branch	93	162	111	137	1296	138
Total	1043	1457	1142	1115	1296	261
seeds						
Mainstem	2586	3215	2444	2544	0	575
Branch	207	375	466	338	3334	439
Total	2775	3591	3023	2882	3334	NS
seed mass			mg $seed^{-1}$			
Mainstem	128	125	126	122	0	8
Branch	134	110	117	107	104	NS
Total	129	124	127	121	121	NS

Mainstem	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	<0.0001
Timing	0.07	0.08	0.30	0.79
Timing x Stress	0.04	0.02	0.38	0.83

Branch	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	0.11
Timing	0.23	0.39	0.30	0.39
Timing x Stress	0.43	0.09	0.46	0.16

Total	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	0.12	0.02	0.07	0.36
Timing	0.11	0.38	0.06	0.72
Timing x Stress	0.11	0.07	0.19	0.89

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.19. Mainstem and branch node number, pod number, seed number, and seed mass for soybean exposed to early-season stress treatments, averaged across four timings for a study in Lexington, Kentucky in 2013.

	Stress					
Yield components	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	LSD¶
nodes			m^{-2}			
Mainstem	599	581	524	517	24	101
Branch	173	165	156	173	796	120
Total	773	747	680	674	820	NS†
pods						
Mainstem	1323	1249	1158	1044	0	201
Branch	229	213	198	205	1377	149
Total	1553	1462	1356	1249	1377	NS
seeds						
Mainstem	3352	2951	2947	2911	0	603
Branch	531	667	492	646	3251	417
Total	3883	3618	3439	3558	3521	NS
seed mass			mg $seed^{-1}$			
Mainstem	157	152	153	143	0	8
Branch	163	156	153	162	162	NS
Average	157	151	152	144	156	NS
Mainstem	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass		
Significance (P values)						
Stress	<0.0001	<0.0001	<0.0001	<0.0001		
Timing	0.79	0.75	0.98	0.83		
Timing x Stress	0.27	0.24	0.76	0.51		
Branch	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass		
Significance (P values)						
Stress	<0.0001	<0.0001	<0.0001	0.93		
Timing	0.85	0.31	0.43	0.98		
Timing x Stress	0.42	0.002	0.002	0.32		
Total	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass		
Significance (P values)						
Stress	0.32	0.26	0.78	0.18		
Timing	0.99	0.82	0.91	0.86		
Timing x Stress	0.29	0.11	0.15	0.23		

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.20. Mainstem and branch node number, pod number, seed number, and seed mass for soybean exposed to early-season stress treatments, averaged across four timings for a study in Hodgenville, Kentucky in 2014.

	Stress					
Yield components	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	LSD¶
nodes			m^{-2}			
Mainstem	560	551	572	544	24	55
Branch	116	157	121	145	796	69
Total	677	707	694	689	820	85
pods						
Mainstem	1159	1080	1224	988	0	102
Branch	133	183	139	134	735	114
Total	1294	1263	1361	1121	735	144
seeds						
Mainstem	2811	2615	3181	2547	0	262
Branch	283	402	286	301	2631	206
Total	3094	3016	3463	2848	2631	NS†
seed mass			mg $seed^{-1}$			
Mainstem	166	149	164	140	0	22
Branch	153	149	138	144	145	NS
Total	160	154	156	149	151	NS

Mainstem	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	<0.0001
Timing	0.21	0.21	0.30	0.52
Timing x Stress	0.62	0.03	0.12	0.72

Branch	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	0.28
Timing	0.24	0.11	0.14	0.13
Timing x Stress	0.21	0.50	0.29	0.24

Total	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	0.007	<0.0001	0.26	0.07
Timing	0.73	0.95	0.65	0.08
Timing x Stress	0.84	0.12	0.42	0.33

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.21. Mainstem and branch node number, pod number, seed number, and seed mass for soybean exposed to early-season stress treatments, averaged across four timings for a study in Lexington, Kentucky in 2014.

			Stress			
Yield components	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	LSD¶
nodes			m^{-2}			
Mainstem	528	554	523	625	24	59
Branch	253	234	243	244	941	100
Total	782	789	766	869	965	119
pods						
Mainstem	1017	1073	1104	1008	0	172
Branch	289	263	322	275	1399	132
Total	1306	1336	1329	1379	1399	NS†
seeds						
Mainstem	2314	2655	2322	2314	0	323
Branch	654	607	776	623	3289	340
Total	2969	3263	3098	3298	3289	NS
seed mass			mg seed^{-1}			
Mainstem	172	166	172	161	0	7
Branch	186	181	187	177	175	4
Total	182	177	181	173	173	5

Mainstem	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	<0.0001
Timing	0.12	0.07	0.06	0.46
Timing x Stress	0.79	0.55	0.89	0.06

