INPUT MANAGEMENT FOR IMPROVING DOUBLE-CROP SOYBEAN MANAGEMENT IN OKLAHOMA

By

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INPUT MANAGEMENT FOR INPROVING DOUBLE-CROP SOYBEAN MANAGEMENT IN OKLAHOMA

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Abstract: Double-crop soybean is a valuable production system in Oklahoma. However, due to the later planting date paired with environmental conditions present throughout the state, the high yield potential is associated with some degree of risk. Due to this high risk, growers have to appropriately manage inputs in order to minimize other risk factors. A trial was established in the spring of 2016 and 2017 near Perkins, Oklahoma on a sandy loam soil. Seven inputs were evaluated (previous wheat variety, seeding rate, row spacing, insecticide, fungicide, in-season N, foliar micronutrients, and seed treatment). These were evaluated based on a standard practice level and a high management level (i.e., farmer practice for N-management would be no additional N applied and high management would be 112 kg ha^{-1} N applied). In addition, a standard practice and high rate management check was added by fixing all inputs at those individual levels to allow comparison of the individual inputs. Stand counts were taken at V3, plant height at R2, NDVI at R3 and yield characteristics (percentage of two- and three-bean pods, pods plant^{-1}, pods node^{-1}, nodes plant^{-1} and seed weight g 1000 seeds^{-1}) were taken at R8. Yield was determined by mechanically harvesting the middle 1.67 m of the plot. The high input system resulted in significantly higher yields than the standard practice system both years. Compared to high management system, only decreasing seeding rate resulted no significant differences (99 kg ha^{-1} increase) with all other treatments resulting in significant decreases (47 to 149 kg ha^{-1} decrease) in 2016. Compared to the high management system, only taking away micronutrients resulted in an increase (80 kg^{-1} ha^{-1}) with all other treatments resulting in decreases (15 to 824 kg ha^{-1} decrease) in 2017. This could indicate that higher seeding rates resulted in too many plants ha^{-1} due to poor environmental conditions and micronutrients are not needed within a double crop system. This increase in yield was possibly due to increased seed weight, lower plant population which resulted in a significant decline in pods plant^{-1} and no significant differences in the number of two- and three-bean pods.

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CHAPTER I

INTRODUCTION

The soybean (*Glycine max* L.) grain has many uses throughout the world, with the primary uses being for meal and oil products. Soybean meal, made from the seed can contain up to 80% protein and is primarily used as animal feed but can be incorporated in many human foods (USB Staff, 2016). Conversely, soybean oil is primary used in the food industry, with consumers using more than 83% of US soybean oil for cooking, baking and/or frying. The remaining soybean oil is integrated into industrial applications, such as adhesives, coatings and printing inks, lubricants, plastics, and specialty products, with further applications in biodiesel (USB Staff, 2016).

Soybean is the dominant oilseed in the United States accounting for about 90 % of the US production. Furthermore, soybean is the second most planted field crop in the United States, with 33.8 million hectares planted in 2017 (USDA, 2017). According to the USDA Economic Research Service, large-scale soybean production did not occur until the 20th century. Following establishment, the soybean production industry began to expand rapidly. This drastic increase in acreage resulted from increased planting flexibility, higher yields, row spacing practices, crop rotations, and lowered production costs. The greatest amount of hectares of soybean are grown in the upper Midwest, which account for more than 80% of the US soybean hectares.

Similar to Midwest, soybean is a major component of Oklahoma cropping systems. According to USDA survey, there were over 222,500 reported hectares planted in Oklahoma during the 2017 production season (USDA, 2017). Soybean is planted throughout the state; however, due to climatic and cultural practices throughout the region, the eastern portion of the state has the highest hectares. In the western portion of the state where precipitation decreases, soybean yield potential lowers, and management becomes more critical.

While a significant amount of the hectares of soybean in Oklahoma is grown as full season production, approximately one-third of the total planted hectares (over 74,000 hectares) are planted within a double-crop system (USDA, 2017). A double-crop system is when two crops are grown and harvested on the same field within a single calendar year. For most of the southern US, this is when producers plant a summer crop following the harvest of a winter crop, which is primarily a small grain. For Oklahoma, winter wheat harvest occurs from late-May until mid-June. Following harvest, soybean is planted within days to weeks, depending on soil moisture at harvest, with planting dates ranging from mid-June to early-July.

Although double-crop production systems have the potential to be very profitable, the higher stress associated with these systems, specifically associated with the later planting, require optimization of other production practices in order to achieve suitable yields. One of the most critical periods for these double-crop systems is rapid emergence and vigorous early season growth. Therefore, planting practices as well as activities conducted at planting, such as row spacing, plant populations, and seed treatments, will greatly influence seedling vigor and survival. With focus placed on management at planting, most tend to overlook late-season management. This is mostly because early season management decision greatly influences the overall yield potential; however, the most sensitive time for biotic and abiotic stresses for soybean occurs during reproductive growth. Therefore, in order to optimize yield, practices during the later season, such as insecticides, fungicides, and fertility, should be carried out and implemented to optimize growth.

CHAPTER II

REVIEW OF LITERATURE

Seeding Rate

Determining optimum seeding rate is difficult. Much of the challenge associated with determining optimum rates comes because of the highly variable environmental conditions immediately following planting. While it may seem that higher planting populations should result in higher crop yields, the literature has produced highly variable results (Costa, 1980; De Bruin and Pedersen, 2008; Oplinger and Philbrook, 1992; and Shibiles and Weber, 1966). The theory behind higher seeding rates that is more plants m^{-2} should be the result in higher yields. However, these higher seeding rates have been shown to result in increased lodging and decreased number of branches per plant (Costa et al., 1980). Shibles and Weber (1966) further emphasized these results. They noted that soybean plants were able to produce more lateral branches at lower populations. In these lower populations, the lateral branches filled the inter-row spaces at lower leaf area index than that of higher populations. Consequently, higher plant populations can delay progression of the plant from vegetative to reproductive growth. This can result in increased vegetative tissue, which can decrease carbohydrates available during seed fill, potentially decreasing yield (Shibles and Weber, 1966). The effect of plant population is dependent on other management factors. Devlin et al. (1995) showed that higher planting rates were more detrimental at wider row spacing. They indicated that this was mainly due to increased intra-row competition compared to if the plants were spaced over a larger area, as with narrower row spacing.

The highly variable effect of plant population on soybean growth and yield is highlighted by the vastly different optimum planting populations documented in the literature. Weber et al. (1966) indicated that maximum yields were achieved at a 105,500 seeds ha^{-1} planting density, while both Oplinger and Philbrook (1992) and De Bruin and Pedersen (2008) documented a need for a much higher plant population (462,200 and 258,600 seed ha^{-1}, respectively) for optimal yields.

Row Spacing

In the early 1990's, soybean production in the United States began to move from a predominantly wide row (≥ 76 cm) cropping system a narrow row (≤ 76 cm) system. According to Hesterman et al. (1987), narrow rows can provide tremendous agronomic and economic benefit, including increased light interception, earlier canopy closure, reduced within row plant competition, reduced soil erosion, and increased yields. Soybean grown in a narrower row spacing results in increased plant height as a means to compete for sunlight (Basnet et al., 1974). In a 3-year study in Michigan, Hesterman et al. (1987) reported 15% higher yields on 50 cm row spacing compared to 76 cm row spacing. Furthermore, they found an additional two to eight percent increase when row spacing decreased to 25.4 cm (Hesterman et al., 1987). This physiological benefit can frequently result in increased yields (De Bruin and Pederson, 2008; Pederson, 2007). The exact increase associated with narrower planted rows varies but ranged from 248 kg ha^{-1} (De Bruin and Pedersen, 2008) to 303 kg ha^{-1} (Pedersen, 2008). The added revenue of soybean in narrow rows was on average \$36 ha^{-1} at \$0.17 kg^{-1} soybeans (Hesterman et al., 1987). While a financial benefit may be present for soybean production in wider rows, a restrictive factor from switching from wider row spacing to more narrow is the cost of investment. As much of the country still plants soybean on wider rows (>76 cm), growers would need to invest in different equipment or modifying current equipment which can add substantial cost to the production system (Norsworthy and Oliver, 2009).

While the literature suggest that, there is not a constant yield increase to wide row soybean production. Walker et al, (2010) indicated that soybean yield was not consistently impacted by row-spacing and environmental conditions played a critical role in determining the value of narrow or wide planted soybean. Heatherly and Hodges (1999) noted that in drought prone regions, row spacing did not significantly influence yields, and theorized that a better yield response would result from production practice that influence water use efficiency. This is critical, as narrower rows were previously thought to result in increased water use efficiency. However, it has been suggested that narrower spacing with soil moisture available early during growth will increase vegetative growth increasing water demand, therefore decreasing soil moisture available during critical reproductive stages (Alessi et al., 1981). Other general benefits have been theorized with wider row spacing, including less crop damage for late-season chemical applications, better seed singulation, and lighter equipment used in field (Vonk, 2013).

Seed Treatment

Seed treatments are designed to manage diseases and insects on emerging seedlings. These treatments will typically consist of an insecticide, fungicide, or combination applied to the seed prior to planting. For soybean, the primary use of seed treatment is to control *Rhizoctonia* root rot, Phytophora root rot, *Pythium* seedling disease, and precursors to other pod and stem blight (Heatherly and Hodges, 1999). These seedling diseases can be quite detrimental and yield and have been shown to be reduced with the use of these fungicide seed treatments (Dorrance et al., 2003). However, Heatherly and Hodges (1999) showed that these seed treatments are only beneficial when germination or emergence occurs in unfavorable conditions, particularly for fungicides, such as cool soil temperature or excessive/deficient drought moisture. This is due to the need for three critical components to be available for infection, including susceptible host, pest present, and appropriate environmental conditions. Most of this is dependent an environmental conditions, due to a host and pest being normally present. Therefore, within the southern Great Plains, adequate conditions can be present during early planting to support the use of seed treatments but conditions are less favorable in later planting (Brunoehler, 1995; Draper et al., 2002). Seed treatments have shown a more consistent growth effect when planted into no-till or reduced tillage systems (Heatherly and Hodges, 1999). This is critical as planting soybean in a double-crop system is typically performed within a high residue environment. Additionally, when seed treatments are applied, the risk of crop failure or crop replant were minimized. This is a result of treated seeds being more vigorous than those from non-treated seeds are. Additionally, these seedlings typically produced earlier, more complete and uniform canopy (Brunoehler, 1995;

Gustafson, Inc., undated; Soybean Digest, 1995). The use of seed treatments can help support the most critical factors of minimizing stress and increase early growth, potentially in the absence or during low-level disease incidence.

Foliar Fungicide

While foliar disease can result in significant reductions in yield, they are still typically less detrimental then other diseases and insects. The literature suggests that foliar fungicides having little impact on crop physiology or crop yield even in the presence of disease, depending on disease, environmental conditions, fungicide used, and incidence (Swoboda and Pedersen, 2009). However, the lack response to fungicide applications is not universally found. Wrather and Koenning (2006) showed a 7.2% decrease in soybean yield due to foliar disease incidence. Some yield responses are more pronounced. Horn et al. (1975) found a 73% yield increase from fungicide when used to control frogeye leaf spot. Yield responses from foliar fungicides are due to minimizing the impact on leaf area and photosynthetic capacity (Bassanezi et al., 2001). Mahoney et al. (2015) emphasized this. They indicated that soybean leaf area was increased by 27 to 45% when Seportia brown spot (*Septoria glycines* Hemmi) was controlled with a fungicide compared to an untreated check, which resulted in a significant increase in yields. Marburger et al. (2016) found that in a high production treatment with fungicide the yield increase ranged from 4.6% to 7.0% of a yield increase compared to the standard practice. However, Marburger et al. (2016) also found that by taking that foliar fungicide out that the yield increase drops to 2.4% to 5.6%. This shows that by applying a fungicide there was a 2.2% to 2.4% decrease in yield. While yield responses can occur, not all yield increases can benefit the production system. According to Heatherly and Hodges (1999), it is believed an economic yield increase from fungicide only occurs in high input, high yielding environments. However, Mahoney et al. (2015) indicated that environmental conditions or disease incidence and economic benefit and profit ranged from \$50.03 ha^{-1} through \$53.73 ha^{-1} depending on environment either favoring or dissuading disease occurrence.

Foliar Insecticide

Similar to diseases, insects can be drastically yield limiting if it occurs during critical production periods. Insects cause yield loss by feeding on foliage, boring into petioles, stems, or seeds, stems, spreading diseases, and damaging seed (Hons and Saladino, 1995). Unlike disease, insect populations are highly dynamic and particularly mobile, with insect populations potentially migrating in or out of a field within a number of days. Additionally, for most insect pests, populations can grow rapidly. Therefore, it is critical to manage these pests when populations are lower. One of the most challenging aspects of insect management is managing around economic thresholds. According to Oerke (2006), it is becoming more economically practical to apply insecticides due to the higher yield loss potential that can occur in high input systems and the lower breakeven probability, which is supported by Orlowski et al. (2016). In a study conducted by Trybom and Jeschke (2017) looking at foliar fungicides and insecticides, an application of pyraclostrobin fungicide at R3 had a yield response of 1.2 kg ha^{-1}, whereas the addition of esfenvalerate insecticide with the fungicide at R3 had a yield response of 1.8 kg ha^{-1}. Therefore, by adding insecticide in conjunction with the fungicide they were able to gain an additional 0.6 kg ha^{-1}. In another study in Illinois, it was found that in a standard system, the addition of an insecticide added an additional 1.2 kg ha^{-1} yield protection, while in a high input system failing to apply an insecticide resulted in a 0.8 kg ha^{-1} yield decrease (Mastrodomenico and Below, 2016).

