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IMPACT OF HIGH-INPUT PRODUCTION PRACTICES ON SOYBEAN YIELD

Daniel L. Jordan
University of Kentucky, jordand1986@gmail.com

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ABSTRACT OF THESIS

IMPACT OF HIGH-INPUT PRODUCTION PRACTICES ON SOYBEAN YIELD

High-input management practices are often heavily marketed to producers to increase soybean [*Glycine max* (L) Merr.] yield in already high-yielding environments. Field research was conducted in three locations within 6 states (Arkansas, Iowa, Kentucky, Louisiana, Michigan, and Minnesota) in 2009 to determine the effect of seed treatment, inoculant, foliar fungicide, additional soil fertility beyond state recommendations, foliar fertilizer, increased population over state recommendations, and narrow row spacing on yield. The high-input system (combination of the management practices) yielded higher than standard-input system (University recommended management practices) in only 8 of the 18 locations. Narrow rows, in both the high and standard-input systems, only increased yield in 4 locations. Inoculant did not increase yield at any location. Foliar fertilizer application and seed treatment increased yield in one location each. The additional soil fertility and fungicide application increased yield in two locations each. The increased population increased yields in 3 of the 18 locations; while an additional fungicide application at R5 only increased yield in 1 location. Foliar fertilizers at rates above commercial use did not increase soybean yield in Kentucky in 2008 or 2009. High-input production practices were largely unsuccessful at increasing soybean yield in these studies.

KEYWORDS: Soybean Yield, Row Spacing, Foliar Fertilizer, Foliar Fungicide, Crop Management

Daniel Jordan

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IMPACT OF HIGH-INPUT PRODUCTION PRACTICES ON SOYBEAN YIELD

By

Daniel L. Jordan

Dr. Chad Lee
Director of Thesis

Dr. Charles Dougherty
Director of Graduate Studies

10-27-2010

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THESIS

Daniel L. Jordan

The Graduate School

University of Kentucky

2010

IMPACT OF HIGH-INPUT PRODUCTION PRACTICES ON SOYBEAN YIELD

THESIS

A Thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Daniel L. Jordan

Lexington, Kentucky

Director: Dr. Chad Lee, Professor of Plant and Soil Science

Lexington, Kentucky

2010

This work is dedicated to the people who have greatly influenced my life, but are no longer here to celebrate this accomplishment. I would not be the person I am today if it wasn't for their presence in my life. They will forever be loved, cherished, and missed; but never forgotten:

Myrtle C. Thompson
March 13, 1916 – August 27, 2002

Gary W. Neal
February 1, 1956 – November 23, 2007

Zollie C. Neal
February 12, 1936 – June 26, 2009

Danny R. Rogers
August 15, 1946 – September 6, 2010

"Death leaves a heartache no one can heal, love leaves a memory no one can steal."

Unknown

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And a very special thanks to my mother, Elizabeth Jordan, for all her love and support. Without her nothing I have accomplished would be possible. Somewhere along the way she taught me that there isn't anything I can't do. Much love and gratitude to my grandfather, H.M. Neal Jr.; who planted and cultivated the love of agriculture in my heart. Thank you to my friends who have listened to me complain and encouraged me along the way.

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Chapter One: Introduction

Soybean [*Glycine Max* (L.) Merr.] is an important grain crop in the United States. In 2008 roughly 30,222,000 hectares of soybeans were harvested across the country, with an average yield of 2.67 Mg ha^{-1} (USDA-NASS, 2009a). With 2008 receipts topping 27 billion dollars the economic significance of the crop is apparent. Breeders, agronomists, and producers alike have worked to produce the highest yields possible to maximize crop value and economic return.

Since soybean yield was first reported by the USDA-NASS in 1924 the national average increased from 0.74 to 2.96 Mg ha^{-1} in 2009, an increase of 300% over 85 years (USDA-NASS, 2009a). Several factors are credited for this increase in yield including plant breeding, crop management, and environmental changes such as increased atmospheric CO_2 concentrations. Many studies have been conducted to determine what individual effect each factor has had on this yield increase. Estimates of the increase due to genetic gain range from 50 to 80% depending on the time frame studied (Specht et al., 1999; Specht and Williams, 1984; Voldeng et al., 1997). It is estimated that the increase in atmospheric CO_2 concentration has contributed 10 to 20% of the yield increase of soybeans from the 1960's to the early 1980's (Allen et al., 1987; Waggoner, 1984). Many widely accepted management practices have also contributed to increased yields. These include the use of herbicides (Burnside and Moomaw, 1977; Pike et al., 1991), narrow-row production (Cooper, 1977; De Bruin and Pedersen, 2008), earlier planting dates, and the reduction of harvest losses (Specht et al., 1999).

Increasing soybean yield continues to be an important focus today as input costs and fuel prices rise. Producers are facing narrowing profit margins and increasing yield and the economic return from management decisions is vital. In addition to normal management decisions producers are exploring the use of fungicides, inoculants, fertilizers and seed treatments to increase yields. For the purpose of this study six management practices were examined: seed treatment, fungicide application, inoculant application, additional soil fertility beyond state recommendations, foliar fertilizer application, and row spacing. These six production practices represent the types of products being marketed to producers with promises of yield increases. The purpose of this study was to evaluate the effect of these management practices on soybean yield when they are used in combination and to determine if they increase yields as advertized.

Seed Treatment

Seed treatments generally consist of an insecticide, a fungicide, or both applied to the seed prior to planting. The aim of seed treatment is to protect the seed or emerging seedling from insects and/or diseases; increasing seedling emergence, seedling vitality, and as a result preventing a yield loss. Most universities only recommend the use of seed treatments when needed in an Integrated Pest Management (IPM) approach. With IPM, other factors such as crop rotation, planting date, soil fertility and cultivar selection are managed to best counteract or reduce insect and disease pressure (USEPA, 2009). In IPM a seed treatment would only be used after the pest threat reached the economic injury level (EIL), or level where possible yield reduction warrants the cost of the treatment.

Companies market the use of soybean seed treatments as cheap insurance against a pest problem. However, many university agronomists question the need for seed treatments unless conditions warrant their use or when the possibility of pest problems is high because of other management decisions. It is generally recommended that seed treatments be used when planting at lower seeding rates, when germination will be delayed because of cool, wet, or very dry soils, or when poor quality seed is used (Malvick, 1998). Wall et al. (1983) conducted a study evaluating three fungicide seed treatments on low quality seed. He reported no yield increase when the seed treatment was applied to seed with reduced quality as a result of damage or age. However, emergence increased as a result of the fungicide treatment when seedlots had a 15% *Phomopsis* spp infection and he also noted yield increases in seedlots with an infection above 50%.

Seed treatments, even when effective, do not always provide season long protection. Dorrance et al. (2003) found that the negative impact on root weight and reduced seedling stand caused by *Rhizoctonia solani* root rot was reduced or prevented in a study involving four fungicide seed treatments. However, disease control was not provided through the entire growing season; cultivar resistance was shown to be beneficial.

In a study evaluating the effects of fungicides on soybean cultivars with partial resistance to *Phytophthora sojae* researchers determined that the number of damped-off seedlings was significantly greater when the infection occurred at planting compared with an infection occurring 5 days after planting (Dorrance and McClure, 2001). Seedlings of a resistant cultivar were not affected regardless of infection date. The partially resistant cultivars could benefit from the fungicide seed treatment as the study demonstrated that preventing the disease infection only five days increased emergence, fresh plant weight, and root weight.

The yield effects from soybean seed treatments are common but not consistent. Guy et al. (1989) observed yield increases in two out of ten soybean cultivars tested in a two-year study. In research conducted in South Dakota, only two out of twenty-one treatments increased yield in a 4 site-year experiment (Draper et al., 2002). Both of those yield increases were at the same site in a low-yielding year. Researchers in Minnesota found no yield difference between 12 treatments combining seed fungicide and insecticide treatments and a control (Potter, 2004). Schulz and Thelen (2008) found that fungicide seed treatments only increased yield in 3 out of 16 site-years (maximum increase of 9.4% over the control). The researchers hypothesize that a month of heavy rains after planting at one site, and early planting and below normal temperatures throughout May at the other sites caused the yield difference. Grau and Gaska (2002) also observed significant yield increases of a fungicide seed treatment versus the control at earlier planting dates, but not at later planting dates. The authors concluded that the probability of a positive yield increase from fungicide treated seed increases with early plantings in no-till or conservation tillage environments (Grau and Gaska, 2002). However, Cox et al. (2008) conducted research on planting dates and seed treatments in the Northeastern United States and found no difference in yield or plant density between two fungicide/insecticide combinations and a control, regardless of planting date.

Overall yield increases from soybean seed treatments seem to occur when plant insect or disease pressure is high. Agreeing with the recommendation that treatments be used when planting at lower seeding rates, when germination will be delayed because of cool, wet, or very dry soils, or when poor quality seed is used (Malvick, 1998). It is unlikely that soybean seed treatments will increase yield under in a high yield environment.

Foliar Fungicide

According to Wrather and Koenning (2006) soybean diseases in the United States caused a yield loss of 9.5 (15.2%), 12.3 (18%) and 6.9 (8.9%) million metric tonnes in 2003, 2004, and 2005, respectively. Yield reductions from foliar diseases, while significant, are often less than those from other plant diseases and pests. In the study by Wrather and Koenning (2006) foliar diseases accounted for only 7.2% of total yield reduction caused by disease over the three year period. Soybean cyst nematode (*Heterodera glycines*) alone caused a greater reduction in yield than all the foliar diseases combined in a given year. Still foliar disease can reduce leaf area and photosynthesis, thereby reducing yield (Bassanezi et al., 2001). Fungicides are often marketed as the cure all for soybean diseases.

In addition, fungicides are often marketed as having physiological effects that can increase yield. Some researchers have observed yield increases attributed to physiological effects from fungicide applications in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Bayles and Hilton, 2000; Grossmann et al., 1999; Grossmann and Retzlaf, 1997). The yield benefit from fungicide applications has been attributed to delayed senescence, increased leaf greenness and leaf area duration, improved water use efficiency, increases in photosynthesis, and increased chlorophyll production (Badenoch-

Jones et al., 1996; Bryson et al., 2000; Grossmann et al., 1999; Grossmann and Retzlaf, 1997; Kuroda et al., 1996). In soybean there is little evidence of yield increases.

In a study conducted in Iowa to assess the physiological effect of fungicides on soybean yield, researchers found no yield difference and observed no physiological differences (Swoboda and Pedersen, 2009). They compared tebuconazole (alpha-[2-(4-chlorophenyl)ethyl]-alpha-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol) and pyraclostrobin (carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3 yl]oxy]methyl] phenyl]methoxy-, methyl ester) alone and in combination over 3 site-years and 4 cultivars in low-disease environments. Hanna et al. (2008), in a two-year study with three locations and two cultivars, also found no yield increase from fungicide applications of azoxystrobin (Methyl (E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate) and propiconazole (1-[[2(2,4-Dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]1-H-1,2,4-triazole) under low disease pressure. Research conducted in South Dakota from 2004-2008 showed no significant yield increase versus untreated checks for combinations of different strobilurin and triazole products (Draper et al., 2006, 2005, 2004; Osborne et al., 2008; Ruden and Ruden, 2007). Septoria brown spot (*Septoria glycines*) was the most detrimental disease the researchers were interested in, however the disease was not present in most years and when it was observed infections were very mild. Researchers in Iowa also found no yield increase from fungicide applications in two separate studies conducted in 2005 involving 20 commercial fungicides (Kassel, 2005; Robertson et al., 2005). They observed low severity infections of septoria brown spot, frogeye leaf spot (*Cercospora sojina*), and bacterial blight (*Pseudomonas savastanoi*).

Yield increases from the use of foliar fungicides have been reported. A benomyl (methyl 1-[(butylamino) carbonyl]-H-benzimidazol-2-yl carbamate) fungicide application increased yield by an average of 6.5% in a three-year study with four cultivars (Copper, 1989). In that study there was a severe infection of septoria brown spot. Slater et al. (1991) showed a similar yield increase of 5.1% averaged over three years, two cultivars, and two levels of irrigation. The incidence of pod and stem blight caused by *Diaporthe phaseolorum* var. *sojae* and *Phomopsis spp.* was high in this study. Heatherly and Sciumbato (1986) observed yield increases of 0.19 (11.7%) and 0.15 (4.6%) Mg ha^{-1} with foliar benomyl application in 1981 and 1983, respectively when they did not observe any disease presence.

A yield increase as a result of fungicide application may not result in an economic return. Dennis (2006) estimated a cost of \$42 to 49 ha^{-1} for the application of two popular commercial strobilurin fungicides. At the 10 year (1999-2008) average soybean price of \$234 Mg^{-1} (USDA-NASS, 2009a) a fungicide application would need to increase yield by more than 0.19 Mg ha^{-1} to be profitable. Disease assessment, and the use of thresholds, is important when determining whether or not to apply foliar fungicides.

Overall fungicide application appears to increase yield in environments where disease pressure is high. In low disease environments few yield increases were observed. Although fungicide application is thought to increase yield as a result of plant physiological effects in other crops, the literature does not demonstrate that soybean has the same response.

Inoculant

The biological fixation of atmospheric nitrogen by the soybean plant makes it one of the most unique grain crops grown in the United States. Nitrogen fixation, a result of the symbiotic relationship between the plant and the bacteria *Bradyrhizobium japonicum* can increase soybean yields significantly in environments where soil nitrogen is limited (Duong et al., 1984; Schulz and Thelen, 2008; Seneviratne et al., 2000; Tien et al., 2002; Unkovich and Pate, 2000). Abendroth et al. (2006) estimated that the nitrogen requirement of a soybean crop could be as high as 350 kg N ha^{-1}. Some studies have shown the capability of this symbiotic relationship to fix up to up to 450 kg N ha^{-1} (Unkovich and Pate, 2000) so in some instances nitrogen fixation is great enough to meet the entire nitrogen demand of the crop. However, more conservative estimates suggest that the uptake of fixed nitrogen can meet 60-89% of total demand. (Abendroth et al., 2006; Tien et al., 2002). The amount of fixed nitrogen used by a plant is often largely dependent on N availability in the soil, with the plants utilizing available soil N prior to fixed N (Salvagiotti et al., 2009).

Other researchers have reported more conservative estimates of the amount of plant N derived from nitrogen fixation; ranging from 220 kg N ha^{-1} to 300 kg N ha^{-1} (Abendroth et al., 2006; Bezdicek et al., 1978; Keyser and Li, 1992; Lindemann and Glover, 2003).

Inoculation of soybean in fields with no previous history of soybean production has been an accepted management practice for some time. Inoculation in fields that have not been in soybean production for over five years is generally recommended (Abendroth et al., 2006; Duong et al., 1983; Lindemann and Glover, 2003). Many producers consider successive yearly applications of soybean inoculants good insurance against poor nodulation and decreased nitrogen fixation because they are relatively inexpensive and easy to use. Some research suggests that successive inoculant applications can increase yield by as much as 4 to 5% but the response is often closer to 1 to 2% (Conley and Christmas, 2006). Schulz and Thelen (2008), however, reported a yield increase in only 6 of 14 site years when fields with a history of soybean production and prior inoculation were re-inoculated. They determined that, with an average increase of 0.09 Mg ha^{-1} and an inoculant cost ranging from \$7 to \$10 ha^{-1}, the return from the application of an inoculant was profitable.