Branch	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	<0.0001	<0.0001	<0.0001	<0.0001
Timing	0.0038	0.03	0.58	0.26
Timing x Stress	0.19	0.24	0.79	0.08

Total	nodes m^{-2}	pods m^{-2}	seeds m^{-2}	seed mass
Significance (P values)				
Stress	0.006	0.81	0.67	0.003
Timing	0.18	0.74	0.74	0.11
Timing x Stress	0.15	0.21	0.84	0.16

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.22. Seed protein and oil concentrations for soybean exposed to early-season stress treatments at four timings for a study in Hodgenville, Kentucky in 2013.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
			g kg^{-1}			
Protein						
V1	371.9	369.1	369.7	367.3	369.9	369.6
V2	368.3	368.9	366.1	364.8	370.4	367.7
V3	370.5	364.3	371.9	364.9	370.9	368.5
V4	368.2	370.3	372.9	368.8	368.4	639.7
Avg.	369.7	368.1	370.2	366.4	369.9	
LSD¶	NS†					
Oil						
V1	199.9	193.6	191.6	193.5	193.6	192.4
V2	191.3	191.3	192.7	191.8	190.2	191.5
V3	190.0	190.7	191.9	194.2	190.8	191.5
V4	192.1	192.1	190.5	191.8	192.2	191.7
Avg.	190.9	191.9	191.7	192.8	191.7	
LSD	NS					

Significance (P values)	Protein	Oil
Stress	0.17	0.51
Timing	0.51	0.74
Timing x Stress	0.64	0.73

† NS, not significant ($p \leq 0.05$)

¶ LSD, least significant difference for the main effect of stress

Table 3.23. Seed protein and oil concentrations for soybean exposed to early-season stress treatments at four timings for a study in Lexington, Kentucky in 2013.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
			g kg^{-1}			
<u>Protein</u>						
V1	362.9	366.0	366.8	366.7	370.0	366.5
V2	365.3	365.3	365.3	369.3	373.0	367.6
V3	365.1	367.7	366.9	365.9	369.8	367.1
V4	364.7	365.0	364.7	372.7	369.5	367.3
Avg.	364.5	366.0	365.9	368.6	370.5	
LSD¶	1.8					
<u>Oil</u>						
V1	190.3	188.8	188.4	186.7	185.3	187.9
V2	188.4	187.6	191.2	184.0	187.5	187.7
V3	188.6	188.6	190.0	186.5	187.6	188.2
V4	189.3	188.2	190.6	183.0	185.9	187.4
Avg.	189.1	188.3	190.0	185.0	186.6	
LSD	1.7					
	<u>Protein</u>	<u>Oil</u>				
Significance (P values)						
Stress	<0.0001	<0.0001				
Timing	0.54	0.75				
Timing x Stress	0.02	0.41				

¶ LSD, least significant difference for the main effect of stress

Table 3.24. Seed protein and oil concentrations for soybean exposed to early-season stress treatments at four timings for a study in Hodgenville, Kentucky in 2014.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
Protein			g kg^{-1}			
V1	362.7	364.9	362.7	366.5	367.9	364.9
V2	364.2	367.8	364.0	364.3	367.5	365.5
V3	364.6	367.3	363.8	365.4	366.8	365.6
V4	364.5	363.9	362.1	367.6	370.0	365.6
Avg.	364.0	366.0	363.2	366.0	368.1	
LSD¶	2.0					
Oil						
V1	190.8	190.2	190.9	187.9	186.1	189.2
V2	190.8	184.7	190.5	190.2	187.9	188.8
V3	191.4	187.9	188.5	188.2	186.9	188.6
V4	190.9	187.7	191.0	187.2	186.7	188.7
Avg.	191.0	187.6	190.2	188.3	186.9	
LSD	1.7					

Significance (P values)	Protein	Oil
Stress	<0.0001	<0.0001
Timing	0.85	0.88
Timing x Stress	0.36	0.25

¶ LSD, least significant difference for the main effect of stress

Table 3.25. Seed protein and oil concentrations for soybean exposed to early-season stress treatments at four timings for a study in Lexington, Kentucky in 2014.

	Stress					
	UTC	Lactofen	Fomesafen	Leaf Removal	Meristem Removal	Avg.
			$g\ kg^{-1}$			
Protein						
V1	378.8	380.2	380.0	379.8	378.8	378.9
V2	376.4	375.7	380.4	373.9	376.4	376.9
V3	381.8	378.0	388.5	373.4	381.8	377.3
V4	382.8	373.8	378.5	373.5	382.8	377.0
Avg.	379.9	376.9	379.1	375.1	379.9	
LSD¶	2.7					
Oil						
V1	189.3	187.3	192.0	188.1	189.3	188.7
V2	190.9	189.0	189.5	188.6	190.9	188.9
V3	189.6	187.8	189.8	188.3	189.6	188.4
V4	187.0	189.6	189.7	186.4	187.0	187.5
Avg.	189.2	188.4	190.2	187.9	189.2	
LSD	1.4					
	Protein	Oil				
Significance (P values)						
Stress	0.0048	<0.0001				
Timing	0.32	0.11				
Timing x Stress	0.07	0.25				

