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THE EFFECTS OF STARTER FERTILIZER ON SOYBEAN INFECTED WITH FUSARIUM VIRGULIFORME OR RHIZOCTONIA SOLANI

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By

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Fusarium virguliforme (Aoki), the fungus that causes sudden death syndrome of soybeans (SDS), is prevalent in most of the soybean (*Glycine max* L. Merr.) production regions throughout the United States. Sudden death syndrome management has been limited to cultural practices and host resistance. *Rhizoctonia solani* (Kühn) is a fungus responsible for pre-emergence and post emergence damping off. Control methods include seed treatments and cultural practices.

Several companies have advocated the use of in-furrow starter fertilizers in soybean production. Promoting root growth and emergence are a couple of the alleged benefits. It is unknown if the increased fertility in the root zone may actually increase or decrease the severity of root or seedling diseases.

An objective of this study is to determine if the starter fertilizers (2-6-16), (7-12-11), (3-10-13) Nachurs Alpine Solutions™ impacts seedling disease caused by *Rhizoctonia solani* and soybean yield. A second objective is to determine if starter-fertilizer influences the incidence and severity of SDS and soybean yield. One trial was infested with *R. solani* at the rate of 0.9 g of inoculum/30.5 centimeters of row. A second trial was infested with *F. virguliforme* at the rate of 2.25 g/30.5 centimeters of row. Inoculum consisted of sterilized white sorghum inoculated with either pathogen. Plots were 3.04 meters wide by 6.1 meters in length with row spacing of 0.76 meters. Trials took place during the growing season of 2014 and 2015. In 2014, a randomized complete block design consisted of 4 treatments

that were replicated 6 times and planted into 4 row plots. Treatments consisted of treated (Metalaxl™, Fluxapyroxad™, Pyraclostrobin™, and Imidacloprid™) or non-treated seed ('Asgrow 4730') combined with either fertilizer (2-6-16) or non-fertilizer. Across both trials, there were no seed treatment and fertilizer rate interactions. In the *R. solani* trial, stand counts were similar between the fertilizer and non-fertilizer treatments. Stand counts were higher when the seed treatment was used. There was no significant difference in soybean yield regardless of treatment. In the *F. virguliforme* trial, stand counts were reduced in the fertilizer treatment when compared to the non-fertilizer treatment. Foliar symptoms of SDS and soybean yield were not affected by treatment. In 2015, there were changes in treatment structure due to additions of fertilizer treatments 7-12-11 and 3-10-13. Seed treatments and randomized complete block design remained for 2015. Stand counts were higher in plots that received fertilizer treatments in the *R. solani* trial. Stand counts were lower in *R. solani* plots with treated seed. Yield was not influenced by seed treatment but was increased by 3-10-13 and 7-12-11 fertilizer treatments. For the *F. virguliforme* trial, reduced stand counts were found in the plots with seed treatments. Seed treatments did not influence yield. Fertilizer did not impact stand or yield. Foliar symptoms of SDS were not influenced by seed treatment or fertilizer.

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CHAPTER 1

INTRODUCTION/LITERATURE REVIEW

With nearly 50 countries producing soybean, *Glycine max* L. Merr., it is the dominant oilseed crop produced and consumed in the world today. The United States is the number one producer of soybean, with 83.7 million acres planted and 3.97 billion bushels harvested in 2014. In the United States, soybean makes up 21% of the harvested cropland acreage and is also the 2nd most planted crop (NASS, 2015). Soybeans are yielding higher than ever before and soybean yield potential continues to increase as genetic technology is improved (Rowntree, et al., 2013). This increase in production drives a need for improved nutrient management in order to supply high yielding cultivars with appropriate amounts of nutrients, as well as timing of nutrient uptake. Improving efficiency of nutrient utilization can ultimately improve soybean productivity (Usherwood, 1998).

Like all plants, soybean requires 16 essential elements for development and completion of its life cycle. Obtained from the atmosphere, carbon, hydrogen, and oxygen are the three primary non-mineral nutrients needed for soybean production. The other thirteen essential elements are obtained from the soil and can be classified into three categories that are based off of the quantities used by plants. Nitrogen, phosphorus and potassium are known as macronutrients and are utilized by the soybean in large quantities. Calcium, magnesium and sulfur are known as secondary nutrients and are taken up in moderate amounts, while the other seven elements are categorized as micronutrients and taken up in minute amounts. The seven micronutrients are boron, chlorine, copper, iron, manganese, molybdenum, and zinc. Each mineral element has a particular role in soybean

development, some promoting vegetative growth while others assist in reproductive functions (Acquaah, 2002).

The three macronutrients, nitrogen (N), phosphorus (P) and potassium (K), are the most important crop nutrients used in agricultural systems (Chude et al., 2004). Most fertility programs that are directed towards increasing crop yield contain N, P and K fertilizers (Vera et al., 2002). Yield is the number one factor that determines removal of the soil nutrients required for the crop (Mallarino et al., 1999). A bushel of soybeans removes about 6.3 pounds of N, 1.5 pounds of P (P_20_5), and 12.8 pounds of K (K_2O) (Heatherly & Elmore, 2004). Portions of these amounts are supplied from the soil's nutrient reserves and symbiotic nitrogen fixation, while the other amounts will come from crop residue decomposition and fertilizer applications (McGrath et al., 2013).

Nitrogen is the most abundant mineral nutrient found in the plant and is key for growth and productivity (Acquaah, 2002). Nitrogen is a constituent for nucleic acids, amino acids and proteins and chlorophyll that promote vegetative growth (Zeiger, 2010). There are two forms of nitrogen that can be taken up by plants, ammonium (NH^{4+}) and nitrate (NO_3^-) (Tisdale et al., 2013). Leguminous crops, such as soybean, meet their demand for nitrogen through a process called biological N fixation. A symbiotic relationship is formed between soybean and the soilborne rhizobia bacteria, *Bradyrhizobium japonicum* J. These rhizobia bacteria attach to soybean roots, colonize the plant and convert atmospheric nitrogen gas to ammonia, and then to nitrate (NO_3^-), which is a nitrogen form that is usable to the plant (McGrath, 2013). However, only 25 to 60% of N in soybean dry matter originates from symbiotic N_2 fixation, with the remainder coming from nitrogen in the soil (Harper, 1974). The process of nitrogen fixation doesn't begin until 14 days after soybean

germination. This information raises enthusiasm for possible benefits of additional nitrogen fertilizer applications to soybeans. Today, nitrogen fertilizer applications to soybean remain a complicated issue due to previous research showing contradicting results. While some research has proven that N applications have increased soybean growth and yield, other results have shown no response or even negative effects (Beard & Hoover, 1971; Diebert et al., 1979; Ham et al., 1975; Welch et al., 1973).

Nitrogen has been the most extensively studied soil nutrient in relation to disease development. An abundant availability of nitrogen can boost the production of young, succulent growth, a lengthened vegetative period, and delayed maturity of the soybean. This can result in the plant being more susceptible to pathogens that are attracted to healthy tissues, as well as giving the pathogen a larger time frame to attack. On the other hand, plants that are deficient in nitrogen are weaker, slower growing and forced into early maturity, making them susceptible to pathogens that are best able to attack weak, slow growing plants. Limited availability of nitrogen has been proven to increase the susceptibility of tomato to wilt caused by *Fusarium oxysporum* f.sp. *lycopersici* S., early blight of many solanaceous plants caused by *Alternaria* spp. and damping off of seedlings caused by infections of *Pythium* spp. (Agrios, 1997).