Inoculation has been shown to be beneficial in fields with no previous history of soybean production, or fields in which soybean has not been produced in over five years. The yield response to inoculation in fields that have a history of soybean production is less consistent. Some researchers have observed yield increase, while many have not. It is likely that the response to inoculation depends on several factors which include the population of *Bradyrhizobium japonicum* which already exists in a given field, soil N availability, and the plant uptake of soil N.

Foliar Fertilization

Yield responses from foliar fertilization have been inconsistent at best. Numerous researchers have evaluated application timing, rates, nutrient source, soil nutrient concentration and uptake, root activity, leaf nutrient absorption, and leaf photosynthetic rates in an attempt to determine the cause of the variation in yield response.

Research conducted by Garcia and Hanway (1976) contributed greatly to this litany of new research. They reported yield increases up to 0.54 Mg ha^{-1} (24%) in 1974 from a foliar treatment consisting of 49, 21, 36, and 9 kg ha^{-1} of N, P, K, and S, respectively. In 1975 a treatment consisting of 80, 8, 24, and 8 kg ha^{-1} of N, P, K, and S, respectively yielded a more impressive 1.04 Mg ha^{-1} (35%) over the control. Moreover, in another experiment in 1975 foliar fertilizer (96, 10, 29, and 5 kg ha^{-1} of N, P, K, and S, respectively) increased yields of two cultivars (Amsoy and Corsoy) by 1.49 (39%) and 1.57 Mg ha^{-1} (44%) over their controls (Garcia and Hanway, 1976).

Proponents of the need for foliar fertilizer often cite the "self destruct" hypothesis proposed by Sinclair and de Wit (1976). They claimed that nutrient remobilization from soybean leaves to the seed hastens leaf senescence and shortens the duration of seed fill, limiting yield. Some researchers have reported that up to 60% of the N, P, and K in the seed may be remobilized from existing plant biomass (Hanway and Weber, 1971; Henderson et al., 1970). In a study conducted using several cultivars with different maturities, remobilization of nitrogen from the biomass to the seed accounted for 30 to 100% of seed N, with more nitrogen being remobilized in later maturing cultivars (Zeiher et al., 1982). Garcia and Hanway (1976) speculated foliar fertilizer applications would minimize the nutrient depletion of soybean leaves caused by remobilization and increase yield. This reduction in nutrient depletion, they hypothesized, delayed senescence of the soybean resulting in a longer duration of leaf photosynthetic activity and seed fill.

Foliar fertilization has been shown to increase leaf nutrient concentrations. However, yield is often not affected even with the increase leaf nutrient concentrations. Leaf photosynthesis and yield were not affected in a study where a foliar fertilizer application of 28, 2.9, 8.4, and 1.2 kg ha^{-1} N, P, K and S, respectively increased leaf nutrient concentrations by 6, 20, and 43% for N, P, and K, respectively (Boote et al., 1978). Boote et al. (1978) estimated that foliar fertilization extended leaf area duration by a day, at most. Parker and Boswell (1980) reported that the application of foliar fertilizer (28, 2.9, 9.5, and 1.7 kg ha^{-1} of N, P, K, and S, respectively) caused a yield decrease and had no effect on leaf nutrient content.

Most of the early research on foliar fertilizers involved high rates of N, P, K and S, although some early studies did include micronutrients. In more recent years the focus has been more on foliar micronutrient applications. Often the research has been focused on known or observed nutrient deficiencies (Boswell et al., 1981; Gettier et al., 1985; Ross et al., 2006). The yield increase from foliar fertilizer applications was more consistent in this situation, as would be expected. Some research has been conducted on soils with no evidence of micronutrient deficiencies and the results have been inconsistent with only a few instances where yield increased (Touchton and Boswell, 1975; Loecker et al., 2010).

Overall many researchers have reported yield increases from foliar fertilizer applications, however, none of them were as large as those reported by Garcia and Hanway (1976) (Haq and Mallarino, 1998; Peele, 1977; Syverud et al., 1980; Vasilas et al., 1980). Most research however, has documented inconsistent results from the application of foliar fertilizer (Binford et al., 2004; Boote et al., 1978; Haq and Mallarino, 1998; Parker and Boswell, 1980; Peele, 1977; Poole et al., 1983; Vasilas et al., 1980).

Based on the literature it appears that yield is largely unaffected by high rates of N, P, K, and S foliar applications; likewise applications of micronutrients also seem to have little effect on yield. Observed yield differences with the application of foliar fertilizers are likely due to nutrient deficiencies.

Row Spacing

Narrow (<76 cm) and wide-row (≥ 76 cm) soybean production systems are employed throughout the United States. According to the USDA-NASS (2009b), around 18% of soybeans produced in the United States in 2009 were grown in row widths less than 25 cm, 43% were grown in widths ranging from 25 to 47 cm, 11% were grown in row widths between 47 to 72 cm, 25% were grown in row widths of 72 to 88 cm, and 3% were grow in row widths greater than 88 cm. Economic factors, such as equipment costs, often play a large role in the decision to convert from a wide-row system to a narrow-row system even though the literature generally concludes that narrow rows often result in higher yields or more yield stability (Bullock et al., 1998; Cooper, 1977; De Bruin and Pederson, 2008; Ethredge et al., 1989; Janovicek et al., 2006; Taylor, 1980; Weber et al., 1966). When narrow row widths show a yield advantage over wide row widths it is generally thought that an increase in light interception is responsible. In order for maximum yield the soybean canopy needs 95% light interception near R1 (Shibles and Weber, 1965; Westgate, 1999). Research on maize, soybean, and sunflower determined that an increase in grain yield from narrow rows was strongly correlated with an increase in light interception at the grain filling stage (Andrade et. al., 2002). An increase in aboveground biomass, light interception, and assimilate utilization are all factors that contribute to yield increases in narrow versus wide-rows (Board et al., 1990; Bullock et al., 1998; Egli, 1994).

Some studies involving narrow-row soybean production systems in the southeast have had mixed results (Cartter and Hartwig, 1963; Hartwig, 1957). Lee (2006) summarized row spacing research on corn and found that row spacings <76 cm had a positive effect on yield in northern United States but that there was a less consistent results south of 43°N latitude. Soybean followed the same pattern with northern climates benefited more consistently from narrow rows that southern climates. Beatty et al. (1982), observed a 15% yield increase in Arkansas for soybean grown in either 18 or 48-cm row widths compared to soybean grown in 96-cm row widths. No yield difference was observed between the 18 and 48-cm row widths. In a three year, three location, study conducted in Iowa De Bruin and Pederson (2008) found that soybean grown in 38-cm row widths yielded 0.25 Mg ha^{-1} (5.6%) greater than soybean grown in 76-cm row widths. The yield increase would economically justify the conversion from a 76 to 38-cm row width on a 144 ha farm with 30% of the area in soybean production. Other studies in the southeastern United States have also showed that narrow-row soybean increases yield (Board et al., 1992; Parvez et al., 1989).

Chapter Two: Foliar Fertilization of Soybeans

INTRODUCTION

Soybean is an important grain crop in the United States. In 2008 roughly 30,222,000 hectares of soybeans were harvested across the country, with an average yield of 2.67 Mg ha^{-1} (USDA-NASS, 2009a). With 2008 receipts topping 27 billion dollars the economic significance of the crop is apparent. Breeders, agronomists, and producers alike have worked to produce the highest yields possible to maximize crop value and economic return. Foliar fertilization has been advertized as a way to increase soybean yield both in agriculture magazines aimed at producers (BioBased USA, 2010) and by companies selling foliar fertilizers (Nutra-Flo, 2007).

Foliar fertilizer research began in 1956 when two researchers from Michigan State H.B. Tukey and S.H. Wittwer, determined via radioactive isotope detection, that nutrients were absorbed, moved throughout the plant, and were utilized when applied to the plant foliage as a liquid. They estimated that soil nutrient applications where 10% efficient, whereas foliar fertilizer applications were about 95% efficient. However, leaf damage from high nutrient rates made it impractical to use foliar fertilization to meet the total nutritional requirement of a crop (Tukey and Wittwer, 1956). Limited by the ability of plant tissue to withstand high rates of nutrient applications researchers investigated the use of foliar fertilizer as a supplement to soil fertility.

Research conducted by Garcia and Hanway (1976) contributed greatly to this litany of new research. They reported yield increases up to 0.54 Mg ha^{-1} (24%) in 1974 from a foliar treatment consisting of 49, 21, 36, and 9 kg ha^{-1} of N, P, K, and S, respectively. In 1975 a treatment consisting of 80, 8, 24, and 8 kg ha^{-1} of N, P, K, and S, respectively yielded a more impressive 1.04 Mg ha^{-1} (35%) over the control. Moreover, in another experiment in 1975 foliar fertilizer (96, 10, 29, and 5 kg ha^{-1} of N, P, K, and S, respectively) increased yields of two cultivars (Amsoy and Corsoy) by 1.49 (39%) and 1.57 Mg ha^{-1} (44%) over their controls (Garcia and Hanway, 1976).

Proponents of the need for foliar fertilizer often cite the "self destruct" hypothesis proposed by Sinclair and de Wit (1976). They claimed that nutrient remobilization from soybean leaves to the seed hastens leaf senescence and shortens the duration of seed fill, limiting yield. Some researchers have reported that up to 60% of the N, P, and K in the seed may be remobilized from existing plant biomass (Hanway and Weber, 1971; Henderson et al., 1970). In a study conducted using several cultivars with different maturities, remobilization of nitrogen from the biomass to the seed accounted for 30 to 100% of seed N, with more nitrogen being remobilized in later maturing cultivars (Zeiher et al., 1982). Garcia and Hanway (1976) speculated foliar fertilizer applications would minimize the nutrient depletion of soybean leaves caused by remobilization and increase yield. This reduction in nutrient depletion, they hypothesized, delayed senescence of the soybean resulting in a longer duration of leaf photosynthetic activity and seed fill.

Foliar fertilization has been shown to increase leaf nutrient concentrations. However, yield is often not affected even with the increase leaf nutrient concentrations. Leaf photosynthesis and yield were not affected in a study where a foliar fertilizer application of 28, 2.9, 8.4, and 1.2 kg ha^{-1} N, P, K and S, respectively increased leaf nutrient concentrations by 6, 20, and 43% for N, P, and K, respectively (Boote et al., 1978). Boote et al. (1978) estimated that foliar fertilization extended leaf area duration by a day, at most. Parker and Boswell (1980) reported that the application of foliar fertilizer (28, 2.9, 9.5, and 1.7 kg ha^{-1} of N, P, K, and S, respectively) caused a yield decrease and had no effect on leaf nutrient content.

In more recent years the focus has been more on foliar micronutrient applications and smaller amounts of macronutrients. Often the research has been focused on known or observed nutrient deficiencies (Boswell et al., 1981; Gettier et al., 1985; Ross et al., 2006). The yield increase from foliar fertilizer applications was more consistent in this situation, as would be expected. Some research has been conducted on soils with no evidence of micronutrient deficiencies and the results have been inconsistent with only a few instances where yield increased (Touchton and Boswell, 1975; Loecker et al., 2010).

Of the research that yield increases from foliar fertilizer applications; none of the observed increases were as large as those reported by Garcia and Hanway (1976) (Haq and Mallarino, 1998; Peele, 1977; Syverud et al., 1980; Vasilas et al., 1980). Most research however, has documented inconsistent or no yield response from the application of foliar fertilizer (Binford et al., 2004; Boote et al., 1978; Haq and Mallarino, 1998; Parker and Boswell, 1980; Peele, 1977; Poole et al., 1983; Vasilas et al., 1980). Based on the literature it appears that yield is largely unaffected by high rates of N, P, K, and S foliar applications, likewise applications of micronutrients also seems to have little effect on yield. Observed yield differences with the application of foliar fertilizers are likely due to nutrient deficiencies.

Most research conducted on foliar fertilization has had much higher nutrient application rates than those used in this study. The nutrient requirement of a soybean plant varies, as does the actual amount of nutrients accumulated in the seed. Table. 2-1 lists the nutrient composition of soybean seed. This can be a useful reference when looking at the rates of foliar fertilizer used in the studies presented. Most of the early research on foliar fertilizers involved high rates of N, P, K and S, although some early studies did include micronutrients. The Garcia and Hanway (1976) study for instance had a nitrogen application of 80 kg ha^{-1}. With a yield of 4.02 Mg ha^{-1} roughly 279 kg of N would be contained in seed. So their foliar fertilizer treatment applied 28.6% of the total seed N.

Objective

Foliar fertilizer use has been heavily advertized to farmers as a way to boost soybean yield, and claims of increased yields in already high yielding environments have been made. The objective of this study was to determine if low rates of foliar fertilizer, comparable to those found in commercial foliar fertilizer products, would increase yield of soybean, particularly in high yield situations, and to determine the effect of application frequency and timing.

MATERIALS AND METHODS

Field research was conducted in 2008 and 2009 to determine the effect of foliar fertilizer on the yield of irrigated (2008, 2009) and non-irrigated soybean (2008). The research was conducted at Spindletop Research Farm near Lexington, Kentucky, (37° 59' 19" N, 84° 28' 39" W). In 2008, the soil type was a Loradale silt loam (2-6% slope, fine, mixed, active, mesic Typic Argiudolls), and was a Mercer silt loam (2-6% slope, fine-silty, mixed, semiactive, mesic Oxyaquic Fragiudalfs) in 2009. In 2008, the study was conducted in a split-plot design with four replications. The main plot was irrigation (irrigated and non-irrigated) and the split-plot was the foliar fertilizer treatments. In 2009, the study was a randomized complete block design with four replications and the entire experiment was irrigated.

In both years, the study was planted no-till following corn using a small plot drill (Hege Equipment Inc., Colwich, KS) in 38-cm rows at a seeding rate of 346,000 seeds ha^{-1}. Seeds were inoculated with *Bradyrhizobium japonicum* (Hi-Stick N/T, Becker Underwood Inc., Ames, IA). In 2008 the plot width was 1.52 m and the length was 12.2 m. In 2009 the plot width was 1.52 m and the length was 9.2 m. Pioneer cultivar 94Y60 (4.6 relative maturity) was used both years. Soil fertilirty was measured at the University of Kentucky Soil Testing Lab and nutrient levels were adequate according to state recommendations. Glyphosate (potassium salt of N-(phosphonomethyl)glycine) was applied preplant both years (1.19 kg a.e. ha^{-1}). In addition, imazethapyr (2-[4,5-hydro-methyl-4-(1-methylethyl)-5-oxo-1H-imidazolyl]-5-ethyl-3-pyridinecarboxylic acid) was applied preplant in 2009 (0.071 kg a.i. ha^{-1}). In season applications of glyphosate (0.94 kg a.e. ha^{-1}) were made as needed to control weeds in both years. Plots were planted 13 May, 2008 and 18 May, 2009.