¶ LSD, least significant difference for the main effect of stress

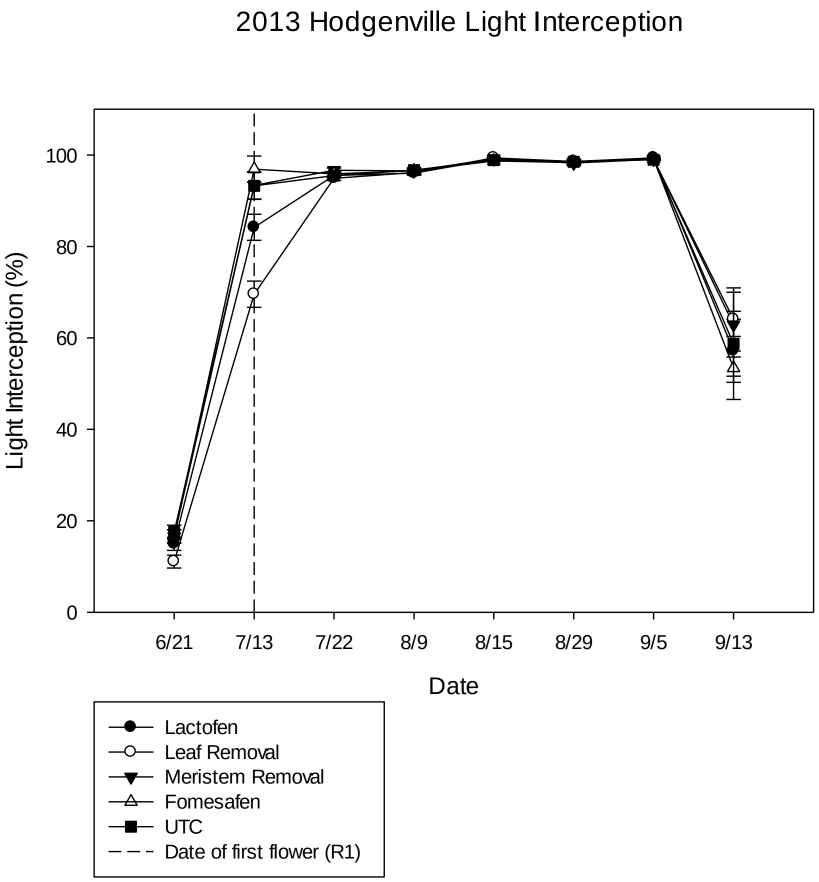

Fig. 3.1. Percent light interception for soybean exposed to early-season stress averaged across four timings for a study in Hodgenville, Kentucky in 2013.

