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# Insecticidal Seed and In-Furrow Treatment Recommendations for Soybean and Sunflower

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# INSECTICIDAL SEED AND IN-FURROW TREATMENT RECOMMENDATIONS FOR SOYBEAN AND SUNFLOWER

BY

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INSECTICIDAL SEED AND IN-FURROW TREATMENT RECOMMENDATIONS

FOR SOYBEAN AND SUNFLOWER

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This dissertation is approved as a creditable and independent investigation by a candidate for a Master of Science in Plant Science degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

INSECTICIDAL SEED AND IN-FURROW TREATMENT RECOMMENDATIONS FOR SOYBEAN AND SUNFLOWER

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Throughout the 2016 and 2017 growing season, field research experiments were replicated across South Dakota. Many times seed treatments are used prophylactic, which is neither good for the producers or the environment. Producers will be able to reduce production costs, if they only use a seed treatment when necessary. The purpose of the first experiment was to determine the effects of seed treatments in combination with planting date and seeding rate on soybean yield. To determine the effects, two years of field data from four eastern South Dakota locations were compared. Within each year and location we compared two planting dates (May vs. June), seven seeding rates (60,000, 80,000, 100,000, 120,000, 140,000, 160,000, and 180,000 seeds per acre), and three seed treatments (untreated control, fungicide only, and a fungicide+insecticide combination) with all treatment factor combinations replicated six times at each location. Stand count data was taken 14 days after soybean emergence. Yield data was collected from the middle two rows of each plot.

The purpose of the second experiment was to determine the influence of commercial and experimental in-furrow insecticides as well as an insecticide seed treatment at two different rates on sunflower yield. This experiment was conducted at two locations near Volga, SD in the 2016 growing season. In 2017, this experiment was replicated once near Volga, SD and once near Highmore, SD. The in-furrow insecticides

included Ethos XB, Capture LFR, Capture 3RIVE and Mustang Maxx. The seed treatment used was Cruiser 5FS at 0.25 and 0.375 mg per seed. These six different treatments were compared to an untreated control. All plots were replicated six times at each location. Stand counts were taken 14 days after emergence. Root injury feeding was collected 28 days after emergence. Yield data was collected from the middle two rows of each plot.

# CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

## Thesis Organization

This thesis contains four chapters, introduction and literature review, soybean seed treatments, sunflower seed treatment and in-furrow, and general conclusion. The first chapter contains an introduction and literature review on soybean (*Glycine max*) farming practices that affect soybean yield, aboveground early season soybean insect pests, belowground soybean insect pests, soybean disease management, sunflower (*Helianthus annuus*) history, importance, growth, and production, sunflower insect management, neonicotinoid seed treatments, and in-furrow insecticides for sunflower. The second chapter covers the effects planting date, seeding rate, and seed treatment have on early season stand counts and yield. It also looks at below ground arthropods and diseases found in these trials. Chapter three contains information on sunflower seed and in-furrow treatments in regards to plant stand and yield. This chapter also encompasses below ground arthropod identification and how they fed on the roots of each treatment. Chapter four covers general conclusions reached about seed and in-furrow treatments from this experiment.

# Literature Review

## *Glycine max* history, importance, and growth

Soybean, *Glycine max* (L.) Merr., is an ancestor of the wild soybean, *Glycine soja* Siebold & Zuccarini (Shurtleff and Aoyagi 2004). Cultivated soybean are believed to have originated from East Asia prior to 1000 B.C., with wild type soybean existing prior (Shurtleff and Aoyagi 2004). Throughout the 18$^{th}$ century soybean was introduced in many different countries in Europe and Asia, however, soybean was not introduced into North America until 1765 (Shurtleff and Aoyagi 2004). Soybean was first grown in Philadelphia in 1804 (Shurtleff and Aoyagi 2004), and was noted to be adapted to the Pennsylvania climate (Gibson and Benson 2005). In the 1920's, soybean production was developed in the U.S. Corn Belt and the acres increased dramatically (Gibson and Benson 2005). The success of soybean was due to the immediate need for soybean oil and soybean meal. In addition, the benefits of using soybean as a rotation crop were soon discovered (Gibson and Benson 2005).

In the 1920's, there were roughly 40,000 hectares (ha) of soybean in the U.S., which is a drastic contrast to the 2015 report of 33.4 million hectares planted in the U.S. (Lawton 2015). In 2016, 2.3 million ha of soybean were planted in South Dakota (USDA 2016). Not only have the soybean acres increased since the 1920's, but the yields have also increased. In 1924, the average soybean yield was 740 kilograms per hectare (kg/ha) (National Statistics for Soybeans). In 2016, the U.S. had average yield of 3497 (kg/ha), indicating that major efforts have been put into improve soybean production (National Statistics for Soybeans). In 2016, South Dakota had an average soybean yield of 3317 (kg/ha) (USDA 2016).

Soybeans are dicotyledonous plants that exhibit epigeal or aboveground emergence (Bennett et al. 1999). During germination, the cotyledons are pulled up to the soil surface by an elongating hypocotyl; because the cotyledons have to be pulled through the soil the best emergence results come from planting depth of 5 centimeters or less (Bennett et al. 1999). The cotyledons provide energy for new plants until it is able to produce its own food. When the cotyledons appear above the soil, the soybean has reached its first growth stage, VE (vegetative emergence). Soybean vegetative stages start with (V) and reproductive stages start with (R), both followed by numbers (Fehr et al. 1971). Vegetative stages are determined by counting the number of nodes on the main stem. The unifoliate node is the first node counted on soybeans, because these are the first true leaves to develop; the two unifoliate leaflets develop on opposite sides of the main stem from one another (Fehr et al. 1971). Completely unrolled unifoliate leaves are known as V1 growth stage (Fehr et al. 1971). All of the following leaves produced by the plant will be trifoliates, which consist of 3 leaflets. The soybean will then enter V2 (first trifoliate unrolled), V3 (third node on main stem beginning with unifoliate node), and V(n) (n nodes on the main stem) where n represents the total number of true leaf nodes on the main stem. The functions of leaves on the soybean plant are to collect solar energy and turn it into chemical energy for the plant. The chemical energy helps the plant grow by producing more roots and leaves. The rate of growth of the plant depends on the amount of leave area available. Axillary buds are growing points on the stem, but remain semi dormant as long as the main bud in the top of the plant is still alive (Bennett et al. 1999). Floral development in soybeans is initiated by environmental factors, such as length of daylight hours (Fehr et al. 1971). The plant will continue in V(n) stage until the days' start getting shorter. Soybeans will than enter (R1), early bloom, when the plant has at least one open flower; at this point the soybean has switched to the reproductive stage. This stage is followed by (R2), when flowers are open at one of the two uppermost nodes (Fehr et al. 1971). Depending on the soybean group number or maturity relative to planting location, soybeans have been observed flowering on plants with as little as 4 nodes or as many as 18 nodes on the main stem (Fehr et al. 1971). Eventually pods grow from the axillary buds during the reproductive stage. Reproductive stages, R3-R6, use the uppermost four nodes to determine growth stages, because pod abortion can cause one of the nodes to fall behind the other nodes on the plant (Fehr et al. 1971). Therefore, the most advanced development at any of the uppermost four nodes is used for determining the growth stage of the soybean plant (Fehr et al. 1971).

South Dakota has a short growing season so it is important to plant early in order to capture more growing days. Both genetics and the environment control soybean maturity groups. The higher the maturity group number, the more time the soybean plant will spend in reproductive stage. There are currently 13 soybean maturity groups in the U.S. ranging from, 000 in North Dakota through 10 in Southern Texas; these groups were made because day length varies with latitude. (Wiatrak et al. 2015). The length of the darkness during the night is what signals soybean to start the reproductive stage. Soybeans planted with a later maturity group then is recommended will flower later than normal and are at risk of a killing frost before the plant is physically mature; however, soybeans planted at an earlier maturity group then recommended will flower earlier, reducing yield potential. Maximum yield is more likely to be reached if there is complete canopy coverage before pod development (R3); significant yield reduction can occur if complete canopy does not happen before beginning of seed fill (R5) (Suhre et al. 2014).

**Farming practices that affect soybean yield**

Soybean production should be initiated based on calendar date, seedbed condition, and weather forecast for 48-hour period after planting. Earlier planted soybean has the maximum yield potential (Chen and Wiatrak 2010 and Licht et al 2013). In South Dakota, the optimum planting days for soybeans is May 5th through the 15th (Clay et al. 2013). A common misunderstanding is that timely planting of soybeans is not as critical as timely corn planting (De Bruin & Pedersen 2008). Growers often delay planting due to concerns of soil temperature and moisture and the greater potential for exposure to seedling diseases and defoliation due to the overwintering generation of bean leaf beetles. (De Bruin & Pedersen 2008). However, when soybean are planted after the optimum planting date their yield potential decreases. Research in Nebraska has shown that soybean yield potential drops 16.8 – 41.9 kg/ha for every day planting occurs after the recommended planting date (Rees and Specht 2009).

In addition, seeding rates can also affect soybean yield potential. High seeding rates of soybean result in a majority of pods on the main stem while low seeding rates compensate lower plant stands by producing branches off the main stem that will set pods (Suhre et al. 2014). A higher seeding rate will help reduce harvest loss by keeping plants from setting pods low on the stem. Conversely, lower seeding rates should be used to reduce the chance of lodging and reduce initial seed costs. Recent studies also have shown that lower seeding rates have the potential to achieve similar yields to high seeding rates. (Staton 2015, Rees et al. 2017). In Iowa, De Bruin and Pedersen (2008) found that maximum soybean yield potential is realized at approximately 288,000 seeds per hectare. This is due to increased branching of low seeding rates that produce more branch nodes and branch pods. Across the state of Minnesota, the seeding rate of 371,000 seeds per hectare was found to achieve the maximum yield (Bennett et al. 1999). In South Dakota, the optimal seeding rate was determined to be between 346,000 and 371,000 seeds per hectare (Clay et al. 2013). The variation in seeding rate recommendations among states could be attributed to many abiotic factors and biotic factors.

**Aboveground early season soybean insect pests**

Insects that defoliate the leaves of early vegetative stage soybean have the potential to reduce stands and also to reduce future growth, pod set, and pod fill. Examples of early season defoliating insects in soybean include: bean leaf beetles and grasshoppers. Defoliation from these insects usually causes cosmetic injury that appears severe, but the associated yield loss can be minor.

Bean leaf beetles overwinter as adults beneath soybean residue or decaying leaves in wooded areas (Lam and Pedigo, 2000). In the early spring, overwintered bean leaf beetles feed on young alfalfa plants, until soybeans emerge (Smelser and Pedigo 1992). Once soybeans emerge, the adults will feed on soybean cotyledons and unifoliates. The adults will then lay eggs in the soybean field and larvae will hatch and feed on the soybean root system (Funderburk et al. 1998). The thresholds for bean leaf beetle management are 30% defoliation prior to bloom and 20% defoliation after (Bennett et al. 1999, Varenhorst et al. 2016).

Grasshoppers are usually only a problem in dry years or the growing season following a dry year. Grasshoppers lay eggs in field boards, near grassy edges, during the late summer into fall (Funderburk et al. 1998). The following spring, the nymphs hatch and proceed through five instars (Funderburk et al. 1998). Adults and nymphs both feed on soybean leaves and pods late in the season usually after natural grass has all dried up.

**Belowground soybean insect pests**

Stand reducing insects attack germinating seeds and the roots of young plants. Some of the common belowground insect pests of soybean include: seedcorn maggots (*Anthomyiidae spp.*), wireworms (*Elateridae spp.*), white grubs (*Phyllophaga spp*.), and cutworms (*Agrotis spp*.) (Bennett et al. 1999). Stand reducing insects are more of a problem in years when seeds are planted into cool and wet soil where germination is delayed. Under perfect conditions soybeans will emerge about 6 days after planting, when unfavorable conditions arise it may take up to 15 days for soybeans to emerge (Staton 2015). When emergence is prolonged plants are more susceptible to insect attacks. Belowground insect pests injure young plants and can result in poor plant stands. Seedcorn maggots feed on the cotyledons underground and can burrow into the seed (Bennett et al. 1999). In Iowa, first generation seedcorn maggot larvae are active and pose early season problems from mid to late May (Funderburk et al. 1983). Seed corn maggot prefer fields with recently incorporated manure, green plant matter, or high organic matter (Paulsrud 2001, Staton 2015).

The predominate white grubs in the area have a 3-year life cycle. The second and third instar larvae stage can cause significant damage to soybean by pruning the roots, killing young plants and reducing stand (Funderburk et al. 1998). White grub damage to soybean is usually patchy and more severe in grassy soils or fields that have been in continuous corn (Funderburk et al.1998). White grubs will feed on the root hairs of field crops, which reduces water and nutrient uptake; early planted fields are subject to greater injury, because they may be the first vegetation available in the spring (Varenhorst et al 2015).

Wireworms are usually not major problem in soybeans. They feed on germinated seed and underground portions of the stem (Funderburk et al. 1998). Wireworm injury to soybean is most likely to occur if the field was previously fallow, grass, or alfalfa; also low laying or poorly drained areas of a field are more prone to wireworm infestation (Funderburk et al. 1998). Wireworm and white grub damage is more likely to occur in fields that are following small grain crops or were previously pasture (Paulsrud 2001, Staton 2015).

There are several species of cutworms that will feed on in soybean (Hammond & Pedigo 1982). Cutworm caterpillars attack seedlings by grinding and cutting through young stems, if disturbed they will curl up into ball (Bennett et al. 1999). Cutworm damage reduces photosynthetic capacity of the leaves, which consequently decreases yield (Hammond & Pedigo 1982). In addition, plants that are clipped or cut during the early vegetative stages are not likely to regrow, which results in permanent stand loss.

Unlike defoliation by above ground pests, damage by below ground pests often remains unnoticed, unless severe feeding occurs (Eastman 1980). Pest are more likely to be an issue if fields with manure applied, cover crops, previously pasture, or previously planted with grass species. To reduce to risk of below ground pest feeding on seedlings it is recommended to destroyed any cover crops or weeds, two to four weeks before planting, this eliminates the insect food source before planting also known as “green bridge”. Germinating seeds and young plants are delicate and lack energy reserves to recover from injuries and survive extended periods of stress, this makes them super susceptible to insects and pathogens during this time (Paulsrud et al 2001). Injury to soybean roots or nodules may be below economic thresholds if looked at independently, but when combined with defoliation on the soybean pod and leaves damage may reduce yield (Eastman 1980). It is difficult to determine below ground feeding damage without digging up plants and assessing what the problem is.

**Soybean Disease Management**

Diseases reduce crop production by reducing photosynthesis, yield, and seed quality. Diseases are intensely influenced by environmental conditions. There are multiple diseases that affect soybeans throughout the growing season. A field history of damping off from Phytophthora (*Phytophthora spp.*) and Pythium (*Pythium spp.*) are the two main disease that would call for the use of a seed treatment; occasionally root rot caused Rhizoctonia *(Rhizoctonia solani.*) and Fusarium (*Fusarium spp*.) can cause early season stand reductions (Yang 2009). These diseases are common when soil is very wet in the first few weeks after planting. They tend to be more of an issue in heavy, poorly drained, compacted or high-residue fields (Malvick 2018). *Phytophthora, Pythium, Rhizoctonia and Fusarium* inoculum survives in diseased plant material from previous years and in the soil for many years (Malvick 2018).

Phytophthora root and stem rot (*Phytophthora spp.*) favors warm and wet soil conditions, especially poorly drained and compacted soils (Bennett et al. 1999). Spores on the soil surface are capable of infecting plants when raindrops splash off the soil surface onto plants. The lower stem of infected plants will have dark brown discoloration from soil line up stem; leaves on older plants are chlorotic stunted and will wilt die, and remain attached to stem (Bennett et al. 1999). Symptoms include: stand reduction, basal stem decay, seed rot, pre emerge, and post emerge damping off (Bennett et al. 1999). Tolerant varieties and fungicide seed treatments are the most effective disease management tools for Phytophthora (Malvick 2018).

Pythium root rot (*Pythium* spp.) favors cool saturated soil, usually found in low areas of field (Bennett et al. 1999). Fields with large amounts of residue with heavy or compacted soils are at the highest risk of Pythium becoming a problem especially in wet environments (Malvick 2018). Young seedlings are most susceptible because soybean plants become more resistant as they mature. This pathogen attacks seeds before or right after germination; the disease creates and narrow mushy hypocotyl (Malvick 2018). Roots, hypocotyl, and cotyledons turn brown, watery, soft, and completely decay (Bennett et al. 1999). The hypocotyl may swell because of death of meristem tissue (Bennett et al. 1999).

Rhizoctonia root rot *(Rhizoctonia spp.)* favors cool damp spring followed by hot dry conditions (Bennett et al. 1999). Rhizoctonia is more likely to occur when soybean germination is delayed due to poor environmental conditions (Malvick 2018). Infected seedling will have reddish brown discoloration on stem, just below the soil line (Bennett et al. 1999). The lesions have a sunken appearance on the root but the root of an infected plant remains firm.

Fusarium Root Rot (*Fusarium spp*.) favors cool, wet soil (Bennett et al. 1999). Infection starts in the lower lateral and taproot. New roots are able to develop from upper taproot, but these shallow roots are prone to fail in dry soils (Bennett et al. 1999). Fusarium will create a patchy appearance in effected areas of the fields, by infecting a couple feet in one row then followed by some uninfected plants followed by more infected plants. Fusarium symptoms include various shades of brown lesions on soybean root systems (Malvick 2018). Once the plant vascular system turns brown or black and will not be able supple plant with enough water.

***Helinathus annuus* history, importance, growth, and production**

Sunflower (*Helianthus annuus L.*) is an annual plant (Martinez-Force 2015) that is native to North America and grows wild in many parts of the U.S. (Berglund 2007). Oilseed sunflowers became an economically important crop in the U.S. in 1966 (Berglund 2007). Since then the edible oilseed crop, sunflower, has been making rapid strides because of it adaptability (Basappa 2004). Sunflower is considered to be in top four most important oilseed plants in the world (Martinez-Force 2015). There are two primary types of sunflowers: oilseed, for vegetable oil production and non-oilseed, for human and bird food markets (Berglund 2007, Martinez-Force 2015).