Irrigation was supplied via drip tape with a 30 cm emitter spacing (The Toro Co., El Cajon, CA). Drip lines were placed 76 cm apart between alternating rows. Vacuum-gauge tensiometers (Soilmoisture Equipment Corp., Santa Barbara, CA) placed at a depth of 0.30 m and irrigation was initiated when soil water potential reached -0.05 MPa.

The study in 2008 included 15 treatments and two levels of irrigation, irrigated and non-irrigated (Table 2-2). Treatment 1 was the untreated control. Treatment 2 was a preplant sulfur (S) treatment (4.04 kg S ha^{-1}) to rule out the effect of sulfur if other sulfur containing fertilizers (zinc sulfate, ammonium sulfate, manganese sulfate, or potassium sulfate) in the study increased yields. Treatments 3 and 4 were boron (B) applications (1.12 kg B ha^{-1}) made prior to emergence and as a foliar application at growth stage R1, respectively. Treatments 5 and 6 were foliar zinc (Zn) treatments (1.12 kg Zn ha^{-1}) made at R1 and R1 plus a second application 1 week later, respectively. A foliar manganese (Mn) application (1.12 kg Mn ha^{-1}) was made for Treatments 7 and 8 at R1 and R1 plus a second application 1 week later, respectively. Treatments 9 (R1), 10 (R1 + 1 week later), and 11 (R1 + 1 week later + 2 weeks later) were foliar nitrogen (N) treatments applied at a rate of 1.18 kg N ha^{-1} at each timing. A foliar application of potassium (K) was applied at a rate of 1.23 kg K ha^{-1} 2 weeks after planting (WAP) for Treatment 12, 2 and 3 WAP for Treatment 13, and 2, 3, and 4 WAP for Treatment 14. Treatment 15 was a foliar application of both nitrogen (1.18 kg N ha^{-1}) and potassium (1.23 kg K ha^{-1}) made 2, 3, and 4 WAP, and applications at R1, 1 week, and 2 weeks later. A subset of the 2008 treatments were used in 2009 with the treatment numbers remaining the same (Table 2-2). They included Treatments 1, 2, 3, 4, 6, 8, 11, 14, and 15.

The rates in this study were meant to be similar to the rates that would be applied with many of the commercial foliar fertilizer products. For comparison the nutrient application rates for two products; Taskforce 2 (Loveland Products, Inc., Greenley, CO) and HarvestMore UreaMate (Stoller Enterprises, Inc., Houston, TX), and the nutrient rates applied in this study are presented in Table 2-3.

Foliar fertilizer treatments and herbicide applications were both made using a CO_2 backpack sprayer with a spray pressure of 241 kPa and an application speed of 4.8 km per hour. The boom length was 1.52 meters with a nozzle (Teejet 11002; Teejet, Wheaton, Illinois) spacing of 50.8 cm.

Crop growth rate (CGR) was measured in 2008 on the irrigated treatments to determine any difference between Treatment 1 (untreated check) and Treatment 15 (N and K 2+3+4 WAP and R1+1 wk+2 wk later). Plants were harvested from 0. 4 m^2 beginning at growth stage R1 and then roughly once weekly until R5, a period in which CGR is believed to be linear (Pederson, 2004). The plant material was dried at 60°C and weighed. Plant dry weight was regressed against time to determine the crop growth rate for each plot. The MIXED procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002) was used for ANOVA for Treatments 1 and 15. Pairwise comparisons of LSMeans were anaylized using α=0.05.

Plots were end-trimmed each year before harvest. In 2008 the harvest area was 1.52 by 10.62 m and in 2009 the harvest area was 1.52 by 7.62 m. Plots were harvested with a Wintersteiger small plot combine (Wintersteiger, Ried, Austria). Seed weight, moisture and test weight were measured with an onboard Harvest Master weigh system (Juniper Systems, Logan, UT). Yield was adjusted to 130 g kg $^{-1}$ moisture.

At harvest a subsample of seed was collected for seed protein and oil determination. Seed protein and oil were analyzed using a Perten DA7200 near infrared seed analyzer (Perten Instruments, Stockholm, Sweden) to determine if foliar fertilizer affected protein or oil concentrations.

Data was combined across years and irrigation level when interactions were not significant. The MIXED procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002) was used for the ANOVA for the dependent variables of yield, seed protein and oil concentration. Treatment means were determined using the LSMeans statement and were compared pairwise and using α=0.05.

RESULTS AND DISCUSSION

The average season temperature in 2008 and 2009 was very similar to the 30-year mean (Table 2-4). Precipitation for the 2008 season was 144 mm lower than the 30-year mean. The precipitation in 2009 was 207 mm higher than the 30-year mean.

Crop Growth Rate

There was no significant CGR difference between Treatment 1 and Treatment 15 (Table 2-5). The average CGR of the two treatments was 13.6 g m^{-2} d^{-1}. The CGR's observed in this study is similar to CGR's observed in other studies. De Bruin and Pedersen (2009) reported the CGR of four cultivars that ranged from 9.7 to 18.0 g m^{-2} d^{-1}, with an average across three locations of 13.2 g m^{-2} d^{-1}. Pedersen and Lauer (2004) reported the CGR for three cultivars that ranged from 11.4 to 13.0 g m^{-2} d^{-1}.

Yield

There was no significant treatment by irrigation interaction. Soybean seed yield did not respond to any fertilizer treatment in 2008 for the irrigated or non-irrigated treatments (Table 2-6). The treatment effect for seed yield in the combined analysis of 2008 irrigated and non-irrigated data was not significant. In 2008 irrigation resulted in a 102% increase in yield. Given the below average amount of rainfall received in 2008 (Table. 2-4) this is not surprising. Mean yields in 2008 were 4.87 and 2.41 Mg ha^{-1} for irrigated and non-irrigated treatments, respectively. Even in a high yielding-irrigated environment, that produced relatively high yields, foliar fertilization did not increase yield. In 2008 the average yield in Kentucky was 2.32 Mg ha^{-1} (USDA-NASS, 2009a).

The yield of the non-irrigated treatments in this study were very close to the average state yield.

There was no significant treatment effect for the 2009 growing season. The mean yield for the 2009 irrigated treatments was 4.60 Mg ha^{-1}. Again, even in a high yielding-irrigated environment, no foliar fertilizer treatment increased yield. For 2009, the average state yield in Kentucky was 3.23 Mg ha^{-1} (USDA-NASS, 2009a). In a generally wet year (Table. 2-4), the yields of the irrigated treatments still out yielded the state average. In the combined analysis of the 2008 and 2009 irrigated data, the year effect was significant, however, the treatment by year interaction was not significant. There were no significant treatment effects for the 2008-2009 combined analysis.

With other research showing inconsistent yield increases with high rates of foliar fertilization it was very unlikely that a yield increase would be observed in this study. However, many foliar fertilizer products marketed to producers today contain lower concentrations of many of the nutrients examined in this study. Even under irrigation in a high yield environment, and with presumably little plant stress, the foliar fertilization treatments did not result in a yield increase. This research indicates that low rates of foliar fertilizer, applied to soybean in a high yield environment, will not increase yields. It is also highly unlikely, under normal field conditions where yield limitations such as water availability exist, that foliar fertilization will increase yield.

Grain Oil and Protein Concentration

There was no significant treatment effect on oil concentration (Table 2-7) in the 2008 irrigated or non-irrigated study. The mean value for oil concentration in 2008 was 213.9 and 234.1 g kg^{-1} for the irrigated and non-irrigated treatments, respectively. There was no significant treatment effect in the combined analysis of the 2008 irrigated and non-irrigated studies. The treatment x irrigation interaction was not significant. The mean oil concentration for the 2008 combined analysis was 224.0 g kg^{-1}.

In 2009, there was no significant treatment effect on oil concentration. The mean oil concentration in 2009 was 217.3 g kg^{-1}. For the combined analysis of the 2008 and 2009 combined data the treatment by year interaction was not significant. There was no significant treatment effect for the combined analysis.

There was no significant treatment effect for protein concentration (Table 2-8) in the 2008 irrigated or non-irrigated studies. The mean values for protein concentration in 2008 were 422.3 and 397.8 g kg^{-1} for the irrigated and non-irrigated treatments, respectively. There was no significant treatment effects for the combined analysis of the 2008 irrigated and non-irrigated treatments. There was no interaction between treatment and irrigation. The mean protein concentration for the 2008 combined analysis was 410.1 g kg^{-1}.

In 2009, there were no significant treatment effects. The mean protein concentration in 2009 was 445.3 g kg^{-1}. For the combined analysis of the 2008 and 2009 data the treatment by year interaction was not significant (p=0.0706) and there was no significant treatment effects.

It is interesting to note that in 2008 the non-irrigated treatments had a higher oil concentration than the irrigated treatments. Also in 2008, the protein concentration of the non-irrigated treatments was lower than that of the irrigated treatments. In soybean, protein and oil concentrations are known to be, in general, negatively correlated (Helms and Orf, 1998; Wilcox and Shibles, 2001). It is unclear however, if water stress in the non-irrigated treatments caused an increase in oil (and therefore a compensative protein decrease), or if the irrigated treatments caused an increase in protein (and therefore a compensative decrease in oil). Seed protein concentration is affected by N remobilization from plant tissues during senescence (Jeppson et al., 1978; Staswick, 1994). Research indicates that N remobilization can account for 30 to 100% of total seed N (Zeiher et al., 1982). The difference in plant height and biomass between the irrigated and non-irrigated treatments was visually apparent by growth stage R1. It is possible that a larger availability of vegetative N resulted in a greater amount of N being redistributed causing an increase in protein in the irrigated treatments. In a source-sink manipulation study Proulx and Naeve (2009) observed that oil concentrations showed a resistance to increases even with when defoliation treatments caused a decrease in protein concentration. This evidence may indicate that irrigation caused a protein increase, and therefore resulted in a decrease in oil concentration.

The protein and oil concentrations in this study are similar to the concentrations reported from similar geographical areas. For data from southern states, Yaklich et al. (2002) reported a 51 year average seed protein and oil concentration of 411 and 209 g kg^{-1}, respectively. Seed from a 2 year study conducted in Indiana also had similar protein and oil concentration values (Robinson et al., 2009).

Overall protein and oil concentrations were not affected by any foliar fertilizer treatment. This agrees with the research of Haq and Mallarino (2005), where oil concentrations were not affected by foliar applications of N, P, K, S, Fe, Zn, and B (3.5, 1.5, 3.0, 0.32, 0.13, 0.02 and 0.03 kg ha^{-1}, respectively) in 18 site-years. Foliar fertilization decreased protein concentrations in 2 of the 18 site-years, but did not affect the oil concentration.

CONCLUSION

The results of this study add to the list of studies in which foliar fertilization did not increase yield (Boote et al., 1978; Haq and Mallarino, 1998; Parker and Boswell, 1980). Multiple foliar fertilizer applications did not affect CGR. In addition, neither yield nor oil and protein concentrations were affected by any foliar fertilizer treatments. Because the foliar fertilizer rates used in this study are comparable to many commercially available foliar fertilizer products it is unlikely that yield increases can be expected from their use in soybean in high yielding environments or in any environment in which soil fertility is adequate.

Table 2-1. Nutrient composition of soybean seed.†

Nutrient	Composition	Removed
	g kg seed^{-1}	kg ha^{-1}‡
N	69.9	209.6
P	7.0	21.1
K	18.0	53.9
S	3.3	10.0
Mg	3.8	11.5
B	1.2	3.6
Cu	0.017	0.050
Fe	0.157	0.471
Mn	0.025	0.076
Zn	0.049	0.147

† Source: Modified from Mitchell, 1999; USDA-ARS, 2009; Wiebold and Scharf, 2000.

‡ Nutrient removal per ha with a 3 Mg yield (2009 average U.S. soybean yield; USDA, 2009a)

Table 2-2. Foliar fertilizer treatment list, 2008 and 2009.

Treatment Number	Element	Product†	Application Method	Timing‡§	Rate	2008	2009
1	check	None	None	None	None	✓	✓
2	S	$CaSO_4$-2(H_2O)	Soil	Preplant	4.04 kg S ha^{-1}	✓	✓
3	B	$Na_2B_4O_7$-5(H_2O)	Soil	Preplant	1.12 kg B ha^{-1}	✓	✓
4	B	$Na_2B_4O_7$-5(H_2O)	Foliar	R1	1.12 kg B ha^{-1}	✓	✓
5	Zn	$ZnSO_4 \cdot 7H_2O$	Foliar	R1	1.12 kg Zn ha^{-1}	✓	
6	Zn	$ZnSO_4 \cdot 7H_2O$	Foliar	R1 + 1 wk later	1.12 kg Zn ha^{-1}	✓	✓
7	Mn	$MnSO_4$	Foliar	R1	1.12 kg Mn ha^{-1}	✓	
8	Mn	$MnSO_4$	Foliar	R1 + 1 wk later	1.12 kg Mn ha^{-1}	✓	✓
9	N	$(NH_4)_2SO_4$	Foliar	R1	1.18 kg N ha^{-1}	✓	
10	N	$(NH_4)_2SO_4$	Foliar	R1 + 1 wk later	1.18 kg N ha^{-1}	✓	
11	N	$(NH_4)_2SO_4$	Foliar	R1 + 1 + 2 wk later	1.18 kg N ha^{-1}	✓	✓
12	K	K_2SO_4	Foliar	2 WAP	1.23 kg K ha^{-1}	✓	
13	K	K_2SO_4	Foliar	2 + 3 WAP	1.23 kg K ha^{-1}	✓	
14	K	K_2SO_4	Foliar	2 + 3 + 4 WAP	1.23 kg K ha^{-1}	✓	✓
15	N, K	$(NH_4)_2SO_4 + K_2SO_4$	Foliar	2 + 3 + 4 WAP R1 + 1 + 2 wk later	1.18 kg N + 1.23 kg K ha^{-1}	✓	✓

† $CaSO_4$-2(H2O) (calcium sulfate or gypsum), $Na_2B_4O_7$-5(H2O) (sodium borate), $ZnSO_4 \cdot 7H_2O$ (zinc sulfate), $MnSO_4$ (manganese sulfate), K_2SO_4 (potassium sulfate), $(NH_4)_2SO_4$ (ammonium sulfate)

‡ wk = week(s)

§ WAP = weeks after planting

Table 2-3. Comercial fertilizer nutrient rates

Nutrient	Taskforce 2†	UreaMate‡	Study
	———	kg ha^{-1}	———
N	0.77	0.28	1.18 (7.08)§
P	0.56	0.56	1.23 (7.38)
K	0.35	1.51	–
B	0.001	0.008	1.12
Co	3.5×10^5	0.0004	–
Cu	0.004	0.017	–
Fe	0.007	–	–
Mn	0.004	0.028	1.12 (2.24)
Mo	3.5×10^5	0.0004	–
Zn	0.004	0.028	1.12 (2.24)

† Loveland Products, Inc., Greenley, CO

‡ Stoller Enterprises, Inc., Houston, TX

§ Single application (total from multiple applications)

Table 2-4. Mean monthly air temperature and precipitation data, Lexington, KY.