It is not only the amount of nitrogen that can affect disease development, but the form of available nitrogen to the host and pathogen can influence incidence and severity of disease as well (Huber & Watson, 1974). Pathogen infection can lead to alterations in host N metabolism and changes in tissue concentrations of both inorganic and organic N (Walters & Ayres, 1980, Walters, 1985). Therefore, the different types and concentrations

of nitrogen available to the pathogen, depends on the plant (host) species, the particular plant organ that is infected, and the type of pathogen (Walters & Bingham, 2007).

The ammonium form of nitrogen has been shown to stimulate many diseases such as *Fusarium* tomato wilt (*F. oxysporum),* root rot of sugar beet caused by *Rhizoctonia solani* K., and root rot of pea and soybean (*Aphanomyces euteiches* f. sp. *pisi* D.*)*. Nitrate arouses root rot of pea and corn caused by *Pythium ultimum* T.*,* root rot in cotton *(Phymatotrichum omnivorum* D.*)* and tomato and tobacco wilt caused by *Ralstonia solanacearum* S. (Huber & Watson, 1974). Studies have shown that the two forms of plant available nitrogen, ammonium and nitrate, often have opposite effects on certain plant diseases. For example, while the nitrate N suppresses *F. oxysporum* of tomato, the ammonium form actually increases disease severity (Woltz & Jones, 1973). The effect of the form of nitrogen is linked to the pH of the soil. Ammonium fertilizer will decrease pH, encouraging diseases that are favored by acidic soil, while the nitrate fertilizer will do the opposite (Agrios, 1997, Sullivan, 2001). The effect of specific forms of nitrogen on disease severity depends on many factors and is not the same for all host-parasitic associations (Huber & Watson, 1974).

Phosphorus is the second nutrient most utilized in the soybean and its application has shown to improve growth, development and yield (Kakar et al., 2002). Phosphorus plays a role in photosynthesis, respiration, cell division and energy storage as well as root growth, nodulation, biological N fixation, and plant maturation (Snyder, 2000; Acquaah, 2002). Phosphorus found in the soil is very low in solubility and not readily available to plants. The two forms of phosphorus that can be taken up by the plant are the orthophosphates $H_2PO_4^-$ and HPO_4^{2-} (Tisdale, 2013). The orthophosphate form can easily

undergo phosphorus fixation, meaning that it is readily precipitated and adsorbed to soil particles, rendering it unavailable to the plant (Zhang, 2006). For the soybean to take up this nutrient in its available form, the root system must come in contact with the P compounds because phosphorus is immobile in the soil. When deficient in P, soybeans may be stunted and show dark green and purple plant parts.

A sufficient supply of phosphorus is important for soybean growth and its ability to sustain or curtail disease, although increasing this nutrient doesn't always lead to disease reduction. Phosphorus provides protection through its role in early root development and energy storage necessary for driving major plant functions. Vigorous roots and a well-developed root system is one of the most important plant defenses against root diseases (Better Crops, 1999). Similar to nitrogen, research has shown contradictory results when looking at the relationship between plant-phosphorus nutrition and disease development. (Jones et al., 1989), showed that the increase of plant available phosphorus increased development of *Fusarium oxysporum* f. sp. *vasinfectum (*Atk.) Snyd. & Hans, causing wilt in cotton. Comparably, (Chauhan et al., 2000) documented that the increase in phosphorus nutrition in cauliflower led to an increase in damping off and stem rot caused by *R. solani*. Alternatively, a lack of phosphorus has been associated with an increase of anthracnose of cowpea, caused by *Colletotrichum lindemuthianum* Sacc. & Magnus*.* The impact that this nutrient has on plant disease development depends on the distinct crop-pathogen interactions.

The third macronutrient, potassium, is known for promoting stem and root growth and plays a role in plant metabolism, protein synthesis, and chlorophyll development (Remison, 2005). Many plant enzymes require potassium for activation and this nutrient is

also critical for cell division, formation of carbohydrates, and translocation of sugars. Potassium is the primary element responsible for regulation of water control in plants, and is known to increase the resistance of certain plants to certain diseases (Acquaah, 2002). Past research has shown significant effects, such as increases in soybean yield in response to K fertilizer applications (Farhad et al., 2010). Potassium can be adsorbed between clay layers and remains relatively immobile due to its positive charge while the soil is negatively charged. The available form of potassium that can be taken up and utilized by the plant is (K^+) (Tisdale, 2013).

Potassium nutrition is also related to disease development. Just like the other two macronutrients, the involvement and influence that this nutrient has on plant disease is a complex matter. When managing crop disease and soil fertility, the rate and form of potassium and its balance with other nutrients in the soil are factors to consider. K^+ can have direct effects on different stages of pathogen establishment and development within the host. This nutrient can also promote the plant's wound healing, indirectly effecting infection of certain pathogens. Potassium affects plant morphology such as hardening the tissues, which results in the improvement of resistance to disease penetration (Perrenoud, 1990). An abundant level of potassium in soybean can delay maturity and senescence and result in allowing a larger time frame for certain pathogens to infect (Agrios, 1997).

In many cases, potassium has been shown to reduce the severity of plant diseases, although high quantities of the nutrient can increase the severity of disease as well. A few diseases that are less effective in the presence of potassium are stem rust of wheat, early blight of tomato, and stalk rot of corn (Agrios, 1997). On the other hand, (Pacumbaba et al.,

1997) found that increased levels of potassium led to an increase in soybean root and stem rot caused by *Phytophthora sojae* K. & G.

Soil fertility and plant nutrition are important components to consider when managing soybean diseases. Nutrition affects the rate of growth and the state of readiness of plants to defend themselves against pathogenic attack (Agrios, 1997). However, in order for a pathogen to successfully colonize a soybean, it requires efficient utilization of nutrient resources that are present in the soybeans tissues (Snoeijers et al., 2000). Soybeans that are grown in soils rich with nutrients such as available N, P, and K, are apt for diseases. Fertilizer applications can cause nutrient-induced changes in both the host and pathogen, leading to an increase or decrease in development of plant disease. The components leading to these changes are diverse and complex and include the effects of mineral nutrients directly on the pathogen, on plant growth and development, and on plant resistance mechanisms (Huber & Wilhelm, 1988).

One of the most important soybean diseases of North and South America, SDS, is influenced by soil fertility (Rupe et al., 1993). First documented in Arkansas in 1971 (Rupe et al., 1988), this disease has spread and continues to cause very large problems in most soybean production regions in the world today. The blue-pigmented soilborne fungus, known as *Fusarium virguliforme* (Aoki, 2003) is the pathogen responsible for causing sudden death syndrome. The fungus infects the soybean roots, colonizes the plant and produces a toxin that translocates throughout the plant. The fungus can colonize and infect roots as soon as two weeks after germination, however signs and symptoms of SDS do not usually appear until flowering or shortly after. Leaf symptoms often include puckering that can later lead to interveinal chlorosis and necrosis, as the major lateral veins remain green.

In severe cases, leaves will shrivel and defoliate, seed development will decrease, pods will abort seeds and plants can even experience premature death (Rupe et al., 1993; Rupe et al., 1988; Yang & Lundeen, 1997). In the United States, yield losses caused by SDS have been recorded as high as 80% under favorable conditions (Roy et al., 1997).