The U.S. is third in sunflower production worldwide; the domestic use and exportation of non-oilseeds has been on the increase (Berglund 2007). The U.S. reached a peak production of sunflower in 1979, with 2.2 million hectares (Berglund 2007). In 2015, the U.S. planted 769,000 hectares of sunflowers (USDA 2016). A majority of the acres planted each year are oilseed sunflowers. Of the 769,000 hectares of sunflower planted in 2015, 647,000 hectares were oilseed varieties with the remaining 122,000 hectares being confection (USDA 2016). Across the U.S. the average sunflower yield is 1,804 kg/ha (USDA 2016). The top 5 sunflower producing states are North Dakota, South Dakota, Kansas, Minnesota, and Colorado; with a small number of acres grown in many other states (Berglund 2007). The state of South Dakota produced 275,000 hectares of sunflower in 2015, with an average yield of 2,065 kg/ha (USDA 2016).

According to the survey, 31% of South Dakota sunflower producers indicated the emergence and stand establishment was their biggest production issue (Lamey et al. 1999). Sunflowers require a proper seedbed to ensure good germination and emergence. Conventional tillage system for sunflowers usually involves at least 2 tillage operations; 2 passes of tillage help with early season weed control, incorporate residue, and pre-emerge herbicides. Minimum and no till systems are becoming more common; both of these systems help to conserve soil moisture, which is needed when sunflowers are planted into dryer climates. A 4-year rotation between sunflower crops is recommended to prevent disease, weed, and insect pressure from building up and phytotoxicity of sunflower residue to following sunflower crop (Grady 2000). In South Dakota, sunflowers are planted between May 11 and June 10, with a majority being planted June 1-10 period (Lamey et al. 1999). The ideal planting depth for sunflowers is 3.8 to 6.4 centimeters depending on soil moisture (Grady 2000). Sunflowers are able to compensate for lower stands by producing larger seed and head size. Oilseed hybrids are usually planted at higher populations then confection type sunflowers; specific planting populations have to adjust for soil type, rainfall potential, and yield goal. Sunflower seeding rates should normally be 10-15 percent above the desired final plant population (Grady 2000). Planting at a 10 percent overage ensures that the final stand will still be in the desired range and accounts for some seeds that will not germinate or seedlings that are killed off. In South Dakota, final plant populations of oilseed sunflowers range from 37,100-49,400 plants per hectare; confection type sunflowers final stand should be 37,100-44,500 plants per hectare (Grady 2000). In places, like western South Dakota, that have high probability of facing drought, agronomic practices like planting date, seeding rate, row spacing, and hybrid selection play an important role in yield determination (Martinez-Force 2015).

Sunflowers are considered dicots, which produce 2 leaves opposite each other during germination. After the sunflower has germinated and emerged the cotyledons open up above the soil, at this time the sunflower has reached the VE (vegetative emergence) growth stage. VE occurs usually about 10 days after planting (Berglund 2007). The rest of the vegetative stages (V1, V2, V3, etc.) are determined by counting the number of true leaves, that measure at least 4 cm; if the lower leaves have fallen off count the leaf scars, where the leaves use to be (Berglund 2007, Martinez-Force 2015). The reproductive stage starts at R1, which occurs when the terminal bud forms a tiny floral head, and forms a star like structure with many points when looking at it from above (Berglund 2007). The next reproductive stage, R2, is reached when the young bud elongates 0.5 to 2.0 cm above the closest leaf stem (Berglund 2007). During R3, the young bud has elongated more than 2 cm above the nearest leaf (Berglund 2007). When the inflorescence begins to open the sunflower has reached R4 growth stage (Berglund 2007). When viewed from directly overtop the young ray flowers become visible. R5 growth stage is the beginning of flowering; this stage has sub stages, determined by a decimal, which correlate to the percent of the head that is flowering (Ex. R5.3 = 30% of the head is flowering, R5.8 = 80% of the head is flowering) (Berglund 2007, Martinez-Force 2015). The sunflower has reached R6 growth stage when flowering is complete and ray flowers begin to wilt away (Berglund 2007). R6 is considered the end of anthesis and the grain fill period begins (Martinez-Force 2015). During R7, the back of the sunflower head just begins to turn pale yellow, starting at the middle (Berglund 2007). Once the majority of the back of the sunflower head is yellow, with green bracts the plant has reached R8 (Berglund 2007). R9 is the last growth stage for sunflowers and considered as physiological maturity, this happens when the back of the head turns brown with yellow bracts (Berglund 2007, Martinez-Force 2015).

Sunflowers are considered as a drought tolerant crop because they produce a deep taproot and are able to extract water from depths most other crops cannot. (Berglund 2007, Martinez-Force 2015). The taproot can reach depths of up to 1.2 meters; using this tap root sunflower on average use about 48 cm of water, from rain or stored soil moisture (Berglund 2007). In a sunflower plant, roots develop faster than leaves; in loose soil taproot elongation of 12 cm per day is possible (Martinez-Force 2015). Sunflowers and soybeans are closely related in water requirements and number of growing days (Berglund 2007).

**Sunflower Insect Management**

Sunflowers can suffer potential losses from diseases, insects, bird, and weeds. These can make sunflowers a high-risk crop if producers do not follow proper integrated pest management (IPM) practices (Berglund 2007). Integrated pest management is a sustainable approach to managing pests by combining biological, cultural, mechanical, and chemical control (Berglund 2007). Producers reported that crop rotation is the most effective means for non-chemical insect control and non-chemical disease management, followed by tillage and hybrid selection respectively (Lamey et al. 1999).

Early season sunflower production is threatened by many insect pests. Sunflower insects of major importance in the northern Great Plains include: cutworm, wireworms, sunflower root weevil, sunflower beetle, and striped flea beetle. These various insect pests emerge at different plant stages and damage multiple parts of the sunflower plant (Basappa 2004). Soils that are excessively cool and wet slow sunflower plant development and allow pest to cause excessive feeding damage which reduces stands (McCornack et al. 2016). Damage from early season pests can be reduced with the use of treated seed.

There are several species of cutworms' larvae that will feed on young sunflowers. Damage from cutworms consists of plants being cut off about 1 inch below the soil surface (Berglund 2007). Wilted or dying plants leaving bare patches in the field can indicate cutworm infestation (Berglund 2007). During the previous summer, in July/August, female cutworm moths lay their eggs in the soil; the eggs do not hatch until the following spring (Berglund 2007). Once hatched in the spring the cutworms feed on the young plants that are just emerging at the time. The cutworm economic threshold is, one cutworm per square foot or if stand losses are approaching lower limit of recommended seeding rate (Meyer et al. 2009, McCornack et al. 2016).

Wireworms are the larvae of click beetles (*Elateridae spp.*), of which have many species (Knodel et al. 2015). Early in the growing season wireworms are near the soil surface and feed on germinating sunflowers and seedlings (Knodel et al. 2015). Wireworms spend 2 to 6 years living in the soil, in the larval stage (Meyer et al. 2009). Infestations are more likely to occur where grasses or grain crop were grown the previous year, because adults are attracted to grasses where they lay their eggs (Meyer et al. 2009). When the risk for crop injury is high an insecticide seed treatment should be used (Knodel et al. 2015). The risk of crop injury from wireworms is difficult, but can be determined by placing bait trap stations in field or sifting through soil samples.

The sunflower root weevils emerge and begin feeding on sunflower foliage; after about 2 weeks the weevils begin to congregate at the soil surface level of the sunflowers (Berglund 2007). The sunflower root weevils then lay their bright yellow eggs; the eggs hatch in mid-July (Berglund 2007). Once hatched, the larvae feed on the epidermal and cortical cells of the roots (Knodel et al. 2015). The larvae are not very mobile and continue to feed on the sunflower roots throughout the summer. This leads to localized damage in the field with wilted and lodged plants (Meyer et al. 2009). The larvae destroy the sunflower root system, which causes the plant to wilt or lodge (Berglund 2007). In mid-August, the sunflowers become dehydrated and form at soil cocoon around the larvae and encapsulate it; sunflower root weevil larvae overwinter within the cocoon in the soil (Knodel et al. 2015).

Sunflower beetles (*Zygogramma exclamationis*) emerge from the soil in late May until early June and feed on the emerging sunflowers (Grady 2000). The adult beetles lay eggs on the stem and underside of leaves, which hatch in about one week (Berglund 2007). Mature larvae then enter the soil to pupate and reemerge as adults and feed for short period of time before returning to soil to overwinter (Berglund 2007). The sunflower beetle rarely reaches economic threshold or one adult on sunflower seedlings or 25% defoliation (McCornack et al. 2016).

Flea Beetles (*Phyllotreta* spp.) emerge from crop residue, field debris, or wooded areas in the spring and feed on a wide range of hosts (Knodel et al 2015, Knodel 2017). Flea beetles can be observed feeding on sunflowers from June through July (Knodel et al 2015). The adult beetles chew through the cotyledons and young leaves. Significant feeding results in plants with a “lacy” or “shot hole” appearance (Knodel et al 2015, Knodel 2017). Damage to the young sunflower plant causes reduced plant stands, uneven growth, and reduced yield (McLallen 2013, Knodel 2017). Sunflowers are most at risk to the flea beetle from emergence through the V4 (Knodel et al 2015). The flea beetle favors warm and dry weather (Knodel 2017). Economic threshold of flea beetles in sunflower is 20 percent seedling stand with damage and follows similar guidelines used for assessing hail damage (Knodel et al 2015). Flea beetles have enlarged hind femurs they use to jump when startled, which makes them hard to collect and estimate population size (Knodel 2017).

**Neonicotinoid seed treatments**

Traditionally, the term seed treatment is used to describe a seed coat that may include insecticides, fungicides, nematicides, fertilizers, or growth enhancers. Insecticide seed treatments are referred to as pesticides applied to seed prior to planting in order to suppress or control pests that attack germinating seedlings (Forsberg et al., 2003). One of the most common insecticide classes used for seed treatments is the neonicotinoid class. Neonicotinoids bind to and activate the nicotinic acetylcholine receptors (nACHRs) (Maienfisch, et al. 2001, Elbert, et al. 2008). Neonicotinoids provide broad spectrum control of many pests, because of its properties it has been one of the fastest growing insecticide classes in modern time (Jeschke et al. 2011). Between 1991 and 2002, seven neonicotinoid insecticides compounds were launched, which include imidacloprid, nitenpyram, thiacloprid, thiamethoxam, clothianidin, dinotefuran, and acetamiprid (Elbert et al. 2008). From 1994 to 2011, neonicotinoid insecticide use increased dramatically, with over 500 registered uses (Douglas and Tooker 2015). Neonicotinoid seed treatment was first registered for use on soybeans in 2004 (Myers and Hill 2014). The active ingredients that are marketed for use on soybean include imidacloprid, thiamethoxam and clothianidin. Imidacloprid and thiamethoxam are chloronicotinyl insecticides, which are absorbed by the plant and are mobile in the xylem (Maienfisch et al. 2001). Neonicotinoid insecticides are highly water-soluble; which results in absorption by the plants and also movement in the xylem (Douglas and Tooker 2015). Other conventional insecticide classes like organophosphates, cabamates, pyrethriods, chlorinated, hydrocarbons, and many others do not have any cross resistance with neonicotinoids, due it its effective mode of action (Nauen and Denholm 2005).

Neonicotinoids are an important group 4A insecticide used throughout the U.S. (Jeschke et al. 2011). Neonicotinoid seed treatments applied to soybean seeds are systemic in roots, leaves, and stem several weeks after planting. These seed treatments can still be found effective in the plant up to 4 weeks after planting (Myers and Hill 2014). Seed treatments help protect young vulnerable plants, even at low dosages (Stoddard et al. 2016). Neonicotinoids have been found to be effective against aphids, whiteflies, leafhoppers, planthoppers, thrips, some moths and beetles (Jeschke et al. 2011). Due to the plant systemic nature, neonicotinoids are able to protect the whole plant which can suppress plant virus diseases and therefore reduce the secondary spread of plant viruses (Jeschke et al. 2011). When imidacloprid is used as seed treatment it is applied at a rate of up to 62.5 grams active ingredients (AI)/100 lbs of seed; thiamethoxam used as a seed treatment is applied at rate of 50-100 grams (AI)/100 lbs of seed (Myers and Hill 2014). Neonicotinoids act through contact and ingestion, resulting in insect death within 24 hours after consumption (Maienfisch et al. 2001, Rice 2004, Elbert et al. 2008).

Without neonicotinoid seed treatments, producers will have to rely on older chemical classes and therefore have to increase the amount of insecticide used, which will negatively affect integrated pest management practices (IPM) (Mitchell 2014). Neonicotinoid seed treatments are a great alternative to broad spectrum foliar insecticides. Foliar sprays and non-systemic insecticides have serious disadvantages in ability to control boring and root feeding insect pests, when compared to neonicotinoids (Stoddard et al. 2016). From 2000 to 2012, virtually all neonicotinoids applied to maize, soybeans, and wheat was applied as seed treatments (Douglas and Tooker 2015). In 2011, it is estimated that 34-44 percent of the soybean acres planted used neonicotinoid-treated seed (Douglas and Tooker 2015). In 2016, about 60-70 percent of soybean acres utilized some type of seed treatment (Robertson et al. 2017) The EPA believes that in most situation seed treatments on soybean will provide insignificant benefits (Myers and Hill 2014). Up to a 75 percent reduction of damaged plants by the striped flea beetle can be achieved by the use of a neonicotinoid seed treatment (McLallen 2013).

One of the issues associated with neonicotinoid seed treatments is their prophylactic use. Many farmers use neonicotinoid-treated soybean seed as insurance, with no particular pest targeted. Neonicotinoid seed treatments could potentially provide insurance against pest that are sporadic and unpredictable year to year (Myers and Hill 2014). When commodity prices increase the use of seed treatments increase, this is because seed treatments have a higher probability of increasing revenue due to smaller yield gains needed to cover the costs of the seed treatment (Esker and Conley 2012). Neonicotinoid seed treatments are popular among producers because they provide a valuable class of insecticide in an easy application method (Mitchell 2014). A trend of earlier planting dates is another reason for increased uses of soybean seed treatments. Seed treatments should be considered for fields grown as seed production, seed that is old, planting in unfavorable conditions, or trying to achieve high yield potential (Paulsrud 2001).

The United States Environmental Protection Agency conducted a study of neonicotinoid seed treatments in soybean and determined that they provide a $0 benefit (Myers and Hill 2014). However, an evaluation of the same data set found there to be a 2.8% yield benefit from the use of neonicotinoid seed treatments (Mitchell 2014). Reduced crop yield and quality would be expected without the continued use in neonicotinoid seed treatments (Mitchell 2014). The insecticidal component helps manage both foliar and soil residing pests, including bean leaf beetle, seedcorn maggot, wireworms, cutworms, and other pests (Rice 2004, Elbert et al. 2008, Gaspar et al. 2015). The fungicidal components of the seed treatment are meant to target seedling damping off diseases like *Pythium*, *Phytophthora*, *Fusarium*, and *Rhizoctonia* spp. (Gaspar et al. 2015). ApronMaxx (mefenoxam [0.0057 mg a.i. per seed] and fludioxonil [0.0039 mg a.i. per seed]) a fungicide only seed treatment showed no gains in plant stand, harvest plant populations, yield, or profitability across 6 different seeding rates when compared to the untreated control (Gaspar et al. 2015). CruiserMaxx (thiamethoxam [0.0762 mg a.i. per seed], mefenoxam [0.0057 mg a.i. per seed], and fludioxonil [0.0039 mg a.i. per seed]) a combination fungicide and insecticide seed treatment showed 21% increase in plant stand, 16% increase in harvest plant population, increase in yield, and profitability (Gaspar et al. 2015). The yield advantage with CruiserMaxx varied with the seeding rate.

In the low seeding rate, 98,800 seeds/ hectare, there was a yield increase of 12%; in the high seeding rate, 345,800 seeds/ hectare, there was 4% yield increase compared to the untreated control (Gaspar et al. 2015). Research has shown that a, fungicide+insecticide, combination seed treatment regularly increased plant stand over untreated soybeans across all environments (Gaspar et al. 2014). To maximize revenue, when a fungicide/insecticide seed treatment is used the seeding rate should be reduced by 50,000 seeds ha compared to the non-treated planting rate. (Cox and Cherney 2011, Gaspar et al. 2015). In areas where there is known high seedling disease pressure, fungicide seed treatments can increase yield; however, in fields with lower or no risk of seedling disease it is unlikely that the fungicide seed treatment will produce an economic return (Yang 2009).

Neonicotinoids are considered reduced risk to applicators because of its low mammalian toxicity (Stoddard et al. 2016). Studies indicate that neonicotinoid seed treatments fit well into IPM systems, because non-target insects are not affected to the same extent as foliar applications of older chemical classes (Paulsrud 2001, Elbert et al. 2008). Other advantages of seed treatments include, low doses of chemical used, optimal application timing, and they are easy to apply (Paulsrud 2001). Relatively low doses of insecticide are used in seed treatments compared to broadcast sprays, this in turn reduces cost of the chemical and potential environmental impacts (Paulsrud 2001). Seed treatments provide a high level of protection against pest and reduce human exposure potential because of the precise mode of how these produces are applied (McLallen 2013). Seed treatments provide optimal timing of application because they are present when needed most, seedling are more vulnerable then mature plants (Paulsrud 2001).

Protection of young plants is enhanced by translocating insecticides in the plant, without harming beneficial insects or pollinators (Elbert et al. 2008). Neonicotinoids can be toxic to honey bees, but studies have revealed that it is unlikely the honey bees will die from the use of seed treatments (Rice 2004). This is partially due to the fact that honey bees seldom feed on young plants that seed treatments have been applied to. One study determined that there were no differences between honey bee colonies in a clothianidin seed treated and untreated control field (Cutler and Scott-Dupree 2007). This study conducted by G. Cutler and C. Scott-Dupree indicated that honey bee colonies places in field with neonicotinoid seed treatment produced the same amount of honey and gained just as much weight as honey bee colonies placed in untreated fields. The same study also found that there were no differences of brood production, number of adult worker bees, colony health, and overwinter survival between colonies in treated and untreated fields (Cutler and Scott-Dupree 2007). Research had determined that beehives are not expected to be affected by neonicotinoid seed treatments (Rice 2004). Insecticide seed treatments are considered "reduced risk" to humans, non-target insects, and the environment (Cutler and Scott-Dupree 2007, Elbert et al. 2008).