Year	Air temperature						Rainfall					
	May	June	July	August	Sept.	Avg. (May-Sept.)	May	June	July	August	Sept.	Total (May-Sept.)
	°C						mm					
2008	16.7	23.3	24.4	23.9	22.2	21.7	112	90	87	55	36	380
2009	18.3	23.3	22.2	22.8	20.6	21.4	153	132	192	115	150	742
30 yr. mean	17.7	22.3	24.5	23.8	20.0	21.7	121	116	122	96	79	535

Table 2-5. LSMeans comparison of CGR, 2008, Lexington, KY.

Treatment Number	Element	Timing†‡	2008 Irrigated
			g m^{-2} d^{-1}
1	check	none	13.2
15	N, K	2 + 3 + 4 WAP, R1 + 1 + 2 wk later	13.9
		Mean	13.6

ANOVA	
Treatment	0.8334
Rep	0.5956

† wk = week(s)

‡ WAP = weeks after planting

§ Means in a column followed by the same letter are not statistically different at the 0.05 probability level (columns lettered only when the treatment effect was significant)

Table 2-6. Comparison of least square means of seed yield, 2008 Irrigated, 2008 non-irrigated, 2008 mean, 2009, and 2008-2009 combined, Lexington, KY.

Treatment Number	Element	Timing†‡	2008 Irrigated	2008 Non-irrigated	2008 Mean	2009 Irrigated	Combined§
			Mg ha^{-1}				
1	check	none	4.85§	2.67	3.76	4.75	4.80
2	S	Preplant	4.87	2.44	3.66	4.64	4.76
3	B	Preplant	4.64	2.43	3.53	4.50	4.57
4	B	R1	5.12	2.76	3.94	4.66	4.89
5	Zn	R1	5.30	2.37	3.83	—	—
6	Zn	R1 + 1 wk later	4.70	2.48	3.59	4.90	4.80
7	Mn	R1	4.86	2.27	3.57	—	—
8	Mn	R1 + 1 wk later	5.15	2.34	3.74	4.27	4.71
9	N	R1	5.02	2.16	3.59	—	—
10	N	R1 + 1 wk later	4.59	2.48	3.53	—	—
11	N	R1 + 1 + 2 wk later	4.80	2.37	3.59	4.59	4.70
12	K	2 WAP	4.92	2.53	3.73	—	—
13	K	2 + 3 WAP	4.81	2.03	3.42	—	—
14	K	2 + 3 + 4 WAP	4.64	2.19	3.42	4.63	4.64
15	N, K	2 + 3 + 4 WAP R1 + 1 + 2 wk later	4.80	2.57	3.68	4.47	4.64
		Mean	4.87	2.41	3.64	4.60	4.72
		ANOVA	*P > f*				
		Treatment (T)	0.5917	0.8923	0.7662	0.1027	0.8685
		Irrigation (I)	—	—	<0.0001	—	—
		Year (Y)	—	—	—	—	0.0460
		T x I	—	—	0.8535	—	—
		T x Y	—	—	—	—	0.2888

† wk = week(s)

‡ WAP = weeks after planting

§ Irrigated data from 2008 and 2009 combined

Table 2-7. Comparison of least square means of seed oil concentration on dry basis, 2008 Irrigated, 2008 non-irrigated, 2008 mean, 2009, and 2008-2009 combined, Lexington, KY.

Treatment Number	Element	Timing†‡	2008 Irrigated	2008 Non-irrigated	2008 Mean	2009 Irrigated	Combined§
			g kg^{-1}				
1	check	none	215.0§	235.0	225.0	219.2	217.1
2	S	Preplant	211.7	232.0	221.8	216.4	214.1
3	B	Preplant	213.7	232.5	223.1	216.5	215.1
4	B	R1	213.7	228.7	221.2	218.9	216.3
5	Zn	R1	213.7	233.7	223.7	—	—
6	Zn	R1 + 1 wk later	216.0	234.0	225.0	214.3	215.4
7	Mn	R1	213.2	236.0	224.6	—	—
8	Mn	R1 + 1 wk later	209.2	232.2	220.7	214.9	212.1
9	N	R1	215.7	236.5	226.1	—	—
10	N	R1 + 1 wk later	215.2	229.7	222.5	—	—
11	N	R1 + 1 + 2 wk later	214.2	233.0	223.6	218.6	216.4
12	K	2 WAP	213.2	237.2	225.2	—	—
13	K	2 + 3 WAP	213.7	235.7	224.7	—	—
14	K	2 + 3 + 4 WAP	214.2	239.5	226.8	219.5	216.9
15	N, K	2 + 3 + 4 WAP R1 + 1 + 2 wk later	215.5	235.7	225.6	217.4	216.4
		Mean	213.8	234.1	224.0	217.3	215.5
		ANOVA	*P > f*				
		Treatment (T)	0.2326	0.2503	0.1382	0.1752	0.1407
		Irrigation (I)	—	—	<0.0001	—	—
		Year (Y)	—	—	—	—	0.0009
		T x I	—	—	0.4439	—	—
		T x Y	—	—	—	—	0.3449

† wk = week(s)

‡ WAP = weeks after planting

§ Irrigated data from 2008 and 2009 combined

Table 2-8. Comparison of least square means of seed protein concentration on dry basis, 2008 Irrigated, 2008 non-irrigated, 2008 mean, 2009, and 2008-2009 combined, Lexington, KY.

Treatment Number	Element	Timing†‡	2008 Irrigated	2008 Non-irrigated	2008 Mean	2009 Irrigated	Combined§
			g kg^{-1}				
1	check	none	419.3§	398.7	409.0	442.3	430.8
2	S	Preplant	425.5	398.7	412.1	444.7	435.1
3	B	Preplant	422.5	400.0	411.2	447.7	435.1
4	B	R1	425.0	401.7	413.3	446.9	435.9
5	Zn	R1	421.2	399.0	410.1	—	—
6	Zn	R1 + 1 wk later	420.0	403.7	411.8	445.1	432.8
7	Mn	R1	423.7	393.0	408.3	—	—
8	Mn	R1 + 1 wk later	427.0	403.2	415.1	442.2	434.6
9	N	R1	422.2	392.7	407.5	—	—
10	N	R1 + 1 wk later	421.0	405.5	413.2	—	—
11	N	R1 + 1 + 2 wk later	420.0	402.2	411.1	444.7	432.3
12	K	2 WAP	423.7	387.5	405.6	—	—
13	K	2 + 3 WAP	425.0	397.2	411.1	—	—
14	K	2 + 3 + 4 WAP	420.2	390.7	405.5	445.1	432.6
15	N, K	2 + 3 + 4 WAP R1 + 1 + 2 wk later	419.0	393.2	406.1	449.3	434.1
		Mean	422.6	397.8	410.1	445.3	433.7
		ANOVA	*P* > *f*				
		Treatment (T)	0.3588	0.1193	0.1244	0.2814	0.7540
		Irrigation (I)	—	—	<.0001	—	—
		Year (Y)	—	—	—	—	<.0001
		T x I	—	—	0.1643	—	—
		T x Y	—	—	—	—	0.0706

† wk = week(s)

‡ WAP = weeks after planting

§ Irrigated data from 2008 and 2009 combined

Chapter Three: High-input Management Practices for Soybean Production

INTRODUCTION

Increasing soybean yield has become a high priority as producers feel economic pressure to produce a greater quantity at a lower cost. Facing increased input costs and narrowing profit margins, even a small increase in yield is important. More and more producers are turning to company advertised products and services to try to increase yield. Many of these products have had inconsistent yield results at best in the published university trials. Yet companies often advertize yield increases that are questionable. Products such as seed treatments (Bayer, 2010a; Becker, 2010), fungicides (BASF, 2010; Bayer, 2010b), inoculants (EMD, 2010), and foliar fertilizer (BioBased USA, 2010; Nutra-Flo, 2007) are advertized regularly in producer aimed magazines, through websites, and also through local agriculture service stores. The purpose of this study was to evaluate high-input management practices consisting of six commonly utilized management practices: seed treatment, fungicide application, inoculant application, additional soil fertility, foliar fertilizer application, and row spacing.

Seed Treatment

Seed treatments generally consist of an insecticide, a fungicide, or both applied to the seed prior to planting. The aim of seed treatment is to prevent the reduction of seedling emergence, seedling vitality, or soybean yield from insects and/or disease. Most universities only recommend the use of seed treatments when needed in an Integrated Pest Management (IPM) approach. With IPM, other factors such as crop rotation, planting date, soil fertility and cultivar selection are managed to best counteract or avoid insect and disease pressure (USEPA, 2009). In IPM a seed treatment would only be used after the pest threat reached the economic injury level (EIL), or level in which the possible yield reduction warrants the cost of the treatment. Companies market the use of soybean seed treatments as cheap insurance against a pest problem. However, researchers question the need for seed treatments unless conditions warrant their use or when the possibility of pest problems is high because of other management decisions. It is generally recommended that seed treatments be used when planting at lower seeding rates, when germination will be delayed because of cool, wet, or very dry soils, or when poor quality seed or infected seed is used (Malvick, 1998). Wall et al. (1983) conducted a study evaluating three fungicide seed treatments on low quality seed. He reported no yield increase when the seed treatment was applied to seed with reduced quality as a result of damage, age, or size. However, emergence increased as a result of the fungicide treatment when seedlots had a 15% *Phomopsis* spp infection and he also noted yield increases in seedlots with an infection above 50%.

Seed treatments, even when effective, do not always provide season long protection. In a study by Dorrance et al. (2003) on four fungicide seed treatments, there was a reduction in the negative effect of *Rhizoctonia solani* on root rot, root weight, and stand. However, the researchers note that disease control was not provided through the entire growing season and that cultivar resistance was beneficial. In a study evaluating the effects of fungicides on soybean cultivars with partial resistance to *Phytophthora sojae* researchers determined that the number of damped-off seedlings was significantly greater when the infection occurred at planting compared with an infection occurring 5 days after planting (Dorrance and McClure, 2001). Seedlings of a resistant cultivar were not affected regardless of infection date. The partially resistant cultivars benefited from the fungicide seed treatment; showing an increase in percent emergence, fresh plant weight, and root weight.

The yield effects from soybean seed treatments are common but not consistent. Guy et al. (1989) observed yield increases in two out of ten soybean cultivars tested in a two-year study. In research conducted in South Dakota, only two out of twenty-one treatments increased yield in a 4-site year (Draper et al., 2002). Both of those yield increases were at the same site in a low yielding year. Researchers in Minnesota found no yield difference between 12 treatments combining seed fungicide and insecticide treatments and a control (Potter, 2004). Schulz and Thelen (2008) found that fungicide seed treatments only increased yield in 3 out of 16 site-years (maximum increase of 0.28 Mg ha^{-1}). The researchers hypothesize that a month of heavy rains after planting at one site, and early planting and below normal temperatures throughout May at the other caused the yield difference. Grau and Gaska (2002) also observed significant yield differences between untreated and fungicide treated soybean seed at earlier planting dates, but not at later planting dates. The authors state that the probability of a positive yield increase from fungicide treated seed increases with early plantings in no-till or conservation tillage environments (Grau and Gaska, 2002). However, Cox et al. (2008) conducted research on planting dates and seed treatments in the Northeastern United States and found no difference in yield or plant density between two fungicide/insecticide combinations and a control, regardless of planting date.

Foliar Fungicide

According to Wrather and Koenning (2006) foliar diseases in the United States caused a yield loss of 0.506, 1.152, and .487 million metric tonnes in 2003, 2004, and 2005, respectively. Yield reductions from foliar diseases, while significant, are often less than those from other plant diseases and pests. In the study by Wrather and Koenning (2006) foliar diseases accounted for only 7.2% of total yield reduction caused by disease over the three year period. Soybean cyst nematode (*Heterodera glycines*) alone caused a greater reduction in yield than all the foliar diseases combined in a given year. Still foliar disease can reduce leaf area, photosynthesis, and yield (Bassanezi et al., 2001), even if not on a large scale nationally.

In addition, fungicides are often marketed as having physiological effects that can increase yield. Some researchers have observed yield increases attributed to physiological effects from fungicide applications in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Bayles and Hilton, 2000; Grossmann et al., 1999; Grossmann and Retzlaf, 1997). The yield benefit from fungicide applications has been attributed to delayed senescence, increased leaf greenness and leaf area duration, improved water use efficiency, increases in photosynthesis, and increased chlorophyll production (Badenoch-Jones et al., 1996; Bryson et al., 2000; Grossmann et al., 1999; Grossmann and Retzlaf, 1997; Kuroda et al., 1996). In soybean there is little evidence of yield increases.

In a study conducted in Iowa to assess the physiological effect of fungicides on soybean yield, researchers found no yield difference and observed no physiological differences (Swoboda and Pedersen, 2009). They compared tebuconazole (alpha-[2-(4-chlorophenyl)ethyl]-alpha-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol) and pyraclostrobin (carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3 yl]oxy]methyl] phenyl]methoxy-, methyl ester) alone and in combination over 3 site-years and 4 cultivars in low disease environments. Hanna et al. (2008), in a two year study with three locations and two cultivars, also found no yield increase from fungicide applications of azoxystrobin (Methyl (E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate) and propiconazole (1-[[2(2,4-Dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]1-H-1,2,4-triazole) under low disease pressure. In five years of studies conducted in South Dakota from 2004-2008 there was no significant yield increase versus untreated checks for many different strobilurin and triazole products and many combinations (Draper et al., 2006, 2005, 2004; Osborne et al., 2008; Ruden and Ruden, 2007). Septoria brown spot (*Septoria glycines*) the major disease of concern in those trials, was not present in most years and when disease was observed infections were very mild. Researchers in Iowa also found no yield increase from fungicide applications in two separate studies conducted in 2005 involving 20 different commercial fungicides (Kassel, 2005; Robertson et al., 2005). They were primarily concerned with low severity infections of septoria brown spot, frogeye leaf spot (*Cercospora sojina*), and bacterial blight (*Pseudomonas savastanoi*).

Yield increases from the use of foliar fungicides have been reported. Cooper (1989) presented data from a three-year study in which three of four cultivars had a significant yield increase (0.35 Mg ha^{-1}) over their respective checks with the application of benomyl (methyl 1-[(butylamino) carbonyl]-H-benzimidazol-2-yl carbamate). In that study there was a severe infection of septoria brown spot. Heatherly and Sciumbato (1986) observed yield increases of 0.19 and 0.15 Mg ha^{-1} with foliar benomyl application in 1981 and 1983, respectively when they did not observe any disease presence. Slater et al. (1991) showed a similar yield increase of 0.17 Mg ha^{-1} averaged over three years, two cultivars, and two levels of irrigation.

A yield increase as a result of fungicide application may not result in an economic return. Dennis (2006) estimated a cost of $42 to 49 ha^{-1} for the application of two popular commercial strobilurin fungicides. At the 10 year (1999-2008) average soybean price of $234 Mg^{-1} (USDA-NASS, 2009a) a fungicide application would need to increase yield by more than 0.19 Mg ha^{-1} to be profitable. Disease assessment, and the use of thresholds, is important when determining whether or not to apply foliar fungicides. decision. The principles of IPM also apply to foliar fungicide use. EIL's can be used to assess the severity of plant pathogens and if their presence is detrimental to crop yield.