Some major factors that can influence SDS development are temperature and moisture of the soil, soybean cyst nematode population densities, planting date, soybean cultivar, maturity date, tillage practices and soil fertility (Rupe et al., 1993; Chong et al., 2004). Management of SDS is limited because fully resistant soybean cultivars have not been developed, although, there are many cultivars available that are less susceptible to SDS. Fungicide seed treatments also have limited efficacy (Njiti, et al., 2002). Sudden death syndrome favors cool and wet conditions, therefore planting later in the spring when conditions are warmer and dry, can reduce incidence and severity of the disease (Roy et al., 1997). Deep tillage has proven to reduce the incidence and severity of SDS, due to reduction in soil compaction, providing a more aerated root zone that promotes root growth and sets back root infection (Vick et al., 2003).

Sudden death syndrome is often associated with high yielding production environments or increased soil fertility, indicating that soil chemical factors may have an effect on the incidence and severity of the disease. Studies have shown that severity of SDS increases under conditions for optimum host growth, such as high levels of available soil P, Mg, and organic matter (Rupe et al., 1993). Research in Iowa indicated that increased K concentrations enhanced the severity of foliar symptoms of SDS (Scherm et al., 1998). Results from a study conducted in Tennessee suggested that increasing fertilizer application rates of potassium chloride (KCl), during planting, led to a decrease in

incidence and severity of foliar symptoms and root rot caused by SDS. The factor responsible for the decrease in disease symptoms turned out to be the chloride and not the potassium (Abney, 1993). Under a controlled environment, (Sanogo & Yang, 2000) found very similar results when looking at the effect of KCl on SDS severity, in which the application decreased symptoms by 36%. On the other hand, the authors found that disease severity was significantly increased by applications of calcium phosphate, potassium phosphate, potassium sulfate, sodium phosphate, and potassium nitrate. In this study, germination of *Fusarium virguliforme* was not affected by potassium or phosphorus treatments, but mycelial growth was enhanced (Sanogo & Yang, 2000).

Rhizoctonia solani (Kühn) is a soilborne fungus that is devastating to soybean production in North and South America. This pathogen causes pre and post emergence damping-off as well as seedling blight, leading to a reduction in stand. Plants that become established and develop a root system may experience root rot and stunting, which can lead to a yield loss of up to 48% in the United States (Yang et al., 2008).

When managing a soilborne fungal pathogen such as *R. solani*, it is important to be aware of the environmental factors such as the physical characteristics of the substrate that both the pathogen and host use for nutrition. The nutrition of both host and pathogen play large roles in the epidemiology of *R. solani* (Parmeter, 1970). This pathogen can grow saprophitically in the soil, on soil organic matter or plant debris (Papavizas et al., 1970). Levels of soil nutrition influence the soybean plant's growth, development and susceptibility to soilborne pathogens. The mycelial growth of *R. solani* and its distribution of nutrients are also influenced by soil nutrition (Otten & Gilligan, 1998; Otten et al., 1999). If abundant nutrient levels increase the host's disease resistance, yet enhance the

pathogen's health, what is the best decision for nutrient management? Once again, a complex interaction between pathogen, host and environment is recognized (Anees et al., 2010).

It has been noted that *R. solani* will grow in dense colonies in areas that are sufficient in nutrients (Anees et al., 2010), however, young plants with access to abundant nutrients have a better chance of surviving early infections (Wherrett, 2016). It is common for diseased plants to first appear in areas that lack water and nutrients, with the additional stress favoring the pathogen (Yang et al., 2008). Deficiencies in soil nitrogen, phosphorus and calcium have shown to increase disease potential of *R. solani* (Parmeter, 1970). Experimental applications of fertilizers to areas infested with *R. solani* have had contradictory results, and the mechanisms behind the effects have remained unclear (Parmeter, 1970; Anees et al., 2010). In some cases, application of fertilizers have shown to reduce the development and establishment of *R. solani*. Papavizas et al., (1975), found that the ammonium form of nitrogen actually decreased saprophytic survival and activity of *R. solani* root rot on table beet, while the nitrate form enhanced growth and activity. Application of ammonium sulfate, urea and sodium nitrate were shown to reduce bare patch and root rot of cereals such as wheat and oats (Hynes, 1937; De Beer, 1965; Chambers, 1966; Macnish, 1985). Combinations of nitrogen plus phosphorus and phosphorus plus potassium fertilizers, were shown to reduce severity of *R. solani* root rot in field peas (Srihuttagum & Sivasithamparam, 1991). N, P and K fertilizer affects on the health of soybeans infected with *R. solani* is a topic that requires investigation.

Managing sudden death syndrome involves control of other pests that could be influencing the severity or impact of the disease. Soybean cyst nematode, *Heterodera*

glycines, is a plant parasitic, soil borne pathogen that infects soybean roots, causing stunting, yellowing of leaves and loss of yield (Davis & Tylka, 2000). Although the pathogen alone causes negative impacts to the soybean, the soybean cyst nematode (SCN) severely enhances symptoms of SDS if both pathogens infect the plant (McLean et al., 1993). There is no current data presenting evidence that SCN and *R. solani* have any interaction (Frohning, 2013). Keeping a balanced nutrient program for soybeans can help limit the negative impacts caused by SCN (Riggs & Wrather, 1992). Adequate levels of potassium allow for thicker cell walls which increases defense against nematode feeding. Potassium does not reduce damage from SCN but helps maintain the plant's defense against the yield robbing damages caused by the nematode (Snyder, 2000). While the nutrient requirements for SCN currently remain unclear (Goheen et al., 2013), the influence of nutrients on SCN also requires further research.

Managing a soil and plant nutrient program requires strict attention towards the time of application, the placement of fertilizer, mineral selection and nutrient form. The management option of placing liquid fertilizer in furrow and in contact with the seed during planting is becoming more popular in soybean production, but has had limited and contradicting evaluations. This type of starter fertilizer application, known as "pop-up", intends to provide nutrients that are unavailable to the soybean in its early growth stages. Placing the fertilizer in the furrow allows the young plant roots to immediately come in contact with nutrients, resulting in a robust root system and foliage that promotes higher yields.

The majority of research conducted on liquid fertilizer that comes in contact with the soybean seed results in the conclusion that this method of application should be

avoided (Clapp & Small, 1967). Early studies have shown that direct contact of fertilizer to the seedling leads to salt toxicity and decreased emergence caused by the high salt concentration of N and K_2O. Therefore, a more common starter application method known as 2x2 placement has become a popular alternative to in-furrow placement. The 2x2 refers to the 2 inches to the side and 2 inches below the placement of the seed, leaving a soil buffer, which is meant to prevent salt toxicity by the fertilizer. This method and other early season starter fertilizer methods such as broadcast applications have shown increases in soybean plant growth and/or grain yield (Sorensen & Penas, 1978; Bly et al., 1998; Starling, et al., 2000; Fu-ti et al., 2010). Over recent years, fertilizer companies have developed new in-furrow products that have very low salt concentrations and are advertised as non-threatening to the soybean seedling.

This raises new interest in the pop-up fertilizer application as a soybean nutrient management option. With this method increasing in popularity, further investigation is needed to understand its influence on other factors that contribute to successful soybean production. It is unknown if the increased fertility in the root zone may actually increase or decrease the severity of root or seedling diseases such as sudden death syndrome or *R. solani* in soybean.