**In-furrow insecticides for sunflower**

An in-furrow applied insecticide can provide plant protection to many early season pests. In-furrow insecticide treatments may provide better control of pests not well controlled by standard seed treatment rates (Stewart 2016). In-furrow applications work by protecting the area directly around the seed, this helps to control pests before they are even able to get to the seed. Many in-furrow insecticides are formulated to be mixed with starter fertilizers producers are commonly using (Stewart 2014). Because many producers are currently using in-furrow fertilizers it is easy to add an insecticide component that will protect the seed from pests. Robinson (2003) states that in-furrow treatments are more beneficial because larger rates are able to be applied and it is actually treating the soil around the seed versus just the seed itself. Stewart (2014, 2016) recommends using in-furrow insecticide treatments over standard seed treatments when new land in going into farm production, there was a live cover crop near the time of planting, and when no burndown herbicides are used in no-till fields. In-furrow insecticide treatments at time of planting can control chewing insects that would potential reduce stand. These treatments are commonly used because rescue treatments are unsuccessful in fields that have suffered heavy insect damage.

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# CHAPTER 2

# DEVELOPING SOYBEAN SEED TREATMENT RECOMMENDATIONS IN SOUTH DAKOTA

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## Abstract

Soybean seed treatments are commonly used as a preventative measure to protect yield from early season pest pressures, despite limited management recommendations. In 2014, the EPA reported a $0 benefit associated with the use of insecticidal seed treatments in Midwestern soybean production. However, an independent evaluation of the same dataset revealed a 2.8% yield benefit associated with insecticidal seed treatments use. Previous studies rarely explored the impact of planting date and seeding rate on insecticide seed treatment efficacies. For this study, we set out to evaluate the impact of location, planting date and seeding rate on the efficacy of insecticidal seed treatments at four South Dakota State University research farms during 2016 and 2017. At each location, treatments were planted early (May) and late (June). For each planting date, soybean were planted at seven seeding rates: 148,200 seeds/ha, 197,600 seeds/ha, 247,000 seeds/ha, 296,400 seeds/ha, 345,800 seeds/ha, 395,200 seeds/ha, and 444,600 seeds/ha. For each seeding rate, three treatments were used: untreated control, fungicide seed treatment, and fungicide+insecticide combination. Stand count data and root samples for disease severity were taken 14 days after soybean emergence. Yield data was collected from the middle two rows of each plot. Our results indicate that the effect of location within South Dakota and planting date significantly impacted overall soybean yield. Although not statistically significant, we did observe yield increases similar to the 2.8% benefit, but could not attribute this to any one factor that was examined.

**Keywords: Soybean, seed treatment, planting date, seeding rate**

## Introduction

Soybean represents an important crop in the North Central Region of the U.S. During 2017 in South Dakota, 2.8 million ha of soybean were planted with an average yield of 2,881 kg/ha (USDA 2017). The annual revenue from soybean production in South Dakota is estimated to be approximately $2.1 billion. Because soybean account for a large portion of agricultural production in South Dakota, insect pest management is vital. For aboveground insect pests, foliar applied insecticides are often used to reduce insect pest populations, while neonicotinoid seed treatments are used to manage belowground and early season insect pests. For the aboveground pests in soybean, economic thresholds are used to determine when management action should occur to prevent yield loss. However, the same principle is not used when determining if insecticide seed treatments are necessary.

For soybean, insecticidal seed treatments are dominated by a single class of insecticides, neonicotinoids. Neonicotinoids class insecticides were first registered for use as seed treatments in soybean in 2004 (Myers and Hill 2014). Since then, adoption of these management tools has resulted in over 50 percent of soybean seeds planted in the U.S. being treated (Porter 2016). There are several reasons why neonicotinoid seed treatment use increased in soybean production. Some of the reasons include the ability to plant soybean earlier in the season, observed increases in stand establishment, and they are considered an early season insurance policy (Porter 2016). In soybean, insecticide seed treatments are labeled for the management of wireworms (Coleoptera: Elateridae), white grubs (Coleoptera: Scarabaeidea), seed corn beetle (Coleoptera: Carabidae), and bean leaf beetle (Coleoptera: Chysomelidae).

The current recommendations for the use of insecticide seed treatments are as follows: 1) planting soybean into fields that were previously grass or small grains may warrant insecticide seed treatment use due to potential pest pressure from wireworms and white grubs, 2) planting soybean into fields with recently incorporated manure, cover crops or weeds, and 3) planting high value soybean (e.g., soybean for seed production) (Bailey et al. 2015). The evidence that these management recommendations are lacking was exemplified by a 2014 report by the Environmental Protection Agency (EPA). The EPA study determined that the use of neonicotinoid seed treatments in soybean provided a $0 benefit to North Central Region soybean farmers and suggested that their use should cease (Myers and Hill 2014). However, their results were contradicted by an independent assessment of the same data set that determined for the North Central Region, insecticide seed treatments provide a 2.8% yield benefit per acre in soybean (Mitchell 2014). However, the issue that still needs to be addressed is determining the factors responsible for the observed 2.8% yield improvement associated with the insecticide seed treatments.

In an effort to determine when seed treatments provide the most economic return, there are several factors that must be examined. For the purpose of this study, we will be highlighting the potential impact of location, planting date, and seeding rate. There is evidence that location can impact the value associated with an insecticide seed treatment. For example, Robertson et al. (2013) tested 10 different soybean seed treatment combinations over four locations in Iowa. Three out of the four locations reported no differences in stand counts among treatments. Similarly, for three of the four locations yield results suggested that any type of seed treatment performed better than the control treatment. Gaspar et al. (2014) examined the effects of various soybean seed treatment combinations across multiple locations in Wisconsin. Their study determined that fungicide+insecticide and fungicide+insecticide+nematicides treatments consistently increased plant stand; however, yields were variable across all treatments (Gaspar et al. 2014). These studies indicate that seed treatment efficacies vary by locations, which may be due to different disease and insect pest pressures.

In addition, there is evidence that timely planting of soybean is important to achieve maximum yield potential (De Bruin & Pedersen 2008). This is especially true in South Dakota where there is already a limited growing season due to amount of sunlight and temperature. Soybean germination starts when soils have warmed to 12.2 Celsius (Clay et al. 2013). The University of Nebraska-Lincoln (2009) determined that late planted soybean will have a 16.8 to 41.9 kg/ha yield loss for each day planting is delayed after May 1. The same is true for other states including South Dakota where the yield loss date varies from May 5$^{th}$ in Southern South Dakota to May 15$^{th}$ in Northern South Dakota (Clay et al. 2013). Planting earlier in the season allows plants to produce more nodes, provide canopy cover faster, and reach larger sizes prior to the first reproductive (R1) growth stage (Clay et al. 2013). These improvements can result in increased yield.

Another factor that may influence the efficacy of insecticide seed treatments is soybean seeding rates. Producers vary their seeding rates for many different reasons. These may include ensuring proper harvest stand, promote growth by greater competition, reduce chance of lodging or diseases, and lowering initial seed cost. Studies by Gapsar et al. (2015) and Staton (2015) determined that lower soybean seeding rates can produce equivalent yields to higher seeding rates, while reducing seed input costs. Lower seeding rates are capable of producing high yields with less plants because plants will produce more branch nodes and pods under lower competition. The ideal seeding rate in South Dakota varies by location and soil type, but planting between 346,000 and 371,000 seeds per hectare was determined to produce the greatest economic return (Clay et al. 2013).

In addition to insecticide seed treatments, fungicide seed treatments help protect developing seedlings early in the season when the soil is wet. These soil conditions are favored by *Phytopthora*, *Pythium*, *Rhizoctonia*, and *Fusarium* (Giesler 2017). All four of the previously listed disease are capable of surviving in the soil for years. *Phytopthora* and *Pythium* are known to cause damping-off of soybean and cause the stem or hypocotyl to become soft and soggy (Sweets 2012 and Giesler 2017). In contrast, *Rhizoctonia* and *Fusarium* are more characteristic of causing root rots in which the roots become discolored, shrunken, and stunted growth of above ground portion (Sweets 2012 and Giesler 2017). Fungicide seed treatments are often used because once the crop is planted there is little that can be done at that point to reduce these early season seedling diseases.

These treatments are often used in combination with an insecticide seed treatment to provide maximum early season protection.

One issue that is observed is that the all of the previously mentioned factors have not been examined in a single study to evaluate their overall impact on insecticide seed treatment efficacy in soybean. For instance, De Bruin and Pedersen (2008) tested the effects of planting date and seeding rate on soybean yield. Their study examined four seeding rates and four planting dates. Results from this study determined that yield potential can be increase by planting earlier in the season and that lower seeding rates may be more profitable than current recommendations (Bruin and Pedersen 2008). Kandel et al. (2016) examined the effects of planting date, seed treatment, and variety over four locations and two years. Early planted plots had a higher disease index than the later planted plots and the use of fungicide seed treatments reduced disease severity, which helped protect yield (Kandel et al 2016).

The overarching similarities of these studies is that the findings indicate the efficacy of seed treatments are affected by numerous factors. In addition to the factors discussed, there is also the potential for other non-manageable abiotic factors such as weather to further alter the usefulness of seed treatments. For example, there are less likely to be early season disease issues in springs that are warm and dry. Therefore, fungicide seed treatments are more likely to show returns on investment in cool wet conditions after planting (Robertson 2013). Also, in years or fields where early season pest and disease pressure is low yield benefits from seed treatments are unlikely (Yang 2009 and Robertson 2013). All of the uncertainty and year to year differences in weather makes it hard to determine when a soybean seed treatment will provide an economic return, because of this many producers decide to use seed treatments as early season insurance (Myers and Hill 2014). This is especially true when commodity prices increase, and seed treatments have a higher probability of increasing revenue due to smaller yield gains needed to cover the seed treatment input costs (Esker and Conley 2012).

Because of the potential for several factors to alter the efficacy and overall yield response of soybean to insecticide seed treatments we conducted an experiment to evaluate some of these factors. The factors examined included location within Eastern South Dakota, planting date, and seeding rate. In addition, we sampled soil to evaluate the presence of known early season belowground insect pests.

## Materials and Methods

### Field Site

This study was conducted during the 2016 and 2017 growing seasons at four South Dakota State University research farms that included the Southeast Research Farm (Beresford, SD), Brookings Research Farm (Brookings, SD), Volga Research Farm (Volga, SD) and Northeast Research Farm (South Shore, SD) for a total of eight location-years. Multiple locations were utilized throughout South Dakota's main soybean production area because of varying environments across the state. For both years, plots were planted into fields that were conventionally tilled.

Each year the first planting date was commenced as soon as conditions were fit and the second planting date was scheduled for one month after, or as close to that as possible according to weather conditions. Individual planting dates for each specific location, and previous crop information for each location can be found in Table 1. There was no fertilizer applied the previous fall or during the spring of 2016 or 2017. There was no pre-emerge herbicide used before planting or before plant emergence during 2016. In 2017, there was a pre-emerge herbicide application of VARSITY WDG (Innvictis Crop Care, Loveland, CO) at labeled rate, to both the early and late planting plots at both the Brookings and Volga locations. In 2017, prior to early planting in Beresford, glyphosate (RoundUp, Monsanto Company, St. Louis, Missouri) and S-metolachlor (Dual Magnum, Syngenta Crop Protection, Greensboro, NC) were applied at label rate. In season weed management, was performed using fomesafen and glyphosate (Flexstar GT 3.5, Syngenta Crop Protection, Greensboro, NC) at Volga and Brookings both years. Post-emerge application of glyphosate was used at the remaining locations.

**Experimental Design**

For both years, glyphosate resistant Mustang seed varieties (Syngenta Seeds Inc, Wilmington, DE) were used. Soybean maturity groups of 1.3, 1.7, 2.0, and 2.3 were used at South Shore, Brookings, Volga, and Beresford respectively. Soybean were planted in 3.0 m by 6.1 m plots using an Almaco four row cone planter (Almaco Inc., Nevada, IA) with 76.2 cm row spacing. Maturity groups were chosen based on location to maximize yield potential in each environment.

**Evaluating the Planting Date and Seeding Rate on Efficacy of Seed Treatments**

We hypothesized that soybean yield benefits associated with insecticidal seed treatments would increase at an earlier planting date and lower seeding rate. We tested this by varying planting date and seeding rates at four locations within South Dakota and measuring soybean stand counts and yield.

We used a total of 42 treatments to test our hypothesis using small field plots at the four previously mentioned locations. Each treatment was a combination of three factors that included planting date, seeding rate, and seed treatment. The planting dates were Early (May) and Late (June) with exact dates varying by location due to field and weather conditions. At each planting date, there were a total of seven seeding rates that included 148,200 seeds/ha, 197,600 seeds/ha, 247,000 seeds/ha, 296,400 seeds/ha, 345,800 seeds/ha, 395,200 seeds/ha, and 444,600 seeds/ha. In 2016, each seeding rate was planted 15 percent over the seeding rate of interest; this was intended to allow for good stand establishment in poor conditions for better determination of yield. Because of great stand establishment success that occurred the first year it was decided that planting an overage was not needed in 2017. At each seeding rate, there were a total of three different seed treatments tested. These included an untreated control, fungicide only: prothioconazole, penflufen, and metalaxyl (EverGol Energy SB, 0.019 mg a.i./seed; Bayer CropScience, Research Park Triangle, NC) and metalaxyl (Allegiance FL, 0.02 mg a.i./seed, Bayer CropScience), and a fungicide+insecticide combination: (EverGol Energy SB, Allegiance FL and Poncho 600, clothianidin, 0.11 mg a.i./seed, Bayer CropScience). For this experiment, we used a randomized complete block design with six blocks for each planting date at each location.

The active ingredients in EverGol Energy help prevent seed rot and damping-off caused by *Pythium, Fusarium,* and *Rhizoctonia* (EverGol Energy 2015). Allegiance FL is added to increase the amount of metalaxyl, higher amounts of metalaxyl are used for better control of *Phythophthora*. The systemic insecticidal component (clothianidin) targets many early season pests, including wireworm, white grub, seedcorn maggot, seed corn beetle, cutworm, soybean aphid, and bean leaf beetle.

**Stand counts.** Stand counts were determined for each plot at 14 d post emergence. Stand counts were collected by counting the number of live plants in 3.0 m of the middle two rows of each plot. The number of plants were converted into plants per hectare and averaged over both rows for a plot average. To assess belowground issues that may be responsible for reduced stand counts and yield, soybean plant and soil samples were collected from the outer most rows of each plot.

**Root disease evaluation.** Also at 14 days' post emergence, 10 plants per plot (5 plants from each of row 1 and 4) were sampled from all plots for disease identification and severity. The ten plants were rated as a whole for percent root disease which was then converted into generic plant disease severity index. In both 2016 and 2017, only plants from the late planting date at each location were plated for disease identification, found in Table 2. Four plants were selected from each plot and in a sterile environment with sterile equipment a 6-mm section of each stem was cut off the plant. Each portion of the stem was dipped in distilled water with 10% bleach for 45 seconds, then transferred to 70% ethanol solution for 45 seconds, and finally placed in distilled water for another 45 seconds. After removing the stem portion from the distilled water they were plated on potato dextrose (PDA) media, sealed, and stored at room temperature for 2 weeks before identification.

**Yield.** When the soybean reached full maturity the center two rows of the plot were combined for yield. Combining only the middle of the plot minimizes interference between plots. Harvest was conducted with a Kincaid 8-XP small plot combine (Kincaid

Equipment Manufacturing., Haven, KS). The plot combine was equipped with a weigh bucket to record the seed and test weight. Percent grain moisture was obtained from a moisture sensor on the combine. All plots were corrected to 13% moisture.

## Statistical Analysis

We tested whether soybean seed treatments would increase yield across multiple locations, planting dates, and seeding rates. To determine these differences on plant stand and yield the data was analyzed using PROC MIXED procedure with SAS statistical software version 9.4 (SAS Institute, Cary, NC). Multi-location analysis was used to examine the effects of soybean seed treatment, seeding rate, and planting date on plant stand and yield. Year, location, planting date, seeding rate, and seed treatment and all interactions were significant and treated as fixed effects; replications within planting date, location, and overall error term were treated as random effects. The level of significance used was 95% and comparisons were conducted using least squares mean test. Non-transformed data was used for making graphs and calculating numerical differences between treatments.

To reduce heteroscedasticity, the stand counts taken on day 14 and yield were natural log transformed. Significant effects were separated using F-protected least-squares mean test. Analysis of the stand count was conducted separately for each year, location, and planting date; data determined that year, location, and planting date were always significant. Yield data analysis was conducted separately for each year and location. Yield was always significant at year, location, and planting date level. The main model analysis was performed in PROC MIXED (SAS Institute, Cary, NC).

For soybean disease evaluations were collected on a disease severity rating scale of 0-100%. Ratings were then converted into disease severity index and analysis was completed in PROC MIXED (SAS Institute, Cary, NC). Again, disease severity was natural log transformed and significant effects were separated using F-protected least-squares mean test. Each year, location, and planting date had data analysis independently.

## Results

**Stand counts.** For most locations in both years, we rejected our null hypothesis that stand counts would not differ between the untreated control and the fungicide or fungicide+insecticide combination at any of the planting dates, or locations. We determined that stand counts were significantly higher in 2016 than in 2017 ($F$=193.49; df=1, 1962; $P$<0.0001). Greater stand counts were expected in 2016 since they were planted with 15 percent overage in seeding rate. Because of the differences in year, stand counts were analyzed by year (Table 3). In 2016, stand counts were significantly different among locations ($F$=50.24; df=3, 983; $P$<0.0001). The Brookings Farm ($t$=9.59; df=1, 983; $P$<0.0001), Northeast Farm ($t$=9.21; df=1, 983; $P$<0.0001), and Volga Farm ($t$=10.88; df=1, 983; $P$<0.0001) had significantly higher stand counts than the Southeast Research Farm. The same trend was found in 2017, where location had a significant impact on stand counts ($F$=4.02; df=3, 968; $P$<0.0074) (Table 4.). However, in 2017, the Brookings Research Farm location had significantly greater stand counts than Southeast Research Farm ($t$=2.71; df=1, 968; $P$<0.0069) and the Northeast Research Farm ($t$=3.08; df=1, 968; $P$<0.0021). Due to the observed significance of location, stand counts were then analyzed by year and location to determine the impact of planting date on stand counts.