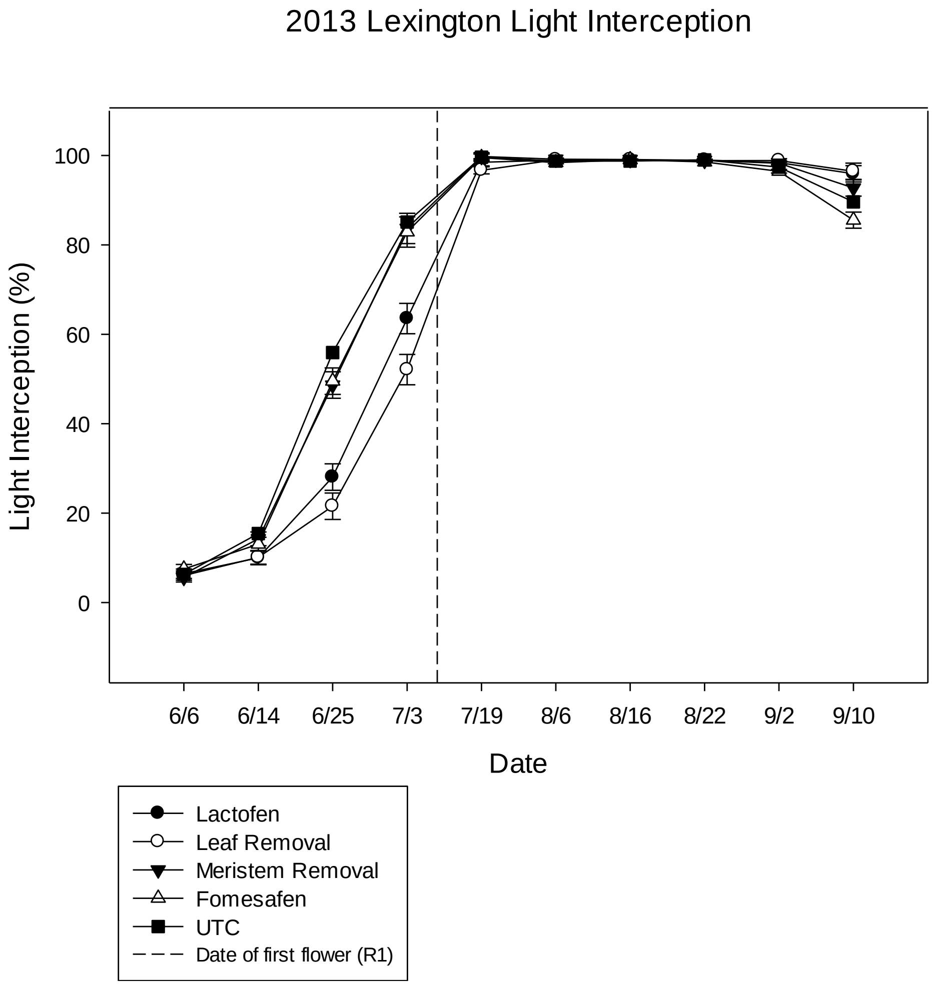

Fig. 3.2. Percent light interception for soybean exposed to early-season stress averaged across four timings for a study in Lexington, Kentucky in 2013.

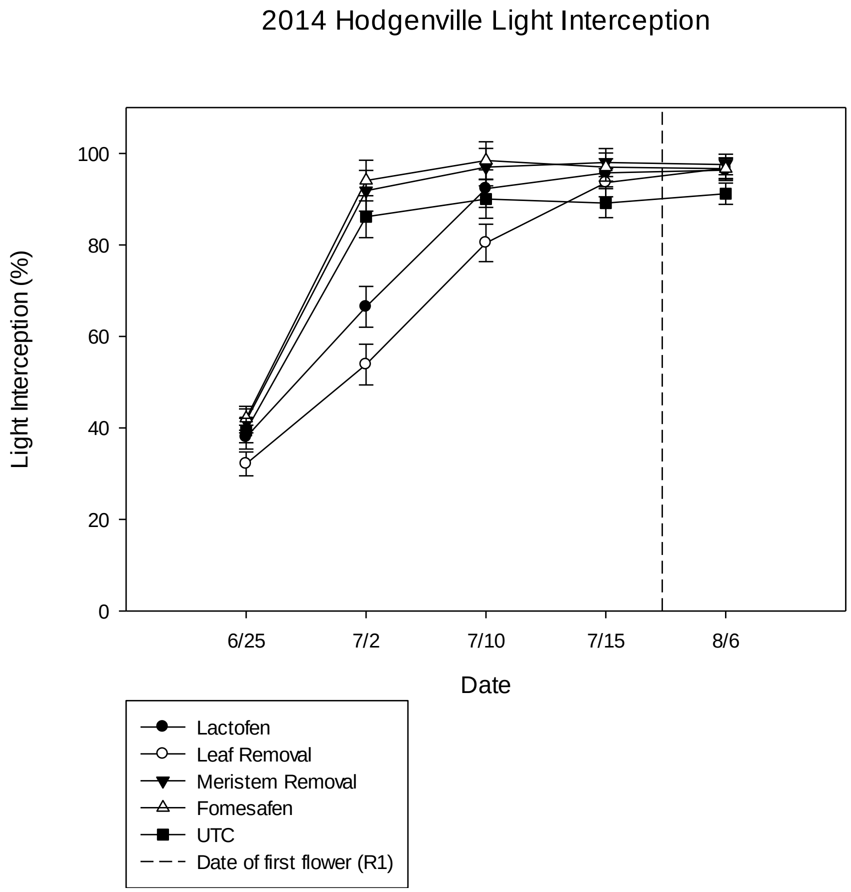

Fig. 3.3. Percent light interception for soybean exposed to early-season stress averaged across four timings for a study in Hodgenville, Kentucky in 2014.