One objective of this study is to determine if in furrow applications of starter fertilizer impact seedling disease caused by *R. solani* and if the applications have impact on yield of soybean. A second objective is to determine if pop-up fertilizer influences the incidence and severity of SDS and soybean yield.

CHAPTER 2

MATERIALS AND METHODS

The data collected from this trial include soil test nutrient analysis, stand counts, yield measurements, nematode counts, rainfall and soil temperature measurements. Accumulated precipitation amounts and statistics were provided by the Illinois State Water Survey and represent data for Carbondale, Illinois. Soil samples were taken just before planting and sent to a laboratory for nutrient analysis. Soil nutrient analysis was generalized over the whole field. Stand counts were taken three times, once a week for three weeks, shortly after emergence. The stand counts were used to establish a pre and post emergence damping-off rating. Yield was measured during harvest with a grain gauge.

Soybean cyst nematode counts were measured from soil samples taken from each plot. Soil samples were filtered through a sieve and put through a centrifugal flotation extraction process, separating cysts from soil. Cysts were then put under a grinder and busted open, releasing eggs. The eggs were stained with a bright pink dye, enabling the human eye to easily detect and quantify the amount of nematode eggs under a microscope. This extraction technique was adapted from Jenkins, 1964.

The inoculum used in this research was sterilized white sorghum infested with either pathogen. The sorghum seed was sterilized by undergoing 2 cycles of extremely high temperatures in an autoclave. Growing on potato dextrose agar, cultures of *R. solani* and *F. virguliforme* were transferred into blender cups with sterile distilled water and sterile potato dextrose broth. Remaining separate, each culture of fungus was homogenized in a blender and poured into 1.36 kg aluminum pans of sterile sorghum. The pans were

covered, sealed and placed in room temperature to grow for 7 days. Infested sorghum was air dried for 48 hours. The dry infested sorghum was placed in furrow with the soybean seeds during planting.

Rhizoctonia solani Trial

In 2014, forty-eight soybean plots were planted in Carbondale, Illinois at a seeding rate of 139,392 seeds per acre. Each plot was infested with *R. solani* during planting at the rate of 0.9 g of inoculum/30.5 centimeters of row. Plots were 3.04 meters wide by 6.1 meters in length with row spacing of 0.76 meters. A randomized complete block design consisted of 4 treatments that were replicated 3 times and planted into 4 row plots. Treatments consist of treated (metalaxl™, fluxapyroxad™, pyraclostrobin™, and imidacloprid™) or non-treated seed (Asgrow 4730) combined with a formula of 2-6-16 fertilizer or no fertilizer. In 2015, an addition of 2 fertilizer formulas were tested, increasing the treatments to 8 and remaining with 3 reps. Fertilizer treatments consisted of three fertilizer formulas: 2-6-16, 3-10-13, 7-12-11 or non-fertilizer. The 2-6-16 fertilizer ingredients were derived from urea, ammonia, phosphoric acid, potassium acetate and potassium hydroxide. 3-10-13 was derived from urea, ammonium hydroxide, ammonium thiosulfate, phosphoric acid, potassium hydroxide, potassium acetate and zinc EDTA. The ingredients that make up 7-12-11 are derived from ammonium hydroxide, urea, phosphoric acid, potassium acetate, and potassium hydroxide. Fertilizer treatments were applied in furrow, during planting, at the rate of 2 gallons per acre. Seed firmers and rubber tubing directed fertilizer placement by falling flush within the furrow.

SDS Trial

Also located in Carbondale, Illinois and consisting of 48 soybean plots, this trial was planted at a seeding rate of 139,392 seeds per acre and infested with *F. virguliforme* at the rate of 2.25 g/30.5 centimeters of row. The trial design and treatments are exactly the same as the *R. solani* trial for both 2014 and 2015. Data collected from this trial include rainfall, soil temperature, soil nutrient analysis, stand counts, nematode counts and SDS foliar symptom ratings. All data were collected the same as the *R. solani* trial except for SDS ratings.

Once foliar symptoms appeared, severity and incidence ratings were taken consistently, once a week for 3 weeks. Severity was rated on a scale from 0 to 9, based on the percentage of leaf area chlorotic, necrotic or defoliated (Gibson et al., 1994): 0 = no detectable leaf symptoms; 1 = 1 to 10% chlorotic or 1 to 5% necrotic; 2 = 10 to 20% chlorotic or less than 10% necrotic; 3 = 20 to 40% chlorotic or 10 to 20% necrotic; 4 = 40 to 60% chlorotic or 20 to 40% necrotic; 6 = up to one third premature defoliation; 7 = one-third to two-thirds premature defoliation; 8 = greater than two-thirds premature defoliation; and 9 = plants prematurely dead. Incidence, or the percentage of plants within the plot that show symptoms, was rated on a 0 to 100 percent scale. Multiplying incidence by severity and dividing by 9 calculates a foliar disease index rating.

CHAPTER 3

RESULTS

Data collected for this research were analyzed using a factorial treatment structure and analysis of variance (ANOVA) using JMP® Pro 12.1.0 by SAS Institute Inc. There were no interactions between the factors: fertilizer or seed treatment (Table 2-5). Individual treatment means were separated using a Fisher's protected t-test. Data from each year were analyzed separately due to different treatments being used across years.

Accumulated precipitation amounts and growing season soil temperatures were provided by the Illinois State Water Survey and represent data for Carbondale, Illinois (Figure 1, Table 6). Trials were planted into warm soils and the growing season precipitation during both years was above the average rainfall for Carbondale, Illinois. Planting in June of 2014, there was an average soil temperature of 77.1˚ F and a total rainfall of 115 mm for the month. This level of precipitation is high compared to the average June rainfall recorded every year since 1998, which is 108.7 mm. In 2015, trials were planted in early May, with soil temperatures averaging 68.4˚ F for the whole month. The total rainfall for May 2015 was 105 mm, 2 mm higher than the normal May rainfall. June of 2015 hit record high levels of precipitation for the state of Illinois and July's rainfall data was also above the average.

2014 SDS Trial

Plant stand was low across the whole SDS trial, ranging from 35,669 to 41,809 plants/ha^{-1}. In plots that received starter fertilizer, a significant decrease in stand was found in the first assessment date (Table 7). The second and third stand ratings followed a

similar trend but differences were not significant. Soybean yield was not affected by either the seed treatment or fertilizer. The soybean yield reached as high as 1,503 Kg/ha^{-1}, which is much higher than the average soybean yield of 1,279 Kg/ha^{-1}, harvested in Jackson County, Illinois, in 2014. Foliar symptoms of SDS increased with severity and incidence later in the season but overall disease pressure was low (Table 8). Foliar symptoms were significantly higher at the third evaluation date, during the R6 growth stage, in plots with the seed treatment. Soybean cyst nematode population densities were not affected by either the seed treatment or fertilizer. SCN egg densities ranged from 1,408 to 2,633 eggs per 100 cc of soil, 21 days after planting.