In 2016, stand counts in the early planting date (*t* =2.32; df=1, 244; *P*<0.0213) were significantly greater than the late planting date at the Volga Research Farm location. In 2016, stands at the Northeast Research Farm location were significantly greater for the late planted soybean (*t*=2.26; df=1, 245; *P*<0.0247) when compared to the early planted soybean. There were no differences in stand counts observed between early and late planted soybean at the Brookings and Beresford locations. In 2017, stand counts at the Southeast Research Farm location in the late planted soybean (*t*=9.31; df=1, 242; *P*<0.0001) had significantly greater stand counts than the early planted soybean. For 2017, at the Volga Research Farm, the early planted soybean (*t*=2.93; df=1, 245; *P*<0.0037) had significantly greater stand counts than the late planted soybean. For 2017, no significant differences were observed for stand counts between the early and late planted soybean at the Brookings Research Farm and Northeast Research Farm locations.

Data were then analyzed by year, location, and planting date. However, due to the fact that seven seeding rates were used significant differences among seeding rates were expected. For this reason, data were then analyzed by year, location, planting date, and seeding rate to determine the impact of treatments on stand counts. For 2016, at the Southeast Research Farm the fungicide+insecticide (*t*=2.62; df=1, 10; *P*<0.0255) had significantly greater stand counts than the fungicide treatment, while neither treatment was significantly different than the untreated control at the 197,600 seed/ha seeding rate. For the same location and planting date, the untreated control (*t*=2.63, df=1, 10; *P*<0.0253) had significantly greater stand counts than the fungicide treatment for the 296,400 seed/ha seeding rate. In the late planting date there were no significant differences among treatments at any of the seeding rates.

In 2016, the Brookings early planting date saw no significant differences in treatments due to populations. However, in the late planting date, the fungicide+insecticide (*t*=2.47; df=1, 10; *P*<0.0329) treatment had significantly greater stand counts than the untreated control at the148,200 seed/ha seeding rate. For the same location and planting date, the fungicide treatment had significantly greater stand count than the fungicide+insecticide (*t*=3.85; df=1, 9; *P*<0.0039) and the untreated control (*t*=3.6; df=1, 9; *P*<0.0058) at 197,600 seed/ha seeding rate. The same trend was found at the 247,000 seed/ha seeding rate, were the fungicide had significantly greater stand than the fungicide+insecticide (*t*=2.3; df=1, 10; *P*<0.0441) and the untreated control (*t*=3.51; df=1, 10; *P*<0.0056). At the 345,800 seed/ha seeding rate, the fungicide treatment had a significantly greater stand than the untreated control (*t*=2.9; df=1, 8; *P*<0.0200) and the fungicide+insecticide (*t*=5.23; df=1,8; *P*<0.0008). A this seeding rate, the untreated control (*t*=2.65; df=1,8; *P*<0.0293) had significantly greater stand than the fungicide+insecticide treatment. At the 395,200 seed/ha seeding rate, the fungicide treatment (*t*=2.42; df=1, 9; *P*<0.0389) had significantly greater stand counts than the fungicide+insecticide. At the 444,600 seed/ha seeding rate, the fungicide treatment had significantly greater stand counts than the fungicide+insecticide (*t*=2.38; df=1, 10; *P*<0.0385) and the untreated control (*t*=2.4; df=1, 10; *P*<0.0370).

For the 2016 early planting date at the Volga Research farm, there were two seeding rates that had significant differences in treatment. The first one occurred at 345,800 seeds/ha, where the fungicide+insecticide (*t*=2.23; df=11, 0; *P*<0.0495) treatment had significantly greater stand counts than the fungicide treatment. This occurred again at the 395,200 seeds/ha seeding rate, where the fungicide+insecticide treatment had significantly higher stand counts than the fungicide treatment ($t=2.28$; df=1, 10; $P<0.0454$). The 395,200 seed/ha seeding rate in the late planting at Volga also had significant differences ($F=14.28$; df=2, 10; $P<0.0012$). For this planting date and seeding rate, the fungicide+insecticide had greater stand counts than the fungicide treatment ($t=2.49$; df=1, 10; $P<0.0318$) and the untreated control ($t=5.34$; df=1, 10; $P<0.0003$). Also the fungicide treatment ($t=2.85$; df=1, 10; $P<0.0174$) had significantly greater stand counts than the untreated control. In the late planting date, at 444,600 seed/ha seeding rate the fungicide treatment ($t=3.46$; df=1, 10; $P<0.0061$) had significantly greater stand than the untreated control.

For the 2016, early planting date at the Northeast Research Farm, significant differences were observed for each of the seeding rates. At 148,200 seed/ha seeding rate, the fungicide ($t=2.9$; df=1, 10; $P<0.0157$) and fungicide+insecticide ($t=4.13$; df=1, 10; $P<0.0020$) had significantly greater stand counts than the untreated control. At the 197,600 seed/ha seeding rate, the fungicide ($t=2.65$; df=1, 10; $P<0.0243$) and fungicide+insecticide ($t=2.62$; df=1, 10; $P<0.0258$) had significantly greater stand counts than the untreated control. The same trend was also found at the 247,000 seed/ha seeding rate, where the fungicide ($t=3.37$; df=1, 10; $P<0.0071$) and fungicide+insecticide ($t=5.15$; df=1, 10; $P<0.0004$) had significantly greater stand counts than the untreated control. At 296,400 seed/ha, the fungicide+insecticide ($t=3.16$; df=1, 10; $P<0.0102$) had significantly greater stand counts than the untreated control. The same trend was observed at the 345,800 seed/ha seeding rate, where the fungicide+insecticide ($t=2.59$; df=1, 10; $P<0.0271$) had significantly greater stand counts than the untreated control. At 395,200 seed/ha, the fungicide ($t=2.33$; df=1, 10; $P<0.0422$) and fungicide+insecticide ($t=4.06$;

df=1, 10; *P*<0.0023) had significantly greater stand counts than the untreated control. In the last seeding rate of 444,600 seed/ha, the fungicide (*t*=3.9; df=1, 10; *P*<0.0029) and fungicide+insecticide (*t*=3.45; df=1, 10; *P*<0.0062) had significantly greater stand counts than the untreated control. There were no significant differences in treatments at any seeding rate for the late planting date.

For the 2017, early planted soybean at the Southeast Research Farm, significant stand count differences were observed at the 148,200 seed/ha seeding rate where the fungicide (*t*=3.24; df=1, 9; *P*<0.0101) and fungicide+insecticide (*t*=2.47; df=1, 9; *P*<0.0357) had significantly greater stand counts than the untreated control. At the 197,600 seed/ha seeding rate, the fungicide (*t*=2.32; df=1, 10; *P*<0.0430) had significantly greater stand counts than the untreated control. The fungicide (*t*=5.37; df=1, 10; *P*<0.0003) and fungicide+insecticide (*t*=5.62; df=1, 10; *P*<0.0002) had significantly greater stand counts than the untreated control at the 395,200 seed/ha seeding rate. At the 444,600 seed/ha seeding rate, the fungicide (*t*=3.23; df=1, 10; *P*<0.0090) and fungicide+insecticide (*t*=3.24; df=1, 10; *P*<0.0001) had significantly greater stand counts than the untreated control.

For the 2017, late planted soybean at the Southeast Research Farm, the fungicide+insecticide (*t*=2.30; df=1, 10; *P*<0.0439) had significantly greater stand counts than the untreated control at the 197,600 seed/ha seeding rate. The 345,800 seed/ha seeding rate had significant differences where the fungicide (*t*=2.36; df=1, 10; *P*<0.0398) and fungicide+insecticide (*t*=2.47; df=1, 10; *P*<0.0001) had significantly greater stand counts than the untreated control.

For the 2017 early planted soybean at the Brookings Research Farm, the fungicide+insecticide ($t$=2.42; df=1, 10; $P$<0.0359) had significantly greater stand counts than the untreated control at the 197,600 seed/ha seeding rate. For the 296,400 seeds/ha, the fungicide+insecticide ($t$=2.57; df=1, 10; $P$<0.0279) had significantly greater stand counts than the untreated control. For the 2017 late planted soybean at the Brookings Research Farm, the fungicide ($t$=2.48; df=1, 8; $P$<0.0379) treatment had significantly greater stand counts than the untreated control at the 296,400 seed/ha seeding rate.

For the 2017 early planted soybean at the Volga Research Farm, the fungicide+insecticide ($t$=2.24; df=1, 10; $P$<0.0487) had significantly greater stand counts than the untreated control at the 148,200 seed/ha seeding rate. There were no significant differences in stand counts due to treatments in any of the seeding rates for the early or late planting date.

For the 2017 early planted soybean at the Northeast Research Farm, the fungicide+insecticide ($t$=2.27; df=1, 9; $P$<0.0496) had significantly greater stand counts than the untreated control at the 148,200 seed/ha seeding rate. At 395,200 seed/ha, the fungicide treatment ($t$=2.5; df=1, 9; $P$<0.0340) had significantly greater stand counts than the untreated control. At 444,600 seed/ha, the fungicide ($t$=2.76; df=1, 8; $P$<0.0247) and fungicide+insecticide ($t$=4.86; df=1, 8; $P$<0.0013) had significantly greater stand counts than the untreated control. There were no significant differences in treatments at any seeding rate of the late planting date at the Northeast Research Farm.

**Root disease severity.** For two locations in 2016 and 2017 we confirmed our hypothesis that the fungicide and fungicide+insecticide reduced disease severity compared to the untreated control. We first determined that year significantly affected root disease severity (*F*=687.5; df=1, 1948; *P*<0.0001) and that root disease severity was significantly greater in 2016 than 2017 (*t*=26.22; df=1, 1948; *P*<0.0001). For this reason, data were next analyzed for location by year. In 2016, there were significant differences in root disease severity among locations (*F*=4.90; df=3, 942; *P*<0.0022) (Table 5). The Southeast Research Farm (*t*=2.58; df=1, 942; *P*<0.0101) and the Northeast Research Farm (*t*=3.74; df=1, 942; *P*<0.0002) had significantly higher disease severity than the Volga Research Farm. However, the disease severity at the Brookings Research Farm was not significantly different when compared to the other locations. In 2017, there were no significant differences in disease severity among locations.

Because differences were observed among location in 2016, data were next analyzed by year and location to determine if planting date affected disease severity. For 2016, disease severity at the Northeast Research Farm (*F*=52.18; df=1,245; *P*<0.0001) and Brookings Research Farm (*F*=5.29; df=1,193; *P*<0.0225) were significantly affected by planting date. For the Northeast Research Farm, the late planting date had significantly greater disease severity when compared to the early planting date (*t*=7.22; df=1, 245; *P*<0.0001). The late planted soybean at the Brookings Research Farm also had significantly greater disease severity when compared to the early planting date (*t*=2.30; df=1,193; *P*<0.0225). No significant differences were observed between the planting dates for the Southeast Research Farm and Volga Research Farm locations in 2016. Because data were sorted by location in 2016, the 2017 data was also sorted by location for differences in planting date. In 2017, there was only on instance were early planting date (*t*=3.1; df=1, 243; *P*<0.0020) had significantly less disease severity than the late planting date at the Southeast Research Farm.

Due to the significant differences observed for planting date, data were next analyzed by year, location and planting date to determine the impact that seeding rates had on disease severity. For 2016, the only location where seeding rates significantly affected disease severity was for the late planting date at the Southeast Research Farm ($F$=2.61; df=6, 112; $P$<0.0208). For the late planting date, the 296,400 ($t$=2.28; df=1, 112; $P$<0.0247), 345,800 ($t$=2.0; df=1, 112; $P$<0.0479), 395,200 ($t$=2.6; df=1, 112; $P$<0.0107), and 444,600 ($t$=2.28; df=1, 112; $P$<0.0247) seed/ha seeding rates had significantly higher disease severity when compared to the 148,200 seeds/ha seeding rate. The 296,400 ($t$=2.28; df=1, 112; $P$<0.0247), 345,800 ($t$=2.0; df=1, 112; $P$<0.0479), 395,200 ($t$=2.6; df=1, 112; $P$<0.0107), and 444,600 ($t$=2.28; df=1, 112; $P$<0.0247) seed/ha seeding rates also had significantly higher disease severity when compared to the 247,000 seeds/ha seeding rate. For 2016, no significant differences in disease severity were detected among seeding rates at the other locations and planting dates. In 2017, there were no significant differences in disease severity due to seeding rates at any of the locations.

Next, data were examined by seeding rates within each location and planting date. Data for the 2016 Southeast Research Farm location were next analyzed to determine the impact of treatments on disease severity. For the 197,600 seeds/ha seeding rate, the fungicide ($t$=3.84; df=1,10; $P$<0.0032) and fungicide+insecticide ($t$=5.4; df=1,10; $P$< 0.0003) treatments had significantly lower disease severity when compared to the untreated control. At the 345,800 seeds/ha rate, the fungicide ($t$=2.33; df=1,9; $P$<0.0448) and fungicide+insecticide ($t$=2.71; df=1,9; $P$<0.00238) treatments had significantly lower disease severity than the untreated control. The fungicide ($t$=3.8; df=1,10; $P$<0.0001) and fungicide+insecticide ($t$=3.04; df=1,10; $P$<0.0125) treatments also had significantly lower disease severity than the untreated control at the 395,200 seed/ha seeding rate. For 2016, there were no significant differences in disease ratings among treatments in the late planting date at Southeast Research Farm location.

In 2016, there were no significant differences in disease severity among soybean treatments for the early planting date at the Brookings Research Farm. However, significant differences were observed for the late planting date. At the 197,600 seed/ha seeding rate, the fungicide+insecticide treatment had significantly lower disease severity than the fungicide ($t$=3.87; df=1, 10; $P$<0.0031) treatment and untreated control ($t$=3.87; df=1, 10; $P$<0.0031). For the 247,000 seed/ha seeding rate, the fungicide ($t$=3.53; df=1, 10; $P$<0.0054) and fungicide+insecticide ($t$=4.98; df=1,10; $P$<0.0005) treatments had significantly lower disease severity than the untreated control. At the 345,800 seed/ha seeding rate, the fungicide+insecticide treatment ($t$=2.93; df=1, 8; $P$<0.0189) had significantly lower disease severity than the untreated control. For the 444,600 seed/ha seeding rate, the fungicide ($t$=2.46; df=1, 10; $P$<0.0339) and fungicide+insecticide ($t$=3.29; df=1, 10; $P$<0.0081) treatments had significantly lower disease severity than the untreated control.

During the early planting date at the Northeast Research Farm in 2016, we observed significant differences in treatments at seeding rates of 148,200, 247,000, 345,800, and 395,200 seed/ha. At the 148,200 seed/ha rate, fungicide ($t$=2.84; df=1, 10; $P$<0.0174) and fungicide+insecticide ($t$=2.84; df=1, 10; $P$<0.0174) treatments had significantly lower disease severity than the untreated control. At 247,000 seed/ha, fungicide ($t$=7.51; df=1, 10; $P$<0.0001) and fungicide+insecticide ($t$=6.56; df=1, 10;

$P<0.0001$) treatments had significantly lower disease severity than the untreated control. At 345,800 seed/ha, again, the fungicide ($t=8.61$; df=1, 10; $P<0.0001$) and fungicide+insecticide ($t=8.61$; df=1, 10; $P<0.0001$) treatments had significantly lower disease severity than the untreated control. At 395,200 seed/ha, the fungicide+insecticide treatment ($t=3.61$; df=1, 10; $P<0.0047$) had significantly lower disease severity than the untreated control. However, there were no differences between the fungicide treatment. In 2016, there were significant treatment effects for the late planted soybean at the Northeast Research Farm, for the seeding rates of 247,000 and 444,600 seed/ha. The 247,000 seed/ha seeding rate resulted in the, the fungicide ($t=3.15$; df=1, 10; $P<0.0104$) and fungicide+insecticide ($t=3.15$; df=1, 10; $P<0.0104$) treatments had significantly lower disease severity than the untreated control. At 345,800 seed/ha the fungicide ($t=2.46$; df=1, 10; $P<0.0335$) and fungicide+insecticide ($t$ =2.46; df=1, 10; $P<0.0335$) treatments had significantly lower disease severity than the untreated control. The same trend was observed at the 444,600 seed/ha where the fungicide ($t$ =2.74; df=1, 10; $P<0.0209$) and fungicide+insecticide ($t$ =2.74; df=1, 10; $P<0.0209$) treatments had significantly lower disease severity than the untreated control.

At the early planting date at Volga in 2016, we detected significant differences in treatment effects only for the 197,600 seeding rate ($F=14.96$; df=2, 10; $P<0.0010$); the untreated ($t$ =2.7; df=1, 10; $P<0.0222$) had significantly higher disease severity than the fungicide+insecticide and the fungicide+insecticide treatment ($t=2.77$; df=1, 10; $P<0.0199$) had significantly higher disease severity than the fungicide treatment. In the 2016, Volga late planting date significant differences in treatments were detected at the 197,600, 296,400, and 395,200 seeding rate. At 197,600 seed/ha, the fungicide+insecticide (*t*=3.16; df=1, 10; *P*<0.0101) had significantly lower disease severity than the untreated control, but either treatment was significantly different then the fungicide treatment. At 296,400 seed/ha, the fungicide (*t*=2.93; df=1, 10; *P*<0.0151) and fungicide+insecticide (*t*=2.93; df=1, 10; *P*<0.0151) treatments had lower disease severity than the untreated. At 395,200 seed/ha, the fungicide treatment (*t*=3.16; df=1, 10; *P*<0.0101) had significantly lower disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide.