Micronutrients

Micronutrients are essential plant minerals that are typically taken up in much lower amounts compared to macronutrients. There are six micronutrients required by plants: zinc (Zn), manganese (Mn), copper (Cu), iron (Fe) boron (B), molybdenum (Mo) and (Heatherly and Hodges, 1999). The element, element symbol, optimal concentration in Mg kg^{-1}, and function within the plant can be seen below in Figure 1 from (Arnall, 2012; Heatherly and Hodges, 1999; Pioneer, 2017).

Figure 1. Functions of micronutrients in plants adapted from Pioneer (2017).

Element	Element Symbol	Concentration	Function in plant
Boron	B	0.02	Important in sugar transport, cell division, and amino acid production
Copper	Cu	0.01-0.03	Component of enzymes, involved with photosynthesis reactions
Iron	Fe	0.05	Component of enzymes, essential for chlorophyll synthesis, and photosynthesis
Manganese	Mn	0.015-0.2	Chloroplast production, cofactor in many plant reaction, activates enzymes
Zinc	Zn	0.02	Component of many enzymes, essential for plant hormone balance and auxin activity
Molybdenum	Mo	0.001-0.005	Involved in nitrogen metabolism, essential in nitrogen fixation by legumes

In a study conducted by Enderson et al. (2015), there was no treatment effect of B, Cu, Mn, and Zn foliar fertilization on yield, even though these applications did increase the concentration in the grain at several locations. Similar results were found by Freeborn et al. (2001) looking at soybean yield response to B. While the overall yield benefit of foliar fertilizers in current literature is limited, some studies report positive results. Caliskan et al. (2008) indicated that early season applications of Fe chelated foliar fertilizer increased growth at mid- to late-reproductive stages as well as seed yield in double-crop across two years in a Mediterranean production system. These benefits were mostly found in more alkaline soils, as these soils are more prone to Fe deficiency. Ross et al. (2006) also indicated a 4 to 130% increase in soybean seed yield when B was applied compared to when no B was applied. They also indicated that B application timing did not influence the yield response. While most of the in-field response of soybeans from foliar fertilizer are highly variable in certain environments, these applications particularly in high yielding environments can improve grain yields.

Late season nitrogen

Nitrogen (N) is required in the greatest quantity of all plant nutrients for most crops. This is because N is a major component of chlorophyll, which uses sunlight energy to produce sugars from water and carbon dioxide (Mosaic, 2016). A deficiency of N causes slowed growth, and older leaves become chlorotic and senesce prematurely due to translocation of N compounds to the growing points (Heatherly and Hodges, 1999). This is a major agricultural input for most agriculture crops, since soybean is a legume, it can typically produce high amounts of N needed for growth and development. This is done through a symbiotic relationship between soybean plant and *Brady rhizobium japonicum,* within this relationship the bacteria produce plant available N and the plant supplies the bacteria with usable photosynthates (Heatherly and Hodges, 1999). This relationship will supply soybean with 70-85% of the total N needed growth and development, with the remainder coming from uptake from the soil. It has been theorized that applications of N, especially when low soil N is available, will be critical to maintain yields. These applications will typically be need late-season as the rapid increase in N usage from late vegetative through early reproductive (Mourtzinis et al., 2018). Wesley et al. (1998) demonstrated this aspect. They showed that soybean was responsive in six of eight site years with an average of 11.8% yield increase across responsive and nonresponsive sites. They theorized that at responsive sites, the soybean plants were well nodulated and had soil available N present, but the soybean plants were not able to take up N at a high enough rate to be efficient.

Double-crop soybean behind wheat provides special problems in terms of N management. Planting no-till into wheat stubble may result in depressed N availability due to microbial immobilization of available soil N during decomposition of wheat residues (Heatherly and Hodges, 1999). Nitrogen applications to double-crop systems production systems aim to overcome these deficiencies. Due to soybean’s ability to fix N and little research done on double-crop soybean, there is a gap in the literature available on this topic.

Summary

With higher soybean prices compared to other commodities, interest has been spurred for maximizing soybean yields through increased inputs use in the production system. However, there is little information available about intensive management of double-crop soybeans on yield and increases and profitability. Currently there is no research being conducted in the southern Great Plains examining management practices for maximizing double-crop soybean yields. In double-crop soybean in Oklahoma the majority of acres follow a winter crop and most farmers apply what they believe is to be enough inputs to grow both the winter crop and double-crop soybean. Through this study, we aim to determine the impact of input management on double-crop production in Oklahoma in terms of productivity and profitability. The hypothesis of this project is that current production practices are not reaching full yield potential for double crop soybean.

CHAPTER III

METHODOLOGY

Field Experiment

The field research was conducted in 2016 and 2017 at the Cimarron Research Station, near Perkins, Oklahoma (35°98’58.89” N, 97°04’60.92” W). The soil series at the location was the Teller series, which is a fine sandy loam with a slope of 0-8%. Temperature and precipitation were collected for this site from a statewide weather station system established and maintained from Oklahoma State University, named the Oklahoma Mesonet (www.mesonet.org). Average temperature and precipitation data are shown in Figure 2 and 3.

Two primary treatment schemes were utilized in 2016 and 2017 and established in a split-plot design. The first treatment, which acted as the main plot, was wheat variety planted prior to establishment of the soybean crop. The two wheat varieties utilized were Bentley and Gallagher. These varieties were chosen, as they possess two different types of growth, low-tillering (Bentley) and high-tillering (Gallagher). Wheat residue from the 2015 planting were utilized for both 2016 and 2017. This is a result of an additional wheat crop, which was planted in 2016, but adequate stands were not achieved. Therefore, separate wheat residue was used the successive year. The wheat crop was planted at 71.5 kg ha^{-1} for both varieties. A total of 132 kg N ha^{-1} were applied with 50% of the N being applied at planting and the remaining 50% at Feekes growth stage 5. An additional 48 kg ha^{-1} of P_2O_5 and K_2O was applied for the 2016 season, while only 10 kg ha^{-1} of P_2O_5 was applied in the 2017 season. All other wheat management practices were conducted based on Oklahoma Cooperative Extension Service best management practices. Throughout the trial, the wheat crop was treated as a single area indifferent of plot area. The yield of the individual plots was not measured but the area as a whole averaged 3,200 kg ha^{-1} in 2016.

The second treatment with acted as the subplot was input treatments which was set up using omission style treatment arrangement. This was done as agronomic management studies have a tendency to investigate important factors independently to make data analyzing easier. As a result, it is believed that this approach could undersell the interaction of some of these factors that take place in today's production systems. As means to compensate for these interactions we used an omission plot arrangement to look at the value of individual inputs within a high input system and compare back to the low or high input check. The studies in 2016 and 2017 consisted of two planting populations, two row spacing's, and two levels (high/low) input management. The breakdown of the treatments and there components are outlined in Table 1 for 2016 and Table 2 for 2017. The products that were used in this study are outlined in Table 3 showing the active ingredient, brand name, application rate and manufacturer.

In 2016, a Monosem (Monosem Inc., Edwardsville, KS) 4-row planter was to plant the soybean crop at 76 and 38 cm row spacing. In 2017, the Monosem 38 cm row-crop planter was used similar to 2016; however, the 76 cm row spacing plots were planted with a John Deere (John Deere, Moline, IL). Channel 4806 R2 soybean cultivar was used in 2016, but this was changed to Channel 4916 R2X/SR in 2017. This change in cultivar was due to seed availability. Glyphosate (potassium salt of N-(phosphonomethyl) glycine) was applied pre-plant both years (1.06 kg a.i. ha^{-1}). In 2016 in season, applications of glyphosate (1.06 kg a.i. ha^{-1}) were made as needed to control weeds. In addition, pyroxasulfone (3-[[[5-(difluorimethoxy)-1-methyl-3-(trifluoromethyl)-1H-pyrazol-4-yl] methyl] sulfonyl]-4, 5-dihydro-5, 5-dimethylisoxazole) was applied pre-plant in 2017 (0.18 kg a.i. ha^{-1}). Paraquat dichloride (1, 1'-dimethyl-4, 4'-bipyridinium dichloride) (1.12 kg a.i. ha $^{-1}$) tank mixed with glyphosate (1.54 kg a.i. ha^{-1}) was applied as a burndown application in late May 2017. In 2017, an in-season diglycolamine salt of dicamba (3, 6-dichlro-*o*-ansic acid) (0.57 kg a.i. ha^{-1}) tank mixed with glyphosate (1.54 kg a.i. ha^{-1}) was applied in mid-July. Plots were planted on 17 June 2016 and 16 June 2017 at a depth of 1.27 cm to 1.91 cm. Cultural practices and treatment application dates are outlined in Table 4.

Irrigation was applied three times in both years at a rate of 2.54 cm per application using an OCMIS Irrigation Gun with a 201 m retractable line (Knutson Irrigation, El Reno, OK). Though irrigation was not a part of the study, due to the sandy nature of the soil irrigation was necessary to keep the study alive.

Foliar micronutrients, fungicide, and insecticide applications were made using a CO_2 backpack sprayer with a spray pressure of 103.4 kPa, spray volume of 140 L ha^{-1} and an application speed of 4.8 km hr^{-1}. Boom length was 1.67 meters with nozzles (Teejet XR 11002; Teejet, Wheaton, Illinois) spaced 50.8 cm apart.

In 2016 and 2017, harvest area was 1.67 m by 6.7 m. Plots were harvested with a Wintersteiger Delta plot combine (Wintersteiger, Reid, Austria) on October 31 in 2016 and 2017. Seed weight, moisture, and test weight were measured with an onboard Harvest Master weigh system (Juniper Systems, Logan, Utah). Yield was adjusted to 13.3%.

In-season data was collected during both vegetative growth and reproductive growth. Early season stand count were collected at the V3-V5 growth stage (Fehr and Caviness, 1977). These were collected by sampling one meter of row at two locations within each plot and averaging the two together to get a plot average. Normalized difference vegetative index (NDVI) was also collected using a handheld Greenseeeker (Trimble Inc. Sunnyvale, California). Readings were collected on the harvest rows at R3. Normalized difference vegetative index (NDVI) is a measure taken from the reflectance of the crop canopy. This NDVI value was used to measure the density of greenness of a patch of land, in this case the soybean canopy. As it does measure the density of greenness, it takes into account both chlorophyll content and total biomass. Therefore, it can be used to indirectly measure either of these two aspects (Hansen and Schjoerring, 2003). Height measurements were also taken on the harvest two or four rows at R2. Whole plant samples were taken prior to harvest by collecting one meter of row from non-harvested rows. These samples were used to evaluate soybean yield characteristics including, number of nodes, pods per node, and seeds per pod. Yield were determined by mechanically harvesting the middle two-rows of the entire plots. These plot weights were used to estimate grain yield on a per hectare basis. In 2017 during harvest, grain subsamples were collected from each plot following determination of plot weights. These subsamples were used for determining protein and oil content using a Perten near infrared seed analyzer (Perten Instruments, Stockholm, Sweden). These samples were not collected in 2016 due to poor seed quality and limited seed availability.

Table 1. Treatment structure for the 2016 study in Perkins, OK.

	Low Input Check (1)	High Input-No Seed Treatment (2)	High Input-No In-Season IPM (3)	High Input-Low Planting Population (4)	High Input-Wide Rows (5)	High Input No Late N (6)	High Input Check (7)
Seed Treatment			X	X	X	X	X
Foliar Fungicide		X		X	X	X	X
Foliar Insecticide		X		X	X	X	X
Micronutrients		X	X	X	X	X	X
Seeding Rate (370K)	X			X			
Seeding Rate (440K)		X	X		X	X	X
Narrow rows (38 cm)		X	X	X		X	X
Wide Rows (76 cm)	X				X		
Late-N (R2)- 112 kg		X	X	X	X		X

Table 2. Treatment structure for the 2017 study in Perkins, OK.

	Low Input Check (1)	High Input- No Seed Treatment (2)	High Input- No In-Season IPM (3)	High Input- Low Planting Population (4)	High Input- Wide Rows (5)	High Input- No Late N (6)	High Input- No Micro-Nutrients (7)	High Input-No Insecticide (8)	High Input- No Fungicide (9)	High Input Check (10)
Seed Treatment			X	X	X	X	X	X	X	X
Foliar Fungicide		X		X	X	X	X	X		X
Foliar Insecticide		X		X	X	X	X		X	X
Micronutrients		X	X	X	X	X		X	X	X
Seeding Rate (370K)	X			X						
Seeding Rate (440K)		X	X		X	X	X	X	X	X
Narrow rows (38 cm)		X	X	X		X	X	X	X	X
Wide Rows (76 cm)	X				X					
Late-N (R2)- 112 kg		X	X	X	X		X	X	X	X

Table 3. Active ingredient, brand name, application rate L ha^{-1}, and manufacturer of products used in 2016 and 2017.