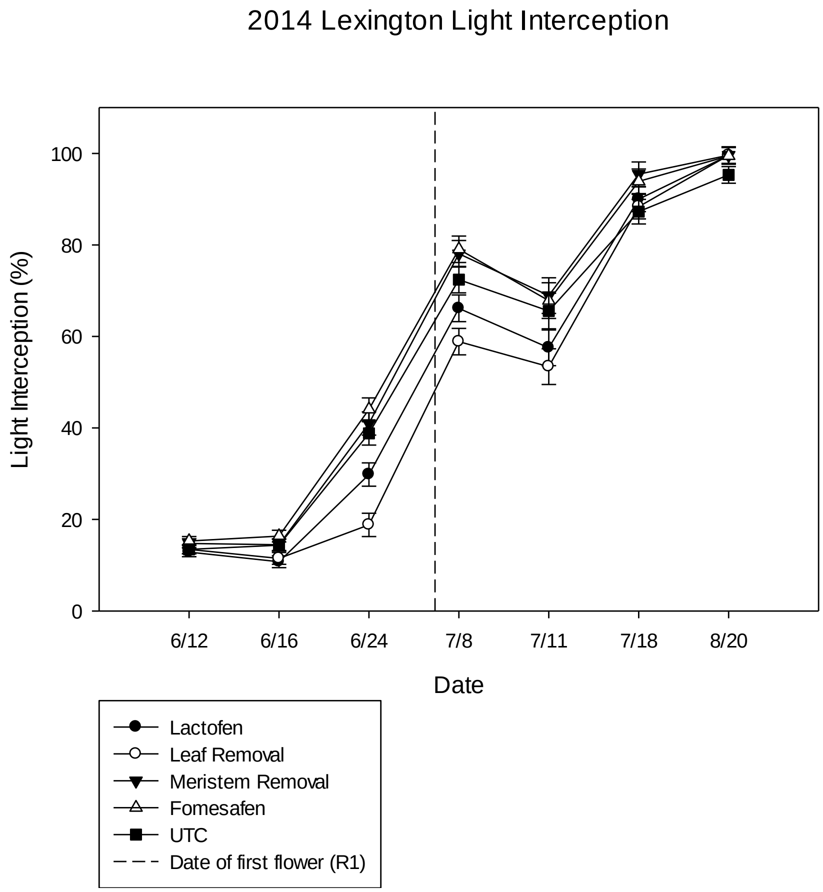

Fig. 3.4. Percent light interception for soybean exposed to early-season stress averaged across four timings for a study in Lexington, Kentucky in 2014.

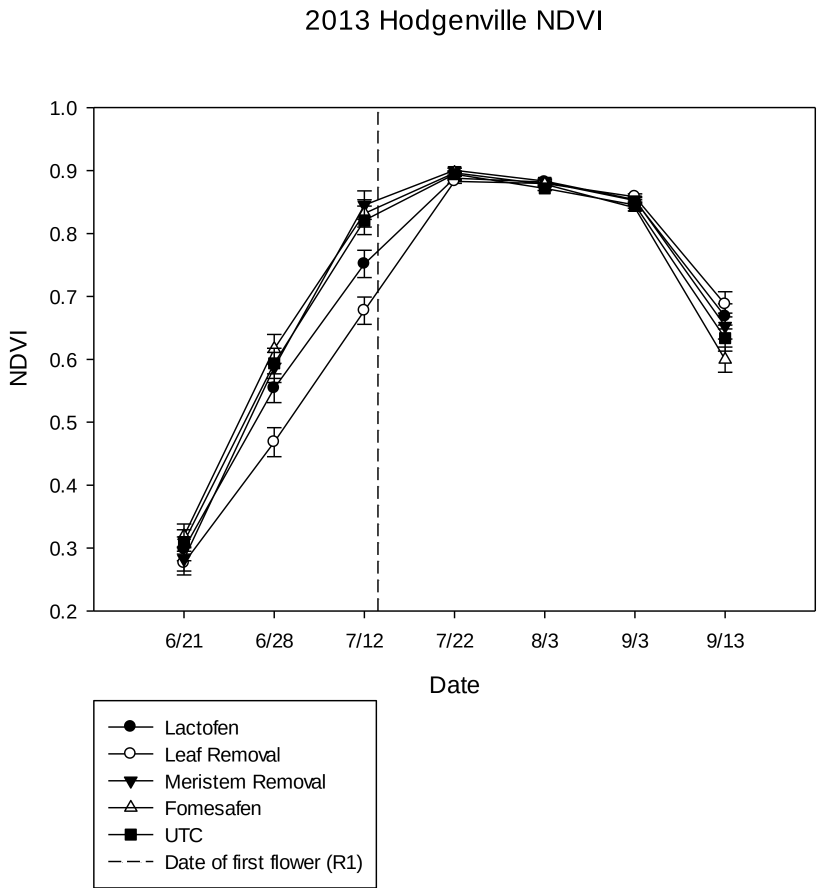

Fig. 3.5. Normalized difference vegetation index (NDVI) values for soybean exposed to early-season stress averaged across four timings for a study in Hodgenville, Kentucky in 2013.