Inoculant

The biological fixation of atmospheric nitrogen by the soybean plant makes it one of the most unique commodity crops grown in the United States. Nitrogen fixation, a result of the symbiotic relationship between the plant and the bacteria *Bradyrhizobium japonicum* can increase soybean yields significantly (Duong et al., 1984; Schulz and Thelen, 2008; Seneviratne et al., 2000; Tien et al., 2002; Unkovich and Pate, 2000). Abendroth et al. (2006) estimated that the nitrogen requirement of a soybean crop is 350 kg N ha^{-1}. Some studies have shown the capability of this symbiotic relationship to fix up to up to 450 kg N ha^{-1} (Unkovich and Pate, 2000) so in some instances nitrogen fixation is great enough to meet the entire nitrogen demand of the crop. However, more conservative estimates suggest that the uptake of fixed nitrogen can meet 60-89% of total demand. (Abendroth et al., 2006; Tien et al., 2002). The amount of fixed nitrogen used by a plant is often largely dependent on N availability in the soil, with the plants utilizing available soil N prior to fixed N (Salvagiotti et al., 2009).

Other researchers have reported more conservative estimates of the amount of N demand fixation meets; ranging from 220 kg N ha^{-1} to 300 kg N ha^{-1} (Abendroth et al., 2006; Bezdicek et al., 1978; Keyser and Li, 1992; Lindemann and Glover, 2003). In a study where soybean yield was statistically similar between treatments inoculated with *B. japonicum* and those not inoculated, the plant uptake of fixed nitrogen increased dramatically over the uptake of soil nitrogen for the inoculated treatment (Tien et al., 2002).

Inoculation of soybean crops in fields with no previous history of soybean production has been an accepted management practice for some time. Inoculation on ground that has not been in soybean production for over five years is generally recommended (Abendroth et al., 2006; Duong et al., 1983; Lindemann and Glover, 2003). Many producers consider successive yearly applications of soybean inoculants good insurance against poor nodulation and decreased nitrogen fixation because of their relative inexpensiveness and ease of use. Some research suggests that successive inoculant applications can increase yield by as much as 4-5% but most often closer to 1-2% (Conley and Christmas, 2006). However, some research on inoculation of fields with a history of soybean production and prior inoculation show inconstant results. Schulz and Thelen (2008) observed a yield increase in only 6 of 14 site years in an inoculation study. They determined that, with an average increase of 0.09 Mg ha^{-1} and an inoculant cost ranging from \$7 to \$10 ha^{-1}, the return from the application of an inoculant was profitable.

Foliar Fertilization

Yield responses from foliar fertilization have been inconsistent at best. Numerous researchers have evaluated application timing, rates, nutrient source, soil nutrient concentration and uptake, root activity, leaf nutrient absorption, and leaf photosynthetic rates in an attempt to determine the cause of the variation in yield response. Research conducted by Garcia and Hanway (1976) contributed greatly to this litany of new research. They reported yield increases up to 0.540 Mg ha^{-1} (24%) in 1974 from a foliar treatment consisting of 49, 21, 36, and 9 kg ha^{-1} of N, P, K, and S, respectively. In 1975 a treatment consisting of 80, 8, 24, and 8 kg ha^{-1} of N, P, K, and S, respectively yielded a more impressive 1.04 Mg ha^{-1} (35%) over the control. Moreover, in another experiment in 1975 foliar fertilizer (96, 10, 29, and 5 kg ha^{-1} of N, P, K, and S, respectively) increased yields of two cultivars (Amsoy and Corsoy) by 1.49 (39%) and 1.57 Mg ha^{-1} (44%) over their controls (Garcia and Hanway, 1976).

Proponents of the validity of yield increases from foliar fertilizer often cite the "self destruct" hypothesis proposed by Sinclair and de Wit (1976). According to Sinclair and de Wit (1976), nutrient remobilization from soybean leaves to the seed hastens leaf senescence and shortens the duration of seed fill, limiting yield. Some researchers have reported that up to 60% of the N, P, and K in the seed may be remobilized from existing plant biomass (Hanway and Weber, 1971; Henderson et al., 1970). In a study conducted using several cultivars with different maturities, remobilization of nitrogen from the biomass to the seed ranged from 30 to 100% with more nitrogen being remobilized in later maturity cultivars (Zeiher et al., 1982). Garcia and Hanway (1976) speculated that minimizing the nutrient depletion of soybean leaves caused by remobilization was the cause of yield increases from foliar fertilization. This reduction in nutrient depletion, they hypothesized, delayed senescence of the soybean resulting in a longer duration of leaf photosynthetic activity and seed fill.

Foliar fertilization can increase leaf nutrient concentrations, but often that increase does not result in a yield increase. With a foliar fertilizer application of 28, 2.9, 8.4, and 1.2 kg ha^{-1} N, P, K and S, respectively leaf nutrient concentrations increased 6, 20, and 43% for N, P, and K, respectively (Boote et al., 1978). However, leaf photosynthesis and yield were no affected. Boote et al. (1978) estimated that leaf area duration was extended by a day, at most, as the result of foliar fertilization. Parker and Boswell (1980) observed a yield decrease with the application of foliar fertilizer (28, 2.9, 9.5, and 1.7 kg ha^{-1} of N, P, K, and S, respectively). They observed few leaf nutrient content increases in the study.

In a study conducted by Vasilas et al. (1980) 44 and 67% ^{15}N labeled urea applied to soybean leaves was taken up in 1976 and 1977, respectively. With a foliar fertilizer application of 21, 2.2, 7, 1.2 kg ha^{-1} of N, P, K, and S, respectively there was no yield increase observed in 1976, and in 1977 yield increased by 1.04 Mg ha^{-1} (33%). Vasilas et al. (1980) attribute the yield increase to the nitrogen in the fertilizer because another treatment with the same rates of P, K, and S did not increase yield compared to the control.

Other researchers have observed yield increases from foliar fertilizer applications, however, none of them showed increase as large as those reported by Garcia and Hanway (1976) (Haq and Mallarino, 1998; Peele, 1977; Syverud et al., 1980; Vasilas et al., 1980). Most documented inconsistent results from the application of foliar fertilizer (Boote et al., 1978; Haq and Mallarino, 1998; Parker and Boswell, 1980; Peele, 1977; Poole et al., 1983; Vasilas et al., 1980).

In general much of the research pertaining to foliar micronutrient applications has been focused on known or observed nutrient deficiencies (Boswell et al., 1981; Gettier et al., 1985; Ross et al., 2006). Some research has been conducted on soils with no evidence of micronutrient deficiencies and the results have been inconsistent with only a few yield increases being observed (Touchton and Boswell, 1975; Loecker et al., 2010).

Row Spacing

Narrow (<76 cm) and wide-row (≥ 76 cm) soybean production systems are employed throughout the United States. According to the USDA-NASS (2009b), in 2009 around 18% of soybeans produced in the United States are grown in row widths less than 25 cm, 43% were grown in widths ranging from 25-47 cm, 11% were grown in row widths between 47-72 cm, 25% were grown in row widths of 72-88 cm, and 3% were grow in row widths greater than 88 cm. Economic factors, such as equipment costs, often play a larger factor in the conversion from a wide-row system to a narrow-row system even though the literature generally concludes that narrow rows often lead to yield increases and more yield stability (Bullock et al., 1998; Cooper, 1977; De Bruin and Pederson, 2008; Ethredge et al., 1989; Janovicek et al., 2006; Taylor, 1980; Weber et al., 1966). When narrow row widths show a yield advantage over wide row widths it is generally thought that an increase in light interception is responsible. In order for maximum yield to be obtained, soybean needs a LAI of around 3.5 (Holshouser and Jones, 2003) by growth stage R5 (Fehr and Caviness, 1977) and 95% light interception near R1 (Shibles and Weber, 1965; Westgate, 1999).

Some studies involving narrow-row soybean production systems in the southeast have had mixed results (Cartter and Hartwig, 1963; Hartwig, 1957). Lee (2006) summarized that row spacings <76 cm in corn had a positive effect on yield in northern United States but that there was a less consistent results south of 43°N latitude. Soybean follows the same pattern, however with more variability in yield response to row width. Beatty et al. (1982), observed a 15% yield increase in Arkansas for soybean grown in either 18 or 48-cm row widths compared to soybean grown in 96-cm row widths. No yield difference was observed between the 18 and 48-cm row widths. In a three year, three location, study conducted in Iowa De Bruin and Pederson (2008) found that soybean grown in 38-cm row widths yielded 0.25 Mg ha^{-1} greater than soybean grown in 76-cm row widths. The yield increase would economically justify the conversion from a 76 to 38-cm row width on a 144 ha farm with 30% of the area in soybean production.

Research on maize, soybean, and sunflower determined that an increase in grain yield from narrow rows was strongly correlated with an increase in light interception at the grain filling stage (Andrade et. al., 2002). An increase in aboveground biomass, light interception, and assimilate utilization are all factors that contribute to yield increases in narrow versus wide-rows (Board et al., 1990; Bullock et al., 1998; and Egli, 1994, respectively).

Objective

Many studies have been conducted to examine the effects of seed treatment, foliar fungicide application, inoculation, soil fertilization beyond state recommendations, foliar fertilization, and row spacing on soybean yield. However, few have been conducted to determine the effect of combining these practices into a single production system. Such multi-variable treatments are far likelier to represent actual on farm practices of producers attempting to maximize yield. These six management practices represent the products being marketed to producers with promises of yield increases. The purpose of this study was to evaluate the individual and combined effect of these management practices on soybean yield.

MATERIALS AND METHODS

Field experiments were conducted in 2009 in Arkansas, Iowa, Kentucky, Louisiana, Michigan, and Minnesota as part of a United Soybean Board funded research project. The cooperators include Jeremy Ross, University of Arkansas; Jason De Bruin and Palle Pedersen, Iowa State University; Jim Board, Louisiana State University; Tim Boring and Kurt Thelen, Michigan State University; and Seth Naeve, University of Minnesota. There were three locations within each state for a total of 18 sites (Table 3-1). Treatments were arranged in a randomized complete block design with six replications. The study consisted of 14 treatments at each location (except at Baton Rouge, LA where narrow row treatments were excluded because of irrigation requirements). Each treatment was a combination of six management practices: seed treatment, inoculation, soil fertility beyond state recommendations, foliar fungicide application(s), foliar fertilizer application, and narrow row spacing (less than 76 cm).

The seed treatment product was Trilex 6000 (Bayer CropScience LP, Research Triangle Park, NC). The seed treatment contains the fungicides trifloxystrobin (2.27 g a.i. per 50 kg seed) and metalaxyl (1.81 g a.i. per 50 kg seed), the insecticide imidacloprid (31.23 g a.i. per 50 kg seed), and a biological fungicide *Bacillus pumilus* (3.12×10^{10} CFU per 50 kg seed). The seed treatment was applied at the manufacturer recommended rate and the seed were planted within the recommended timeline after the treatment.

Vault LV (Becker Underwood, Inc Ames, IA) was the inoculant used for the experiment. It was applied to the seed at a rate of 102 mL per 50 kg seed, which delivered 5.1×10^{11} viable cells of *Bradyrhizobium japonicum* per 50 kg of seed.

All sites in the study were fertilized to meet individual state recommendations. Some treatments received an additional pre-emergence soil fertilizer application of 84 kg P ha^{-1}, 56 kg K ha^{-1}, 22 kg S ha^{-1}, 0.5 kg B ha^{-1}, 2 kg Mn ha^{-1}, 0.5 kg Zn ha^{-1}.

The foliar fungicide pyraclostrobin (carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]- phenyl]methoxy-, methyl ester) was applied at a rate of 219.6 g a.i. ha^{-1} at growth stage R3. The foliar fertilizer was Task Force 2 (Loveland Products, Inc, Greeley, CO). Task Force 2 was applied at a rate of 4.68 L ha^{-1} at growth stage R1 delivering 0.77 kg N ha^{-1}, 0.56 kg P ha^{-1}, 0.35 kg K ha^{-1}, 0.001 kg B ha^{-1}, 3.5×10^{-5} kg Co ha^{-1}, 0.004 kg Cu ha^{-1}, 0.007 kg Fe ha^{-1}, 0.004 kg Mn ha^{-1}, 3.5×10^{-5} kg Mo ha^{-1}, and 0.004 kg Zn ha^{-1}.

The treatments for the study are presented in Table 3-2. Treatment 1 was the check and received no additional inputs. Treatment 2 was considered the high-input system and consisted of all six of the management practices. Treatment 3 consisted of all the management practices except for narrow row spacing. Treatment 4 was all of the management practices except for the foliar fertility. Treatment 5 was all of the management practices except for the additional soil fertility. Treatment 6 consisted of all the management practices except inoculation. Treatment 7 was all of the management practices except for the foliar fungicide application. Treatment 8 consisted of all the management practices except for seed treatment. Treatment 9 focused on late season management practices and included only the foliar fungicide, foliar fertility, and narrow row practices. Treatment 9 was the early season management treatment and consisted of the seed treatment, inoculation, additional soil fertility, and narrow row practices. Treatment 11 consisted of all the management practices except for the foliar fungicide and narrow row spacing practices. Treatment 12 consisted of only the narrow row management practice. Treatment 13 consisted of all of the management practices, but in addition the population was increased by 247,100 seeds ha^{-1}. Treatment 14 consisted of all the management practices, with the population increased by 247,100 seeds ha^{-1} and an additional fungicide application of propiconazole (1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-1,2,4-triazole) and azoxystrobin (methyl (E)-2-[2-[6-(2-cyanophenoxy)pyrimidin-4-yl]oxyphenyl]-3-methoxy-prop-2-enoate) (182.2 g a.i. ha^{-1} and 108.6 g a.i. ha^{-1}, respectively) applied at R5.

Testing all possible combinations of the six factors would result in a very large experiment. Consequently the treatments were arraigned to evaluate specific comparisons (Table 3-3). The study has two standard-input treatments, one with narrow rows (Treatment 12) and one with wide rows (Treatment 1) to compare row width effects in the standard-input system. There were two high-input systems, one with narrow (Treatment 2) and one with wide rows (Treatment 3) to determine the effect of row spacing in a high-input system. The effect of high-inputs in narrow rows was evaluated by comparing the high-input narrow row treatment (Treatment 2) and the standard-input narrow row treatment (Treatment 12). The high-input wide row treatment (Treatment 3) was compared to the standard-input wide row treatment (Treatment 1) to determine the yield difference between high and standard inputs with a wide row spacing. Also included in the study are Treatments 4 through 8; each having one of the different factors omitted. These treatments were designed to be compared to the high-input narrow row treatment (Treatment 2) to assess the value of an individual factor. Treatment 9 was a narrow row late season management treatment (foliar fungicide and foliar fertility), while

Treatment 10 was a narrow row early season management treatment (seed treatment, inoculant, and soil fertility). These treatments were compared to each other and to Treatment 2 (high-input with narrow rows). Treatment 11 (high-input with wide rows and no foliar fungicide) was compared with Treatment 7 (high-input with narrow rows and no foliar fungicide), to distinguish any change in pathogen incidence or severity and subsequent yield differences between narrow and wide rows. Treatments 13 and 14 were considered ultra-high yield treatments. The seeding rate for both was increased by 247,100 seeds ha^{-1} and Treatment 14 had an additional foliar fungicide application at R5. Treatment 13 and Treatment 2 were compared to determine any difference caused by plant population. A comparison of Treatment 13 and 14 determined any benefit from an additional foliar fungicide application.