2015 SDS Trial

Starter fertilizer applications did not affect stand. The plant population was low, ranging from 18,863 to 27,912plants/ha^{-1} (Table 9). Stand was significantly lower in plots that contained treated seed during the first and third ratings. Soybean yield was not influenced by fertilizer or seed treatment. The trial's lowest yield was 1,690 Kg/ha^{-1}. Foliar symptoms of SDS were not influenced by seed treatment or fertilizer application (Table 10). The disease pressure in 2015 was even lower than what was experienced in 2014. Foliar symptoms of SDS were not visible until very late in the season, therefore, only two disease ratings were taken before senescence. Fertilizer or seed treatment did not impact SCN egg densities. In 2015, SCN egg samples were taken later in the season and were much higher compared to 2014 samples. The densities ranged from 3,183 to 3,716 SCN eggs per 100 cc of soil.

Rhizoctonia Trial 2014

Soybean stand did not differ between the fertilizer treatments but stand was impacted by seed treatment (Table 11). Plant population was higher in plots that received seed treatment at the second rating interval. The first and third stand assessment intervals also had more plants in plots with seed treatment but these differences were not statistically different. Overall soybean stand was low compared to the seeding rate, ranging from 32,995 to 43,664 plants/ha^{-1} across the whole trial. Soybean yield was not influenced by seed treatment or fertilizer. Soybean cyst nematode densities were not influenced by seed treatment. SCN egg densities were relatively low ranging from 1,058 to 1,392 eggs per 100 cc of soil.

Rhizoctonia Trial 2015

In 2015, the *R. solani* trial was located in a different field than the previous year. Significant effects of fertilizer on stand were observed in all three rating intervals (Table 12). At the first rating interval, plots with no fertilizer treatment had significantly less stand than the other three fertilizer treatments. On 5/27/15, stand in the no-fertilizer plots was significantly less than those which contained the 2-6-16 and 7-12-11 fertilizer treatments, but were not different than the 3-10-13 treatment. In 2015, seed treatment had the opposite affect on stand than it did in 2014. For the first two rating intervals, a significant decrease in stand was seen in plots that received seed treatment compared to the non-treated plots. The third rating demonstrated a common pattern. Plant population ranged from 29,616 to 37,255 plants/ha^{-1} throughout the trial. Soybean yield was significantly less in the plots with no fertilizer and 2-6-16, as compared to the other two fertilizer treatments. Soybean yield ranged from 1,637 to 1,806 Kg/ha^{-}1, much higher than the

average for the region. Soybean cyst nematode densities were not affected by seed treatment or fertilizer. However, they were much higher than densities found in 2014 samples. SCN egg densities ranged from a count of 3,133 to 4,041 eggs per 100 cc of soil.

CHAPTER 4

DISCUSSION/CONCLUSION

In 2014 and 2015, both pathogen trials had low levels of stand counts compared to the seeding rate. Patches of bare soil were frequently witnessed throughout all trials and non-germinated seeds were dug up to confirm decay. The Acceleron seed treatment used in this research contains metalaxl, fluxapyroxad, pyraclostrobin and imidacloprid, claiming to control *Rhizoctonia solani, Pythium, Phytophthora,* and *Fusarium* seedling diseases. Low stand counts found in plots containing seed treatment suggests the possibility that all natural or artificially inoculated pathogens were not controlled. There are no published data supporting inconsistencies with this particular seed treatment. However, non-distinct results and even stand reductions in field trials receiving fungicide seed treatments have been reported (Bradley, 2008; Dorrence, 2003; Urrea et al., 2013).

The Rhizoctonia trial exhibited symptoms of disease pressure through seed decay, pre and post emergence damping off in 2014. Damping off was observed along with red lesions on the hypocotyl of affected plants. Plots with treated seed had higher stand counts than non-treated plots; demonstrating seedling disease pathogens played a role in decreasing stands. The *R. solani* trial was located in a different field in 2015 and had lower incidence of post emergence damping off. Plant stand was low and pre-emergence damping off and seed decay was confirmed by digging up rotted seed. In 2015, stand was lower in plots that had seed treatment for both pathogen trials. These results contradict the data recorded in the 2014 *R. solani* trial and do not match up with results found in the 2014 SDS trial. When aiming to control soybean seedling diseases caused by *Fusarium, Rhizoctonia,*

Phytophthora, and *Pythium* spp., Bradley, (2008), reported that seed treatments consisting of azoxystrobin and metalaxyl had significantly decreased stand compared to non-treated seed in one of the trial locations. The researchers did not find similar results in other locations, indicating that environment played a role in stand establishment (Bradley, 2008). The efficacy of fungicide seed treatment against *R. solani* is related to the environment, specific isolate and density of inoculum (Nelson, 1996). Published literature does not provide data on a chemical or biological fungicide product that administers 100 percent control of *R. solani* in soybean. Seeing a stand decrease in seed treatment plots during 2015 but not in 2014, implies that differing weather conditions could have been a contributing factor. The fact that decreased stand establishment in seed treatment plots was seen in both pathogen trials, also indicates that environmental conditions played a role and not one single inoculated pathogen or the other. Interactions between indigenous beneficial microorganisms and plant pathogens may have been directly or indirectly influenced by seed treatment, possibly impacting stand. The rhizosphere is full of beneficial bacteria and fungi that affect the population density, movement and metabolic activities of plant pathogens by three types of interactions. These interactions are competition for space and nutrients, antagonism and hyperparasitism (Raaijmakers, 2009).

If targeted pathogens are controlled, an ecological window may open for non-targeted pathogens that compete for nutrition (Srivastava & Shalini, 2008). Estevez de Jensen C. et al, 2002, noted that a phenomenon of microbial antagonism causing suppression of disease often exists in the soil. Controlling or inhibiting soil microorganisms that have an antagonistic relationship and suppress disease may allow plant pathogens a greater chance of infection. It is possible that targeted pathogens such as *R. solani* may have

only been moderately controlled by seed treatment, especially in an environment with supplemental inoculation. If a fungicide only partially controls a fungal pest, this may put the organism under stress and prompt the use of defense mechanisms such as production of toxins that could be detrimental to plant health (Benbrook, 2006).

Lack of emergence may have also been caused by high strength fungal inoculum in direct contact with the seed. Batches of inoculum made in a laboratory setting may have varying levels of pathogenic strength or ability, depending on the strain and density of inoculum. For future reference, artificial inoculum should be evaluated for a calculation of colony forming units (CFU), estimating the number of viable fungal cells or spores located on each grain of infested sorghum.

All trials had yields that were higher than the average yield for Jackson County, Illinois. Soil nutrient analysis revealed adequate levels of potassium and phosphorus required for the soybean life cycle in all fields over both years (Table 1). Research has shown that starter fertilizers are more likely to influence yield in nutrient deficient environments. Starter fertilizer is not a maintenance or build-up application, but is used to speed up the process of emergence and promote a uniform stand. Minimizing the delay of emergence and speeding up root growth and establishment decreases the window of infection for seedling and early season pathogens, possibly indirectly influencing stand or yield (Agrios, 1997; Nafziger, 2009).

Significantly higher yield measurements were found in plots receiving the 7-12-11 and 3-10-13 fertilizer treatments in the 2015 *R. solani* trial. The increased amount of accessible phosphorus in these two fertilizer treatments may have attributed to the cause of higher stand and yield measurements. Hankinson, (2015) found increases in soybean

yield when starter fertilizer consisting of triple superphosphate (TSP) and DAP was applied to soils with adequate phosphorus levels. Although fields were adequate in phosphorus nutrition, phosphorus is immobile in the soil and may not be accessible to the plant until the root system covers more soil volume. The idea that direct contact of phosphorus application to the seed makes the nutrient easily attainable, speeding up growth and ultimately increasing yield, should be investigated.