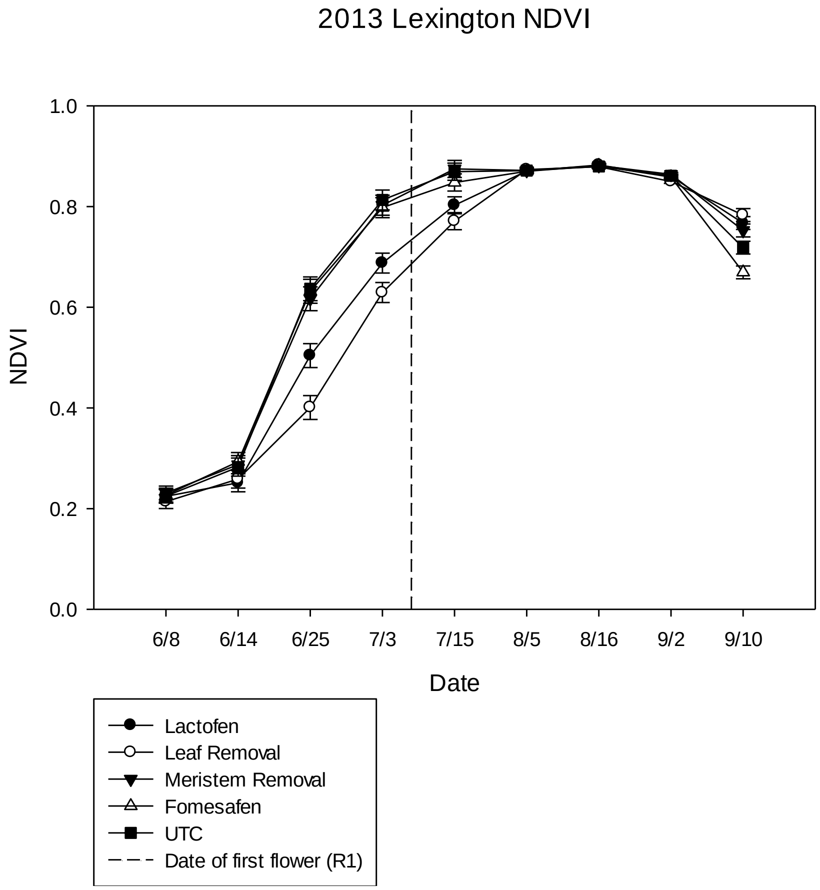

Fig. 3.6. Normalized difference vegetation index (NDVI) values for soybean exposed to early-season stress averaged across four timings for a study in Lexington, Kentucky in 2013.

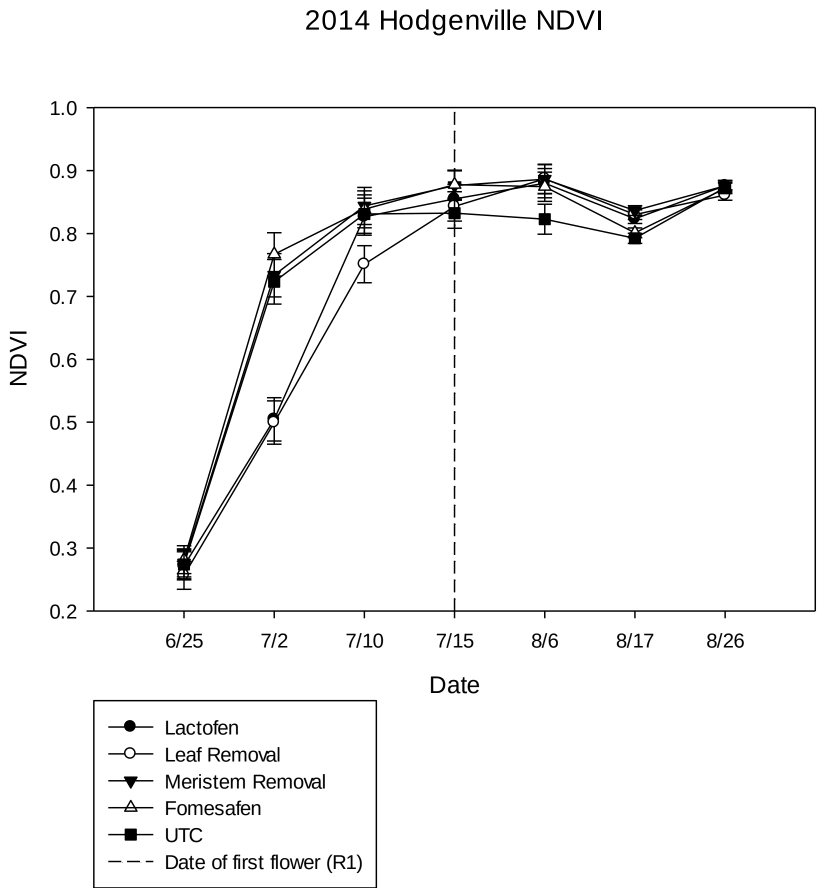

Fig. 3.7. Normalized difference vegetation index (NDVI) values for soybean exposed to early-season stress averaged across four timings for a study in Hodgenville, Kentucky in 2014.