Active Ingredient	Brand name	Application Rates (L ha^{-1})	Manufacturer
pyraclostrobin, metalaxyl, fluxapyroxad; imidacloprid	Acceleron	0.003 L kg $seed^{-1}$	Monsanto Company, St. Louis, MO.
.20-.30-3.20-.001-2.10%B-Fe-Mn-Mo-Zn	Max- IN for Beans	4.6 L ha^{-1}	Winfield United, Arden Hills, MN
pyraclostrobin	Headline	0.9 L ha^{-1}	BASF, Research Triangle Park, NC
Lamba-cyhalothrin; Chlorantraniliprole	Besiege	0.7 L ha^{-1}	Syngenta, Greensboro, NC
46-0-0%N-P2O5 -K2O	Urea	112 kg ha^{-1}	Chouteau Lime Company, Pryor OK

Table 4. Planting, treatment application, and harvest dates in 2016 and 2017

	Planting date	Micro-nutrients	Late Season N	Foliar fungicide	Foliar Insecticide	Harvesting date
2016	6/17	7/20	8/5	8/23	8/23	10/31
2017	6/15	7/13	8/4	8/18	8/18	10/31

Figure 2. Monthly air temperature and precipitation observed at Perkins, Oklahoma in 2016.

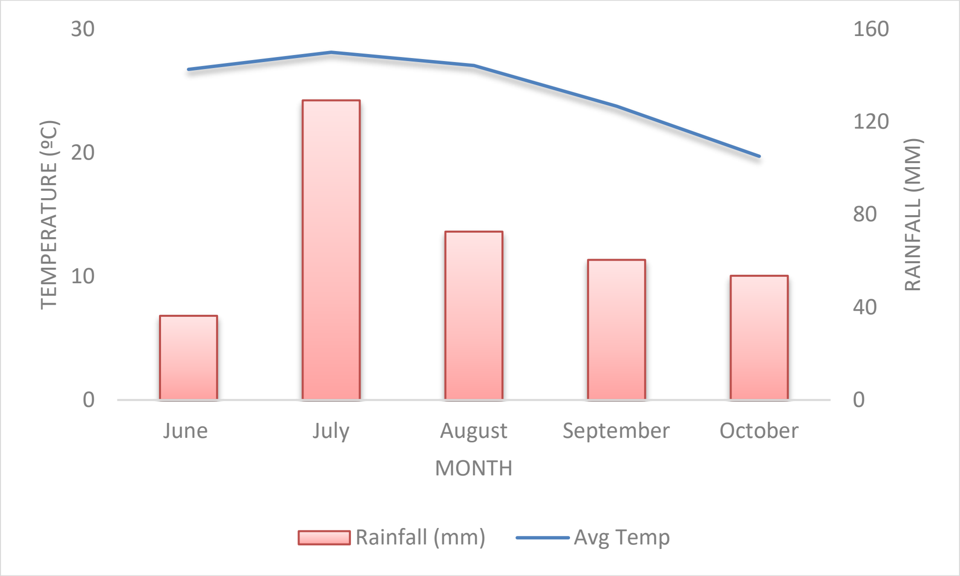
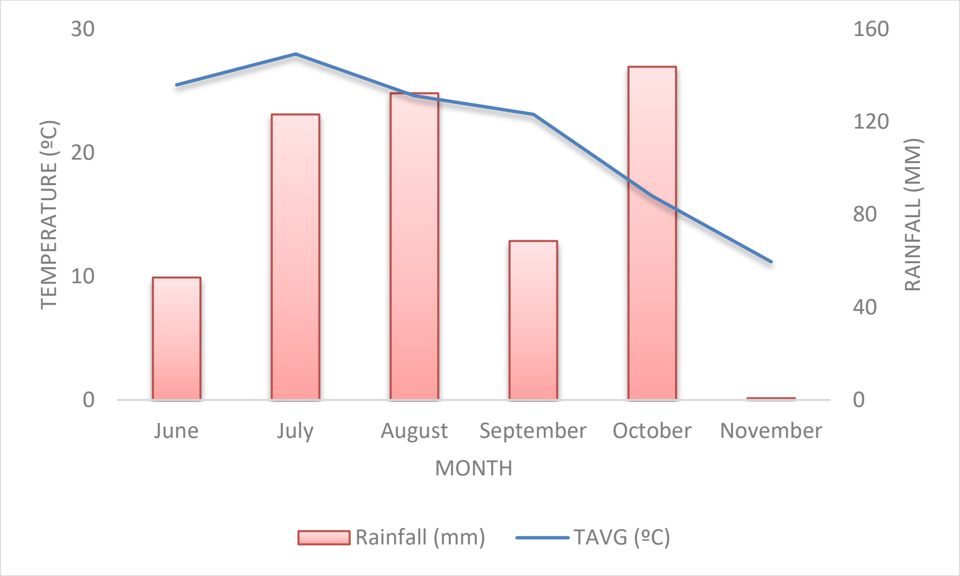


Figure 3. Monthly air temperature and precipitation observed at Perkins, Oklahoma in 2017.



Farmer Demonstrations:

Farmer demonstrations were also conducted during 2016 and 2017 concurrently as means to validate the work done in the small-plot trail. Multiple field-scale demonstrations in 2016 and 2017. In 2016 the demonstrations were located in Haskell (Eastern Research Station) (35°44’31” N, 95°38’03” W), Afton (36°43’41” N, 94°56’08” W), and Miami (36°54’32” N, 94°49’60.27” W). These demonstrations consisted of the farmer providing at least two strips of their field equivalent to the cooperator’s header width wide; therefore, the exact width and length of these demonstrations varied between each individual location Table 5 and 6. Within these strips, one harvest pass was left and managed according to the producer’s typical management system. The other harvest strip was superimposed a high input management treatment similar to the high input check treatment (treatment 7 in 2016 and treatment 10 in 2017) of the small-plot trial detailed above. Because of the dynamic nature of producer common practice, no consistent treatments could be compared. In 2016, the intensive management scheme consisted of an application of Max-In for Beans (2-0-0) (4.64 L ha^{-1}) at V3 and an application of pyraclostrobin (fungicide) (0.87 L ha^{-1}), Besiege (insecticide) (0.73 L ha^{-1}), and Max-In for Beans (micronutrients) (4.64 L ha^{-1}) at R3. Products used and application timings are listed in Table 7 along with the active ingredient, brand name, and manufacturer in Table 8.

In 2017, a low, medium, and high level of the intensive treatment was incorporated to compare to the farmer practice strip. This was to identify the input level that was most profitable compared to the farm practice. The locations in 2017 were Blackwell (36°52’43” N, 97°18’04” W), Afton (36°40’27” N, 94°58’57” W), and Miami

(36°54’40” N, 94°48’36” W). The intensive management scheme in 2017 consisted of Gradual N (30-0-0) at a high (18.71 L ha^{-1}), medium (14.03 L ha^{-1}), and low (9.35 L ha^{-1}) rate as recommended based on the label of the product. This product was tanked mixed with Max-In for Beans (2% Nitrogen, 0.2% Boron, 0.3% Iron, 3.20% Manganese, 0.01% Molybdenum, and 2.10% Zinc) (high- 4.64 L ha^{-1}, medium- 3.48 L ha^{-1}, and low- 2.64 L ha^{-1}) at growth stage V5. Then at R3 Besiege (insecticide), pyraclostrobin (fungicide), and another application of Max-In for Beans was tank mixed at high (4.64 L ha^{-1} Max-In, 0.73 L ha^{-1} Besiege, and 0.87 L ha^{-1} pyraclostrobin), medium (3.48 L ha^{-1} Max-In, 0.55 L ha^{-1} Besiege, and 0.66 L ha^{-1} pyraclostrobin) and low rates (2.64 L ha^{-1} Max-In, 0.37 L ha^{-1} Besiege, and 0.44 L ha^{-1} pyraclostrobin) according to the label of each product. Products used and application timing are listed in Table 9 along with the active ingredient, brand name, and manufacturer in Table 10.

All applications in 2016 and 2017 were made with a John Deere 3320 tractor and 378.5 L three-point sprayer set at 103.4 kPa and spray volume of 187 L ha^{-1}. Application speed was 6.44 km hr^{-1}. Boom length was 9.44 m with nozzles (Teejet TT 11003 (Teejet, Wheaton, Illinois) spaced 50.8 cm apart.

Temperature and precipitation data for the 2016 growing season are given in Figures 4 and 5. The dominant soil series at each location where as follows: Afton and Miami Taloka Silt Loam; and Haskell Parsons Silt Loam. Temperature and precipitation for 2017 are given in Figure 6 and 7. The dominant soil series in 2017 was the same for Afton and Miami, with Blackwell having a Kirkland Silt Loam.

Table 5. Location, width (m), length (m), and area ha^{-1} of demonstration strips in 2016

Location	Width (m)	Length (m)	Area (ha^{-1})
Miami	9.1	292.6	0.27
Afton	10.7	364.2	0.39
Haskell	1.5	76.2	0.01

Table 6. Location, treatment, width (m), length (m), and area ha-1 of demonstration strips in 2017

Location	Treatment	Width (m)	Length (m)	Area (ha^{-1})
Afton	High	10.7	159.1	0.17
	Medium	10.7	162.2	0.17
	Low	10.7	170.1	0.18
	Farmer	10.7	178.6	0.19
Blackwell	High	9.1	487.7	0.44
	Medium	9.1	487.7	0.44
	Low	9.1	487.7	0.44
	Farmer	9.1	487.7	0.44
Miami	High	9.1	363.6	0.33
	Medium	9.1	363.6	0.33
	Low	8.7	363.6	0.32
	Farmer	9.1	363.6	0.33

Table 7. Locations, application rates, products, and growth stage at time of application in 2016

Location	Growth Stage	Max-In	Headline (pyraclostrobin)	Besiege (Lamba-cy)	Growth Stage
Afton	V3	4.64 L ha^{-1}			V3
	R3	4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}	R3
Miami	V3	4.64 L ha^{-1}			V3
	R3	4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}	R3
Haskell	V3	4.64 L ha^{-1}			V3
	R3	4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}	R3

Table 8. Active ingredient, brand Name, and manufacturer of products used in demonstration strips in 2016

Active Ingredient	Brand name	Manufacturer
.20-.30-3.20-.001-2.10%B-Fe-Mn-Mo-Zn	Max- IN for Beans	Winfield United, Arden Hills, MN
pyraclostrobin	Headline	BASF, Research Triangle Park, NC
Lamba-cyhalothrin; Chlorantraniliprole	Besiege	Syngenta, Greensboro, NC

Table 9. Location, rate of product applied, and growth stage at time of application in 2017

Location	Growth Stage	Rate	Gradual N	Max-In	Headline (pyraclostrobin)	Besiege (Lamba-cy)
Afton	V5	High	18.71 L ha^{-1}	4.64 L ha^{-1}		
		Medium	14.03 L ha^{-1}	3.48 L ha^{-1}		
		Low	9.35 L ha^{-1}	2.64 L ha^{-1}		
	R3	High		4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}
		Medium		3.48 L ha^{-1}	0.66 L ha^{-1}	0.55 L ha^{-1}
		Low		2.64 L ha^{-1}	0.44 L ha^{-1}	0.37 L ha^{-1}
Miami	V5	High	18.71 L ha^{-1}	4.64 L ha^{-1}		
		Medium	14.03 L ha^{-1}	3.48 L ha^{-1}		
		Low	9.35 L ha^{-1}	2.64 L ha^{-1}		
	R3	High		4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}
		Medium		3.48 L ha^{-1}	0.66 L ha^{-1}	0.55 L ha^{-1}
		Low		2.64 L ha^{-1}	0.44 L ha^{-1}	0.37 L ha^{-1}
Blackwell	V5	High	18.71 L ha^{-1}	4.64 L ha^{-1}		
		Medium	14.03 L ha^{-1}	3.48 L ha^{-1}		
		Low	9.35 L ha^{-1}	2.64 L ha^{-1}		
	R3	High		4.64 L ha^{-1}	0.87 L ha^{-1}	0.73 L ha^{-1}
		Medium		3.48 L ha^{-1}	0.66 L ha^{-1}	0.55 L ha^{-1}
		Low		2.64 L ha^{-1}	0.44 L ha^{-1}	0.37 L ha^{-1}

Table 10. Active ingredient, brand Name, and Manufacturer of products used in demonstration strips in 2017

Active Ingredient	Brand name	Manufacturer
30-0-0 %N-P2O5-K2O (slow release)	Gradual N	Winfield United, Arden Hills, MN
.20-.30-3.20-.001-2.10%B-Fe-Mn-Mo-Zn	Max- IN for Beans	Winfield United, Arden Hills, MN
pyraclostrobin	Headline	BASF, Research Triangle Park, NC
Lamba-cyhalothrin; Chlorantraniliprole	Besiege	Syngenta, Greensboro, NC

Figure 4. Monthly air temperature and precipitation observed at Haskell, Oklahoma in 2016.