Each state followed their individual university recommendations for optimum planting date, planting population, tillage system, nutrient requirements, row spacing, and weed control. Adapted soybean cultivars were used in each state (Table 3-1). In general, best management practices were utilized for maximum yield according to agronomic recommendations in each state.

Leaf nutrient concentration was determined by taking a sample of 20 fully developed trifoliate leaves from three of the replications of treatments 2 (high-input with narrow rows), 4 (high-input with narrow rows without foliar fertility), 5 (high-input with narrow rows without extra soil fertility), and 12 (standard-input with narrow rows). The leaf samples were taken three weeks after the foliar fertilization treatment was applied and sent to be Midwest Laboratories, Inc. (Omaha, NE) to be analyzed for nitrogen, phosphorus, potassium, sulfur, magnesium, calcium, sodium, iron, manganese, boron, copper, and zinc. The ANOVA of the leaf nutrient concentration data was calculated using the MIXED procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002). The LSMeans statement was used to determine treatment means. Means were separated using the pdiff option with $\alpha=0.05$.

Yield was measured in all six states by using small plot combines for harvesting. Yield was adjusted to 130 g kg^{-1} moisture. Yield data was analyzed statistically with ANOVA. Data was combined across location within states when location x treatment interactions were not significant. The MIXED procedure of SAS was used for the ANOVA. Treatment was considered as a fixed effect and rep(location), location, and location x treatment were considered random. Treatment means were determined using the LSMeans statement and a means comparison was delineated using the pdiff option with $\alpha=0.05$ in order to evaluate specific comparisons of interest.

Specifications for each site were as follows:

Arkansas

Experiments were conducted near Colt (35° 7' 53" N, 90° 48' 40" W); Keiser (35° 40' 28" N, 90° 5' 59" W); and Weiner, AR (35° 37' 13" N, 90° 53' 54" W). Plots were planted 9 June, 23 June, and 9 June, respectively. Plots were 1.52 m by 6.1 m at all locations. The row spacing for the narrow row treatments was 38 cm and, for the wide row treatments, 76 cm. Normal plant population was 370,650 plants ha^{-1}. Stine cultivar S-4392-4 was used at all three locations. At Colt and Wiener, S-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)-,(S)) (0.61 kg a.i. ha^{-1}) plus fomesafen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-

nitrobenzamide) (0.13 kg a.i. ha^{-1}), and glyphosate (potassium salt of N-(phosphonomethyl)glycine) (0.58 kg a.e. ha^{-1}) were applied pre-emergence. At Keiser 1.07 kg a.i. ha^{-1} of S-metolachlor was applied pre-emergence. Glyphosate (0.63 kg a.e. ha^{-1}) was applied at all three locations as needed for weed control.

Iowa

Experiments were conducted near Corning (40° 59' 28" N, 94° 44' 13" W); Hudson (42° 24' 23" N, 92° 27' 19" W); and Story City, IA (42° 11' 10" N, 93° 35' 30" W). Plots were planted 20 May, 11 May, and 19 May, respectively. The plot size at all locations was 3.05 m by 7.62 m. The row spacing for the narrow row treatments was 38 cm and, for the wide row treatments, 76 cm. The normal population was 370,650 plants ha^{-1}. Dekalb cultivar DKB27-52 was used at all three locations. At Corning fluazifop-p-butyl (Butyl(R)-2-[4-[[5-(triluoromethyl)-2-pyrid-inyl]oxy]phenoxy]propanoate) plus fenoxaprop-P-ethyl ((+)-ethyl-2-[4-[6-(chloro-2-benzoxazolyl)oxy]phenoxy]propanoate) (0.14 kg a.i. ha^{-1} and 0.04 kg a.i. ha^{-1}, respectively) and glyphosate (0.95 kg a.e. ha^{-1}) were applied to control weeds. An additional glyphosate application (1.26 kg a.e. ha^{-1}) was applied in season. At Hudson a preplant herbicide application of S-metolachlor plus fomesafen (1.22 kg a.i. ha^{-1} and 0.27 kg a.i. ha^{-1}, respectively) was made. An in season application of fluazifop-p-butyl plus fenoxaprop-P-ethyl (0.18 kg a.i. ha^{-1} and 0.05 kg a.i. ha^{-1}, respectively) and glyphosate (1.26 kg a.e. ha^{-1}) was also made. At Story City location S-metolachlor plus fomesafen (0.91 kg a.i. ha^{-1} and 0.20 kg a.i. ha^{-1}, respectively) was applied preplant. Fluazifop-p-butyl plus fenoxaprop-P-ethyl (0.14 kg a.i. ha^{-1} and 0.04 kg a.i. ha^{-1}, respectively) and glyphosate (0.95 kg a.e. ha^{-1}) was applied in season. Fluazifop-p-butyl plus fenoxaprop-P-ethyl (0.18 kg a.i. ha^{-1} and 0.05 kg a.i. ha^{-}

^{1}, respectively) and glyphosate (1.26 kg a.e. ha^{-1}) were applied a second time during the growing season.

Kentucky

Experiments were conducted near Lexington (37° 59' 19" N, 84° 28' 39" W); New Haven (37° 39' 28" N, 85° 35' 27" W); and Oak Grove, KY (36° 39' 54" N, 87° 26' 34" W). Plots were planted 18 May, 19 May, and 20 May, respectively. Plots were 1.52 m by 7.62 m at all locations. The row spacing for the narrow row treatments was 38 cm and, for the wide row treatments, 76 cm. Normal plant population was 321,230 plants ha^{-1}. Stine cultivar S-4020-4 was used at all three locations. At New Haven glyphosate (1.11 kg a.e. ha^{-1}) and sulfentrazone ({N-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide) (0.42 kg a.i. ha^{-1}) were applied pre-plant. Glyphosate (1.18 kg a.e. ha^{-1}) and imazethapyr ([2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) (0.07 kg a.i.) was applied pre-emergence in both Lexington and Oak Grove. In season applications of glyphosate (1.11 kg a.e. ha^{-1}) were made at all three locations as needed for weed control.

Louisiana

Experiments were conducted near Baton Rouge (30° 27' 2" N, 91° 9' 16" W); Crowley (30° 12' 50" N, 92° 22' 28" W); and St. Joseph, LA (31° 56' 25" N, 91° 17' 8" W). Plots were planted 17 April, 15 April, and 15 May, respectively. Plots were 0.97 m by 10.97 m at Baton Rouge, 1.62 m by 7.62 m at Crowley, and 2.03 m by 7.62 m at St. Joseph. Row spacing for the narrow rows was 41 and 51 cm at Crowley and St. Joseph, respectively. There were no narrow row treatments at Baton Rouge due to in-furrow irrigation limitations. The row spacing for wide row treatments was 96 cm at Baton Rouge, 81 cm at Crowley, and 102 at St. Joseph. The normal population was 494, 200 plants ha^{-1}. Stine cultivar S-4782-4 was used at all three locations. At Baton Rouge glyphosate (0.84 kg a.e. ha^{-1}) was applied pre-emergence and in season as needed for weed control. At Crowley and St. Joseph, flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-iso-1,3(2H)-dione) (0.072 kg a.i. ha^{-1}) was applied pre-emergence and glyphosate (0.84 kg a.e. ha^{-1}) was applied was applied in season as needed to control weeds.

Michigan

Experiments were conducted near Branch (43° 56' 5" N, 86° 6' 50" W); East Lansing (42° 44' 13" N, 84° 29' 1" W); and Tuscola, MI (43° 19' 35" N, 83° 39' 25" W). Plots were planted 23 May, 1 June, and 19 May, respectively. Plots were 6.09 m by 12.19 m at all locations. Row spacing for the narrow row treatments was 38 cm and, for the wide row treatments, 76 cm. The normal population was 432,425 plants ha^{-1}. The Dekalb cultivar DKB27-52 was used at all three locations. At all locations, s-metolachlor plus metribuzin ([4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one]) (1.11 kg a.i. ha^{-1} plus 0.26 kg a.i. ha^{-1}) was applied pre-emergence. Glyphosate (0.84 kg a.e. ha^{-1}) was applied as needed for in season weed control at all locations as well.

Minnesota

Experiments were conducted near Becker (45° 22' 16" N, 93° 52' 24" W); St. Paul (44° 56' 39" N, 93° 5' 9" W); and Waseca, MN (44° 4' 39" N, 93° 30' 26" W). Plots were planted 4 May, 6 May, and 10 May, respectively. The plot size at all locations was 3.05 m by 9.14 m. The row spacing for the narrow row treatments was 51 cm and, for the wide row treatments, 76 cm. The normal population was 247,000 plants ha^{-1}. Asgrow cultivar AG2002 was used at all three locations. At Becker, trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine) plus imazethapyr was applied preplant and incorporated (0.56 kg a.i. ha^{-1} and 0.07 kg a.i. ha^{-1}, respectively). In season applications of glyphosate (1.26 kg a.e. ha^{-1}) were made as needed for weed control. At St. Paul, glyphosate (1.26 kg a.e. ha^{-1}) was used for weed control during the season. At the Waseca location trifluralin plus imazethapyr was applied preplant (0.84 kg a.i. ha^{-1} and 0.07 kg a.i. ha^{-1}, respectively). Glyphosate (1.26 kg a.e. ha^{-1}) was applied as needed for in season weed control.

RESULTS AND DISCUSSION

The average temperature throughout the growing season was similar to the 30 year average for the Colt, Weiner, Lexington, New Haven, Oak Grove, and St. Joseph locations (Table 3-4). The Keiser, Baton Rouge, and Crowley locations were slightly warmer than the 30-year season average. Total precipitation was above average in 2009 at the Colt, Keiser, Weiner, Lexington, Oak Grove and St. Joseph locations. New Haven was within 7 mm of its season average, while Baton Rouge and Crowley were well below the 30 year average (204 and 106 mm, respectively).

Yield

There was a significant location x treatment interaction when all sites were combined ($p= < 0.0001$; data not shown), so yield data is presented for each location arranged by latitude (Table 3-5). Specific comparisons are presented in Table 3-6. The five-year state mean yields and the study mean for each state are presented in Table 3-7 for comparison purposes. Study mean yields were above the five-year mean yield in each state for all states but Michigan. Yields from the studies in the five other states were in high-yielding environments.

Eleven out of the 18 total locations had a significant treatment effect for seed yield (Table 3-5). There were three locations in Arkansas with a significant treatment effect; two locations in Kentucky, Michigan and Minnesota had a significant treatment effect. Both Iowa and Louisiana had one location each where there was a significant treatment effect.

Treatment 14 (ultra-high input, additional foliar fungicide) was among the highest-yielding treatments in 10 of the 11 locations with a significant treatment effect; while Treatment 13 (ultra-high input) was among the highest in 9 locations (Table 3-5). The high-input narrow row treatment (Treatment 2) was among the highest yielding treatments in 7 locations. Treatment 1 (standard input, wide row) was among the lowest yielding treatment in all 11 locations with a significant treatment effect. Treatment 12 (standard input, narrow row) was among the lowest yielding treatments in 9 of the 11 locations. Treatment 3 (high-input wide row) was among the lowest yielding treatments in 7 locations.

For the comparisons of interest, a yield increase in the high input system compared with the standard input system occurred most often with a narrow row spacing. In narrow rows, high inputs (Treatment 2) yielded 25% greater than standard inputs (Treatment 12) in 5 of the 18 sites (Table 3-6). Those 5 locations were Crowley, LA, Story City, IA, Branch, MI, Becker, MN and Waseca, MN (Table 3-5). In wide rows, high inputs yielded higher than standard inputs (Treatment 3 vs. Treatment 1) at 3 locations (Crowley, LA, Weiner, AR, and New Haven, KY).

In the comparison of high inputs versus ultra-high inputs in narrow rows (seeding rate increase of 274,000 seeds ha^{-1}) both yield increases and decreases were observed. In narrow rows, ultra-high inputs (Treatment 13) yielded 23% higher than high inputs (Treatment 2) at three sites (Kaiser, AR, Lexington, KY, and New Haven, KY). Conversely, ultra-high inputs (Treatment 13) yielded 16% less than high inputs (Treatment 2) at the Becker, MN location. Soybean yield typically reaches a plateau at relatively low populations and increasing the population beyond this point does not increase yield (Edwards and Purcell, 2005; Norsworthy and Frederick, 2002; Pederson and Lauer, 2002). The results from 14 of the locations in this study support this idea.

Including an additional foliar fungicide at R5 in the ultra-high input system (Treatment 14 vs. Treatment 13) increased yields by 27% at one site (Crowely, LA) (Table 3-5). Interestingly, Treatment 14 resulted in yields at least 25% greater than any other treatment at Crowley. Furthermore, all yields at Crowley were less than half of yields at the other two sites in LA. Most likely, a late-season disease drastically reduced yields at Crowley. While the yield increase from the foliar fungicide was impressive at Crowley, the additional fungicide had no effect on yield at the other 17 sites. In addition, the high-input treatment containing foliar fungicide (Treatment 2) yielded 19% higher than the high-input treatment without foliar fungicide (Treatment 7) in two locations (Lexington, KY and Story City, IA).

Ultra high inputs increased yields by 24% compared with standard inputs in narrow rows (Treatment 12) at six locations (Kaiser, AR, Lexington, KY, New Haven, KY, Story City, IA, Branch, MI and Waseca, MN) and by 129% at Crowley, LA (Table 3-5). Again, the Crowley site had large ranges in yield in a low-yielding environment.

At two locations (Story City, IA and Branch, MI) the additional soil fertility increased yields by 19% (Treatment 2 vs. Treatment 5) (Table 3-6). These yield increases indicate that either fertilizer applied to recommended rates was not sufficient; however, this occurrence is only at two sites out of 18 total. Perhaps error in either soil sampling or soil testing explains these two sites.

Narrow rows resulted in yield increases compared with wide rows under similar management systems in only 4 out of 36 comparisons (Table 3-6). Narrow rows yielded 18% greater than wide rows in the high input system (Treatment 2 vs. Treatment 3) in three sites (New Haven, KY, Becker, MN and Waseca, MN) (Table 3-5). Narrow rows yielded 23% greater than wide rows in a standard input system (Treatment 12 vs. Treatment 1) at only Colt, AR (Tables 3-5, 3-6). While most research indicates that narrow rows increase yields in northern climates (De Bruin and Pederson, 2008; Lee, 2006; Oplinger and Philbrook, 1992), in this study, narrow rows increased yields in only two sites out of nine northern sites

Leaf Nutrient Concentration

Leaf nutrient concentration data is presented in the appendix (Table A-1 through Table A-7). Because foliar fertilization and additional soil fertility had no effect on yield (with the exception of Michigan), leaf nutrient concentration data is presented in the appendix. The effect of foliar fertilization (Treatment 2 vs. Treatment 4) on yield was not significant in the statistical analysis of any of the states or the combined analysis (Table 3-7). In addition, Michigan was the only state in which the pair-wise mean comparison to determine the effect of soil fertility on yield was significant. No leaf nutrient concentrations differences were observed.