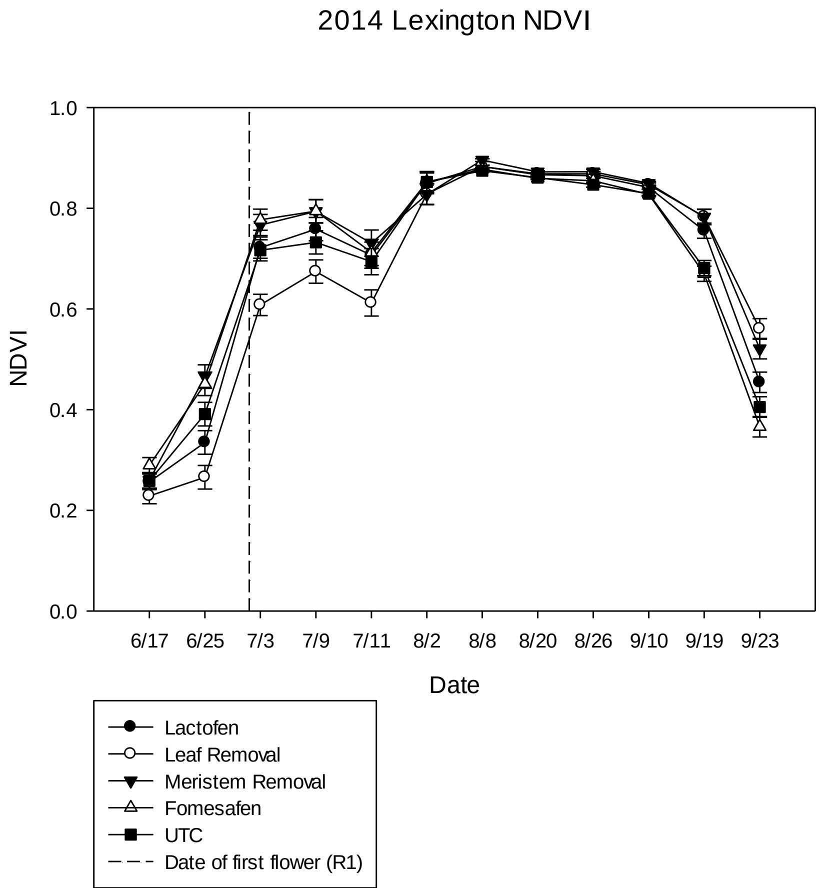

Fig. 3.8. Normalized difference vegetation index (NDVI) values for soybean exposed to early-season stress averaged across four timings for a study in Lexington, Kentucky in 2014.

Chapter IV: Conclusion and Implications

National High Yield Study

Less than 50% of study environments responded to increased inputs above standard management. Soybean seed yield responses to inputs and management treatments also varied greatly by environment. Yield responses were rarely observed for seed treatments, likely because the high seeding rate (432,000 seed ha^{-1}) provided adequate stands for maximum yield. Yield responses were also rare for a number of other individual inputs such as the defoliant (lactofen), foliar fertilizer, and N,N’ -diformyl urea. Responses to management varied by region, with South and Central study locations showing limited responses to increased inputs and northern locations showing large responses to additional inputs. The input-intensive management systems (SOYA) often resulted in the greatest yield increases observed in this study. While combining a number of additional inputs above standard management practices often resulted in increased soybean yield, break-even analysis indicated that the input-intensive soybean management strategy has almost no chance of increasing grower profitability due to the high cost of purchasing and applying the additional inputs.

One of the main findings of this study is that foliar insecticide application had the greatest probability for breaking even across all environments, in some cases resulting in break-even probabilities approaching 100%, and showing relatively high break-even probabilities at low yield levels and soybean sale prices. This would seem to suggest that soybean growers should always apply a foliar insecticide regardless of insect pest pressure but this 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. The application of foliar insecticides regardless of pest pressure would greatly increase selection pressure in favor of resistant individuals and populations, potentially leading to widespread insecticide resistance and other adverse environmental effects. Instead of considering planned insecticide sprays regardless of pest pressure should closely monitor insect populations through scouting. However, both growers and researchers should consider that established treatment thresholds may need to be adjusted downward for modern, high-yielding soybean.

Following established soybean management recommendations developed by university research and extension programs will allow soybean producers to maximize soybean yield under most circumstances. Growers in the Mid-South and lower Midwest are unlikely to see positive economic returns from increasing inputs in their soybean management systems, while growers in the upper Midwest may see responses to certain additional inputs, especially at higher yield levels and soybean prices. Recently lower soybean prices have likely caused growers to decrease input expenditures; however soybean prices will undoubtedly increase again causing growers to again consider additional inputs to increase soybean yield. Grower should focus on ensuring that basic agronomic principles, such as adequate seeding rates, adapted varieties, proper soil fertility, and pest scouting are optimized and should not expect yield increases for additional inputs.