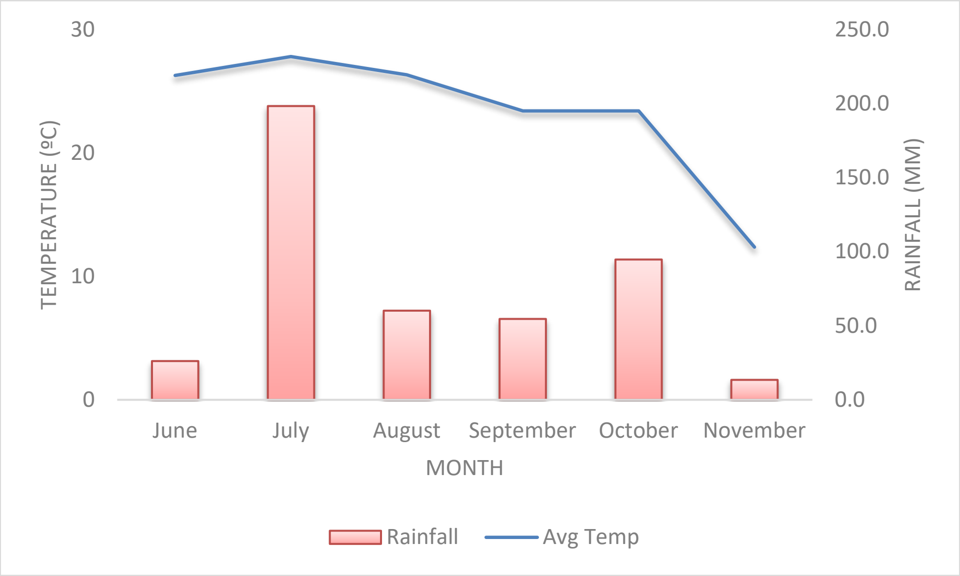


Figure 5. Monthly air temperature and precipitation observed at Miami, Oklahoma in 2016.

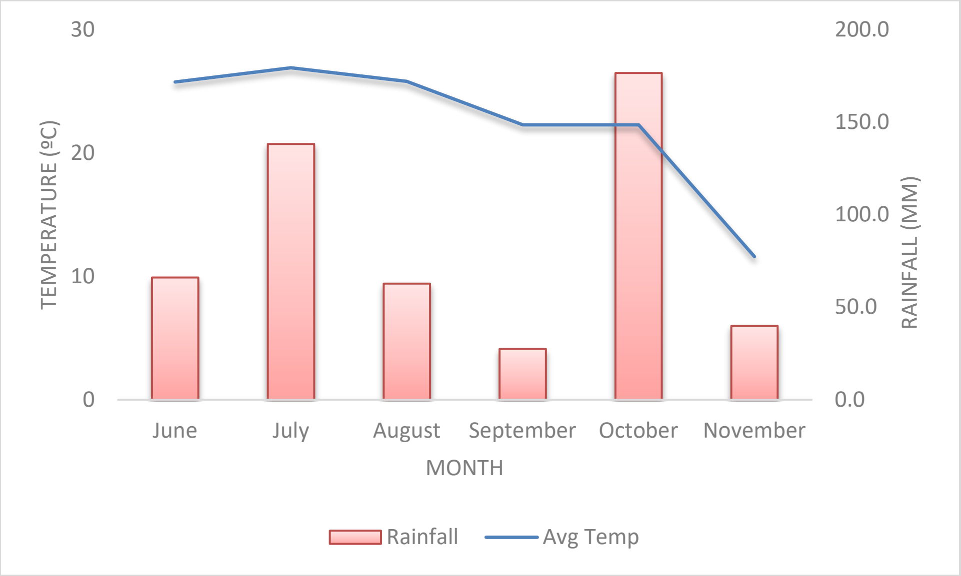


Figure 6. Monthly air temperature and precipitation observed at Blackwell, Oklahoma in 2017.

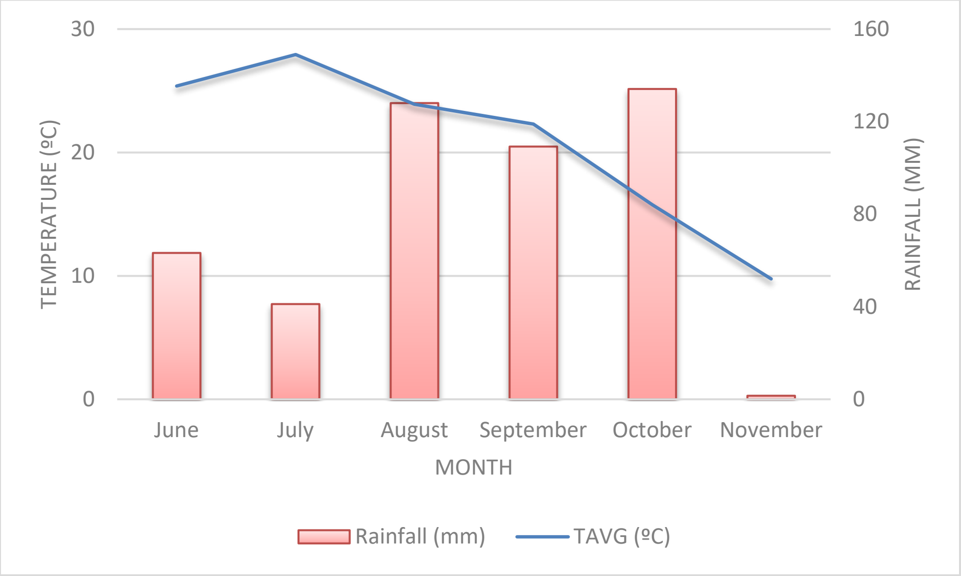
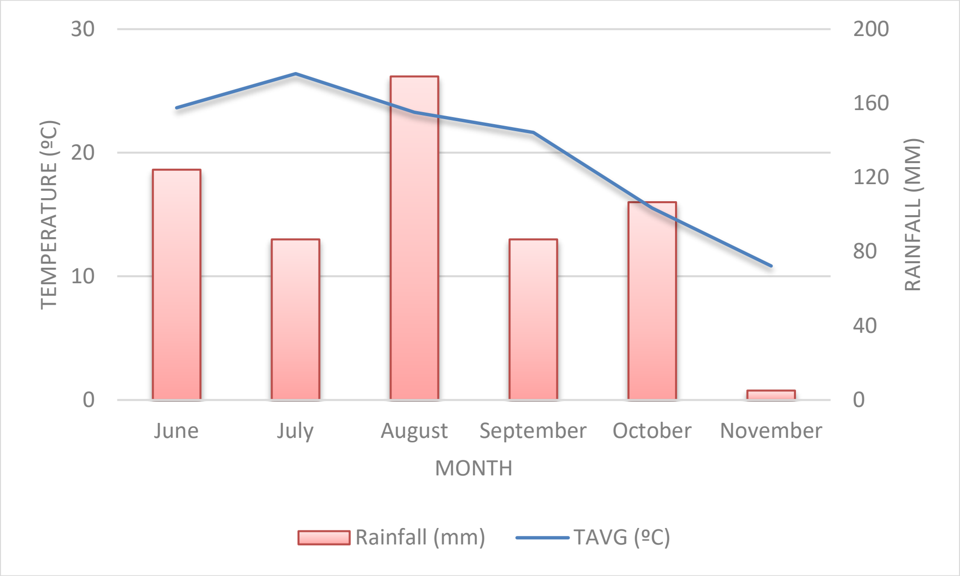


Figure 7. Monthly air temperature and precipitation observed at Miami, Oklahoma in 2017.



Statistical Analysis

Stand counts, height, NDVI, yield characteristics, and yield was analyzed using SAS software version 9.4 (SAS, 2013). For grain yield, stand counts, height, NDVI, and yield characteristics, an initial analysis was conducted to determine the response of soybean crop yield to treatments between years. Results of that analysis suggested that all components should be kept separately between years. An analysis of variance (ANOVA) using PROC MIXED with a Dunnett test at a 95% confidence level was used to determine between treatment means for each year individually. For this analysis, previous wheat variety characteristic, treatment, and previous wheat variety characteristic x treatment were considered fixed effects. Replications and the overall error term were considered the random effects. An LSMeans statement was used in order to evaluate significant differences of interactions between treatment, previous wheat variety, and the given data collected. All figures were constructed in Microsoft EXCEL.

CHAPTER IV

Results and Discussion

Grain Yield:

In the 2016 season, the low input management treatment yielded an average of 1401 kg ha^{-1}, which is lower than the yields typically recorded for double-crop production within the state (1440 kg ha^{-1}). These lower yields can be partially attributed to the environmental conditions experienced during the season, particularly during late July and early August. During this period, the soybean plant was progressing through pod development and pod fill the two most critical stages for stress (Casteel, 2010). Above average temperatures and low precipitation resulted in higher stress and diminished yields.

During 2016 season, the high input treatment resulted in significantly higher yields than the low input check 1550 kg ha^{-1} to 1401 kg ha^{-1} (Table 6). This significant increase in yield indicated that the traditional management of soybean did not meet the full potential of the crop, even with the environmental conditions resulting in diminished yield potential during the 2016 season. When comparing treatments to the high input treatment, there was no significant difference for any of the other treatments. In fact, reducing the planting rate from 444,600 seeds ha^{-1} to 370,500 seeds ha^{-1} resulted in a slight, but non-significant, increase in yields.

The increased yield associated with the lower planting rates could indicate increased stress associated with a warmer summer and sporadic periods of dry conditions was compounded the increased plant population. Costa et al. (1980) and Shibles and Weber (1966) observed a yield increase in soybean when lowering the planting population. Costa et al. (1980) indicated that decreased yield with higher planting population could be attributed to decreased branching and decreased stalk integrity. With the exception of decreasing seeding rates to the lower planting rate, all treatments resulted in a numerical decrease in soybean grain yield compared to the check. This non-significant decrease from the high-input check indicates that all these production aspects had a slight impact on yields but no single production input significantly impacted yields in these conditions. This is further supported by the fact that, only the high-input check and the high-input treatment with decreased seeding rates resulted in a significant increase over the low-input check. However, this lack of difference from the low-input check could be a result of decreased inputs paired with the increased stress of the higher seeding rates.

The 2017 season was noted for having more consistent yields throughout the growing season with more favorable rainfall patterns and more mild temperatures. This resulted in more favorable conditions for soybean production at the location site. The low input management treatment yielded an average of 1052 kg ha^{-1}. Compared to 2016, average yield for the low input management treatments were significantly lower than the state average (1440 kg ha^{-1}). This could have indicated that the environmental conditions were unfavorable and overall yields would be lower compared to 2016, conversely, the high input management treatment and applied treatments, with the exception of wide rows, significantly increased yields over the lower input treatment. This demonstrated that the yield potential for 2017 was higher than that of 2016 and the low treatment scheme resulted in highly deficient soybean system.

During the 2017 season, the high input treatment resulted in significantly higher yields than the low input 1876 kg ha^{-1} to 1052 kg ha^{-1}(Table 11). This again indicated that the traditional management of soybean at lower rates did not meet its full yield potential, given the favorable environmental conditions experienced in the 2017 season. When compared to the high input treatment, shifting the application rate from high to low did not significantly influence yields. In fact, reducing the planting rate from 444,600 seeds ha^{-1} to 370,500 seeds ha^{-1}, which resulted in higher yields in 2016, resulted in a slight but not significant decrease in yield. This decrease associated with the lower planting rates indicated that the environmental conditions were suitable to support the extra 74,100 seeds ha^{-1}. Oplinger and Philbrook (1992) and De Bruin and Pederson (2008) observed a yield increase in soybean when raising the planting population but required a higher production potential. De Bruin and Pederson (2008) indicated that increased yield with higher planting population could be attributed to soils and environmental conditions that could support higher plants per square meter. As opposed to 2016, significant increases in grain yields of the applied treatments over the low-input check does not give adequate information due to the better environmental conditions. As these treatments contain all variables associated with the high input check with the exception of a single production variable. Therefore, it would be difficult to differentiate the benefit of an individual production practice. However, this does further emphasize the difference in production potential between 2016 and 2017. It also demonstrates that high input soybean production can produce significantly higher soybean yields compared to traditional practices as long as environmental conditions exist to support higher production potential.

In both 2016 and 2017, previous wheat variety significantly influenced soybean grain yield. In both seasons, the higher tillering wheat variety resulted in significantly higher yields, when averaged across treatments. In 2016, the yield benefits of the higher tillering wheat variety ranged from 763 kg ha^{-1} through 40 kg ha^{-1} with an average of 254 kg ha^{-1} (Table 13). The benefit of tillering from the previous wheat variety varied but was more pronounced in 2017, with an average of 391.8 kg ha^{-1} but ranged from 793 kg ha^{-1} through 2 kg ha^{-1} (Table 15). There is no literature that has indicated the physiology of the previous crop had any influence on grain yield of the successive crop in a double-crop system. The benefits of the higher tillering wheat variety providing a greater benefit of grain yields could be associated with stress, particularly moisture stress, in-season. With increased tillering there is an increased amount of biomass in the field, this increased biomass will provide better coverage and water savings in-season that a more single stem wheat variety will not be able to provide.

Table 11. Yield kg ha^{-1} and significance level as compared to the high and low check during 2016 and 2017 in Perkins, OK.