CONCLUSION

According to the results of this study, high-input management practices are largely unsuccessful in increasing soybean yields. High inputs yielded higher than standard inputs (in wide or narrow rows) in only 8 of the 18 locations. Narrow rows, in both the high and standard-input systems, only increased yield in 4 locations. Inoculant did not increase yield at any location. Foliar fertilizer application and seed treatment increased yield in one location each. The additional soil fertility and fungicide application increased yield in two locations each. The increased population increased yields in 3 of the 18 locations; while an additional fungicide application at R5 only increased yield in 1 location.

More sites and years of data are needed to determine the probability of yield increase to additional management factors. In addition, an economic analysis comparing input costs and different commodity prices for soybeans would be needed to help determine when and if any management strategies are more profitable.

While the yield increased from some of the increased management practices are interesting, the yield increases are not consistent enough over the range of sites to justify any recommendations at this point.

Table 3-1. High input management systems location information.

Location		Soil Series†	Plot size		Tillage	Previous crop	Row Spacing		Target Population		Date		Variety
			width	length			narrow	wide	normal	+250,000	Planting	Harvest	
			—— m ——				— cm —		— plants ha^{-1} —				
Colt , AR	35°7'53" N, 90°48'40" W	Calloway silt loam	1.52	7.62	fall, spring	rice	38	76	370,650	617,750	6/9	10/21	S-4392-4
Keiser, AR	35°40'28" N, 90°5'59" W	Sharkey silty clay	1.52	7.62	fall, spring	corn	38	76	370,650	617,750	6/23	10/21	S-4392-4
Weiner, AR	35°37'13" N, 90°53'54" W	Henry silt loam	1.52	7.62	fall	soybean	38	76	370,650	617,750	6/9	10/21	S-4392-4
Corning, IA	40°59'28" N, 94°44'13" W	Macksburg silty clay loam	3.05	7.62	fall, spring	corn	38	76	370,650	617,750	5/20	10/20	DKB27-52
Hudson, IA	42°24'23" N, 92°27'19" W	Nevin silty clay	3.05	7.62	fall, spring	corn	38	76	370,650	617,750	5/11	10/13	DKB27-52
Story City, IA	42°11'10" N, 93°35'30" W	Kossuth silty clay loam	3.05	7.62	fall, spring	corn	38	76	370,650	617,750	5/19	10/11	DKB27-52
Lexington, KY	37°59'19" N, 84°28'39" W	Mercer silt loam	1.52	9.14	no-till	corn	38	76	321,230	568,330	5/18	11/12	S-4020-4
New Haven, KY	37°39'28" N, 85°35'27" W	Lindside silt loam	1.52	9.14	no-till	corn	38	76	321,230	568,330	5/19	11/5	S-4020-4
Oak Grove, KY	36°39'54" N, 87°26'34" W	Pembroke silt loam	1.52	9.14	spring	corn	38	76	321,230	568,330	5/20	10/26	S-4020-4

†Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs); Sharkey silty clay (very-fine, smectitic, thermic Chromic Epiaquerts); Henry silt loam (coarse-silty, mixed, active, thermic Typic Fragiaqualfs); Macksburg silty clay loam (fine, smectitic, mesic Aquertic Argiudolls); Nevin silty clay (fine-silty, mixed, superactive, mesic Aquic Pachic Argiudolls); Kossuth silty clay loam (fine-loamy, mixed, superactive, mesic Typic Endoaquolls); Mercer silt loam (fine-silty, mixed, semiactive, mesic Oxyaquic Fragiudalfs); Lindside silt loam (fine-silty, mixed, active, mesic Fluvaquentic Eutrudepts); Pembroke silt loam (fine-silty, mixed, active, mesic Mollic Paleudalfs)

Table 3-1. Continued.

Location		Soil Series†	Plot size		Tillage	Previous crop	Row Spacing		Target Population		Date		Variety
			width	length			narrow	wide	normal	+250,000	Planting	Harvest	
			—— m ——				—— cm ——		— plants ha^{-1} —				
Baton Rouge, LA	30°27'2" N, 91°9'16" W	Commerce silt loam	3.05	9.14	fall, spring	wheat	n/a‡	96	247,100	494,200	4/17	9/15	S-4782-4
Crowley, LA	30°12'50" N, 92°22'28" W	Crowley silt loam	3.25	7.62	spring	fallow	41	81	247,100	494,200	4/15	9/30	S-4782-4
St. Joseph, LA	31°56'25" N, 91°17'8" W	Sharkey clay	4.06	7.62	fall, spring	sorghum	51	102	247,100	494,200	5/15	10/1	S-4782-4
Branch, MI	43°56'5" N, 86°6'50" W	Fox sandy loam	6.10	12.19	fall, spring	corn	38	76	432,425	679,525	5/23	10/22	DKB27-52
East Lansing, MI	42°44'13" N, 84°29'1" W	Capac loam	6.10	12.19	fall, spring	corn	38	76	432,425	679,525	6/1	10/27	DKB27-52
Tuscola, MI	43°19'35" N, 83°39'25" W	Tappan-Lando loam	6.10	12.19	fall, spring	corn	38	76	432,425	679,525	5/19	11/23	DKB27-52
Becker, MN	45°22'16" N, 93°52'24" W	Hubbard Coarse Loam	3.05	9.14	spring	rye	51	76	247,100	494,200	5/4	10/18	AG2002
St Paul, MN	44°56'39" N, 93°5'9" W	Waukegan Silt Loam	3.05	9.14	spring	corn	51	76	247,100	494,200	5/6	10/16	AG2002
Waseca, MN	44°4'39" N, 93°30'26" W	Webster Clay Loam	3.05	9.14	spring	corn	51	76	247,100	494,200	5/10	10/21	AG2002

†Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts); Crowley silt loam (fine, smectitic, thermic Typic Albaqualfs); Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts); Fox sandy loam (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludalfs); Capac loam (fine-loamy, mixed, active, mesic Aquic Glossudalfs); Tappan-Lando loam (fine-loamy, mixed, active, calcareous, mesic Typic Endoaquolls); Hubbard Coarse Loam (sandy, mixed, frigid Entic Hapludolls); Waukegan Silt Loam (fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls); Webster Clay Loam (fine-loamy, mixed, superactive, mesic Typic Endoaquolls);

‡ No narrow row treatments due to irrigation requirements

Table 3-2. High input management systems treatment list.

Treatment†		Management Practice‡					
		Seed treatment	Fungicide	Inoculant	Additional soil fertility	Foliar fertility	Row spacing <76 cm
1	Low input–wide row						
2	High input–narrow row	+	+	+	+	+	+
3	High input–wide row	+	+	+	+	+	
4	High input–narrow row w/o foliar fertility	+	+	+	+		+
5	High input–narrow row w/o soil fertility	+	+	+		+	+
6	High input–narrow row w/o inoculant	+	+		+	+	+
7	High input–narrow row w/o fungicide	+		+	+	+	+
8	High input–narrow row w/o seed treatment		+	+	+	+	+
9	Late season management–narrow row		+			+	+
10	Early season management–narrow row	+		+	+		+
11	High input–wide row w/o foliar fungicide	+		+	+	+	
12	Low input–narrow row						+
13	Ultra high input–narrow row§	+	+	+	+	+	+
14	Ultra high input–narrow row + additional fungicide§#	+	+	+	+	+	+

† High input includes: seed trt (trifloxystrobin: 2.27 g a.i. per 50 kg seed, metalaxyl: 1.81 g a.i. per 50 kg seed, imidacloprid: 31.23 g a.i. per 50 kg seed), foliar fungicide (pyraclostrobin: 219.6 g a.i. ha^{-1} at R3), inoculant (Vault LVL), soil fertility (84 kg P ha^{-1}, 56 kg K ha^{-1}, 22 kg S ha^{-1}, 0.5 kg B ha^{-1}, 2 kg Mn ha^{-1}, 0.5 kg Zn ha^{-1}), foliar fertility (4.68 L ha^{-1} at R1; Task Force 2: 11-8-5 plus 0.2 g B kg^{-1}, 0.005 g Co kg^{-1}, 0.5 g Cu kg^{-1}, 1.0 g Fe kg^{-1}, 0.5 g Mn kg^{-1}, 0.005 g

‡ A (+) in a column under a management practice heading denotes that the management practice was used in that treatment

Table 3-3. Treatment comparisons of most interest.

Treatment Comparison			Factor Evaluated
12 Low input–narrow row	vs.	1 Low input–wide row	Narrow vs. wide row (low inputs)
2 High input–narrow row	vs.	3 High input–wide row	Narrow vs. wide row (high inputs)
1 Low input–wide row	vs.	3 High input–wide row	High vs. low input (wide rows)
2 High input–narrow row	vs.	12 Low input–narrow row	High vs. low input (narrow rows)
2 High input–narrow row	vs.	4 High input–narrow row w/o foliar fertility	High input vs. high input w/o foliar fertility
2 High input–narrow row	vs.	5 High input–narrow row w/o soil fertility	High input vs. high input w/o soil fertility
2 High input–narrow row	vs.	6 High input–narrow row w/o inoculant	High input vs. high input w/o innoculant
2 High input–narrow row	vs.	7 High input–narrow row w/o fungicide	High input vs. high input w/o fungicide
2 High input–narrow row	vs.	8 High input–narrow row w/o seed treatment	High input vs. high input w/o seed treatment
9 Late season mgmt.–narrow row	vs.	10 Early season management–narrow row	Early season mgmt vs. late season mgmt
2 High input–narrow row	vs.	9 Late season management–narrow row	Full season mgmt. vs late season mgmt.
2 High input–narrow row	vs.	10 Early season management–narrow row	Full season mgmt. vs early season mgmt.
7 High input–narrow row w/o fungicide	vs.	11 High input–wide row w/o foliar fungicide	narrow vs. wide rows (high input w/o foliar fungicide)
13 Ultra high input–narrow row	vs.	2 High input–narrow row	Ultra high vs. high input (narrow rows)
13 Ultra high input–narrow row‡	vs.	14 Ultra high input–narrow row + fungicide	Ultra high vs. high input w/ add'l foliar fungicide

Table 3-4. Mean monthly air temperature and precipitation data during growing season, 2009.

Location	Air Temperature							Rainfall						
	May	June	July	Aug.	Sept.	Avg. (May-Sept.)	30 yr. avg. (May-Sept.)	May	June	July	Aug.	Sept.	Total (May-Sept.)	30 yr. avg. (May-Sept.)
	°C							mm						
Colt, AR	21.1	26.1	25.0	25.0	23.3	24.1	24.0	220	52	217	69	200	758	438
Keiser, AR	22.2	27.8	26.7	26.7	24.4	25.6	24.4	196	54	215	30	220	716	496
Weiner, AR	20.0	27.2	25.6	24.4	21.7	23.8	24.4	181	133	241	103	246	904	445
Corning, IA	15.6	22.2	20.6	21.1	17.8	19.4	20.1	53	77	96	101	8	335	539
Hudson, IA	15.6	20.6	20.0	20.6	17.2	18.8	20.3	94	91	140	136	53	515	563
Story City, IA	15.6	21.1	20.6	20.6	17.2	19.0	19.7	142	80	59	99	29	409	513
Lexington, KY	18.3	23.3	22.2	22.8	20.6	21.4	21.7	153	132	192	115	150	742	535
New Haven, KY	18.9	23.9	22.2	23.9	21.1	22.0	21.7	120	111	158	31	126	545	553
Oak Grove, KY	18.9	24.4	23.3	23.9	21.7	22.4	22.8	147	67	213	53	82	561	502
Baton Rouge, LA	25.0	28.3	28.9	27.8	26.1	27.2	26.0	56	15	114	166	141	491	694
Crowley, LA	24.4	28.9	28.9	28.3	26.7	27.4	26.4	93	43	222	89	128	575	680
St. Joseph, LA	23.3	27.2	27.2	26.7	25.0	25.9	26.1	151	17	228	109	90	595	491
Branch, MI	12.2	16.7	17.2	18.9	15.6	16.1	16.7	61	55	21	89	25	251	434
East Lansing, MI	13.9	18.9	19.4	20.0	16.7	17.8	18.1	104	113	74	164	18	472	395
Tuscola, MI	15.0	18.9	19.4	20.0	17.2	18.1	18.3	53	138	89	84	33	396	419
Becker, MN	14.4	17.8	19.4	21.1	19.4	18.4	18.3	13	85	30	90	13	231	489
St Paul, MN	15.6	19.4	20.6	20.6	18.9	19.0	19.3	14	59	58	150	11	292	526
Waseca, MN	16.7	20.0	18.9	20.6	18.9	19.0	18.5	27	45	51	70	18	211	519

Table 3-5. Comparison of least square means of yield by state and location, 2009.

	Treatment	Louisiana			Arkansas			Kentucky		
		Baton Rouge	Crowley	St. Joseph	Colt	Keiser	Weiner	Hopkins-ville	Lexington	New Haven
		Mg ha^{-1}								
1	Standard input–wide row	4.22	0.57 ef	4.63	3.91 e	3.49 b	4.18 c	4.36	4.56 cde	1.90 e
2	High input–narrow row	n/a	0.84 bcd	4.72	4.69 abcd	3.37 b	4.69 abc	4.27	5.14 bc	2.66 bcd
3	High input–wide row	4.62	0.82 bcd	4.42	4.05 de	3.38 b	4.75 ab	4.21	4.78 bcde	2.01 e
4	High input–narrow row w/o foliar fertility	4.26	0.82 bcd	4.71	5.03 ab	3.61 b	4.69 abc	4.47	4.78 bcde	2.84 abc
5	High input–narrow row w/o soil fertility	4.54	0.77 bcde	4.62	4.63 abcd	3.18 b	4.54 bc	4.67	4.41 cde	3.14 ab
6	High input–narrow row w/o inoculant	4.74	0.77 bcde	4.66	5.04 a	3.60 b	4.53 bc	4.28	4.95 bcd	2.87 abc
7	High input–narrow row w/o foliar fungicide	4.36	0.71 cde	4.42	4.74 abc	3.74 b	4.49 bc	4.07	4.14 de	2.76 abc
8	High input–narrow row w/o seed treatment	5.06	0.99 b	4.6	4.65 abcd	3.38 b	4.51 bc	4.24	4.14 de	2.67 bcd
9	Late season management–narrow row	5.14	0.62 def	4.87	4.43 bcde	3.52 b	4.49 bc	4.68	3.98 e	2.77 abc
10	Early season management–narrow row	4.87	0.93 bc	4.56	4.58 abcde	3.38 b	4.36 bc	4.36	4.24 de	2.81 abc
11	High input–wide row w/o foliar fungicide	n/a	0.56 e	4.57	4.34 cde	3.45 b	4.46 bc	4.13	4.44 cde	2.13 de
12	Standard input–narrow row	n/a	0.42 f	4.57	4.80 abc	3.63 b	4.27 bc	4.16	4.61 bcde	2.33 cde
13	Ultra high input–narrow row	5.17	0.96 b	4.67	5.23 a	4.30 a	5.09 ab	4.45	6.05 a	3.25 a
14	Ultra high input–narrow row + add'l fungicide	5.16	1.33 a	4.68	5.18 a	4.70 a	5.22 a	4.48	5.45 ab	3.12 ab
	Mean	4.74	0.79	4.62	4.66	3.62	4.59	4.35	4.69	2.66
	ANOVA	*P > f*								
	Treatment	0.2591	<0.0001	0.126	0.0043	0.003	0.0231	0.4491	0.0008	<0.0001

† Means in a column followed by the same letter are not statistically different at the 0.05 probability level (columns lettered only when the treatment effect was significant)

Table 3-5. Continued.