Although there were no significant differences in disease severity at any location in 2017, data were still analyzed by location, planting date, and seeding rate for significant differences in disease severity due to seed treatment (Table 6). Starting at the Southeast Farm, at 148,200 seed/ha seeding rate in the early planting date the fungicide+insecticide (*t*=2.9; df=1, 9; *P*<0.0180) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. In the early planting date, at the Southeast Farm, at 296,400 seed/ha seeding rate the fungicide+insecticide (*t*=3.68; df=1, 10; *P*<0.0040) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. In the same planting date and location, at 395,200 seed/ha the fungicide (*t*=2.72; df=1, 10; *P*<0.0220) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. Again, in the early planting date at the Southeast Farm, at 444,600 seed/ha the fungicide+insecticide (*t*=2.7; df=1, 10; *P*<0.0220) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. Then in the late planting date at the Southeast Farm, at 345,800 seed/ha, the fungicide (*t*=2.37; df=1, 10; *P*<0.0390) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. In the late planting date of the same location, at 444,600 seed/ha the fungicide+insecticide ($t$=2.98; df=1, 10; $P<0.0140$) and fungicide ($t$=2.98; df=1,10; $P<0.0140$) had significantly less disease severity than the untreated control.

In 2017 at the Brookings Farm in the early planting date, at 148,200 seed/ha seeding rate, the fungicide+insecticide ($t$=2.50; df=1, 10; $P<0.0310$) and fungicide ($t$=2.50; df=1,10; $P<0.0310$) had significantly less disease severity than the untreated control. Within the same location and planting date, at 217,000 seed/ha seeding rate the fungicide ($t$=2.95; df=1, 10; $P<0.0150$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. Again, at 395,200 seed/ha the fungicide ($t$=2.76; df=1, 10; $P<0.0200$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. As for the late planting date at the Brookings Farm, at 148,200 seed/ha the fungicide ($t$=2.96; df=1, 10; $P<0.0140$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. At 296,400 seed/ha, the fungicide+insecticide ($t$=2.87; df=1, 10; $P<0.0170$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. At 395,200 seed/ha, the fungicide+insecticide ($t$=2.40; df=1, 10; $P<0.0370$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. Lastly, at the 444,600 seed/ha seeding rate in the late planting date at Bookings, the fungicide+insecticide ($t$=2.7; df=1, 10; $P<0.022$) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide.

In 2017, at the early planting date at Northeast Farm, at 148,200 seed/ha the fungicide+insecticide ($t$=2.99; df=1, 10; $P$<0.0140) and fungicide ($t$=2.34; df=1,10; $P$<0.0420) had significantly less disease severity than the untreated control. At the Northeast Farm of the early planting date, at 197,600 seed/ha the fungicide+insecticide ($t$=2.92; df=1, 10; $P$<0.0150) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. At 296,400 seed/ha the fungicide+insecticide ($t$=4.25; df=1, 10; $P$<0.0020) and fungicide ($t$=5.92; df=1,10; $P$<0.0001) had significantly less disease severity than the untreated control. Differences were also found at the Northeast Farm, in the late planting date at 197,600 seed/ha the fungicide ($t$=2.67; df=1, 10; $P$<0.024) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. Also, at 217,000 seed/ha the, the fungicide+insecticide ($t$=2.43; df=1, 10; $P$<0.0360) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. At 296,400 seed/ha in the late planting date, the fungicide+insecticide ($t$=3.11; df=1, 10; $P$<0.0110) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. At 444,600 seed/ha the fungicide ($t$=2.57; df=1, 10; $P$<0.0280) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide.

The Volga Farm, in the early planting of the 2017 season had multiple significant differences. At 148,200 seed/ha the fungicide+insecticide ($t$=3.38; df=1, 10; $P$<0.0070) and fungicide ($t$=2.51; df=1,10; $P$<0.0310) had significantly less disease severity than the untreated control. At 197,600 seed/ha fungicide+insecticide ($t$=2.73; df=1, 10; $P$<0.0210) and fungicide ($t$=2.73; df=1,10; $P$<0.0210) had significantly less disease severity than the untreated control. At 217,000 seed/ha, the fungicide+insecticide ($t$=4.06; df=1, 10; $P$<0.0020) and fungicide ($t$=3.55; df=1,10; $P$<0.0050) had significantly less disease severity than the untreated control. At 296,400 seed/ha the fungicide+insecticide ($t$=4.89; df=1, 10; $P$<0.0001) and fungicide ($t$=5.42; df=1,10; $P$<0.0001) had significantly less disease severity than the untreated control. At 345,800 seed/ha, the fungicide ($t$=2.66; df=1, 10; $P$<0.0240) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide+insecticide. At 444,600 seed/ha the fungicide+insecticide ($t$=2.94; df=1, 10; $P$<0.0150) and fungicide ($t$=2.94; df=1,10; $P$<0.0150) had significantly less disease severity than the untreated control. As for the late planting date at the Volga Farm, the 148,200 seed/ha seeding rate, the fungicide+insecticide ($t$=3.77; df=1, 10; $P$<0.0040) and fungicide ($t$=2.39; df=1,10; $P$<0.0380) had significantly less disease severity than the untreated control. At 197,600 seed/ha in the late planting date, the fungicide+insecticide ($t$=3.11; df=1, 10; $P$<0.0110) had significantly less disease severity than the untreated control, and neither treatment was different than the fungicide. At 217,000 seed/ha the fungicide+insecticide had significantly less disease severity than the fungicide ($t$=3.43; df=1, 10; $P$<0.0060) and the untreated ($t$=4.00; df=1,10; $P$<0.003).

**Yield.** For most comparisons, we our hypothesis that the fungicide and fungicide+insecticide would have significantly greater yield than the untreated control. We first determined that year significantly impacted yield ($F$=198.44; df=1, 1990; $P$<0.0001). We determined that yield was significantly greater in 2016 ($t$=14.12; df=1, 1990; $P$<0.0001) than in 2017. Yield data was next examined by location within each year. In 2016, yield among locations was significantly different ($F$=99.05; df=3, 992; $P$<0.0001) (Table 7). The Southeast Research Farm ($t$=6.92; df=1, 992; $P$<0.0001), Brookings Research Farm ($t$=13.93; df=1, 992; $P$<0.0001), and Northeast Research Farm ($t$=15.25; df=1, 992; $P$<0.0001) yielded significantly lower than the Volga Research Farm. The Brookings Research Farm ($t$=6.95; df=1, 992; $P$<0.0001) and Northeast Research Farm ($t$=8.26; df=1, 992; $P$<0.0001) also yielded significantly lower than the Southeast Research Farm.

In 2017, yield was again significantly different among locations ($F$=90.47; df=3, 987; $P$<0.0001) (Table 8). The Southeast Research Farm ($t$=9.36; df=1, 987; $P$<0.0001), Brookings Research Farm ($t$=13.51; df=1, 987; $P$<0.0001) and Volga Research Farm ($t$=14.89; df=1, 987; $P$<0.0001) yielded significantly lower than the Northeast Research Farm. The Brookings Research Farm ($t$=4.17; df=1, 987; $P$<0.0001) and Volga Research Farm ($t$=5.47; df=1, 987; $P$<0.0001) yielded significantly lower than the Southeast Research Farm.

Yield data was next analyzed by planting date within each year and location. For 2016, the early planting date yield was significantly greater than the later planting date at Southeast Research Farm ($F$=94.52; df=1; $P$<0.0001), Brookings Research Farm ($F$=621.24; df=1; $P$<0.0001) and Volga Research Farm ($F$=1433.60; df=1; $P$<0.0001) (Table 8). However, the late planting date yielded significantly better than the early planting date at the Northeast Research Farm location ($F$=547.65; df=1; $P$<0.0001) (Table 8). In 2017, yields for the early planting date were significantly better than the late planting date for the Southeast Research Farm ($F$=51.45; df=1; $P$<0.0001) and Northeast Research Farm ($F$=157.00; df=1; $P$<0.0001) (Table 8). For 2017, the late planting date yielded significantly better than the early planting date at the Brookings Research Farm (*F*=32.45; df=1; *P*<0.0001) and Volga Research Farm (*F*=42.87; df=1; *P*<0.0001) (Table 8).

Yield data was next analyzed by seeding rates within each planting date and year. For 2016, seeding rates significantly affected yield for the early planted soybean at the Northeast Research Farm (*F*=7.54; df=6, 114; *P*<0.0001). For the early planting date, the 148,200 seed/ha seeding rate yielded significantly greater than 444,600 seed/ha (*t*=5.11; df=1, 114; *P*<0.0001), 395,200 seed/ha (*t*=5.96; df=1, 114; *P*<0.0001), 345,800 seed/ha (*t*=4.37; df=1, 114; P<0.0001), 296,400 seed/ha (*t*=3.28; df=1, 114; P<0.0014), 247,000 seed/ha (*t*=3.90; df=1, 114; *P*<0.0002), and 197,600 seed/ha (*t*=2.59; df=1, 114; P<0.0108) seeding rates. The 197,600 seed/ha (*t*=3.37; df=1, 114; *P*<0.0010), 247,000 seed/ha (*t*=2.06; df=1, 114; *P*<0.0416), and 296,400 seed/ha (*t*=2.68; df=1, 114; *P*<0.0084) seeding rates yielded significantly greater than the 345,800 seed/ha seeding rate. There were no significant differences in yield at this location for the late planted soybean.

For the 2016 Volga Research Farm, the early (*F*=2.30; df=6, 114; *P*<0.0001) and late (*F*=3.72; df=6, 114; *P*<0.0001) planted soybean both had significant differences in yield among seeding rates. In the early planting date at Volga, the 148,200 seed/ha seeding rate yielded significantly lower than the 444,600 seed/ha (*t*=2.99; df=1, 114; *P*<0.0034), 395,200 seed/ha (*t*=2.34; df=1, 114; *P*<0.0209), 345,800 seed/ha (*t*=2.29; df=1, 114; *P*<0.0236), 296,400 seed/ha (*t*=2.67; df=1, 114; *P*<0.0086), 247,000 seed/ha (*t*=3.30; df=1, 114; *P*<0.0013) and 197,600 seed/ha (*t*=2.35; df=114; *P*<0.0203) seeding rate. For the late planting date, the 247,000 seeds/ha yielded significantly greater than the

148,200 seed/ha ($t=3.70$; df=1, 114; $P<0.0003$) and 197,600 seed/ha ($t=3.22$; df=1, 114; $P<0.0017$) seeding rates. The 345,800 seed/ha seeding rate yielded significantly greater than the 148,200 seed/ha ($t=3.35$; df=1, 114; $P<0.0011$) and 197,600 seed/ha ($t=2.86$; df=1, 114; $P<0.0050$) seeding rates.

For the 2016, late planted soybean at the Brookings Research Farm, yield for the 444,600 seed/ha rate was significantly greater than the 345,800 seed/ha ($t=2.46$; df=1, 112; $P<0.0155$), 296,400 seed/ha ($t=2.32$; df=1, 112; $P<0.0221$), 247,000 seed/ha ($t=4.78$; df=1, 112; $P<0.0001$), 197,600 seed/ha ($t=4.74$; df=1, 112; $P<0.0001$) and 148,200 seed/ha ($t=8.28$; df=1, 112; $P<0.0001$) seeding rates. For the 395,200 seed/ha rate, yield was significantly greater than the 247,000 seed/ha ($t=3.28$; df=1, 112; $P<0.0014$), 197,600 seed/ha ($t=3.24$; df=1, 112; $P<0.0016$) and 148,200 seed/ha ($t=6.78$; df=1, 112; $P<0.0001$) seeding rates. The 345,800 seed/ha seeding rate yielded significantly greater than the 247,000 seed/ha ($t=2.25$; df=1, 112; $P<0.0263$), 197,600 seed/ha ($t=2.21$; df=1, 112; $P<0.0288$) and 148,200 seed/ha ($t=5.70$; df=1, 112; $P<0.0001$) seeding rates. Yield for the 296,400 seed/ha rate were significantly greater than 247,000 ($t=2.39$; df=1, 112; $P<0.0185$), 197,600 ($t=2.35$; df=1, 112; $P<0.0204$), and 148,200 ($t=5.84$; df=1, 112; $P<0.0001$) seed/ha rates. The 148,200 seed/ha rate had significantly lower yields than the 247,000 seed/ha ($t=3.35$; df=1, 112; $P<0.0007$) and 197,600 seed/ha ($t=3.54$; df=1, 112; $P<0.0006$) seed/ha rate.

Again in 2017, yield data was analyzed by seeding rates within each planting date and year. In Beresford, the early planting had significant differences in yield (F=8.79; df=6, 112; $P<0.0001$). The 148,200 seed/ha seeding rate yielded significantly lower than 444,600 seed/ha ($t=5.98$; df=1, 112; $P<0.0001$), 395,200 seed/ha ($t=6.23$; df=1, 112;

*P*<0.0001), 345,800 seed/ha (*t*=5.23; df=1, 112; *P*<0.0001), 296,400 seed/ha (*t*=5.31; df=1, 112; *P*<0.0001), 247,000 seed/ha (*t*=4.83; df=1, 112; *P*<0.0001), and 197,600 seed/ha (*t*=4.23; df=1, 112; *P*<0.0001) seed/ha seeding rate. There were no significant difference in yield due to seeding rates in the Beresford late planting date in 2017.

Brookings early planting date in 2017 did have significant differences in yield due to seeding rates (*F*=2.48; df=6, 109; *P*<0.0272). The 444,600 seed/ha (*t*=3.03; df=1, 109; *P*<0.0031), 395,200 seed/ha (*t*=3.15; df=1, 109; *P*<0.0021), and 345,800 seed/ha (*t*=2.70; df=1, 109; *P*<0.0081) seeding rates yielded significantly greater than the 148,200 seed/ha seeding rate. In the same year, Brookings late planting did not see any significant differences in yield due to seeding rates.

Again in 2017, stats were run separately for each planting date in South Shore; both the early (*F*=20.69; df=6, 114; *P*<0.0001) and late (F=54.75; df=6, 114; P<0.0001) planting dates had significant yield differences due to seeding rate. In the early planting date, the 444,600 seed/ha seeding rate yielded significantly greater than the 296,400 (*t*=2.11; df=1, 114; *P*<0.0368), 247,000 seed/ha (*t*=3.95; df=1, 114; *P*<0.0001), 197,600 seed/ha (*t*=6.28; df=1, 114; *P*<0.0001), and 148,200 seed/ha (*t*=8.57; df=1, 114; *P*<0.0001) seeding rates. Also, the 395,200 seed/ha seeding rate yielded significantly greater than the 247,000 seed/ha (*t*=3.72; df=1, 114; *P*<0.0003), 197,600 seed/ha (*t*=6.05; df=1, 114; *P*<0.0001), and 148,200 seed/ha (*t*=8.34; df=1, 114; *P*<0.0001). The 345,800 seed/ha seeding rate yielded significantly greater than the 247,000 seed/ha (*t*=2.48; df=1, 114; *P*<0.0148), 197,600 seed/ha (*t*=4.81; df=1, 114; *P*<0.0001), and 148,200 seed/ha (*t*=7.10; df=1, 114; *P*<0.0001) seeding rate. The 296,400 seed/ha and 247,000 seed/ha seeding rate yielded significantly higher than 197,600 seed/ha (*t*=4.16; df=1, 114;

$P<0.0001$) ($t=2.33$; df=1, 114; $P<0.0216$) and 148,200 seed/ha ($t=6.45$; df=1, 114; $P<0.0001$) ($t=4.62$; df=1, 114; $P<0.0001$), respectively. Lastly, the 197,600 seed/ha seeding rate yielded better than the 148,200 seed/ha ($t=2.29$; df=1, 114; $P<0.0239$) seed/ha seeding rate. As for the late planting date, the 444,600 seed/ha seeding rate yielded significantly greater than the 345,800 seed/ha ($t=2.14$; df=1, 114; $P<0.0349$), 296,400 seed/ha ($t=2.87$; df=1, 114; $P<0.0049$), 247,000 seed/ha ($t=4.12$; df=1, 114; $P<0.0001$), 197,600 seed/ha ($t=7.28$; df=1, 114; $P<0.0001$), and 148,200 seed/ha ($t=14.96$; df=1, 114; $P<0.0001$) seeding rates. The 395,200 seed/ha seeding rate yielded significantly greater than the 296,400 seed/ha ($t=2.68$; df=1, 114; $P<0.0084$), 247,000 seed/ha ($t=3.93$; df=1, 114; $P<0.0001$), 197,600 seed/ha ($t=7.09$; df=1, 114; $P<0.0001$), and 148,200 seed/ha ($t=14.77$; df=1, 114; $P<0.0001$) seeding rates. The 345,800 seed/ha seeding rate yielded significantly greater than the 247,000 seed/ha ($t=1.98$; df=1, 114; $P<0.0496$), 197,600 seed/ha ($t=5.14$; df=1, 114; $P<0.0001$) and 148,200 seed/ha ($t=12.82$; df=1, 114; $P<0.0001$) seeding rates. The 296,400 seed/ha seeding rate yielded significantly greater than the 197,600 seed/ha ($t=4.41$; df=1, 114; $P<0.0001$) and 148,200 seed/ha ($t=12.08$; df=1, 114; $P<0.0001$). The 247,000 seed/ha seeding rate also yielded significantly greater than the 197,600 seed/ha ($t=3.161$; df=1, 114; $P<0.0020$) and 148,200 seed/ha ($t=10.84$; df=1, 114; $P<0.0001$). Lastly the 197,600 seed/ha ($t=7.68$; df=1, 114; $P<0.0001$) seed/ha seeding rate yielded significantly greater than the 148,200 seed/ha seeding rate.