Sudden death syndrome disease pressure was low in both years. In fact, foliar symptoms were too low to discern any differences among treatments in 2015. Soil moisture and temperature are important factors in development and expression of SDS foliar symptoms. *F. virguliforme* most commonly causes SDS under cool, moist conditions (Hirrel, 1987; Rupe et al. 1993; Scherm & Yang, 1996). Although moist conditions have proven to create an environment that favors *F. virguliforme*, it is apparent that there is level of precipitation that disturbs that favorable environment. In 1995, Rupe and Gbur noticed that too much soil moisture during vegetative growth can reduce or delay development of SDS symptoms (Rupe & Gbur, 1995; Roy et al., 1997). It is possible that growing season precipitation was too high for the onset of disease in 2015. June totaled 229.1 mm of rainfall, which is a record high for the history of Illinois and much higher than the average collected over the past 18 years, which is 108.7 mm. July was also above average at 154.9 mm compared to the normal 103.9 mm. Both years, trials were planted into soil temperatures between 20-25 C˚, which is a favorable temperature for the disease (Scherm, 1996). With a goal to observe SDS foliar symptoms and discern differences amongst treatments, future research trials should be planted earlier in the season when temperatures are as cool as 15 C˚ and soils are moist but not overly saturated.

In the 2014 SDS trial, lower stand counts were observed in plots with fertilizer application during all 3 rating intervals, with the first rating significantly lower. These differences were not observed in the *R. solani* trials, which could indicate a synergistic relationship between fertilizer and the SDS inoculum, although, there are no published data to support this. In 2015, fertilizer did not impact stand in the SDS trial, pointing towards the possibility that the environment and weather conditions played an important role in the disease severity. Also in 2014, SDS foliar symptoms were more prominent in plots that received a seed treatment, possibly suggesting that the chemical treatment had controlled or influenced soil borne pathogens that are antagonists or compete with *F. virguliforme* for nutrition. The seed treatment included in this research was not a means of control for SDS. Removing antagonists or competitive organisms could possibly allow *F. virguliforme* to have a larger success rate in infecting its host, the soybean plant. Antagonistic and competitive relationships between soil microorganisms do exist (Estevez de Jensen et al. 2002), but were not investigated in this research. When exploring seed treatment effects on *F. virguliforme* and development of SDS, Weems et al., (2015) noticed a reduction in seed germination when fungicide seed treatment was applied. Considerations for this explanation involved the idea that toxic effects from seed treatment could have reduced germination or that treatments could have had negative effects on beneficial microorganisms that aid in seedling development (Weems et al., 2015; Raaijmakers et al. 2009).

Artificial inoculum may have had a different level of strength between years. Effects on soybean germination with direct contact of artificial inoculum to the seed requires investigation. Natural occurring inoculum of pathogenic organisms should be identified and

density estimates should be calculated in order to further understand the influence that seed treatment has on non-targeted microorganisms and how it directly or indirectly impacts stand counts.

Soybean cyst nematode egg counts were above the threshold of 500 eggs per 100 cc of soil in all trials over both years and were not influenced by any treatments. In 2015, the R. solani trial was located in a different field and could have been the reason for differing levels of SCN eggs between years. Differences in SCN egg densities were seen between years in both pathogen trials, possibly due to samples being taken later in the season in 2015. Early season samples during 2014 had fewer SCN eggs. Shortly after planting, SCN eggs hatch due to stimulants being released by newly established soybean roots. Egg population increases later in the season when females mature and produce eggs (Davis & Tylka, 2000).

This study was intended to give producers a better understanding of their returns when investing in starter fertilizers. Soybean producers who spend resources on nutrient inputs need to consider the interactions between supplemental nutrient content and microorganism activity in their soils. Sufficient information on the topic is currently lacking and requires further investigation. The lack of consistent results found in this research do not provide solid evidence that starter fertilizer benefits or hinders production of soybeans infested with *Rhizoctonia solani* or *Fusarium virguliforme*. However, these findings do not rule out such possibilities. This study benefits the agricultural community by contributing the only current data regarding this topic. Important factors and recommendations can be passed along to future researchers who aim to examine the influences of starter fertilizer applications on soybeans grown in pathogen-infested environments.

In field trials, soils should be sampled to identify and quantify naturally existing microorganisms that could play a role in the plant disease complex. To remove microbial variability and complication, greenhouse trials could be performed in sterilized soils where the only fungal pathogen present is the one of desired examination. In field and greenhouse trials, inoculum source, strength, CFUs and type of inoculum application should be considered. Analyzing the influence of starter fertilizer products on *R. solani* and *F. virguliforme* mycelial growth in a laboratory setting could help comprehend fungal nutrient uptake. If significant differences in growth are recorded, eventually the size of mycelium and quantification of CFUs could be tested for any interactions with incidence and severity of disease symptoms in a greenhouse or field trial. More accurately and efficiently, PCR could be used to quantify the abundance of DNA molecules that would possibly be influenced by fertilizer applications.

Field trials need to be conducted in nutrient deficient soils and compared to soils with adequate nutrient levels. Current research suggests that stand and yield increase due to starter fertilizer application is more commonly recorded in nutrient deficient environments. An alleged benefit of starter fertilizer application is that producers can plant earlier in the season and have available nutrients when temperatures are cooler and soil nutrients have not undergone mineralization yet. This research study was planted into warm soils and did not explore impacts by temperature. Future trials should be planted into cool soils, insuring that mineralization has not occurred yet. Planting into cooler soils also delays emergence and creates an environment more suitable for many plant pathogens, allowing researchers to witness symptoms and possibly discern differences between treatments. According to the results found in this study, it would not be feasible

for soybean producers to invest in starter fertilizers when production soils are adequate in nutrients.

Table 1

Soil Test Values for Fields Inoculated with Fusarium virguliforme and Rhizoctonia solani in 2014 and 2015

Field Name	Year	pH	P (kg/ha^{-1})	K (kg/ha^{-1})	Ca (kg/ha^{-1})	O.M. (%)	CEC (meq/100g)
SIUC ARC 8E	2014	7.1	106.2	303.1	3,505.1	1.6	9.5
SIUC ARC 8E	2015	7.3	104.5	315.4	4,316	1.8	11.4
SIUC ARC 19N	2015	7.3	114.6	433.3	4,291.7	2.0	11.4

Note. 8E was inoculated with F. virguliforme and 19N was inoculated with R. solani in 2015.