Treatment	**Yield**		**Significance**			
	2016	**2017**	**2016**		**2017**	
	kg ha^{-1}		**Significance to Low Input**[a]	**Significance to High Input**[a]	**Significance to Low Input**[a]	**Significance to High Input**[a]
Low Input Check	1401	1052	-	0.03	-	0.007
High Input- No Seed Treatment	1427	1788	NS	NS	0.01	NS
High Input- No In-Season IPM	1439	1720	NS	NS	0.04	NS
High Input- No Insecticide	*	1621	*	*	0.05	NS
High Input- No Fungicide	*	1708	*	*	0.04	NS
High Input- Low Planting Population	1649	1621	0.02	NS	0.05	NS
High Input- Wide Rows	1503	1430	NS	NS	NS	NS
High Input- No Late N	1489	1861	NS	NS	0.007	NS
High Input- No Micronutrients	*	1956	*	*	0.002	NS
High Input Check	1550	1876	0.03	-	0.007	-

[a] Abbreviation - NS: non-significant according to Dunnett's test at $p<0.05$, * - Treatment was not part of study in that year

Table 12. Yield kg ha^{-1} by wheat variety characteristic during 2016 in Perkins, OK

Variety	Yield kg ha^{-1}
Low tillering	1382
High tillering	1636

Table 13. Yield kg ha^{-1} and significance differences between varieties by treatment and during 2016 in Perkins, OK

Treatment	Previous wheat characteristic	Yield[a] kg ha^{-1}
Low input check	Low tillering	1375a
	High tillering	1476a
High input- No seed treatment	Low tillering	1418a
	High tillering	1470a
High input- No in-season pest management	Low tillering	1072a
	High tillering	1835b
High input- Low population	Low tillering	1687a
	High tillering	1648a
High input- Wide rows	Low tillering	1244a
	High tillering	1784b
High input- No in-season N	Low tillering	1383a
	High tillering	1646a
High input check	Low tillering	1492a
	High tillering	1595a

[a] Means within a treatment followed by the same letter are not significantly different according to Dunnetts test at $p<0.05$.

Table 14. Yield kg ha^{-1} by variety during 2017 in Perkins, OK

Variety	Yield kg ha^{-1}
Low tillering	1469
High tillering	1873

Table 15.Yield kg ha^{-1} and significance differences between varieties by treatment during 2017 in Perkins, OK.

Treatment	**Previous wheat characteristic**	**Yield^{a} kg ha^{-1}**
Low input check	Low tillering	878a
	High tillering	1224a
High input- No seed treatment	Low tillering	1584a
	High tillering	1992a
High input- No in-season pest management	Low tillering	1610a
	High tillering	1821a
High input- Low population	Low tillering	1369a
	High tillering	1873a
High input- Wide rows	Low tillering	1055a
	High tillering	1805b
High input- No in-season N	Low tillering	1682a
	High tillering	2061a
High input- No micronutrients	Low tillering	1917a
	High tillering	1994a
High input- No fungicide	Low tillering	1700a
	High tillering	1702a
High input- No insecticide	Low tillering	1224a
	High tillering	2017b
High input check	Low tillering	1673a
	High tillering	2076a

[a] Means within a treatment followed by the same letter are not significantly different according to Dunnetts test at $p<0.05$.

Yield Characteristics:

Yield characteristics are frequently used to determine, the specific growth and developmental process that resulted in the increased yield when significant yield benefits exist. This could not only allow for determining what physiological trait resulted in the yield increase, but indicate yield benefit that could be expected over several different environmental conditions or genetic materials.

The yield for the low input treatment in 2016 yielded 1401 kg ha $^{-1}$, and the high input treatment yielded 1550 kg ha $^{-1}$. In the 2016 season, the low input management treatment had an average of 54.2% two-bean pods, 34.3% three-bean pods, and 11.8% one or no-bean pods. This high percentage of two-bean pods and low percent of three-bean pods can partially be attributed to environmental conditions experienced during the season, in particular late July and early August. While the low input check did have 15.8 nodes plant^{-1} and 29.2 pods plant^{-1}, which was similar to all other treatments, a decrease in yield of 150 kg ha^{-1} was still observed. This percentage of two- and three-bean pod differences is a result of the soybean plant, which was progressing through pod development and fill, the most critical stages for trying to avoid stress. The above average daytime temperatures and low precipitation resulted in higher stress and diminished pod fill. This resulted in decreased pod fill and formation. Conversely, the high input treatment, which had all the treatments applied at high rates, resulted in lower percentage of two-bean pods and higher percentage of three-bean pods. However, the high input treatment did result in the higher number of one or no bean pods than the low input. This indicated that the traditional management system of soybean at the lower input rates did not reach their full potential. When comparing the high input treatment, not applying an IPM treatment resulted in significantly ($P < 0.05$) higher percentage of two-bean pods and lower percentage of three-bean pods. The increase in two-bean pods and decrease in three-bean pods could indicate that an IPM treatment is key to not allow a pest issue to compound the already stressed situation caused by the environment. This is contrary to what Swoboda and Pedersen (2009), which stated that foliar fungicides having little impact on crop physiology or crop yield even in the presence of disease, depending on disease, environmental conditions, fungicide used, and incidence. However, it is supported by Bassanezi et al. (2001) which said responses from foliar fungicide are due to minimizing the impact on leaf area and photosynthetic capacity. Mahoney et al. (2015) found that leaf area increased by 27 to 45% when Septoria brown spot (*Septoria glyclines* Hemmi) was controlled using a fungicide compared to the untreated check. All other treatments did result in increased percentages of two-bean pods; however, in terms of three-bean pods, the high input check was average. This is further supported when comparing the low input check, where only the no IPM treatment was numerically higher in two-bean pods and lower in three-bean pods. This could indicate that, IPM is necessary even in years that the yield potential is not there.

In the 2016 season, the low input management treatment on average had 15.8 nodes plant^{-1}, 29.2 pods plant^{-1}, and 1.88 pods node^{-1}. While this is lower than what is normally expected, this is due to environmental conditions experienced during the season. Because of these conditions during the reproductive stages, high stress was experienced, and pod and node formation was hurt. The high input treatment resulted in a higher amount of nodes, but lower amounts of pods and pods per node. This indicated the plant sacrificed pods and pods per node to fill the pods with more beans in the high input system because of the poorer environmental conditions during in the 2016 season. When compared to the high input treatment, all treatments except the low density and no late season N treatments had more pods per plant. However, the high input treatment did have the highest nodes per plant, but the lowest pods per node. With that said, none of the differences were significant.

In 2017, a similar percentage of two- and three-bean pods were found with a lower percentage of one- or no-bean pods. The more even percentage of two- and three-bean pods indicated more optimal conditions experienced during 2017 compared to 2016. This was mainly due to adequate moisture through the growing season the soybean plant did not encounter the stress it did during the 2016 season. However, the increased percentage of one- or no-bean pods compared to 2016 suggested that the low input treatment just ran out of the necessary sugars to fill those extra pods.

During the 2017 season, the high input treatment resulted in a lower percentage of two-bean pods and higher percentage of three-bean pods compared to 2016. In 2016, 43.8% two-bean pods and 39.8% three-bean pods, and in 2017, 43.0% two-bean pods and 41.3% three-bean pods. This indicated that much more favorable environmental conditions accounted for more three-bean pods. This also indicated that percentage of two- or three-bean pods might not be a good yield indicator. When comparing the high input treatment, only the no IPM treatment resulted in a significant difference. Nonetheless, the no seed protection and no micronutrients treatments did result in a numerical difference. The increase in three-bean pods suggested that seed treatment was not needed in this season due to the adequate conditions. This is supported by Heatherly and Hodges (1999) who stated that seed treatments are only shown to be of benefit when germination or emergence occurs in unfavorable conditions, particularly for fungicides, such as cool soil temperature or excessive/deficient drought moisture, and those conditions were not experienced. Another observation that can be made is that the application of micronutrients caused a decrease in three-bean pods. This is surprising as there is no literature out there to support that the application of micronutrients actually has a negative impact on the plant physiologically.

In the 2017 season, the low input management treatment averaged 21.5 nodes plant^{-1}, 47.25 pods plant^{-1}, and 2.21 pods node^{-1}. Due to better environmental conditions than 2016, higher node and pod counts were observed. As a result of these conditions, the soybean plant was not stressed during node and pod development, allowing the plant produce more pods and nodes.

During the 2017 season, the high input treatment resulted in a similar number of nodes, pods plant^{-1} and pods node^{-1} compared to the low treatment check. Which is surprising considering there was an 800 kg ha $^{-1}$ advantage in favor of the high input check. This indicated that there might be other non-measured factors that were affecting yield. Compared to both the high input and low input checks, no treatments resulted in a significant change in number of nodes, pods plant^{-1}, or pods node^{-1}. If we compare this to the yield of the treatments this is surprising as compared to the low input check all other treatment with the exception of the wide row treatment yielded significantly higher. In terms of comparing these results to the high input check, the only treatment that yielded significantly different was the low input check.

In the 2016 season, the low input management treatment had a 1,000 seed weight of 112 g. The weight of the treatments were very similar. There were numerical differences as the low input check had the lowest seed weight. The highest seed weight was observed in the low population treatment. This could indicate that low population resulted the right combination for the environmental conditions and that higher populations resulted in too many plants for the system. The low input check suggested that the use of added inputs increased seed weight and that a high input system was of benefit in increasing seed weight.

During the 2016 season, the high input check resulted in lower seed weight than all but the no IPM treatment and low input check. This may signal that the extra inputs in year with poor environmental conditions the plant was stressed and did not have the necessary other factors to translate the higher inputs into increased seed weight. When comparing the high input treatment, only low population and wide rows resulted in a significant difference ($P<0.05$). The increase in seed weight could indicate that higher population and narrow rows has a negative impact on seed weight in extremely dry years in a double-crop situation.

In the 2017 season, the low input management treatment had a 1,000 seed weight of 99.70 g. The weight of the treatments was widely variable. However, none were significantly different from the low input check. The highest seed weight was observed in the no micronutrient treatment with the lowest coming from the no insecticide treatment. This could indicate that the application of micronutrients caused some kind of physiological negative affect resulting in decreased seed weight. The no insecticide treatment could indicate that there may have been an insect issue resulting in the insect to take necessary energy from the plant that it needed to make more weight per seed.

During the 2017 season, the high input check resulted in lower seed weight than all but the no IPM and no insecticide. When comparing the high input treatment, only not applying micronutrients resulted in a significant difference ($P < 0.05$). The increase in seed weight could indicate that the application of micronutrients is not necessary in a double-crop situation and if you do apply, are lowering the yield potential. This is somewhat surprising as work done by Orlowski et al. (2016) showed that the use of micronutrients had no significant effect on seed weight all environments. In the case of the no IPM and no insecticide treatments, this result is similar to the results of Orlowski et al. (2016). Were they found that taking away a foliar fungicide application from the high input treatment resulted in a decrease in seed weight of 2.1 mg seed^{-1}, but by also taking away both the foliar fungicide and insecticide applications an additional 1.5 mg seed^{-1} was lost showing the importance of a foliar IPM in protecting seed weight.

Table 16. Percent two-bean pods, percent three-bean pods, nodes plant^{-1}, pods plant^{-1}, pods node^{-1}, and seed weight g 1000 seeds^{-1} by treatment during 2016 in Perkins, OK.

Treatment	**Percent two-bean Pods**	**Percent three-bean Pods**	**Significance two-bean to High Input**	**Significance three-bean to High Input**	**Nodes per Plant**	**Pods per Plant**	**Pods per Node**	**Seed weight** g 1000 seeds^{-1}
Low input check	54.2%	34.2%	0.07	0.66	15.8	29.2	1.9	112
High input- No seed treatment	44.0%	38.8%	1.00	1.00	15.6	26.2	1.7	129
High input- No in-season pest management	61.1%	23.4%	0.001	0.006	17.4	27.3	1.6	118
High input- Low population	46.0%	42.3%	0.98	0.98	12.9	22.9	1.8	137
High input- Wide rows	46.8%	34.0%	0.98	0.62	15.3	25.8	1.8	130
High input- No in-season N	46.0%	45.5%	0.99	0.63	12.7	20.7	1.9	127
High input check	43.8%	39.8%	*	*	17.8	23.6	1.6	124

Table 17. Percent two-bean pods, percent three-bean pods, nodes plant^{-1}, pods plant^{-1}, pods node^{-1}, and seed weight g 1000 seeds^{-1} by treatment during 2017 in Perkins, OK.

Treatment	**Percent two-bean Pods**	**Percent three-bean Pods**	**Significance two-bean to High Input**	**Significance three-bean to High Input**	**Nodes per Plant**	**Pods per Plant**	**Pods per Node**	**Seed weight** g 1000 seeds^{-1}
Low input check	41.5%	39.8%	0.99	0.99	21.5	47.3	2.2	99.7
High input- No seed treatment	38.0%	48.1%	0.43	0.40	21.1	50.9	2.4	110.0
High input- No in-season pest management	43.6%	39.3%	1.00	0.99	20.8	48.2	2.4	86.9
High input- Low population	40.3%	45.3%	0.93	0.87	21.4	49.7	2.4	100.6
High input- Wide rows	43.6%	43.0%	1.00	0.99	19.8	42.9	2.2	102.3
High input- No in-season N	41.3%	44.1%	0.99	0.97	21.4	47.8	2.3	90.8
High input- No micronutrients	38.1%	48.1%	0.43	0.39	18.8	51.3	2.7	122.7
High input- No fungicide	37.2%	46.9%	0.26	0.60	22.3	44.6	2.0	97.3
High input- No insecticide	43.3%	38.5%	1.00	0.98	18.5	42.4	2.3	77.7
High input check	43.0%	41.3%	*	*	20.6	45.1	2.2	93.5

In-season Growth Parameters

Early season plant populations could be an indication of several things. One of these aspects is early season seedling vigor. This early season vigor can be greatly altered by several aspects, including environmental conditions, early-season disease, and optimum planting conditions (Bradley, 2008; Dorrance et al., 2003). Therefore, primary treatment impacting early season plant populations should be seed treatments and planting populations, as they can impact the potential for early season disease or total seeds on a per hectare, respectively. The high-input check, which had both higher plant population and seed treatment, significantly increased early season plant population compared to the low-input check, which had neither seed treatments nor higher plant populations, with 181,000 plants ha^{-1} and 303,000 plants ha^{-1}, respectively (Table 18). The high-input management treatments consisting of no seed treatment and lower seed population did not result in a significant influence of early season plant population compared to the high-input check. However, there was still a significant increase in early season plant population when compared to the low-input check. However, treatments that contained seed treatments increased emergence percentage by nearly 10% compared to those without seed treatment, excluding the low-input check. Gaspar et al. (2014) which found that the use of fungicide + insecticide seed treatments consistently increased plant stands supports this result.