There was a similar trend in 2017, at the Volga Research Farm, where the early ($F=2.41$; df=6, 114; $P< 0.0312$) and late ($F=6.78$; df=6, 114; $P<0.0001$) planting dates had significant differences in yield due to seeding rates. In the early planting date at

Volga, the 148,200 seed/ha seeding rate yielded significantly lower than the 197,600 seed/ha (*t*=2.35; df=1, 114; *P*<0.0205), 345,800 seed/ha (*t*=2.61; df=1, 114; *P*<0.0103), 395,200 seed/ha (*t*=3.44; df=1, 114; *P*<0.0008), and 444,600 seed/ha (*t*=2.53 df=1, 114; *P*<0.0128) seeding rates. In the late planting of Volga, the 444,600 seed/ha seeding rate yielded significantly higher than 345,800 seed/ha (*t*=2.67; df=1, 114; *P*<0.0086), 296,400 seed/ha (*t*=2.42; df=1, 114; *P*<0.0172), 247,000 seed/ha (*t*=2.77; df=1, 114; *P*<0.0065), 197,600 seed/ha (*t*=4.26; df=1, 114; *P*<0.0001), and 148,200 seed/ha (*t*=5.24; df=1, 114; *P*<0.0001) seeding rate. The 395,200 seed/ha seeding rate yielded significantly greater than the 345,800 seed/ha (*t*=2.02; df=1, 114; *P*<0.0460), 247,000 seed/ha (*t*=2.12; df=1, 114; *P*<0.0364), 197,600 seed/ha (*t*=3.60; df=1, 114; *P*<0.0005), and 148,200 seed/ha (*t*=4.58; df=1, 114; *P*<0.0001). The 148,200 seed/ha seeding rate was significantly lower than then 345,800 seed/ha (*t*=2.57; df=1, 114; *P*<0.0115), 296,400 seed/ha (*t*=2.82; df=1, 114; *P*<0.0056), and 247,000 seed/ha (*t*=2.47; df=1, 114; *P*<0.0151).

Next yield data was sorted by year, location, and planting date to determine if there were significant differences in yield due to seed treatments. This determined that in 2016 there were two locations in the late planting date where seed treatments significantly affected yield. These included the Southeast Research Farm (*F*=3.92; df=2, 118; *P*<0.0225) and Northeast Research Farm (*F*=3.11; df=2, 118; *P*<0.0482). In 2017, treatment significantly affected yield for the early planting date at the Southeast Research Farm (*F*=5.09; df=2, 116; *P*=0.0076) and Volga Research Farm (*F*=3.68; df=2, 118; *P*=0.0282).

Differences in yield due to seed treatments were not consistently detected. Data was next analyzed by year, location, planting date, and seeding rate to determine differences in yield due to seed treatments at individual seeding rates. At the Southeast Research Farm, in 2016, yield differences due to treatment were detected. In the early planting date, at 247,000 seed/ha, the fungicide+insecticide ($t=3.22$; df=1,10; $P<0.0090$) yielded significantly greater than the untreated control. In the 395,000 seed/ha seeding rate of the late planning date at the Southeast Research Farm, the fungicide+insecticide ($t=2.45$; df=1,10; $P<0.0350$) yielded significantly greater than the untreated control.

At the Brookings Research Farm, in 2016, yield differences due to treatment were detected at multiple seeding rates. In the early planting date, at 296,400 seed/ha seeding rate the fungicide ($t=2.63$; df=1,10; $P<0.0253$) and untreated control ($t=2.91$; df=1,10; $P<0.0155$) yielded better than the fungicide+insecticide treatment. At 395,200 seed/ha seeding rate the fungicide+insecticide treatment ($t=2.53$; df=1,10; $P<0.0299$) yielded significantly greater than the fungicide treatment. At the 197,600 seed/ha seeding rate of the late planting date at Brookings Research Farm, the fungicide ($t=2.47$; df=1,10; $P<0.0331$) treatment yielded higher than the fungicide+insecticide treatment.

In 2016, at the Volga Research Farm there were yield differences due to seed treatment detected. It first occurred in the late planting date at 345,800 seed/ha seeding rate, the untreated control ($t=2.24$; df=1,10; $P<0.0489$) yielded significantly greater than the fungicide+insecticide treatment. Again, at the 444,600 seed/ha seeding rate the untreated control yielded significantly higher than the fungicide ($t=2.55$; df=1,10; $P<0.0288$) and fungicide+insecticide ($t=2.71$; df=1,10; $P<0.0221$) treatments.

Lastly, at the Northeast Research Farm there were yield differences due to seed treatment at multiple seeding rates. In the early planting date, at 247,000 seed/ha seeding rate the fungicide ($t=2.36$; df=1,10; $P<0.0398$) yielded significantly greater than the fungicide+insecticide. In the late planting date at 197,600 seed/ha seeding rate the fungicide ($t$=2.68; df=1,10; $P$<0.0230) treatment yielded significantly higher than the untreated control.

## Discussion

The results of this study indicate that location, planting date and seeding rate all affect soybean stand counts, disease severity and yield in South Dakota. However, treatment only affected the stand counts, disease severity and yield for a limited amount of locations and planting dates within this study. For this study, fungicide and fungicide+insecticide seed treatments did not reliably improve yields at all locations for the two planting dates and seven seeding rates. However, this may further indicate the importance of these additional factors when determining when seed treatments should be used as a management strategy. As previously mentioned, there are many abiotic and biotic factors that may affect soybean stand counts, disease severity and yield each year.

The 2016 results indicate the importance of location and early season climate on soybean production. At the Southeast, Volga, and Brookings Research Farms the early planted soybean had significantly better stand counts than the later planting date. However, the opposite was true for the Northeast Research Farm. This can be attributed to early season moisture, and a lack of precipitation at the Northeast Research Farm. When comparing this to 2017, we observed that late planted soybean stand counts were significantly greater only at the Southeast Research Farm. Early planted soybean at the Volga Research Farm had significantly better stand counts than the late. No significant differences were observed for the other planting dates at the other locations. Differences in the 2017 response may be attributed to cool and wet conditions that were present.

The effect that the factors tested on yield were also examined. The results from this study indicate that more timely precipitation events in 2016 created higher yielding environments across the state. In 2016, three of the four location received rainfall totals for the growing season greater than the 30-year rainfall average (South Dakota Mesonet); South Shore was the only location that year to receive below average rainfall. In 2016, the yield at the Northeast Research Farm was significantly lower for the early planted soybean when compared to the late planted soybean. However, the early planted soybean at the Southeast, Volga and Brookings Research Farms all yielded significantly better than the late planted soybean. This is likely due to the differences in precipitation that were observed. In 2017, the early planted soybean at the Southeast and Northeast Research Farms yielded significantly better than the later planted soybean. However, the opposite was observed for the Brookings and Volga Research Farms. In 2017, early season rainfall was accompanied by low air temperatures which resulted in unfavorable conditions for germination, this may have led to the fungicide and fungicide+insecticide treatments usually yielding greater than the untreated control. We acknowledge that early season management practices cannot easily take into account climatic factors, however, they likely have an impact on the efficacy of seed treatments.

Another factor that did not greatly impact yield was the variation in stand counts. During drier years, the lower seeding rates yielded better than high seeding rates. For both years, seeding rates were not a major factor in determining statistical differences in yield. However, trends for 2016 indicated that lower seeding rates often yielded better. In 2017, the trend was that higher seeding rates tended to yield better. With that being said producers may be capable of lowering their initial seeding rate without reducing yield;

this practice can save the producer seed expenses up front. These findings are consistent with research conducted in other states (Bertram and Pedersen, 2004; Epler and Staggenborg, 2008; and Cox et al. 2010).

We observed that statistical yield differences were not consistently affected by seed treatments. During 2016, yield differences due to seed treatments were observed at the Northeast Research Farm and for 2017, yield differences due to seed treatments were observed at the Volga Research Farm. However, the Southeast Research Farm had more observed numerical responses to seed treatments. In general, the fungicide+insecticide treatment yielded at least 100.5 kg/ha better than the untreated control 47 percent of the time. On average, the 100.5 kg/ha yield advantage due to the fungicide+insecticide treatment is enough to pay for the treatment. This may be in part due to increased observations of aboveground early season insect pests at this location. Large populations of bean leaf beetles (Coleoptera: Chrysomelidae) and various species of grasshopper nymphs (Orthopthera: Acrididae) were observed during the early vegetative stages during both 2016 and 2017 at the Southeast Research Farm (Fehr and Caviness 1977).

Although statistically speaking this data did not provide a clear indication of a consistent 2.8% yield benefit or a clear benefit to statewide usage of seed treatments, we did observe numerical indication that for a majority of the locations a 2.8% yield benefit was observed. However, this data demonstrates the need for further examination and re-evaluation of the currently prescribed seed treatment recommendations to ensure that soybean production results in a positive economic return for the producer.

The analysis of yield data showed no consistent trends between seeding rate and seed treatment. Before using a seed treatment, it may be beneficial to determine if early season diseases and pest are located in your field. By doing this, every field should be treated on a case by case basis, eliminating the wide spread use of unneeded seed treatment use. However, this may be difficult to accomplish based on early season producer schedules. Results indicate that yield may depend more on site specific environmental conditions, such as rainfall events during flowering or pod fill stage, than seeding rate changes. Because of all the different small factors that play into yield at a specific location, recommendations should be made at a regional level within state instead of trying to create a multi-state regional recommendations.

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Table 1. Previous crop and planting date by location

| Year | Location | Previous Crop | Early Planting Date | Late Planting Date |
|---|---|---|---|---|
| 2016 | Beresford | Corn | May 19 | June 22 |
| | Brookings | Soybean | May 3 | June 2 |
| | South Shore | Spring wheat | May 3 | June 1 |
| | Volga | Spring wheat | May 2 | June 1 |
| 2017 | Beresford | Corn | May 16 | June 19 |
| | Brookings | Milo | May 5 | May 31 |
| | South Shore | Spring wheat | May 3 | June 2 |
| | Volga | Corn | May 5 | May 31 |

Table 2. Soybean disease isolation

| Year | Location | Fusarium | Macrophomina | Diaporthe | Rhizoctonia |
|---|---|---|---|---|---|
| 2016 | Beresford | 41 | 3 | 0 | 0 |
| | Brookings | 9 | 5 | 3 | 4 |
| | South Shore | 11 | 0 | 6 | 0 |
| | Volga | 5 | 2 | 1 | 1 |
| 2017 | Beresford | 16 | 8 | 0 | 1 |
| | Brookings | 10 | 1 | 1 | 1 |
| | South Shore | 6 | 0 | 1 | 10 |
| | Volga | 11 | 15 | 10 | 0 |

Table 3-8.

[1]Letters represent significant differences among locations (column 1).
[2]Letters represent significant differences among planting dates (column 2 vs column 6).
[3]Letters represent significant differences among seeding rates within each planting date (column 1 & column 6).
[4]Letters represent significant differences among seed treatments within each specific seeding rate (rows).

Table 3. 2016 Stand count data

| **Year/ Location[1]** | **Planting date[2]/ Seeding Rate (Thousands of seeds/Ha)[3]** | **Stand Counts by treatment (Thousands of seeds/Ha)[4]** | | | **Planting date[2]/ Seeding Rate (Thousands of seeds/Ha)[3]** | **Stand Counts by treatment (Thousands of seeds/Ha)[4]** | | |
|---|---|---|---|---|---|---|---|---|
| | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** |
| **2016** | May*b* | | | | June*a* | | | |
| **Northeast*a*** | **148.2** | *135.2*±4.0*b* | 152.1±4.0*a* | 160.0±5.1*a* | **148.2** | 170.7±6.7 | 168.6±8.9 | 178.2±10.3 |
| | **197.6** | 182.5±5.4*b* | 200.5±6.8*a* | 199.8±2.7*a* | **197.6** | 212.3±5.4 | 232.4±10.2 | 210.5±6.4 |
| | **217.0** | 203.7±4.4*b* | 234.6±6.6*a* | 252.8±9.2*a* | **217.0** | 249.3±9.0 | 254.3±13.5 | 245.7±11.6 |
| | **296.4** | 242.8±12.2*b* | 169.3±10.5*ab* | 184.8±5.3*a* | **296.4** | 286.9±6.1 | 291.6±8.2 | 299.8±7.7 |
| | **345.8** | 268.3±9.4*b* | 299.1±12.9*ab* | 304.8±8.1*a* | **345.8** | 325.3±12.8 | 315.2±15.4 | 312.7±13.6 |
| | **395.2** | 289.4±4.6*b* | 322.8±7.0*a* | 351.8±18.3*a* | **395.2** | 327.8±13.9 | 322.1±16.6 | 327.4±12.8 |
| | **444.6** | 310.2±12.2*b* | 374.1±15.7*a* | 365.5±11.8*a* | **444.6** | 362.9±8.6 | 358.6±17.1 | 366.8±12.8 |
| | May*a* | | | | June*b* | | | |
| **Volga*a*** | **148.2** | 177.5±7.7 | 161.4±8.5 | 165.0±5.1 | **148.2** | 138.1±9.7 | 143.1±9.1 | 161.7±9.4 |
| | **197.6** | 202.6±3.9 | 218.1±7.2 | 208.4±5.6 | **197.6** | 157.7±12.0 | 189.4±10.1 | 207.7±13.9 |
| | **217.0** | 251.1±8.1 | 257.9±10.1 | 261.1±11.7 | **217.0** | 215.5±9.6 | 232.8±12.8 | 220.2±11.5 |
| | **296.4** | 294.8±4.6 | 291.2±15.9 | 316.3±4.9 | **296.4** | 276.2±11.8 | 282.8±12.8 | 279.4±18.6 |
| | **345.8** | 341.1±11.7*ab* | 317.8±16.6*b* | 357.6±13.2*a* | **345.8** | 288.7±9.3 | 307.0±18.9 | 303.1±11.6 |
| | **395.2** | 366.2±22.6*b* | 359.7±12.7*b* | 411.4±9.6*a* | **395.2** | 312.0±6.9*c* | 359.7±16.0*b* | 405.3±12.9*a* |
| | **444.6** | 420.3±8.1 | 431.8±14.4 | 403.8±12.5 | **444.6** | *350.8*±15.0*b* | 461.9±13.6*a* | 394.5±30.6*ab* |
| | May | | | | June | | | |
| **Brookings*a*** | **148.2** | 159.7±18.5 | 189.4±34.6 | 196.2±35.9 | **148.2** | 162.1±8.8*b* | 187.6±8.7*ab* | 194.4±10.7*a* |
| | **197.6** | 185.1±12.9 | 221.1±7.8 | 227.0±32.5 | **197.6** | 199.7±3.2*b* | 265.8±12.5*a* | 204.4±16.6*b* |
| | **217.0** | 229.9±10.7 | 288.7±29.3 | 245.7±17.8 | **217.0** | 223.8±11.1*b* | 284.0±11.8*a* | 243.2±12.8*b* |
| | **296.4** | 284.6±18.1 | 229.9±29.2 | 304.7±9.2 | **296.4** | 243.9±7.2 | 288.3±17.6 | 174.6±20.2 |
| | **345.8** | 283.7±29.7 | 344.3±14.3 | 290.5±28.6 | **345.8** | 284.8±11.7*b* | 333.1±12.8*a* | 245.3±12.6*c* |
| | **395.2** | 342.1±24.9 | 375.3±9.8 | 316.0±38.2 | **395.2** | 287.3±11.7*ab* | 362.8±8.8*a* | 288.0±29.9*b* |
| | **444.6** | 328.9±40.1 | 405.1±9.8 | 417.8±19.2 | **444.6** | 323.1±12.3*b* | 370.1±16.2*a* | 323.5±11.6*b* |
| | May | | | | June | | | |
| **Southeast*b*** | **148.2** | 133.1±12.2 | 122.3±3.0 | 134.1±6.5 | **148.2** | 161.7±18.1 | 174.3±10.6 | 163.2±14.0 |
| | **197.6** | 160.0±7.7*ab* | 149.2±11.3*b* | 180.8±10.2*a* | **197.6** | 176.1±11.0 | 184.3±11.3 | 175.7±11.0 |
| | **217.0** | 200.8±12.8 | 189.7±5.6 | 181.1±7.0 | **217.0** | 199.4±11.3 | 201.6±6.1 | 193.0±12.3 |
| | **296.4** | 237.1±11.8*a* | 199.4±9.2*b* | 219.1±11*ab* | **296.4** | 204.4±6.4 | 215.9±3.5 | 209.4±10.9 |
| | **345.8** | 236.3±8.0 | 245.0±12.4 | 232.0±10.0 | **345.8** | 198.3±11.8 | 211.6±15.0 | 207.7±9.3 |
| | **395.2** | 260.0±14.0 | 258.2±11.5 | 287.3±15.0 | **395.2** | 214.1±9.0 | 229.2±5.5 | 217.0±9.3 |
| | **444.6** | 288.7±25.9 | 275.4±27.2 | 317.4±22.8 | **444.6** | 218.8±3.2 | 224.5±9.3 | 229.9±14.5 |