	Treatment	Iowa			Michigan			Minnesota		
		Corning	Hudson	Story City	Branch	East Lansing	Tuscola	Becker	St. Paul	Waseca
		Mg ha^{-1}								
1	Standard input–wide row	4.54	4.02	3.41 f	2.31 ab	2.65	2.83 cde	4.82 de	4.21	4.18 def
2	High input–narrow row	4.64	4.33	4.63 a	2.45 a	2.88	2.90 abcde	5.8 a	4.23	4.63 ab
3	High input–wide row	4.79	3.95	4.22 abcd	2.3 ab	2.49	2.85 bcde	5.2 bcd	4.14	4.26 cdef
4	High input–narrow row w/o foliar fertility	4.87	4.15	4.5 ab	2.56 a	2.83	3.04 ab	5.27 bcd	4.50	4.61 ab
5	High input–narrow row w/o soil fertility	4.56	4.11	3.94 de	2.04 b	2.60	2.91 abcd	5.47 abc	4.35	4.63 ab
6	High input–narrow row w/o inoculant	4.67	4.42	4.58 a	2.54 a	2.74	3.08 a	5.38 abc	4.32	4.42 abcdef
7	High input–narrow row w/o foliar fungicide	4.71	4.01	4.09 bcde	2.3 ab	2.83	2.88 bcde	5.43 abc	4.10	4.38 abcdef
8	High input–narrow row w/o seed treatment	4.41	4.37	4.55 ab	2.49 a	2.88	2.89 bcde	5.62 ab	4.18	4.52 abcd
9	Late season management–narrow row	4.9	4.19	4.43 abc	2.27 ab	2.56	2.71 e	5.61 ab	4.44	4.56 abc
10	Early season management–narrow row	4.49	4.02	4.28 abcd	2.51 a	2.84	2.89 bcde	5.5 abc	4.25	4.35 bcdef
11	High input–wide row w/o foliar fungicide	4.75	4.13	3.99 cde	2.46 a	2.87	2.78 de	4.52 e	4.13	4.09 f
12	Standard input–narrow row	4.65	4.19	3.68 ef	1.95 b	2.74	2.84 cde	5.22 bcd	4.31	4.12 ef
13	Ultra high input–narrow row	4.76	4.09	4.5 ab	2.43 a	2.85	2.98 abc	5.01 cde	4.10	4.71 a
14	Ultra high input–narrow row + add'l fungicide	4.52	4.32	4.52 ab	2.58 a	2.96	3.00 abc	5.17 bcd	4.14	4.46 abcde
	Mean	4.66	4.16	4.24	2.37	2.77	2.90	5.29	4.24	4.42

ANOVA	Corning	Hudson	Story City	Branch	East Lansing	Tuscola	Becker	St. Paul	Waseca
	P > f								
Treatment	0.6843	0.1843	<0.0001	0.0247	0.3706	0.0273	0.0003	0.6696	0.0046

† Means in a column followed by the same letter are not statistically different at the 0.05 probability level (columns lettered only when the treatment effect was significant)

Table 3-6. Number of locations with a treatment comparison of significance, α=0.05, 2009.

Treatment Comparison				Locations with Significant Difference
12	vs.	1	Narrow vs. wide row (standard inputs)	1
2	vs.	3	Narrow vs. wide row (high inputs)	3
3	vs.	1	High vs. standard input (wide rows)	3
2	vs.	12	High vs. standard input (narrow rows)	5
2	vs.	4	High input vs. high input w/o foliar fertility	1
2	vs.	5	High input vs. high input w/o soil fertility	2
2	vs.	6	High input vs. high input w/o inoculant	NS
2	vs.	7	High input vs. high input w/o fungicide	2
2	vs.	8	High input vs. high input w/o seed treatment	1
9	vs.	10	Early season mgmt vs. late season mgmt	1
2	vs.	9	Full season mgmt. vs. late season mgmt.	1
2	vs.	10	Full season mgmt. vs. early season mgmt.	1
7	vs.	11	narrow vs. wide rows (high input w/o foliar fungicide)	2
13	vs.	2	Ultra high vs. high input (narrow rows)	3
13	vs.	14	Ultra high vs. ultra high input w/ add'l foliar fungicide	1

† Total of 18 locations, 11 had significant treatment effects

Table 3-7. Five year average state soybean yields.†

Location	Yield						
	2005	2006	2007	2008	2009	5 Year Mean	Study Mean
	Mg ha^{-1}						
Arkansas	2.29	2.35	2.42	2.56	2.52	2.43	4.29
Iowa	3.53	3.40	3.50	3.13	3.43	3.40	3.50
Kentucky	2.89	2.96	1.85	2.32	3.23	2.65	3.38
Louisiana	2.29	2.42	2.89	2.22	2.62	2.49	4.35
Michigan	2.59	3.09	2.69	2.49	2.69	2.71	2.68
Minnesota	3.06	2.99	2.86	2.56	2.69	2.83	4.65

† Source: USDA-NASS, 2009

Appendix

Table A-1. LSMeans comparison of leaf nutrient concentrations, Arkansas, 2009.

Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
	g kg^{-1}						mg kg^{-1}				
2 High input–narrow row	53.18	4.43	20.62	3.36	4.74	15.15	164.07	168.02	9.85	58.91	73.37
4 High input–narrow row w/o foliar fertility	53.63	4.54	20.99	3.43	4.65	13.53	153.22	153.89	12.89	61.22	87.33
5 High input–narrow row w/o soil fertility	54.99	4.41	20.88	3.31	4.40	13.81	139.19	130.40	11.72	59.79	75.37
12 Low input–narrow row	54.17	4.38	20.25	3.36	4.61	15.47	154.44	170.78	10.00	58.78	94.33
Mean	53.99	4.44	20.69	3.36	4.60	14.49	152.73	155.77	11.11	59.67	82.60
ANOVA	*P > f*										
Treatment	0.9272	0.8345	0.8459	0.7924	0.6527	0.7274	0.3774	0.5202	0.2556	0.7426	0.2750
Location	0.0059	<0.0001	<0.0001	<0.0001	0.4342	0.0622	<0.0001	<0.0001	0.1175	<0.0001	0.0004
Rep(Location)	0.2877	0.9280	0.2892	0.3571	0.9738	0.7569	0.5897	0.6046	0.4302	0.3176	0.5722

Table A-2. LSMeans comparison of leaf nutrient concentrations, Iowa, 2009.

Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
	g kg^{-1}						mg kg^{-1}				
2 High input–narrow row	61.61	4.93	25.60	3.62	3.18	11.02	139.11	65.00	11.89	60.89 a†	37.11
4 High input–narrow row w/o foliar fertility	63.06	5.30	25.98	3.71	3.52	11.64	147.67	70.78	12.22	61.33 a	41.11
5 High input–narrow row w/o soil fertility	61.27	4.88	25.66	3.60	3.50	11.36	137.00	66.11	12.00	57.67 ab	37.89
12 Low input–narrow row	63.61	4.82	24.12	3.66	3.58	11.69	135.89	66.44	11.44	54.44 b	38.22
Mean	62.39	4.98	25.34	3.64	3.45	11.43	139.92	67.08	11.89	58.58	38.58
ANOVA	*P > f*										
Treatment	0.2637	0.1836	0.2157	0.8443	0.1681	0.5675	0.2889	0.6335	0.5919	0.0300	0.1924
Location	<0.0001	0.0126	<0.0001	0.0028	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001
Rep(Location)	0.2251	0.4400	0.0540	0.8508	0.0161	0.3387	0.3496	0.0097	0.3917	0.0112	0.4325

† Means in a column followed by the same letter are not statistically different at α=0.05 (columns lettered only when the treatment effect was significant)

Table A-3. LSMeans comparison of leaf nutrient concentrations, Kentucky, 2009.

	Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
		g kg^{-1}						mg kg^{-1}				
2	High input–narrow row	57.06	4.22	20.17 a†	3.35	3.34	13.95	105.22	156.33 b	10.44	58.00	49.78
4	High input–narrow row w/o foliar fertility	59.35	4.29	20.42 a	3.53	3.28	13.79	109.11	207.89 a	9.67	60.11	57.11
5	High input–narrow row w/o soil fertility	60.30	4.45	20.20 a	3.46	3.37	14.47	109.00	158.67 b	10.44	60.56	49.56
12	Low input–narrow row	60.16	4.05	17.72 b	3.28	3.20	12.89	107.78	144.11 b	10.56	55.22	48.11
	Mean	59.22	4.25	19.63	3.41	3.30	13.78	107.78	166.75	10.28	58.47	51.14

ANOVA	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
	P > f										
Treatment	0.1067	0.0675	0.0191	0.1413	0.6589	0.0575	0.9048	0.0084	0.4179	0.3987	0.2562
Location	<0.0001	<0.0001	0.0013	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0106	<0.0001	<0.0001
Rep(Location)	0.3018	0.0871	0.0393	0.1719	0.7708	0.6470	0.9656	0.6179	0.0301	0.2163	0.4881

† Means in a column followed by the same letter are not statistically different at α=0.05 (columns lettered only when the treatment effect was significan

Table A-4. LSMeans comparison of leaf nutrient concentrations, Louisiana, 2009.

Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
	g kg^{-1}						mg kg^{-1}				
2 High input–narrow row	42.68	3.79	21.34	3.48	4.68	15.72	254.50	145.17	13.50	76.00 ab†	102.33
4 High input–narrow row w/o foliar fertility	46.48	4.04	21.83	3.66	5.28	17.24	193.83	135.17	14.00	78.83 a	113.17
5 High input–narrow row w/o soil fertility	44.36	3.90	20.88	3.51	4.83	15.97	321.83	134.83	13.67	73.50 bc	105.17
12 Low input–narrow row	43.66	3.71	20.74	3.33	4.60	15.47	451.50	133.50	13.33	68.50 c	101.67
Mean	44.30	3.86	21.20	3.49	4.85	16.10	305.42	137.17	13.63	74.21	105.59
ANOVA	*P > f*										
Treatment	0.2637	0.2825	0.7431	0.3997	0.0697	0.1633	0.5114	0.8045	0.8068	0.0040	0.6460
Location	<0.0001	<0.0001	<0.0001	0.1349	<0.0001	<0.0001	0.0054	<0.0001	0.0443	<0.0001	<0.0001
Rep(Location)	0.9441	0.5413	0.1500	0.8139	0.4380	0.8535	0.7256	0.2431	0.5673	0.7987	0.7281

† Means in a column followed by the same letter are not statistically different at α=0.05 (columns lettered only when the treatment effect was significant)

Table A-5. LSMeans comparison of leaf nutrient concentrations, Michigan, 2009.

Treatment		Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
		$g\ kg^{-1}$						$mg\ kg^{-1}$				
2	High input–narrow row	51.46	3.72	22.38	3.26	2.69	11.84	122.62	89.02	11.22	62.88	42.54
4	High input–narrow row w/o foliar fertility	51.64	3.95	23.53	3.09	2.84	11.32	120.65	85.12	11.31	54.74	41.47
5	High input–narrow row w/o soil fertility	51.96	3.83	22.80	3.13	2.73	11.02	118.27	89.02	10.14	54.53	42.50
12	Low input–narrow row	52.74	3.86	23.01	3.32	2.81	11.53	125.22	99.44	10.89	54.67	43.33
	Mean	51.95	3.84	22.93	3.20	2.77	11.43	121.69	90.65	10.89	56.70	42.46

ANOVA	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
	$P > f$										
Treatment	0.3443	0.5328	0.6832	0.2403	0.4589	0.6686	0.7499	0.6817	0.5327	0.5072	0.8625
Location	<0.0001	<0.0001	0.9808	<0.0001	0.1213	0.1856	0.4246	<0.0001	<0.0001	<0.0001	<0.0001
Rep(Location)	0.7950	0.0617	0.1892	0.7259	0.2882	0.8129	0.0853	0.7324	0.1674	0.9417	0.4321

Table A-6. LSMeans comparison of leaf nutrient concentrations, Minnesota, 2009.

	Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Magnesium	Calcium	Iron	Manganese	Copper	Boron	Zinc
		g kg^{-1}						mg kg^{-1}				
2	High input–narrow row	59.70	5.10	26.24	3.66	3.52	10.20	154.56	93.89	7.67	52.89	44.56
4	High input–narrow row w/o foliar fertility	63.26	4.97	26.40	3.77	3.43	9.98	154.56	91.33	8.33	52.56	43.44
5	High input–narrow row w/o soil fertility	60.14	5.33	28.29	3.70	3.63	10.42	156.56	94.33	8.22	50.44	45.00
12	Low input–narrow row	60.72	5.01	26.73	3.77	3.59	9.85	170.11	93.78	8.33	49.11	44.11
	Mean	60.95	5.10	26.92	3.72	3.54	10.11	158.95	93.33	8.14	51.25	44.28
	ANOVA	*P > f*										
	Treatment	0.0713	0.2284	0.1335	0.3819	0.4802	0.1530	0.1125	0.8257	0.6839	0.0719	0.9023
	Location	<0.0001	<0.0001	0.0076	<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0689
	Rep(Location)	0.2234	0.0938	0.4604	0.8137	0.0066	0.0688	0.0140	0.0086	0.4071	0.0344	0.0069

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VITA

The author, Daniel L. Jordan, was born July 26th, 1986 near Bardstown, KY. He was raised by his mother, Elizabeth Jordan, on the family farm. After graduating from Spencer County High School in May 2004, he enrolled at Berea College in Berea, Kentucky in August 2004. While earning his Bachelor of Science degree in Agriculture and Natural Resources the author worked on the Berea College farm; first as a general laborer and then as the manager of the Crops and Maintenance enterprise. He also served terms as Treasurer and President of the Berea College Agriculture Union, as well as Reporter for the Berea chapter of the agriculture honor society, Delta Tau Alpha. Daniel had the fortune to spend a month in both Costa Rica and New Zealand during his time at Berea College. He graduated from Berea College in December 2007 and enrolled at the University of Kentucky and began work on his Master of Science degree in Crop Science in January 2008. Daniel served as a graduate research assistant under his adviser, Dr. Chad Lee, while at the University of Kentucky. Upon graduation the author hopes to find a job that serves the agriculture industry and rural Kentucky, to build his own house, and to return to the family farm.