Overall, 2017 resulted in high emergence rates with an average of 319,000 across all treatments. Similar to 2016, the high-input check significantly increased plant populations compared to the low-input check, with 355,000 and 242,000, respectively (Table 18). However, removing seed treatments and decreasing population from the high-input check resulted in a significant decrease in plant population early in the season. Emergence percentage was still maintained at approximately 10% higher when a seed treatment was used compared with treatments without seed treatment. The differences between years could be explained by the conditions that existed around planting. In 2016, drier conditions existed. This lowered potential of early season diseases but also decreased the sustainable plant population, indicative of the overall lower plant populations. In 2017, not only did sites receive higher precipitation at and around planting, but soils were also cooler. This resulted in larger potential impacts on seed treatment but also increased sustainable plant populations. Bradley (2008) noted the benefit of seed treatment on soybean stands early in the production season. However, it was noted that this was not consistently seen. The benefits of soybean seed treatment will mostly be seen when planted into poor soil conditions (Tekrony and Egli. 1991; Bradley, 2008; Heatherly and Hodges 1999). While these suboptimal soil conditions are typically associated with earlier planting dates associated with increased moisture and lower soil temperatures, the increased stress associated with the later planting of double-crop production could attribute to the value of seed treatments.

The NDVI in 2016 was very low across all treatments with an average of 0.18. This is due to the below average conditions early in the season with higher temperatures and below average moisture. In addition, limited irrigation was applied earlier in reproduction due to mechanical restrictions. Therefore, water stress substantially decreased biomass production. Normalized difference vegetative index significantly decreased between low input treatment and high input treatment, 0.19 and 0.17, respectively (Table 18). This was not expected with the decreased growth with the early season stress paired with the narrower row spacing associated with the high input treatments compared to the low input. The decrease in NDVI may indicate that with the increased stressed coupled with the high input scheme that the yield potential was not there to support the extra inputs. Eliminating the late-season N applications did decrease NDVI values but did not significantly influence these values. This could indicate that during these high stress environments, this late-season N application did not produce any healthier plants, according to NDVI values. Even with better conditions in 2017 and better NDVI values, no significant decrease in NDVI values were seen between high-input check and the high-input plots without late-season N. However, it must be indicated these plots had substantially better growth resulting in very high NDVI values (0.83 average). Therefore, a saturate of NDVI with little visual soil background resulted limiting the detection of differences between these two treatments. This theory is supported by Hatfield et al (2008) which states that saturation occurs because of the wavelength of the main absorption wavelength of pigments being relatively the same as the chlorophyll. In 2017, there was also a significant increase in NDVI value when comparing the high-input check to the low-input check, 0.84 to 0.75, respectively. This reiterates the much higher growth potential in 2017 compared to the previous year (Table 19).

Similar to all the other in-season management, 2016 resulted in lower in-season plant height compared to 2017. For 2016, plant height for the low-input management significantly increased compared to the high-input check (Table 18). This differs compared to what was expected, as the high-input check was with narrower row spacing. Traditionally, wider rows with consistent row spacing will result in higher intra-row plant would be expected resulting in taller plants. However, Taylor (1980) also found this observation where increases in row spacing resulted in increased plant height. This is further emphasized by the only treatment that significantly differed from the high-input check was when the high-input system had wide rows. This effect was not found in 2017, where low-input check was lower compared to the high-input check, 81.5 cm compared to 85 cm, respectively (Table 19), which Pederson and Lauer (2003) support when they found height decreased as row spacing increased from 19 cm. However, similar to 2016, shifting to wider row spacing within the high-input systems resulted in a numerical increase in plant height, 87.5 cm. This would indicate that wider row spacing resulted in decreased stress in 2016 when conditions were below average. However, when conditions were better, the higher-input system resulted in taller plants.

Table 18. Early season stands (plants ha^{-1}), NDVI, and plant height (cm) by treatment during 2016 in Perkins, OK

Treatment	**Early season stands**	**NDVI**	**Plant height**
	(thousand) Plants ha-1		cm
Low input check	181	0.19	65.2
High input- No seed treatment	322	0.19	56.6
High input- No in-season pest management	369	0.17	56.8
High input- Low population	322	0.19	56.8
High input- Wide rows	328	0.17	64.6
High input- No in-season N	325	0.17	52.7
High input check	303	0.17	57.6

Table 19. Early season stands (plants ha^{-1}), NDVI, and plant height (cm) by treatment during 2017 in Perkins, OK

Treatment	**Early season stands** (thousand) Plants ha^{-1}	**NDVI**	**Plant height** cm
Low input check	242	0.75	81.5
High input- No seed treatment	308	0.83	84.6
High input- No in-season pest management	319	0.84	83.5
High input- Low population	324	0.83	86.1
High input- Wide rows	283	0.78	87.3
High input- No in-season N	340	0.85	80.0
High input- No micronutrients	355	0.85	82.9
High input- No fungicide	315	0.84	83.1
High input- No insecticide	353	0.84	84.9
High input check	355	0.84	84.9

Overall, the physiology of previous wheat variety did not have a consistent impact on in-season growth parameters. In 2016, there is some indication that planting under the higher tillering wheat varieties could result in better crop establishment, with higher early season plant populations. However, several treatments with lower tillering wheat varieties resulted in significantly higher plant populations. Furthermore, some minor decreases in plant population early, did not affect plant growth parameters later in the season (Table 20). The impact of wheat variety in 2017 was even less pronounced than in 2016 (Table 21). This would indicated that any further differences in crop yield would be a result of later season stressors as no significant impact could be noted early in the season.

Table 20. Early season stands (plants ha^{-1}), NDVI, and plant height (cm) by treatment and previous wheat characteristic during 2017 in Perkins, OK

Treatment	**Previous wheat characteristic**	**Early season stands** (thousand) Plants ha-1	**NDVI**	**Plant height** cm
Low input check	Low tillering	163	0.21	63.5
	High tillering	200	0.17	67.0
High input- No seed treatment	Low tillering	301	0.20	54.6
	High tillering	344	0.18	58.6
High input- No in-season pest management	Low tillering	387	0.18	53.3
	High tillering	351	0.16	60.3
High input- Low population	Low tillering	362	0.19	55.9
	High tillering	284	0.19	57.7
High input- Wide rows	Low tillering	251	0.16	58.8
	High tillering	406	0.18	70.4
High input- No in-season N	Low tillering	355	0.17	49.5
	High tillering	297	0.16	56.1
High input check	Low tillering	312	0.19	50.8
	High tillering	297	0.16	59.4

Table 21. Early season stands (plants ha^{-1}), NDVI, and plant height (cm) by treatment and previous wheat characteristic during 2017 in Perkins, OK

Treatment	**Previous wheat characteristic**	**Early season stands** (thousand) Plants ha^{-1}	**NDVI**	**Plant height** cm
Low input check	Low tillering	253	0.70	82.7
	High tillering	231	0.80	80.3
High input- No seed treatment	Low tillering	322	0.80	82.2
	High tillering	294	0.83	87.0
High input- No in-season pest management	Low tillering	308	0.84	83.3
	High tillering	330	0.83	83.7
High input- Low population	Low tillering	326	0.82	84.3
	High tillering	322	0.84	87.9
High input- Wide rows	Low tillering	333	0.76	85.7
	High tillering	244	0.80	88.9
High input- No in-season N	Low tillering	337	0.85	78.9
	High tillering	340	0.85	81.1
High input- No micronutrients	Low tillering	376	0.84	78.9
	High tillering	333	0.85	86.8
High input- No fungicide	Low tillering	317	0.84	84.6
	High tillering	314	0.83	81.6
High input- No insecticide	Low tillering	340	0.83	86.5
	High tillering	358	0.84	83.5
High input check	Low tillering	351	0.84	83.2
	High tillering	358	0.84	86.5

Oil and Protein

Analysis could not be conducted in 2016 due to lower subsample collection and poor sample quality.

For protein in 2017, treatment average was 39% protein, with a low of 37% from the no late season N treatment and a high of 40.5% from the no IPM treatment. These results, even the lowest protein treatment, were higher than the standard for soybean of 34.4%. No treatment significantly differed from the high input check. The largest decrease from the high input check resulted from the removal of late season N (Table 22). This could indicate that N may be correlated with soybean protein in a similar manner to that of wheat, with later-season N resulting in higher grain protein in lieu of it being contributed to increased biomass. These results differed from the literature, which has found no increase in protein or oil content when adding N (Kaur et al., 2017; Wood et al., 1993). In terms of the impact of in-season IPM, this would indicate this late season infestation would have an impact on grain quality. As there are several pod and seed feeding insects, higher infestation could result in significant damage to the seed directly from the insect of allow for post-secondary infection from diseases (Kanobe et al., 2015).

However, if we compare these percentages to United Soybean Board (2014) every treatment including the low input check was higher in oil. In 2017, oil content across all treatments averaged 20% with a low of 18.9% in the no IPM treatment and high of 20.6% in the no late season N treatment (Table 22). This shows an inverse relationship between protein and oil content, where the lowest protein was where no in-season N was applied but resulted in the highest oil content (Hymowitz et al., 1972). There were no significant differences in oil when compared to the high or low input check. These results could indicate that a lack of foliar protection from insect and fungi results in a decrease in oil content. If we compared these results to the average oil, content documented by United Soybean Board (2014) the only treatment that is similar to their average is the no IPM with all other treatments being higher the average.

Table 22. Protein and oil content by treatment during 2017 in Perkins, OK

Treatment	**Protein**	**Oil**
Low input check	38.2	20.1
High input- No seed treatment	38.7	20.5
High input- No in-season pest management	40.5	18.9
High input- Low population	38.8	20.4
High input- Wide rows	40.0	19.8
High input- No in-season N	37.2	20.6
High input- No micronutrients	39.7	19.9
High input- No fungicide	39.1	20.0
High input- No insecticide	38.7	20.3
High input check	38.9	20.1

Overall, the physiology of the previous wheat variety did not have a consistent impact on protein and oil content. In 2017, the only year we were able to collect protein and oil content due to poor conditions in 2016, there were two treatment that showed a difference between the two wheat characteristics, while the variety with the better result was not consent.

Farmer Demonstrations:

During the 2016 season, the implication of our high input management treatment on top of what the producer was already doing increased grain yield an average of 446 kg ha^{-1} across the three locations (Table 23). This increase comes out to \$156.10 hectare^{-1} (based on \$0.35 kg^{-1}) increase in revenue generated. However, in order to determine if this system actually increased profit we need to take into account the \$284.44 per hectare cost of the inputs. Therefore, with the revenue generated minus the cost, a net loss of \$126.34 hectare^{-1} could be expected. This indicates that it was not feasible to do the high input system given the price at the time, as we needed an 807 kg ha^{-1} increase in grain yield or \$0.63 kg^{-1}. The largest difference was seen in Miami with an increase of 463 kg ha^{-1} difference in the farmer practice and high input treatment. If we compare the results seen in 2016 from the demonstrations to the results of, the small plot study similarities can be seen as the high input system increased grain yield compared to the farmer practice (low input check). The economic return and profit at \$0.35, \$0.59, \$0.80 of each location can be seen in Table 25.

In 2017, the high rate of the high input management increased yield an average of 232 kg ha^{-1} (Table 24), which resulted in an \$82.20 ha^{-1} increase in revenue (based on \$0.35 kg^{-1}). However, the cost of the high rate was \$193.00 ha^{-1}, resulting in a loss of \$110.80 ha^{-1}. The medium rate increased yield an average of 266 kg ha^{-1}, which resulted to \$93.10 ha^{-1} increase in revenue; however, the cost of this treatment was \$145 per hectare, resulting in a loss of \$51.90 per hectare. The low rate increased yield by 94 kg ha^{-1}, which figures to \$32.90 per hectare increase in revenue, however the treatment cost \$97.00 ha^{-1}, resulting in a loss of \$64.10 ha^{-1} (Table 26). These results would indicate that it is not feasible apply inputs at the high rate, further evaluation indicated that producers would need a 679 kg ha^{-1} increase in grain yield or \$1.02 kg^{-1} for these applications to be economically viable. Additionally, growers would need 511 kg ha^{-1} increased in yield or \$0.67 kg^{-1} for the medium rate, and 342 kg ha^{-1} increase in yield or \$1.25 kg^{-1} for the low rate. The economic return and profit at \$0.35, \$0.59, \$0.80 of each location can be seen in Table 26. The largest difference between the farmer practice rate and high management rate was seen at Miami were the medium application rate increased yield by 518 kg ha^{-1}. Conversely, a slight yield decline was noted at Afton 10 kg ha^{-1} when the low input was compared to farmer practice. These results show that the yield response to be expected is more based on and controlled by the environment. This can be supported when comparing Blackwell and the other two locations. The growing conditions were more favorable at Afton and Miami compared to Blackwell. Blackwell had a long period of drought from shortly after planting to late July resulting in a less noticeable response between rates and the farmer practice. If we compare the results of the demos to the small-plot study in 2017, we can still see similarities in the results with the high input system out yielding the low input system.