Table 4. 2017 Stand count data

| Year/ Location[1] | Planting date[2]/ Seeding Rate (thousands of seeds/Ha)[3] | Stand Counts by treatment (Thousands of seeds/Ha)[4] | | | Planting date[2]/ Seeding Rate (thousands of | Stand Counts by treatment (Thousands of seeds/Ha)[4] | | |
|---|---|---|---|---|---|---|---|---|
| | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** |
| **2017** | May | | | | June | | | |
| **Northeast*b*** | **148.2** | 108.5±10.5*b* | 132.3±23.2*ab* | 151.0±28.6*a* | **148.2** | 130.9±27.7 | 110.5±8.8 | 136.6±22.9 |
| | **197.6** | 160.1±13.2 | 175.4±20.2 | 165.3±4.5 | **197.6** | 141.3±9.1 | 154.6±9.2 | 140.2±9.5 |
| | **217.0** | 185.4±19.6 | 177.3±10.5 | 191.5±7.6 | **217.0** | 156.0±8.4 | 171.8±11.6 | 179.3±9.3 |
| | **296.4** | 200.5±24.2 | 224.9±15.4 | 214.5±7.3 | **296.4** | 200.5±14.4 | 191.9±13.8 | 193.3±5.6 |
| | **345.8** | 222.1±8.8 | 241.0±10.1 | 145.0±6.4 | **345.8** | 213.5±8.6 | 230.6±10.3 | 235.6±12.6 |
| | **395.2** | 238.1±5.6*b* | 173.3±8.5*a* | 263.6±13.7*ab* | **395.2** | 246.6±6.9 | 243.2±5.5 | 239.6±8.8 |
| | **444.6** | 147.9±4.4*b* | 184.9±12.4*a* | 315.5±11.9*a* | **444.6** | 269.0±5.5 | 266.1±7.8 | 260.7±10.1 |
| | May*a* | | | | June*b* | | | |
| **Volga*ab*** | **148.2** | 120.9±10.7*b* | 139.5±6.2*ab* | 148.8±9.3*a* | **148.2** | 125.5±5.7 | 111.9±9.3 | 121.9±14.9 |
| | **197.6** | 162.3±8.7 | 171.4±9.2 | 167.8±8.3 | **197.6** | 143.5±13.0 | 159.6±7.5 | 172.1±16.2 |
| | **217.0** | 190.4±12.5 | 185.4±13.4 | 205.9±7.8 | **217.0** | 187.0±10.8 | 184.7±9.7 | 179.0±4.8 |
| | **296.4** | 210.9±10.3 | 225.6±16.7 | 233.1±13.8 | **296.4** | 202.3±4.3 | 206.6±5.7 | 212.3±11.4 |
| | **345.8** | 245.0±11.5 | 147.5±10.9 | 271.1±13.8 | **345.8** | 215.9±10.8 | 204.8±18.3 | 235.6±8.2 |
| | **395.2** | 287.6±15.8 | 291.2±14.3 | 306.3±10.4 | **395.2** | 248.5±10.0 | 236.0±14.3 | 266.8±9.6 |
| | **444.6** | 307.7±11.1 | 310.2±15.8 | 310.6±25.4 | **444.6** | 266.1±7.4 | 242.8±25.4 | 290.1±12.0 |
| | May | | | | June | | | |
| **Brookings*a*** | **148.2** | 128.8±9.9 | 130.9±7.3 | 126.2±8.3 | **148.2** | 153.5±8.9 | 187.6±23.3 | 151.2±14.7 |
| | **197.6** | 152.1±7.6*b* | 159.2±5.5*ab* | 175.0±8.4*a* | **197.6** | 199.0±20.8 | 204.1±13.8 | 198.8±8.2 |
| | **217.0** | 175.7±7.8 | 187.6±6.8 | 187.2±7.0 | **217.0** | 195.1±21.1 | 215.2±23.6 | 245.9±16.7 |
| | **296.4** | 204.8±14.2*b* | 209.4±8.0*ab* | 258.9±27.7*a* | **296.4** | 200.1±21.9*b* | 267.3±10.6*a* | 228.1±19.1*ab* |
| | **345.8** | 227.4±11.0 | 257.5±12.3 | 245.7±5.8 | **345.8** | 205.7±23.9 | 263.8±17.1 | 241.4±14.9 |
| | **395.2** | 257.5±5.0 | 288.0±16.9 | 278.7±5.0 | **395.2** | 315.8±7.8 | 233.1±16.7 | 256.5±36.4 |
| | **444.6** | 291.2±12.7 | 290.9±16.2 | 298.8±17.7 | **444.6** | 256.1±16.2 | 280.8±21.3 | 256.5±14.9 |
| | May*b* | | | | June*a* | | | |
| **Southeast*b*** | **148.2** | 94.7±5.2*b* | 118.7±6.9*a* | 112.8±3.4*a* | **148.2** | 134.5±3.8 | 138.8±7.7 | 146.3±5.6 |
| | **197.6** | 114.4±5.6*b* | 144.5±15.4*a* | 135.9±8.0*ab* | **197.6** | 150.3±6.1*b* | 167.8±8.1*ab* | 175.0±8.8*a* |
| | **217.0** | 158.8±25.6 | 140.3±9.0 | 141.3±8.9 | **217.0** | 198.0±5.5 | 205.9±14.1 | 213.4±4.0 |
| | **296.4** | 146.7±11.7 | 158.5±4.8 | 166.1±8.8 | **296.4** | 254.3±6.5 | 264.7±9.5 | 261.8±8.7 |
| | **345.8** | 179.0±5.6 | 187.2±12.3 | 185.4±7.2 | **345.8** | 269.0±8.6*b* | 285.8±7.3*a* | 286.6±6.8*a* |
| | **395.2** | 172.1±5.6*b* | 215.9±10.3*a* | 217.7±8.3*a* | **395.2** | 326.4±24.2 | 312.4±12.6 | 338.2±12.7 |
| | **444.6** | 291.2±10.2*b* | 215.8±7.9*a* | 252.9±11.0*a* | **444.6** | 350.8±12.5 | 355.4±9.2 | 384.5±18.3 |

Table 5. 2016 Disease ratings

| **Year/ Location[1]** | **Planting date[2]/ Seeding Rate (thousands of seeds/Ha)[3]** | **Disease severity rating[4]** | | | **Planting date[2]/ Seeding Rate (thousands of seeds/Ha)[3]** | **Disease severity rating[4]** | | |
|---|---|---|---|---|---|---|---|---|
| | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** |
| **2016** | May*a* | | | | June*b* | | | |
| **Northeast*a*** | **148.2** | 20.5*b* | 11.5*a* | 11.5*a* | **148.2** | 18.0 | 12.8 | 14.2 |
| | **197.6** | 14.2 | 12.8 | 8.8 | **197.6** | 20.5 | 14.2 | 15.5 |
| | **217.0** | 20.5*b* | 7.5*a* | 8.8*a* | **217.0** | 25.5*b* | 14.2*a* | 14.2*a* |
| | **296.4** | 14.2 | 10.2 | 10.2 | **296.4** | 18.0 | 14.2 | 15.5 |
| | **345.8** | 23.0*b* | 7.5*a* | 7.5*a* | **345.8** | 23.0*b* | 14.2*a* | 14.2*a* |
| | **395.2** | 16.7*b* | 11.5*ab* | 7.5*a* | **395.2** | 16.7 | 15.5 | 14.2 |
| | **444.6** | 14.2 | 10.2 | 10.2 | **444.6** | 23.0*b* | 15.5*a* | 15.5*a* |
| | May | | | | June | | | |
| **Volga*b*** | **148.2** | 15.3 | 14.2 | 14.0 | **148.2** | 16.7 | 12.8 | 12.8 |
| | **197.6** | 18.0*c* | 8.8*a* | 12.8*b* | **197.6** | 15.5*b* | 12.8*ab* | 10.2*a* |
| | **217.0** | 12.8 | 15.3 | 14.2 | **217.0** | 15.5 | 12.8 | 11.5 |
| | **296.4** | 8.8 | 16.9 | 10.2 | **296.4** | 15.5*b* | 10.2*a* | 10.2*a* |
| | **345.8** | 10.2 | 12.8 | 12.8 | **345.8** | 15.5 | 12.8 | 10.2 |
| | **395.2** | 8.8 | 10.2 | 10.2 | **395.2** | 14.2*b* | 8.8*a* | 11.5*ab* |
| | **444.6** | 10.2 | 14.0 | 8.8 | **444.6** | 15.5 | 10.2 | 11.5 |
| | May*a* | | | | June*b* | | | |
| **Brookings*ab*** | **148.2** | 12.8 | 9.5 | 13.9 | **148.2** | 14.2 | 14.2 | 14.2 |
| | **197.6** | 12.8 | 15.3 | 7.5 | **197.6** | 15.5*b* | 15.5*b* | 10.2*a* |
| | **217.0** | 11.5 | 11.5 | 13.9 | **217.0** | 20.5*b* | 11.5*a* | 8.8*a* |
| | **296.4** | 13.5 | 7.5 | 9.5 | **296.4** | 19.2 | 10.2 | 16.9 |
| | **345.8** | 12.8 | 10.2 | 11.5 | **345.8** | 21.5*b* | 12.8*ab* | 12.8*a* |
| | **395.2** | 15.5 | 17.3 | 12.8 | **395.2** | 18.0 | 14.2 | 12.8 |
| | **444.6** | 12.3 | 15.5 | 10.2 | **444.6** | 16.7*b* | 11.5*a* | 10.2*a* |
| | May | | | | June | | | |
| **Southeast*a*** | **148.2** | 15.5 | 14.2 | 12.3 | **148.2*a*** | 12.8 | 12.8 | 10.2 |
| | **197.6** | 18.0*b* | 10.2*a* | 7.5*a* | **197.6*ab*** | 16.7 | 11.5 | 11.5 |
| | **217.0** | *18.0* | 11.5 | 12.8 | **217.0*a*** | 12.8 | 11.5 | 11.5 |
| | **296.4** | 16.7 | 11.5 | 12.8 | **296.4*b*** | 20.5*b* | 11.5*a* | 16.7*ab* |
| | **345.8** | 15.5*b* | 10.7*a* | 10.2*a* | **345.8*b*** | 15.5 | 15.5 | 12.3 |
| | **395.2** | 15.5*b* | 8.8*a* | 10.2*a* | **395.2*b*** | 18.0 | 13.9 | 15.5 |
| | **444.6** | 15.5 | 12.8 | 12.8 | **444.6*b*** | 17.8 | 18.0 | 12.8 |

Table 6. 2017 Disease ratings

| Year/ Location[1] | Planting date[2]/ Seeding Rate (thousands of seeds/Ha)[3] | Disease severity rating[4] | | | Planting date[2]/ Seeding Rate (thousands of | Disease severity rating[4] | | |
|---|---|---|---|---|---|---|---|---|
| | | Untreated | Fungicide | Fungicide + Insecticide | | Untreated | Fungicide | Fungicide + Insecticide |
| **2017** | May | | | | June | | | |
| **Northeast** | **148.2** | 19.0*b* | 9.7*ab* | 5.8*a* | **148.2** | 12.7 | 6.7 | 8.5 |
| | **197.6** | 15.2*b* | 6.7*ab* | 5.0*a* | **197.6** | 12.7*a* | 5.0*a* | 5.8*ab* |
| | **217.0** | 9.7 | 6.7 | 8.8 | **217.0** | 11.8*b* | 5.8*ab* | 5.0*a* |
| | **296.4** | 22.8*b* | 5.8*a* | 7.5*a* | **296.4** | 15.2*b* | 8.8*ab* | 5.0*a* |
| | **345.8** | 9.7 | 5.0 | 8.8 | **345.8** | 8.8 | 7.2 | 7.5 |
| | **395.2** | 11.3 | 5.8 | 5.8 | **395.2** | 8.5 | 4.2 | 5.8 |
| | **444.6** | 14.3 | 6.7 | 8.8 | **444.6** | 10.2*b* | 5.8*a* | 6.7*b* |
| | May | | | | June | | | |
| **Volga** | **148.2** | 18.2*b* | 5.0*a* | 3.3*a* | **148.2** | 15.3*b* | 7.2a | 4.2*a* |
| | **197.6** | 15.2*b* | 5.0*a* | 5.0*a* | **197.6** | 10.2*b* | 6.7*ab* | 5.8*a* |
| | **217.0** | 19.0*b* | 5.0*a* | 4.2*a* | **217.0** | 8.8*b* | 7.5*b* | 4.2*a* |
| | **296.4** | 22.8*b* | 3.3*a* | 4.2*a* | **296.4** | 10.2 | 5.8 | 6.3 |
| | **345.8** | 7.5*b* | 4.2*a* | 5.0*ab* | **345.8** | 5.8 | 5.8 | 5.8 |
| | **395.2** | 5.0 | 5.5 | 5.0 | **395.2** | 12.1 | 5.8 | 5.8 |
| | **444.6** | 11.3*b* | 4.2*a* | 4.2*a* | **444.6** | 12.7 | 7.2 | 6.3 |
| | May | | | | June | | | |
| **Brookings** | **148.2** | 18.2*b* | 5.0*a* | 5.0*a* | **148.2** | 8.8*b* | 4.2*a* | 8.5*ab* |
| | **197.6** | 8.8 | 3.3 | 5.0 | **197.6** | 12.0 | 9.3 | 8.5 |
| | **217.0** | 18.2*b* | 4.2*a* | 6.7*ab* | **217.0** | 11.3 | 10.7 | 8.0 |
| | **296.4** | 13.5 | 9.7 | 5.8 | **296.4** | 7.5*b* | 5.5*ab* | 4.7*a* |
| | **345.8** | 14.3 | 5.8 | 5.8 | **345.8** | 14.0 | 11.5 | 7.7 |
| | **395.2** | 15.2*b* | 9.7*ab* | 4.2*a* | **395.2** | 16.5*b* | 8.5*ab* | 6.3*a* |
| | **444.6** | 9.7 | 5.0 | 5.0 | **444.6** | 12.8*b* | 7.2*ab* | 6.3*a* |
| | May*b* | | | | June*a* | | | |
| **Southeast** | **148.2** | 15.7*b* | 5.8*ab* | 3.3*a* | **148.2** | 7.5 | 7.5 | 8 |
| | **197.6** | 5.8 | 5.0 | 5.0 | **197.6** | 15.2 | 6.7 | 8.8 |
| | **217.0** | 6.7 | 5.5 | 5.0 | **217.0** | 12.7 | 7.5 | 6.7 |
| | **296.4** | 15.2*b* | 9.7*ab* | 3.3*a* | **296.4** | 8.0 | 5.8 | 5.0 |
| | **345.8** | 6.7 | 6.7 | 4.2 | **345.8** | 9.3*b* | 5.8*a* | 6.7*ab* |
| | **395.2** | 15.2*b* | 5.8*a* | 7.5*ab* | **395.2** | 12.7 | 6.7 | 6.7 |
| | **444.6** | 10.5*b* | 4.2*ab* | 3.3*a* | **444.6** | 11.5*b* | 5.0*a* | 5.0*a* |

Table 7. 2016 Yield data

| **Year/ Location**[1] | **Planting date**[2]**/ Seeding Rate (thousands of seeds/Ha)**[3] | **Yield by treatment (kg/ha)**[4] | | | **Planting date**[2]**/ Seeding Rate (thousands of seeds/Ha)**[3] | **Yield by treatment (kg/ha)**[4] | | |
|---|---|---|---|---|---|---|---|---|
| | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** |
| **2016** | May*b* | | | | June*a* | | | |
| **Northeast*c*** | **148.2*a*** | 4249±151 | 4205±268 | 3556±119 | **148.2** | 4715±157 | 4669±109 | 4736±66 |
| | **197.6*b*** | 3886±170 | 3839±177 | 3883±115 | **197.6** | 4540±85*b* | 4788±92*a* | 4661±46*ab* |
| | **217.0*b*** | 2723±93*ab* | 3908±176*a* | 3583±111*b* | **217.0** | 4663±111 | 4696±86 | 4607±86 |
| | **296.4*b*** | 3842±201 | 3858±178 | 3720±172 | **296.4** | 4548±43 | 4767±71 | 4679±168 |
| | **345.8*bc*** | 3657±123 | 3611±59 | 3801±179 | **345.8** | 4706±157 | 4668±91 | 4606±111 |
| | **395.2*c*** | 3379±128 | 3657±162 | 3599±171 | **395.2** | 4658±63 | 4723±67 | 4642±134 |
| | **444.6*bc*** | 3658±211 | 3556±119 | 3654±119 | **444.6** | 4518±128 | 4738±123 | 4600±132 |
| | May*a* | | | | June*b* | | | |
| **Volga*a*** | **148.2*b*** | 5470±101 | 5368±80 | 5351±64 | **148.2*b*** | 4350±85 | 4377±52 | 4459±111 |
| | **197.6*a*** | 5659±128 | 5532±80 | 5460±121 | **197.6*b*** | 4306±117 | 4453±30 | 4520±69 |
| | **217.0*a*** | 5577±89 | 5625±66 | 5624±111 | **217.0*a*** | 4606±77 | 4610±122 | 4704±70 |
| | **296.4*a*** | 5556±79 | 5541±92 | 5611±101 | **296.4*ab*** | 4497±66 | 4589±57 | 4492±52 |
| | **345.8*a*** | 5656±79 | 5486±119 | 5491±89 | **345.8*a*** | 4758±70*a* | 4585±51*ab* | 4504±127*b* |
| | **395.2*a*** | 5631±92 | 5502±77 | 5509±119 | **395.2*ab*** | 4554±94 | 4532±72 | 4563±82 |
| | **444.6*a*** | 5546±87 | 5574±61 | 5644±108 | **444.6*ab*** | 4657±53*a* | 4461±60*b* | 4451±48*b* |
| | May*a* | | | | June*b* | | | |
| **Brookings*c*** | **148.2** | 4717±168 | 4953±151 | 4745±240 | **148.2*d*** | 3433±163 | 3252±155 | 3087±68 |
| | **197.6** | 4697±67 | 4661±128 | 4796±168 | **197.6*c*** | 3637±141*ab* | 3739±104*a* | 3358±114*b* |
| | **217.0** | 4942±147 | 5028±91 | 4873±133 | **217.0*c*** | 3491±84 | 3744±96 | 3470±83 |
| | **296.4** | 5104±28*a* | 5054±91*a* | 4591±188*b* | **296.4*b*** | 3800±108 | 3834±76 | 3786±57 |
| | **345.8** | 4899±105 | 4948±103 | 4837±105 | **345.8*b*** | 3941±219 | 3802±195 | 3668±79 |
| | **395.2** | 4931±75*ab* | 4772±70*b* | 5033±75*a* | **395.2*ab*** | 3900±131 | 3848±55 | 3941±70 |
| | **444.6** | 4992±69 | 5059±104 | 4911±112 | **444.6*a*** | 3957±132 | 4145±104 | 4080±94 |
| | May*a* | | | | June*b* | | | |
| **Southeast*b*** | **148.2** | 4977±97 | 4939±104 | 5101±96 | **148.2*b*** | 3989±347 | 4213±110 | 4304±128 |
| | **197.6** | 4885±117 | 4904±72 | 4824±69 | **197.6*ab*** | 4039±201 | 4269±253 | 4455±258 |
| | **217.0** | 4633±86*b* | 4844±54*ab* | 5067±143*a* | **217.0*a*** | 4420±153 | 4489±253 | 4583±164 |
| | **296.4** | 4653±162 | 5009±150 | 4799±85 | **296.4*ab*** | 4035±276 | 4301±165 | 4417±126 |
| | **345.8** | 4868±149 | 4920±80 | 5070±86 | **345.8*a*** | 4600±217 | 4345±238 | 4623±155 |
| | **395.2** | 4905±85 | 4776±94 | 4802±66 | **395.2*a*** | 4136±250*b* | 4590±116*ab* | 4758±153*a* |
| | **444.6** | 4900±106 | 4999±132 | 4926±144 | **444.6*a*** | 4566±150 | 4427±184 | 4586±189 |