Lactofen Study

The removal of the apical meristem shifted pod and seed production from mainstem nodes to branch nodes. Total node number was increased in only two out of four environments, indicating that meristem removal is potentially only a marginal strategy to increase node number. However, despite the increased node number apical meristem removal and the resulting increase in branching never led to increased soybean seed yield and in half of the study environments decreased seed yield. It was apparent through visual observation as well as yield component analysis that lactofen was unable to kill the apical meristem at any growth stage. Lactofen application did not affect soybean yield in two environments and decreased soybean yield in two other environments. The use of lactofen for high-yield management is unnecessary. Lactofen should only be applied to early vegetative soybean for weed control purposes. Even if post emergence weed control is necessary with a PPO type herbicide, the use of a herbicide that causes less physical damage, such as fomesafen, should be strongly considered over lactofen. Other practices that seek to stress young soybean such as leaf removal (ie. mowing young soybean) are also unnecessary and should not be performed.

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Vita

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Education:

- **M.S. Crop Science, Cornell University** (2012)
  - Thesis: Agronomics and Economics of Soybean Row-Spacing in New York
    - Co-Major Professor: Toni DiTommaso
    - Co-Major Professor: Bill Cox
    - Cumulative GPA: 3.7

- **B.S. Agricultural Science, Cornell University** (2010)
  - Cum laude
    - Co-Advisor: Toni DiTommaso
    - Co-Advisor: John Losey
    - Cumulative GPA: 3.6

Professional Experience:

- Graduate Research Assistant, University of Kentucky, 2012-present.
- Graduate Research Assistant, Cornell University, 2010-2012.
- Undergraduate research assistant, Cornell University, 2006-2010.
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Awards and Honors:

- Gerald O. Mott Meritorious Graduate Student Award, American Society of America, 2015.
- ASA, CSSA, SSSA Graduate Student Leadership Conference Participant- Long Beach, California 2014.
- Head of Cornell and UK Weed Science Teams from 2012-2014.
- Graduate Student Representative of the Northeastern Weed Science Society.
- Founder and President of University of Kentucky Integrated Plant and Soil Science Graduate Student Association.
- Northeastern Weed Science Society 2013 Graduate Student Paper Contest-2nd place paper.
- University of Kentucky Department of Plant and Soil Sciences 2013 Graduate Student Symposium-1st place Ph.D. presentation.
- Gamma Sigma Delta Honor Society of Agriculture Member 2013.

Teaching Experience:

Teaching Assistant:

- CSS 4150, Field Cropping Systems
- CSS 3150, Weed Ecology
- AEM 3050, Farm Business Management
- CSS 1900, Sustainable Agriculture
- PLS 366, Fundamentals of Soil Science

Guest Lecturer:

- PLS 404, Integrated Weed Management
- CSS 2940, Introduction to Agricultural Machinery

Professional Organizations:

- American Society of Agronomy
- Crop Science Society of America
- Soil Science Society of America
- Weed Science Society of America
- Northeastern Weed Science Society
- Gamma Sigma Delta

Publications:

Refereed Journal:

- **Orlowski, J.M.**, W.J. Cox, A. DiTommaso and W.A. Knoblauch. 2012. Planting Soybean with a Grain Drill Inconsistently Increases Yield and Profit. Agron J. 104:1065-1073.

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- **Orlowski, J.M.** and C.D. Lee. 2013. Alternative use of PPO herbicides in high yield soybean management. Abstracts from the Joint Annual Meetings of the Weed Science Society of America and Northeastern Weed Science Society. February 4-7, Baltimore, MD. No. 147.
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- Marburger, D.A., B.J. Haverkamp, R.G. Laurenz, **J.M. Orlowski**, E.W. Wilson, S. Casteel, S.P. Conley, C.D. Lee, E.D. Nafziger, K.L. Roozeboom, W.J. Ross, K.D Thelen and S.L. Naeve. Agronomic Maximization of Soybean Yield and Quality: Variety x Management Interactions. Joint Annual Meeting of the ASA-CSSA-SSSA, Tampa, FL. November 3-6, 2013. Abstract# 104-20.
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- Laurenz, R.G., B.J. Haverkamp, D.A. Marburger, **J.M. Orlowski**, E.W. Wilson, S. Casteel, S.P. Conley, C.D. Lee, E.D. Nafziger, K.L. Roozeboom, W.J. Ross, K.D. Thelen, P. Tumbalam and S.L. Naeve. Agronomic Maximization of Soybean Yield and Quality: Agronomic Input Effect On Isoflavone Levels. Joint Annual Meeting of the ASA-CSSA-SSSA, Tampa, FL. November 3-6, 2013. Abstract# 104-27.
- **Orlowski, J.M.** and C.D. Lee. 2014. Alternative use of PPO herbicides in high yield soybean management. In: Grover A.E. (ed.) Proceedings of the 68th Annual Meeting of the Northeastern Weed Science Society: 68.
- **Orlowski, J.M.,** C.D. Lee and G.L. Gregg. Early season lactofen application affects soybean yield and yield components. Joint Annual Meeting of the ASA-CSSA-SSSA, Long Beach, California. November 2-5, 2014. Abstract# 87454.
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