Table 23. Yield (kg ha^{-1}) of the farmer practice and demo strips during 2016 in Afton, Haskell, and Miami, OK.

Location	**Farmer Practice Yield**	**Demo Yield**	**Difference**
	kg/ha^{-1}	kg/ha^{-1}	kg/ha^{-1}
Afton	3578	4004	426
Miami	3897	4360	463
Haskell	4918	5366	448

Table 24. Grain yield (kg ha^{-1}) of the farmer practice and demo strips during 2017 in Afton, Blackwell, and Miami, OK.

Location	**Rate**	**Yield** kg/ha^{-1}	**Difference compared to Farmer practice** kg/ha^{-1}
Afton	High	3153	368
	Medium	3015	230
	Low	2775	-10
	Farmer Practice	2785	*
Blackwell	High	2339	81
	Medium	2309	51
	Low	2289	31
	Farmer Practice	2258	*
Miami	High	3028	246
	Medium	3301	518
	Low	3044	261
	Farmer Practice	2783	*

Table 25. Difference compared to farmer practice kg ha^{-1}, return, cost of treatment, and profit during 2016 in Afton, Haskell, and Miami Oklahoma.

Location	Difference compared to Farmer practice	Return @$0.35/kg	Return @ $0.59/kg	Return @ $0.67/kg	Cost of Treatment	Profit @ 0.35/kg	Profit @ 0.59/kg	Profit @ $0.80/kg
	kg ha^{-1}				\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}
Afton	426	$149.10	$251.34	$285.42	$284.22	($135.12)	($32.88)	$1.20
Haskell	463	$162.05	$273.17	$310.21	$284.22	($122.17)	($11.05)	$25.99
Miami	448	$156.80	$264.32	$300.16	$284.22	($127.42)	($19.90)	$15.94

Table 26. Difference compared to farmer practice kg ha^{-1}, return, cost of treatment, and profit during 2017 in Afton, Blackwell, and Miami, OK.

Location	Rate	Difference compared to Farmer practice	Return @$0.35/kg	Return @ $0.59/kg	Return @ $0.80/kg	Cost of Treatment	Profit @ 0.35/kg	Profit @ 0.59/kg	Profit @ $0.80/kg
		kg ha^{-1}				\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}	\$ ha^{-1}
Afton	High	368	$128.80	$217.12	$294.40	$193.00	($64.20)	$24.12	$101.40
	Medium	230	$80.50	$135.70	$184.00	$145.00	($64.50)	($9.30)	$39.00
	Low	-10	($3.50)	($5.90)	($8.00)	$97.00	($100.50)	($102.90)	($105.00)
Blackwell	High	81	$28.35	$47.79	$64.80	$193.00	($164.65)	($145.21)	($128.20)
	Medium	51	$17.85	$30.09	$40.80	$145.00	($127.15)	($114.91)	($104.20)
	Low	31	$10.85	$18.29	$24.80	$97.00	($86.15)	($78.71)	($72.20)
Miami	High	246	$86.10	$145.14	$196.80	$193.00	($106.90)	($47.86)	$3.80
	Medium	518	$181.30	$305.62	$414.40	$145.00	$36.30	$160.62	$269.40
	Low	261	$91.35	$153.99	$208.80	$97.00	($5.65)	$56.99	$111.80

CHAPTER V

Conclusion

This study aimed at identifying whether growers were limiting grain yields in Oklahoma double-crop soybean production systems due to input or management practice. Interactions identified between high input component and wheat variety characteristic were consistent in terms of yield. The results suggested previous wheat variety physiological characteristic was an important management strategy to maximizing soybean yield. Overall, a higher tillering wheat variety resulted in higher yields. In regards to input management, result suggested that growers could increase yields with increased input management intensity but the value of these inputs is very environmentally driven. The high input system did increase yields compared to the low input, traditional management. The results showed that of the high input components, in season IPM is the most influenced factor regardless of environmental condition. However, in years were we have poor environmental conditions, lowering the plant population and widening row spacing is also of benefit. While seed treatment did not influence yield, we did see a 10% increase in emergence from those with seed treatment.

The farmer demonstrations validated the small-plot study increase in grain yield from the use of a high input system. However, when economic cost-benefit aspects were evaluated, there was an indication that these inputs did not greatly benefit farm value. It was seen that inputs increased yields by 366 kg ha^{-1}, which equates to an average of \$128.10 ha^{-1} increase in revenue; however, that increase cost us \$232.22 ha^{-1} resulting in a net loss of \$104.12 ha^{-1} at a soybean price of \$0.35 kg^{-1}. With the implementation of generic insecticides and fungicides along with an increase in the price of soybean per kg to \$0.55 kg^{-1}.

In conclusion, with current "Farmer's Practice" treatments, we are underselling yields. With that said the environmental conditions are a bigger factor than what any one input can overcome by itself. Regardless of the environmental conditions, seed treatment did increase early season stands by 10%. If producers are looking for ways to improve double-crop yields, they should start by considering, planting a high tillering wheat variety to help maximize moisture retention in their soybean crop. Foliar IPM is an important input to consider if looking at a high management system as it was seen to protect against late season pest attacks maximizing yield potential. The one input that was seen to not be needed was foliar micronutrients, which decreased yield. However, none of this important if we do not see an increase in commodity prices as shown by the farmer demonstrations, as a high input system is not profitable at today's prices. At today's commodity prices our current farmer practices are the economically smart way to go.

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APPENDICES

2016 growing season data:

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	plants	nodes	pods	2 bean pods	3 bean pods	nodes/ plant	pods/ plant	pods/ node	Yield (kg/ha)
101	1	1	Bentley	114726	0.23	58.42	16	185	352	141	153	11.6	22	2	726.5
102	2	1	Bentley	358519	0.2	55.88	26	260	412	117	206	10.0	16	2	929.8
103	3	1	Bentley	444563	0.22	50.8	26	200	341	147	160	7.7	13	2	1006.0
104	4	1	Bentley	415881	0.22	50.8	24	219	331	136	151	9.1	14	2	1194.0
105	5	1	Bentley	243793	-	-	-	-	-	-	-	-	-	-	706.2
106	6	1	Bentley	516267	0.2	38.1	25	158	205	130	75	6.3	8	1	558.9
107	7	1	Bentley	301156	0.25	38.1	24	140	195	87	44	5.8	8	1	457.3
201	7	2	Bentley	315496	0.17	45.72	30	289	550	275	165	9.6	18	2	1556.6
202	4	2	Bentley	344178	0.17	50.8	29	249	604	217	242	8.6	21	2	1639.6
203	6	2	Bentley	344178	0.17	45.72	29	149	730	335	294	5.1	25	5	1724.7
204	1	2	Bentley	164919	-	58.42	-	-	-	-	-	-	-	-	1428.9
205	5	2	Bentley	215111	0.15	66.04	23	237	513	246	175	10.3	22	2	1092.4
206	2	2	Bentley	358519	0.2	45.72	33	280	462	268	103	8.5	14	2	939.9
207	3	2	Bentley	315496	0.19	45.72	30	274	570	360	80	9.1	19	2	787.5
301	4	3	Bentley	344178	0.19	68.58	30	254	478	230	212	8.5	16	2	2161.7
302	7	3	Bentley	286815	0.17	63.5	28	292	452	245	155	10.4	16	2	1859.7
303	1	3	Bentley	157748	0.25	71.12	24	244	472	283	157	10.2	20	2	2033.4
304	2	3	Bentley	157748	0.21	55.88	-	-	-	-	-	-	-	-	2273.7
305	6	3	Bentley	215111	0.15	58.42	25	207	342	233	75	8.3	14	2	1947.0
306	5	3	Bentley	308326	0.17	55.88	17	132	198	110	65	7.8	12	2	1699.4
307	3	3	Bentley	329837	0.17	55.88	28	238	344	181	98	8.5	12	1	1275.3
401	4	4	Bentley	344178	0.16	53.34	25	252	373	186	151	10.1	15	1	1753.6
402	6	4	Bentley	344178	0.15	55.88	27	261	364	188	136	9.7	13	1	1300.7

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	plants	nodes	pods	2 bean pods	3 bean pods	nodes/ plant	pods/ plant	pods/ node	Yield (kg/ha)
403	7	4	Bentley	344178	0.17	55.88	23	332	391	196	122	14.4	17	1	2094.7
404	2	4	Bentley	329837	0.17	60.96	-	-	-	-	-	-	-	-	1529.3
405	1	4	Bentley	215111	0.15	66.04	23	234	447	263	137	10.2	19	2	1310.8
406	3	4	Bentley	458904	0.14	60.96	26	243	426	245	91	9.3	16	2	1219.4
407	5	4	Bentley	236622	0.15	58.42	21	210	468	211	163	10.0	22	2	1476.5
501	1	1	Gallagher	236622	0.2	66.04	17	374	595	321	203	22.0	35	2	1476.9
502	2	1	Gallagher	329837	0.2	55.88	19	466	836	390	219	24.5	44	2	1628.0
503	3	1	Gallagher	358519	0.13	55.88	28	448	658	462	112	16.0	24	1	2101.6
504	4	1	Gallagher	301156	0.18	55.88	24	330	600	288	252	13.8	25	2	2000.5
505	5	1	Gallagher	272474	0.18	66.04	28	364	616	278	216	13.0	22	2	1852.5
506	6	1	Gallagher	444563	0.17	50.8	30	345	480	165	270	11.5	16	1	1458.2
507	7	1	Gallagher	301156	0.13	58.42	25	463	597	187	347	18.5	24	1	1478.5
601	7	2	Gallagher	229452	0.18	55.88	22	440	628	261	297	20.0	29	1	1334.1
602	4	2	Gallagher	186430	0.18	55.88	25	475	575	267	241	19.0	23	1	1669.2
603	6	2	Gallagher	258133	0.18	53.34	22	484	795	278	448	22.0	36	2	1804.6
604	1	2	Gallagher	136237	0.15	66.04	18	450	800	448	256	25.0	44	2	1524.2
605	5	2	Gallagher	293985	0.18	66.04	20	560	952	421	332	28.0	48	2	1588.9
606	2	2	Gallagher	444563	0.21	55.88	18	396	674	236	379	22.0	37	2	1280.4
607	3	2	Gallagher	344178	0.2	50.8	18	465	791	530	159	25.8	44	2	1026.3
701	4	3	Gallagher	372859	0.22	58.42	18	306	728	364	313	17.0	40	2	1178.7
702	7	3	Gallagher	344178	0.19	60.96	17	323	743	298	335	19.0	44	2	1877.8
703	1	3	Gallagher	200770	0.19	66.04	17	248	521	293	168	14.6	31	2	1332.6
704	2	3	Gallagher	243793	0.16	60.96	16	288	512	252	214	18.0	32	2	1407.4
705	6	3	Gallagher	193600	0.16	60.96	20	402	540	185	313	20.1	27	1	1580.3
706	5	3	Gallagher	659674	0.2	76.2	26	624	858	380	278	24.0	33	1	1816.6
707	3	3	Gallagher	315496	0.18	71.12	18	648	907	607	182	36.0	50	1	2283.8

2017 growing season data:

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	Plants	nodes	pods	2 bean pods	3 bean pods	pods/ node	nodes/ plant	pods/ plant	Yield (kg/ha)	seed weight	Protein	Oil
101	1	1	Bentley	272474	0.64	78.7	20	386	912	288	328	2.4	19.3	46	711.1	68.8	38.3	18.0
101	1	1	Gallagher	243793	0.8	76.2	24	506	1219.2	490	506	2.4	21.1	51	1213.0	91.2	37.4	20.9
102	2	1	Bentley	344178	0.82	76.2	26	481	1201.2	489	502	2.5	18.5	46	938.1	83.9	40.2	20.0
102	2	1	Gallagher	329837	0.84	84.5	21	389	877.8	323	401	2.3	18.5	42	1252.7	94.9	39.0	20.0
103	3	1	Bentley	258133	0.77	77.5	24	430	948	427	353	2.2	17.9	40	1010.8	82.9	41.6	18.0
103	3	1	Gallagher	372859	0.83	82.6	35	830	1333.5	662	515	1.6	23.7	38	1531.8	61.9	41.5	18.1
104	4	1	Bentley	301156	0.81	75.6	30	513	1074	492	384	2.1	17.1	36	764.0	81.8	40.3	19.6
104	4	1	Gallagher	344178	0.85	84.5	22	532	1106.6	425	526	2.1	24.2	50	1903.0	106.3	41.1	19.6
105	5	1	Bentley	315496	0.68	87.6	28	596	1184.4	532	498	2.0	21.3	42	1058.1	84.6	41.0	19.2
105	5	1	Gallagher	272474	0.78	87.6	39	698	1333.8	667	507	1.9	17.9	34	1761.9	99	41.4	19.0
106	6	1	Bentley	372859	0.85	74.9	31	849	1602.7	707	707	1.9	27.4	52	1573.6	80.3	37.5	20.6
106	6	1	Gallagher	344178	0.86	79.4	38	912	2147	779	1075	2.4	24	57	1691.2	11.9	41.1	18.6
107	7	1	Bentley	401541	0.8	64.1	33	370	640.2	231	297	1.7	11.2	19	1625.4	147.4	42.9	18.3
107	7	1	Gallagher	358519	0.86	83.8	21	473	945	292	561	2.0	22.5	45	1620.1	108.2	41.5	18.8
108	8	1	Bentley	387200	0.84	83.8	32	672	1241.6	435	624	1.8	21	39	746.9	69.1	41.5	19.0
108	8	1	Gallagher	344178	0.85	78.1	40	872	1372	624	508	1.6	21.8	34	1355.0	80	41.8	18.4
109	9	1	Bentley	315496	0.87	79.4	26	510	1263.6	541	348	2.5	19.6	49	801.0	71.4	40.2	19.3
109	9	1	Gallagher	372859	0.84	76.2	34	598	1118.6	493	439	1.9	17.6	33	1200.8	82.1	38.7	19.8
110	10	1	Bentley	358519	0.81	81.3	22	524	1086.8	475	361	2.1	23.8	49	1641.5	86	38.9	19.6
110	10	1	Gallagher	358519	0.83	76.2	32	694	1260.8	544	560	1.8	21.7	39	-	53.8	40.8	17.7
201	5	2	Bentley	308326	0.77	86.4	37	781	1986.9	895	925	2.5	21.1	54	1148.4	92.6	38.5	20.7
201	5	2	Gallagher	265304	0.74	89.5	34	636	1397.4	588	615	2.2	18.7	41	1836.4	123.3	40.6	20.3
202	1	2	Bentley	293985	0.72	88.9	33	822	1815	729	746	2.2	24.9	55	943.7	92.5	37.9	20.0

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	Plants	nodes	pods	2 bean pods	3 bean pods	pods/ node	nodes/ plant	pods/ plant	Yield (kg/ha)	seed weight	Protein	Oil
202	1	2	Gallagher	186430	0.82	81.3	37	788	1443	625	599	1.8	21.3	39	1462.8	117.2	38.2	21.3
203	10	2	Bentley	286815	0.85	78.7	22	405	948.2	273	486	2.3	18.4	43	1114.5	93.8	39.3	19.8
203	10	2	Gallagher	344178	0.83	91.4	33	673	1590.6	726	660	2.4	20.4	48	2156.0	91.9	37.7	21.5
204	4	2	Bentley	372859	0.84	86.4	28	560	1433.6	529	630	2.6	20	51	1038.1	78.1	37.8	19.8
204	4	2	Gallagher	358519	0.85	87.6	27	707	1458	500	716	2.1	26.2	54	1633.4	109.4	37.8	21.3
205	3	2	Bentley	401541	0.87	86.4	30	597	1575	675	450	2.6	19.9	53	1319.2	72.1	39.2	19.2
205	3	2	Gallagher	286815	0.86	87.0	14	318	704.2	301	284	2.2	22.7	50	1789.2	97	41.1	18.7
206	6	2	Bentley	387200	0.84	81.3	40	1060	2196	1068	640	2.1	26.5	55	1506.2	89	33.4	22.8
206	6	2	Gallagher	301156	0.85	83.2	33	812	1795.2	789	782	2.2	24.6	54	2056.8	132.7	40.4	20.1
207	2	2	Bentley	301156	0.81	85.1	23	465	1173	520	490	2.5	20.2	51	1673.0	80.5	41.1	19.3
207	2	2	Gallagher	243793	0.83	89.5	21	542	1430.1	546	716	2.6	25.8	68	2683.2	142.1	39.7	20.2
208	7	2	Bentley	372859	0.86	86.4	30	690	1716	609	930	2.5	23	57	1440.7	116.4	39.4	20.2
208	7	2	Gallagher	301156	0.85	87.6	37	644	2430.9	955	1191	3.8	17.4	66	1867.6	118.3	39.4	20.0
209	9	2	Bentley	415881	0.86	91.4	25	475	1030	450	435	2.2	19	41	1366.6	82.6	39.8	20.0
209	9	2	Gallagher	301156	0.85	85.1	26	432	1079	520	367	2.5	16.6	42	1946.2	92.3	39.5	19.7
210	8	2	Bentley	358519	0.86	91.4	27	629	1225.8	505	510	1.9	23.3	45	1959.6	113.9	38.9	20.5
210	8	2	Gallagher	387200	0.85	80.0	34	745	1550.4	619	558	2.1	21.9	46	-	83.6	40.5	18.7
301	8	3	Bentley	164919	0.8	80.6	28	650	1895.6	669	997	2.9	23.2	68	1183.4	-	-	-
301	8	3	Gallagher	179259	0.77	80.6	31	515	837	180	570	1.6	16.6	27	1944.4	128.4	37.5	22.1
302	9	3	Bentley	344178	0.79	88.9	25	473	1015	433	340	2.1	18.9	41	955.0	34.7	39.7	19.4
302	9	3	Gallagher	387200	0.82	86.4	31	561	1205.9	462	558	2.1	18.1	39	2226.0	106.9	38.6	21.1
303	1	3	Bentley	315496	0.72	88.3	30	708	1647	720	657	2.3	23.6	55	760.7	78.9	37.8	20.9
303	1	3	Gallagher	358519	0.81	81.3	35	588	1323	627	371	2.3	16.8	38	1373.4	118.4	37.9	21.2
304	6	3	Bentley	315496	0.83	78.7	30	501	1167	435	576	2.3	16.7	39	1184.8	89.7	33.9	22.1
304	6	3	Gallagher	372859	0.82	81.9	27	478	974.7	419	392	2.0	17.7	36	2145.7	113.6	36.2	22.2
305	2	3	Bentley	272474	0.85	86.4	27	599	1296	464	737	2.2	22.2	48	1582.9	94.4	38.8	20.4

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	Plants	nodes	pods	2 bean pods	3 bean pods	pods/ node	nodes/ plant	pods/ plant	Yield (kg/ha)	seed weight	Protein	Oil
305	2	3	Gallagher	272474	0.86	87.6	26	585	1167.4	390	629	2.0	22.5	45	2802.5	128.9	37.1	21.6
306	5	3	Bentley	372859	0.79	91.4	23	414	830.3	370	324	2.0	18	36	911.4	98.3	41.2	19.1
306	5	3	Gallagher	207941	0.84	91.4	37	636	1446.7	581	648	2.3	17.2	39	1367.1	119.9	41.9	19.1
307	7	3	Bentley	401541	0.85	78.7	32	758	2185.6	778	1114	2.9	23.7	68	1715.9	108.7	37.3	21.9
307	7	3	Gallagher	358519	0.86	88.3	31	549	2073.9	806	952	3.8	17.7	67	2425.7	121.4	39.7	20.1
308	4	3	Bentley	329837	0.8	83.8	21	494	1152.9	395	573	2.3	23.5	55	1977.4	114	38.6	21.4
308	4	3	Gallagher	301156	0.84	88.3	24	427	1528.8	665	804	3.6	17.8	64	1623.5	109.6	39.6	20.6
309	10	3	Bentley	387200	0.87	85.1	24	370	940.8	408	377	2.5	15.4	39	2290.4	115.9	37.7	20.7
309	10	3	Gallagher	401541	0.86	91.4	32	746	1552	902	464	2.1	23.3	49	2000.9	109.7	39.2	20.4
310	3	3	Bentley	301156	0.87	81.3	43	1127	2343.5	1118	877	2.1	26.2	55	2116.2	112.2	38.5	20.8
310	3	3	Gallagher	387200	0.85	73.7	30	543	1764	708	771	3.2	18.1	59	-	82.9	39.4	18.9
401	5	4	Bentley	293985	0.81	77.5	37	884	1809.3	681	825	2.0	23.9	49	1101.0	66.2	37.5	20.7
401	5	4	Gallagher	229452	0.82	87.0	41	828	1955.7	869	861	2.4	20.2	48	2254.1	134.7	38.0	20.6
402	10	4	Bentley	372859	0.81	87.6	26	517	1063.4	447	442	2.1	19.9	41	1643.6	83	38.5	20.4
402	10	4	Gallagher	329837	0.85	87.0	26	567	1359.8	528	658	2.4	21.8	52	2384.8	113.9	39.3	20.5
403	9	4	Bentley	301156	0.81	86.4	34	622	1407.6	622	581	2.3	18.3	41	1773.3	40.4	37.8	20.8
403	9	4	Gallagher	372859	0.85	86.4	32	634	1728	736	755	2.7	19.8	54	2695.6	111.3	36.0	22.4
404	4	4	Bentley	301156	0.82	91.4	37	792	1639.1	733	673	2.1	21.4	44	1697.7	95	37.3	21.1
404	4	4	Gallagher	286815	0.84	91.4	30	627	1308	588	558	2.1	20.9	44	2330.2	110.2	38.6	20.6
405	1	4	Bentley	129067	0.73	74.9	19	486	1092.5	395	538	2.2	25.6	58	1096.8	113.5	37.6	21.3
405	1	4	Gallagher	136237	0.77	82.6	27	524	1053	524	429	2.0	19.4	39	850.6	117.1	40.3	17.7
406	3	4	Bentley	272474	0.82	88.3	44	801	1839.2	792	801	2.3	18.2	42	1992.6	96.4	40.5	19.4
406	3	4	Gallagher	272474	0.85	91.4	43	847	2137.1	796	968	2.5	19.7	50	2087.6	89.5	42.2	18.4
407	7	4	Bentley	329837	0.86	86.4	38	654	1314.8	631	475	2.0	17.2	35	2885.6	122	37.4	21.3
407	7	4	Gallagher	315496	0.86	87.6	27	481	1444.5	583	621	3.0	17.8	54	2064.1	138.8	40.5	19.0
408	2	4	Bentley	372859	0.84	81.3	19	424	1151.4	418	543	2.7	22.3	61	2142.8	139.8	36.8	21.4

Plot	TRT	Rep	Variety	Population (ha)	NDVI	Height (cm)	Plants	nodes	pods	2 bean pods	3 bean pods	pods/ node	nodes/ plant	pods/ plant	Yield (kg/ha)	seed weight	Protein	Oil
408	2	4	Gallagher	329837	0.82	86.4	21	393	980.7	380	462	2.5	18.7	47	1230.5	115.1	37.4	21.3
409	8	4	Bentley	358519	0.87	82.6	34	728	1363.4	595	551	1.9	21.4	40	2908.6	98.9	37.4	20.9
409	8	4	Gallagher	344178	0.85	87.6	25	725	1455	513	713	2.0	29	58	1836.3	103.2	38.0	20.5
410	6	4	Bentley	272474	0.86	80.6	29	522	1374.6	545	690	2.6	18	47	2462.8	133.8	35.9	22.0
410	6	4	Gallagher	358519	0.85	80.0	27	429	1155.6	435	535	2.7	15.9	43	-	75.5	39.8	17.0

Table 1A. Product cost at ha^{-1} and $plot^{-1}$ basis in 2016 for small-plot study

Product	rate ha^{-1}	cost ha^{-1}	cost $plot^{-1}$
Max- In	4.6 L ha^{-1}	$ 71.58	$0.13
Urea	112 kg ha^{-1}	$ 37.65	$0.07
Foliar Fungicide (Headline)	0.9 L ha^{-1}	$ 88.07	$0.16
Insecticide (Besiege)	0.7 L ha^{-1}	$ 52.99	$0.10
Seed treatment	2.66 mL kg $seed^{-1}$	$ 32.10	$0.06
Total cost		**$ 282.40**	**$0.53**

Table 2A. Product cost at ha^{-1} and $plot^{-1}$ basis in 2017 for small-plot study

Product	rate ha^{-1}	cost ha^{-1}	cost $plot^{-1}$
Max- In	4.6 L ha^{-1}	$ 28.64	$0.13
Urea	112 kg ha^{-1}	$ 41.98	$0.19
Foliar Fungicide (Headline)	0.9 L ha^{-1}	$ 75.85	$0.35
Insecticide (Besiege)	0.7 L ha^{-1}	$ 59.75	$0.27
Seed treatment	2.66 mL kg $seed^{-1}$	$ 32.10	$0.15
Total Cost		**$ 238.32**	**$1.09**

Table 3A. Product cost L^{-1} for 2016 and 2017

Product	price L^{-1} 2016	price L^{-1} 2017
Max In	$ 15.32	$ 6.13
Foliar Fungicide (Headline)	$ 100.51	$ 86.41
Insecticide (Besiege)	$ 72.56	$ 81.96
Gradual N	-	$ 2.55

VITA

Kody Michael Leonard

Candidate for the Degree of

Master of Science

Thesis: INPUT MANAGEMENT FOR IMPROVING DOUBLE-CROP SOYBEAN MANAGEMENT IN OKLAHOMA

Major Field: Plant and Soil Science

Biographical: Born in Joplin, Missouri

Education:

Completed the requirements for the Master of Science in your major at Oklahoma State University, Stillwater, Oklahoma in May, 2018.

Completed the requirements for the Bachelor of Science in Plant and Science at Oklahoma State University, Stillwater, Oklahoma in 2016.

Experience:

Graduate Research Assistant: Oklahoma State University – Summer 2016 - current

Professional Memberships:

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Crop Science Society of America
Soil Science Society of America