Table 2
Test of Fixed Effects on Plots Inoculated with Fusarium virguliforme in 2014*, Using a Fit Model Analysis*

Plant Population-6/26/14			
Effect	DF	F Value	Pr>F
Replication	5	1.91	0.153
Seed Treatment	1	0.03	0.875
Fertilizer	1	4.84	0.044
Seed Treatment * Fertilizer	1	0.46	0.509

Plant Population-7/3/14			
Effect	DF	F Value	Pr>F
Replication	5	1.59	0.223
Seed Treatment	1	0.09	0.767
Fertilizer	1	3.24	0.092
Seed Treatment * Fertilizer	1	0.35	0.563

Plant Population-7/10/14			
Effect	DF	F Value	Pr>F
Replication	5	1.49	0.251
Seed Treatment	1	0.55	0.469
Fertilizer	1	3.17	0.092
Seed Treatment * Fertilizer	1	0.59	0.455

Yield			
Effect	DF	F Value	Pr>F
Replication	5	1.28	0.323
Seed Treatment	1	2.54	0.132
Fertilizer	1	0.03	0.853
Seed Treatment * Fertilizer	1	0.14	0.713

Note. Prob>F is the p-value for the effect test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 3
Test of Fixed Effects on Plots Infested with Fusarium virguliforme in 2015*, Using a Fit Model Analysis*

Plant Population-5/20/15			
Effect	DF	F Value	Pr>F
Replication	2	1.61	0.213
Seed Treatment	1	5.32	0.026
Fertilizer	3	1.26	0.301
Seed Treatment * Fertilizer	3	1.13	0.346

Plant Population -5/27/15			
Effect	DF	F Value	Pr>F
Replication	2	1.24	0.300
Seed Treatment	1	2.41	0.128
Fertilizer	3	1.77	0.168
Seed Treatment * Fertilizer	3	1.37	0.265

Plant Population -6/3/15			
Effect	DF	F Value	Pr>F
Replication	2	0.42	0.660
Seed Treatment	1	4.39	0.043
Fertilizer	3	2.24	0.099
Seed Treatment * Fertilizer	3	1.22	0.316

Yield			
Effect	DF	F Value	Pr>F
Replication	2	3.87	0.029
Seed Treatment	1	0.30	0.586
Fertilizer	3	2.01	0.117
Seed Treatment * Fertilizer	3	0.59	0.625

Note. Prob>F is the p-value for the effect test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 4
Test of Fixed Effects on Plots Infested with Rhizoctonia solani in 2014*, Using a Fit Model Analysis*

Plant Population-6/26/14			
Effect	DF	F Value	Pr>F
Replication	5	0.88	0.517
Seed Treatment	1	4.07	0.063
Fertilizer	1	0.55	0.471
Seed Treatment * Fertilizer	1	0.01	0.965

Plant Population-7/3/14			
Effect	DF	F Value	Pr>F
Replication	5	0.39	0.851
Seed Treatment	1	5.13	0.040
Fertilizer	1	0.45	0.512
Seed Treatment * Fertilizer	1	0.02	0.899

Plant Population-7/10/14			
Effect	DF	F Value	Pr>F
Replication	5	0.15	0.975
Seed Treatment	1	2.44	0.141
Fertilizer	1	0.90	0.358
Seed Treatment * Fertilizer	1	0.02	0.899

Yield			
Effect	DF	F Value	Pr>F
Replication	5	3.07	0.045
Seed Treatment	1	0.08	0.781
Fertilizer	1	0.01	0.924
Seed Treatment * Fertilizer	1	0.98	0.339

Note. Prob>F is the p-value for the effect test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 5
Test of Fixed Effects on Plots Inoculated with Rhizoctonia solani in 2015*, Using a Fit Model Analysis*

Plant Population-5/20/15			
Effect	DF	F Value	Pr>F
Replication	2	11.8	0.0004
Seed Treatment	1	3.99	0.0014
Fertilizer	3	9.78	0.0145
Seed Treatment * Fertilizer	3	0.22	0.8806

Plant Population-5/27/15			
Effect	DF	F Value	Pr>F
Replication	2	11.4	0.0001
Seed Treatment	1	10.3	0.0027
Fertilizer	3	3.30	0.0300
Seed Treatment * Fertilizer	3	0.33	0.8052

Plant Population-6/3/15			
Effect	DF	F Value	Pr>F
Replication	2	7.43	0.0019
Seed Treatment	1	3.26	0.0787
Fertilizer	3	4.96	0.0052
Seed Treatment * Fertilizer	3	0.54	0.6585

Yield			
Effect	DF	F Value	Pr>F
Replication	2	11.8	0.0001
Seed Treatment	1	0.18	0.6712
Fertilizer	3	7.77	0.0004
Seed Treatment * Fertilizer	3	0.09	0.4357

Note. Prob>F is the p-value for the effect test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 6
Average Soil Temperature Throughout the 2014 and 2015 Growing Seasons in Carbondale, IL.

Year	2014				2015			
Month	May	June	July	August	May	June	July	August
Temperature (˚F)	68.5	77.1	76.4	78.5	68.4	77.8	81.5	77.8

Table 7
Soybean Stand and Yield as Influenced by Fertilizer and Seed Treatment in Plots Inoculated with Fusarium virguliforme in 2014

Factor	Plants/ha^{-1}			Yield (Kg/ha^{-1})
Date	6/26/14	7/3/14	7/10/14	
No Fertilizer	40,928 a	41,427	41,809	3,557
Starter Fertilizer	35,669 b	37,049	37,578	3,591
Prob>F[a]	0.0438	0.0921	0.0952	0.8527
Seed Treatment	38,107	38,871	38,812	3,439
Non-Treated	38,489	39,606	40,575	3,708
Prob>F[a]	0.8751	0.7668	0.4695	0.1317

Note. Means within columns followed by similar letters are not different ($P \leq 0.05$) for each factor, according to Fisher's protected LSD test

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 8

Foliar Disease Symptoms of Fusarium virguliforme and Soybean Cyst Nematode Densities as Influenced by Fertilizer and Seed Treatment in 2014

	9/5/14			9/12/14			9/19/14				7/9/14
Factor	DI[b]	DS[c]	DX[d]	DI[b]	DS[c]	DX[d]	DI[b]	DS[c]	DX[d]	AUDPC[e]	SCN Eggs/100cc[f]
No Fertilizer	10.4	2.70	3.40	17.1	2.80	5.90	20.4	2.80	7.80	97.9	1,408
Starter Fertilizer	12.3	2.30	3.80	22.2	2.50	7.00	29.2	3.20	9.80	113.8	2,633
Prob > F[a]	0.64	0.32	0.80	0.14	0.37	0.69	0.21	0.61	0.50	0.72	0.135
Non-treated	8.50	2.30	2.31	14.3	2.60	4.00	19.2	3.10	5.70	67.1	1,650
Seed Treatment	14.2	2.60	4.92	25.0	2.80	8.80	30.4	2.80	11.9	144.5	2,391
Prob > F[a]	0.17	0.55	0.12	0.47	0.65	0.11	0.11	0.41	0.05	0.09	0.354

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

[b]DI=Disease Incidence, rating 0-100%

[c]DS=Disease Severity, rating 0-9; 0 = no detectable leaf symptoms; 1 = 1 to 10% chlorotic or 1 to 5% necrotic; 2 = 10 to 20% chlorotic or less than 10% necrotic; 3 = 20 to 40% chlorotic or 10 to 20% necrotic; 4 = 40 to 60% chlorotic or 20 to 40% necrotic; 6 = up to one third premature defoliation; 7 = one-third to two-thirds premature defoliation; 8 = greater than two-thirds premature defoliation; and 9 = plants prematurely dead

[d]DX=Disease Index=DI * DS/9

[e]AUDPC=Area Under the Disease Pressure Curve

[f]Soybean cyst nematode eggs per 100cc of soil

Table 9

Plant Population and Yield as Influenced by Fertilizer and Seed Treatment in Plots Inoculated with Fusarium virguliforme in 2015

Factor	Plants/ha^{-1}			Yield-Kg/ha^{-1}
Date	5/20/15	5/27/15	6/3/15	
No Fertilizer	27,912	27,794	26,502	4,178
2-6-16	27,794	26,854	24,680	4,182
3-10-13	22,095	20,861	18,863	4,468
7-12-11	26,208	25,327	24,269	4,344
Prob>F[a]	0.3010	0.1687	0.0996	0.1174
Non Treated	28,794	27,001	25,885	4,320
Treated Seed	23,211	23,417	21,272	4,267
Prob>F[a]	0.0266	0.1286	0.0427	0.5863

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 10
Foliar Disease Symptoms of Fusarium virguliforme and Soybean Cyst Nematode Densities as Influenced by Fertilizer and Seed Treatment in 2015

Date	8/28/15			9/4/15				8/21/15
Factor	DI[b]	DS[c]	DX 1[d]	DI[b]	DS[c]	DX 2[d]	AUDPC[e]	SCN eggs/100cc[f]
No fertilizer	0.25	0.25	0.03	0.58	0.16	0.02	0.160	3,716
2-6-16	0.16	0.16	0.02	0.16	0.25	0.06	0.288	3,317
3-10-13	0.16	0.16	0.02	0.58	0.16	0.02	0.128	3,183
7-12-11	0.66	0.66	0.15	0.66	0.83	0.20	1.225	3,650
Prob>F[a]	0.39	0.16	0.18	0.61	0.14	0.27	0.230	0.532
Treated	0.33	0.21	0.04	0.33	0.25	0.07	0.401	3,487
Untreated	0.29	0.42	0.06	0.41	0.45	0.08	0.500	3,695
Prob>F[a]	0.86	0.25	0.77	0.79	0.37	0.85	0.817	0.708

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

[b]DI = Disease Incidence, percentage of plants that show symptoms of SDS within plot; 0-100%

[c]DS = Disease Severity, rating 0-9; 0 = no detectable leaf symptoms; 1 = 1 to 10% chlorotic or 1 to 5% necrotic; 2 = 10 to 20% chlorotic or less than 10% necrotic; 3 = 20 to 40% chlorotic or 10 to 20% necrotic; 4 = 40 to 60% chlorotic or 20 to 40% necrotic; 6 = up to one third premature defoliation; 7 = one-third to two-thirds premature defoliation; 8 = greater than two-thirds premature defoliation; and 9 = plants prematurely dead

[d]DX = Disease Index=DI * DS/9

[e]AUDPC = Area Under the Disease Pressure Curve

[f]Soybean cyst nematode eggs per 100cc of soil

Table 11

Soybean Plant Population, Yield and Soybean Cyst Nematode Densities as Influenced by Fertilizer and Seed Treatment in Plots Inoculated with Rhizoctonia solani in 2014

Factor	Plants/ha^{-1}			Yield-Kg/ha^{-1}	SCN Eggs/100cc
Date	6/26/14	7/3/14	7/10/14		7/9/14
No Fertilizer	35,698	36,991	34,729	3,415	1,364
Starter Fertilizer	38,636	40,050	40,107	3,398	1,383
Prob>F[a]	0.4707	0.5117	0.3587	0.9239	0.4468
Seed Treatment	33,171	33,377	32,995	3,382	1,388
Non Treated	41,163	43,664	41,841	3,415	1,356
Prob>F[a]	0.0634	0.0400	0.1409	0.7816	0.5196

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

Table 12

Plant Population, Yield and Soybean Cyst Nematode densities as Influenced by Fertilizer and Seed Treatment in Plots Inoculated with Rhizoctonia solani in 2015

Factor	Plants/ha^{-1}			Yield (Kg/ha^{-1})	SCN eggs/100cc
Date	5/20/15	5/27/15	6/3/15		8/21/15
No fertilizer	31,026 b	30,439 b	29,616 b	4,086 b	4,041
2-6-16	36,550 a	35,962 a	33,729 ab	4,046 b	3,891
3-10-13	35,081 a	33,024 ab	35,962 a	4,398 a	3,133
7-12-11	37,255 a	35,669 a	36,844 a	4,462 a	3,216
Prob > F[a]	0.015	0.030	0.005	0.0004	0.418
Non Treated	37,373 a	36,055 a	35,345	4,230	3,587
Seed Treatment	32,584 b	31,497 b	32,731	4,263	3,554
Prob > F[a]	0.001	0.003	0.078	0.6712	0.942

Note. Means within columns followed by similar letters are not different (P ≤ 0.05) for each factor, according to Fisher's protected LSD test.

[a]Prob>F is the p-value for the test. There were no interactions between the factors: fertilizer or seed treatment. Individual treatment means were separated using a Fisher's protected t-test.

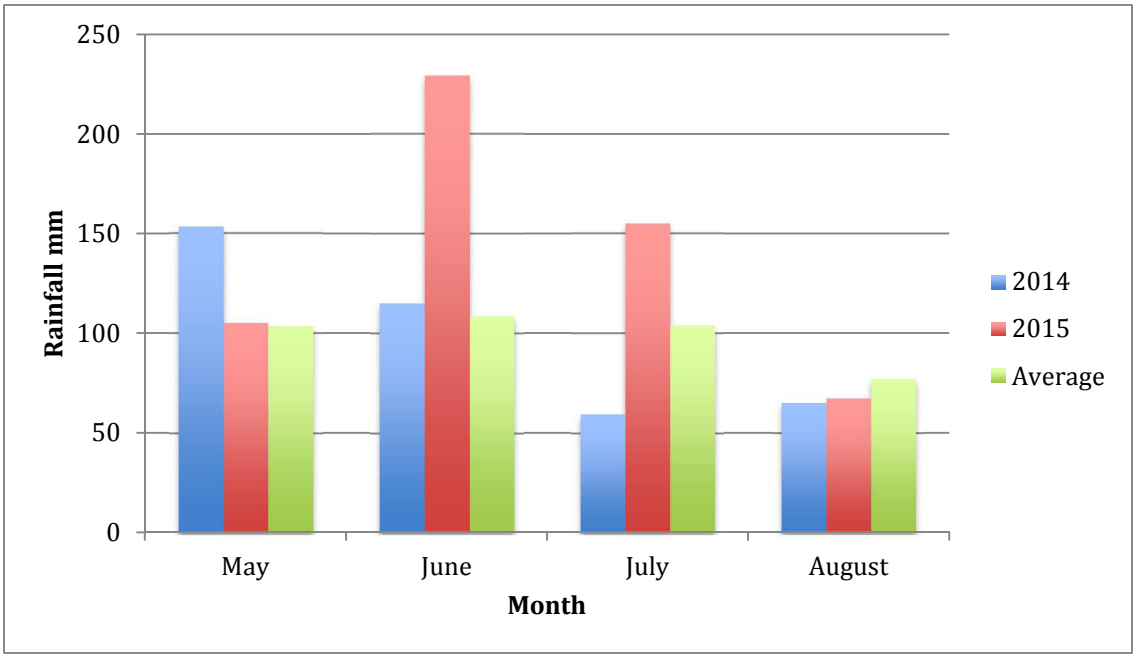

Fig. 1. Comparison of rainfall received during the soybean growing season in 2014 and 2015, and the average of growing-season precipitation during 1998-2015, at Carbondale, Illinois.

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The Effects of Starter Fertilizer on Soybean Infected with Fusarium virguliforme or Rhizoctonia solani

Major Professor: Jason Bond

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