Table 8. 2017 yield data

| Year/ Location[1] | Planting date[2]/ Seeding Rate (thousands of seeds/Ha)[3] | Yield by treatment (kg/ha)[4] | | | Planting date[2]/ Seeding Rate (thousands of | Yield by treatment (kg/ha)[4] | | |
|---|---|---|---|---|---|---|---|---|
| | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** | | **Untreated** | **Fungicide** | **Fungicide + Insecticide** |
| **2017** | May*a* | | | | June*b* | | | |
| **Northeast*a*** | **148.2*d*** | 4456±108 | 4365±104 | 4576±57 | **148.2*d*** | 3376±171 | 3434±81 | 3529±125 |
| | **197.6*c*** | 4328±163*b* | 4664±102*ab* | 4999±89*a* | **197.6*c*** | 4134±91 | 3993±155 | 3881±110 |
| | **217.0*b*** | 4797±108 | 4850±119 | 4909±82 | **217.0*b*** | 4185±114 | 4356±122 | 4224±82 |
| | **296.4*b*** | 4938±97 | 5097±107 | 5007±81 | **296.4*b*** | 4285±125 | 4506±130 | 4292±52 |
| | **345.8*ab*** | 5012±78 | 5153±116 | 5048±48 | **345.8*ab*** | 4381±143 | 4510±91 | 4383±108 |
| | **395.2*ab*** | 5154±80*ab* | 5356±70*a* | 5356±70*b* | **395.2*a*** | 4675±77 | 4570±69 | 4530±68 |
| | **444.6*a*** | 5196±110 | 5260±90 | 5260±90 | **444.6*a*** | 4533±92 | 4606±108 | 4694±84 |
| | May*b* | | | | June*a* | | | |
| **Volga*c*** | **148.2*b*** | 3468±111 | 3503±106 | 3701±75 | **148.2*b*** | 3742±135 | 3780±161 | 3789±152 |
| | **197.6*a*** | 3559±79*b* | 3843±202*ab* | 3960±108*a* | **197.6*b*** | 3896±59 | 3694±138 | 3969±95 |
| | **217.0*ab*** | 3552±75 | 3812±100 | 3712±105 | **217.0*ab*** | 3873±143 | 3992±118 | 4108±76 |
| | **296.4*ab*** | 3556±70*b* | 3647±133*ab* | 3951±88*a* | **296.4*ab*** | 3893±118 | 4071±78 | 4111±148 |
| | **345.8*a*** | 3799±145 | 3770±138 | 3872±186 | **345.8*ab*** | 3900±84 | 3962±157 | 4143±113 |
| | **395.2** | 3893±85 | 3924±109 | 3839±113 | **395.2*a*** | 4084±133 | 4267±52 | 4230±122 |
| | **444.6*a*** | 3857±97 | 3679±128 | 3858±110 | **444.6*a*** | 4277±175 | 4318±101 | 4191±101 |
| | May*b* | | | | June*a* | | | |
| **Brookings*c*** | **148.2*b*** | 3088±210 | 3289±237 | 3472±324 | **148.2** | 4215±82 | 4047±242 | 4202±270 |
| | **197.6*ab*** | 3461±294 | 3717±256 | 3546±188 | **197.6** | 4014±224 | 4096±312 | 3977±271 |
| | **217.0*ab*** | 3685±262 | 3933±220 | 3381±190 | **217.0** | 3804±205*b* | 4387±136*a* | 4283±201*ab* |
| | **296.4*ab*** | 3345±220 | 3961±293 | 3767±293 | **296.4** | 4297±140 | 4343±164 | 4203±70 |
| | **345.8*a*** | 4085±230 | 3715±261 | 3767±361 | **345.8** | 4090±230 | 4109±259 | 4348±146 |
| | **395.2*a*** | 3810±229 | 3804±306 | 4431±198 | **395.2** | 3993±247 | 4374±139 | 4216±238 |
| | **444.6*a*** | 3842±206 | 4342±203 | 3742±232 | **444.6** | 4039±303 | 4386±240 | 4009±272 |
| | May*a* | | | | June*b* | | | |
| **Southeast*b*** | **148.2*b*** | 3350±236*b* | 3694±210*ab* | 3828±413*a* | **148.2** | 3929±91 | 3894±134 | 3769±110 |
| | **197.6*a*** | 4170±210 | 4304±355 | 4419±179 | **197.6** | 3386±609 | 3735±152 | 3957±89 |
| | **217.0*a*** | 4137±255*b* | 3623±679*ab* | 4684±201*a* | **217.0** | 4108±103 | 3900±97 | 3822±80 |
| | **296.4*a*** | 4277±201 | 4471±91 | 4518±164 | **296.4** | 3778±263 | 3950±75 | 4110±101 |
| | **345.8*a*** | 4317±142 | 4495±112 | 4416±213 | **345.8** | 3826±65*b* | 4035±100*b* | 4035±100*a* |
| | **395.2*a*** | 4452±170 | 4543±182 | 4707±132 | **395.2** | 3797±59 | 3799±106 | 4030±99 |
| | **444.6*a*** | 4426±245 | 4622±166 | 4539±87 | **444.6** | 3955±87*ab* | 3926±72*b* | 4176±44*a* |

# CHAPTER 3

## INSECTICIDE SEED TREATMENTS AND IN-FURROW INSECTICIDES FOR WIREWORM MANAGEMENT IN DAKOTA SUNFLOWERS

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### Abstract

Insecticide seed treatments are commonly used in sunflowers to protect stands and ultimately yield from soil insect pests, especially wireworms (Coleoptera: Elateridae). However, the use of insecticide seed treatments is often prophylactic and not based on insect pest densities, action thresholds or evidence of their effectiveness against insect pests. In sunflowers, there is limited evidence to support the use of insecticide seed treatments. The objective of this study was to compare commercial and experimental in-furrow pyrethroid insecticides to neonicotinoid seed treatment at the labeled and 1.5x labeled rate for wireworm management in sunflowers of South Dakota and North Dakota. The in-furrow insecticides tested included bifenthrin, bifenthrin + biological, and zeta-cypermethrin. The seed treatment tested was thiamethoxam at 0.25 (1x rate) and 0.375 mg per seed (1.5x rate). These five different insecticide treatments were compared to an untreated control. The study was conducted during the 2016 and 2017 growing season in South Dakota with two locations each year. In North Dakota, it was conducted at one site over the past three growing seasons (2015, 2016, and 2017). The highest root injury rating scores (i.e., 1 being a dead plant, 10 being no evidence of feeding) and highest yield were observed when insecticide treatments were present. However, there were no clear differences among treatments due to low densities of wireworms at some field sites. Results indicate early season insect management can be achieved through the use of either insecticide seed or in-furrow treatments in sunflower.

**Keywords:** sunflower, in-furrow, seed treatment, pest management, wireworm

## Introduction

In both North Dakota and South Dakota, sunflowers, *Helianthus annuus* L. (Asterales: Asteraceae) represent an important oil seed crop with approximately 428,967 combined hectares planted annually (Martinez-Force 2015, NASS 2018a, NASS 2018b). One of the reasons that sunflowers are successful in the Dakota's is their drought tolerance characteristics, which is due to the long tap root that is surrounded by many smaller lateral roots (Berglund 2007, Martinez-Force 2015). Sunflowers planting populations usually range from 37,100 to 49,400 seeds/hectare (Grady 2000). Although increased planting populations are often used to combat early season stand loss from insect pests and diseases they also make sunflower more susceptible to other insect pests later in the season and represent an additional input cost (Meyer et al. 2009). Due to the use of low seeding rates protection of sunflower stands (i.e., early season insect management) is important to ensure proper stand establishment and optimized yields.

The most economically damaging early season insect pests that attack sunflowers in the Northern Great Plains include several species of cutworms (Lepidoptera: Noctuidae), wireworms (Coleoptera: Elateridae), sunflower root weevil, *Baris strenua*

LeConte (Coleoptera: Curculionidae), sunflower beetle, *Zygogramma exlamationis* Fabricius (Coleoptera: Chrysomelidae), and palestriped flea beetle, *Systena blanda* Melsheimer (Coleoptera: Chrysomelidae) (Charlet et al. 1987, Knodel et al. 2015). These insect pests can have a negative impact on root development, plant stands, plant photosynthetic capabilities and ultimately reduce sunflower yield (Knodel et al. 2015). As a result, early season management of these pests is important for establishing healthy stands and protecting yield.

Because emergency treatments do not exist for belowground pests after planting, preventative or targeted approaches are often implemented at planting. As documented for other crops, neonicotinoid seed treatments provide a window of protection against feeding injury from early season soil and defoliating insect pests (Wilde et al. 2004, Johnson et al. 2008, Vernon et al. 2013a). Similarly, the effectiveness of in-furrow insecticides for early season belowground insect pest management has also been demonstrated in other crops (Gregory and Musick 1976, Mayo and Peters 1978). Both of these management options are employed prior to or at planting to prevent crop injury. Although they are used in sunflower, there is no empirical evidence to indicate if one treatment provides benefits over the other.

Of the previously mentioned early season belowground insect pests of sunflower, the species complex of wireworms is often economically damaging. In sunflower fields, wireworms can be commonly found near the soil surface during the early season where they feed on the root systems of sunflower seedlings (Knodel et al. 2015). Depending on the species, wireworms may spend two to six years living in the soil before emerging as adult click beetles (Meyer et al. 2009). Wireworm populations are more frequently observed in fields with a no-till management system and they tend to prefer fields that have been previously planted to grass or small grain crops (Meyer et al. 2009). The Integrated Pest Management (IPM) strategies available for wireworm management include delayed planting dates, increased seeding rate, crop rotation with legume crop, tillage, and insecticides (Knodel et al. 2015).

For aboveground early season insect pests, the sunflower beetle and palestriped flea beetle are noted for their ability to cause significant defoliation, which results in subsequent stand loss and ultimately yield loss (Knodel et al. 2015). Adult sunflower beetles emerge in the spring and begin feeding on the leaves of seedling sunflowers (Berglund 2007). Palestriped flea beetles are also capable of causing severe early season defoliation to seedling sunflowers. Substantial flea beetle populations lead to plants with a “lacy” or “shot hole” appearance (Knodel 2017). As a result of these two early season defoliators and other pests, neonicotinoid insecticide seed treatments are highly adopted for use in sunflower production (Bredeson and Lundgren 2015).

Although neonicotinoid seed treatments are a practical option in situations where one or more early season insect pests has to potential to cause severe crop injury, they may not be best suited for wireworm management (Wilde et al. 2004, Vernon et al. 2009). In sunflower, thiamethoxam is the only seed treatment active ingredient that is currently marketed (Varenhorst and Wagner 2018). When insecticide seed treatments are implemented for the management of wireworms they provide suppression rather than mortality (Vernon et al. 2009). Van Herk et al. (2008) observed that thiamethoxam was not as effective for wireworm management as chlorpyrifos. They also determined that wireworm mortality could be improved by using a doubled rate (Van Herk et al. 2008).

Additional studies observed the same limited management of neonicotinoid seed treatments towards wireworm populations with wireworms showing no signs of mortality days after exposure (Vernon et al. 2009, Van Rozen et al. 2013). Due to wireworm lifecycles, it is important to both reduce feeding but also reduce populations to prevent subsequent seasonal losses to the pest (Vernon et al. 2009). The exposure to neonicotinoids without mortality also increases the risk of resistance developing in wireworm populations towards these products (Van Rozen et al. 2013). This indicates that neonicotinoid seed treatments may not be the best management strategy for wireworms.

Although neonicotinoid seed treatments do not reduce wireworm populations, there are other insecticide classes that are capable at reducing wireworm populations. An alternative management option in sunflower is the use of in-furrow broad-spectrum insecticides (i.e., organophosphate, carbamate and pyrethroid active ingredients) (Olson et al. 2008) to protect seeds and the root systems of emerging seedlings. These treatments are applied to the soil directly around the seed at the time of planting. In-furrow insecticide treatments may provide better population management of insect pests that are otherwise not well managed other treatments (Stewart 2016). In sunflower, there are a total of 15 insecticides labeled for in-furrow use in sunflower, however, 13 have the active ingredient chlorpyrifos (i.e., organophosphate class) and two have the active ingredient zeta-cypermethrin (i.e., pyrethroid class) (Varenhorst and Wagner 2018). In-furrow insecticides may also reduce unintended mortality of aboveground beneficial insects present in sunflower (Gontijo et al. 2014a, Gontijo et al. 2014b, Moscardini et al. 2014).

Integrated pest management practices are essential for reducing potential losses from diseases, insects, and weeds. While IPM represents a sustainable approach for managing pests by combining biological, cultural, mechanical, and chemical management (Berglund 2007) it can only be successful when management recommendations exist and are disseminated to stakeholders. For sunflowers, these recommendations do not exist for early season insect pest management. The purpose of this study was to compare the efficacies of insecticidal seed treatments to in-furrow insecticides for managing early season insect pests, with specific emphasis placed on wireworm management. Due to the deterrence rather than mortality effect observed with neonicotinoid seed treatment management of wireworms, we hypothesized that broad-spectrum in-furrow insecticides would provide additional seedling protection from early season insect pests when compared to neonicotinoid seed treatments. The objective of this study was to develop preliminary management recommendations for the use of insecticides (i.e., seed treatments or in-furrow applications) for sunflower production by evaluating 1) root rating injury, 2) stand establishment, and 3) yield.

## Materials and Methods

### Field Site

This study was conducted in North Dakota during 2015, 2016, and 2017 and in South Dakota during 2016 and 2017. For both states, two field sites were used each year, except North Dakota in 2016. The field sites were selected based on scouting and a positive identification of wireworm populations.

#### *North Dakota*

This study had five location years in North Dakota during 2015, 2016 and 2017. In 2015, one field was planted near Linton, ND and one field near Rogers, ND. Wireworm populations were confirmed at the Linton but not at Rogers locations. In 2016, there was only one North Dakota location for this trial at Mohall, ND, with confirmed wireworm populations. In 2017, two trials were established near Mohall, ND with wireworm populations confirmed at both of these locations. In North Dakota, all locations utilized no-till practices. The previous crop and planting date information for all North Dakota location years and plan can be observed in Table 1.

All North Dakota locations utilized a seeding rate of 55,946 seeds/ha. No commercial fertilizer was applied prior to planting. Herbicide applications at Rogers location in 2015 consisted of a post emergence herbicide application of *Beyond* (BASF Corporation, Research Triangle Park, NC) using the labeled rate. There was no herbicide application to Mohall field 1 in 2017. At all of the other locations glyphosate (RoundUp, Monsanto Company, St. Louis, Missouri) was applied prior to planting.

***South Dakota***

In South Dakota, this study had 4 location years over the course of the 2016 and 2017 growing seasons. During the 2016 growing season, two separate fields were planted at the South Dakota State University Research Farm in Volga, South Dakota. In 2017, one field was planted at the Volga Research Farm and the second field was planted in a producer’s field near Onida, SD. In 2016, both trials were conventionally tilled prior to planting; however, in 2017 both trials were conducted on no-till ground. The previous crop and planting date information for all South Dakota location years and plan can be observed in Table 1.

In 2016, sunflowers were planted at 61,750 seeds/ha and in 2017 they were planted at 49,400 seeds/ha. During 2016, sunflowers were planted at a higher seeding rate to account for potential germination issues. However, due to high germination rates the seeding rate was reduced in 2017. For this study, no fertilizers were applied to the target fields. No pre-emergent herbicides were used to reduce weeds. Before planting occurred each year, a burndown application of glyphosate was used one week prior to planting. No foliar insecticides or fungicides were used on any of the experimental fields.

**Experimental Design**

For this experiment, we used a randomized complete block design. For South Dakota, each treatment was replicated six times at each location. In North Dakota, treatments were replicated five times at each location. For both States and all location years, each plot was four rows (3.0 m) wide with a 76.2 cm row spacing. North Dakota's individual plot length was 7.6 m. and South Dakota locations had individual plot length of 9.1 m. North Dakota plots were planted using a 2 row Seed Research Equipment Solutions (SRES, Hutchinson, KS), in-furrow products were mixed in stainless steel containers that were pressurized with CO2. In South Dakota, plots were planted using an Almaco four row planter (Almaco Inc., Nevada, IA) equipped with 11.36 Liter stainless steel containers and industrial connections (107-BG, R&D sprayers, Opelousas, LA) that are pressured by an air compressor for in-furrow insecticides.

**Efficacies of Seed and In-Furrow Treatments in Sunflower**

We hypothesized that in-furrow insecticides would provide increased stand counts, root injury ratings and yield when compared to insecticide seed treatments. For this experiment, there were a total of six treatments. Treatments included an untreated control, zeta-cypermethrin applied in-furrow at a rate of 0.33 mL/ha (Mustang Maxx, FMC Corporation, Philadelphia, PA), bifenthrin applied in-furrow at a rate of 0.33 mL/ha (Capture LFR, FMC Corporation, Philadelphia, PA), bifenthrin plus *Bacillus amyloliquefaciens* strain D747 (i.e., a biological agent with fungicidal properties) applied in-furrow at a rate of 0.33 mL/ha (Ethos XB, FMC Corporation, Philadelphia, PA), thiamethoxam applied as seed treatment at a rate of 0.25 mg a.i./seed (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC), and thiamethoxam applied as a seed treatment at a rate of 0.375 mg a.i./seed (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC). Of the tested in-furrow insecticides only Mustang Maxx is currently labeled for use in sunflower (Varenhorst and Wagner 2018). The labeled rate for thiamethoxam is 0.25 mg a.i./seed. However, the 1.5x rate of 0.375 was included to evaluate the potential for increased rates to provide additional management of belowground insect pests (Van Herk et al. 2008). For both years in both North Dakota and South Dakota, the commercial sunflower variety Cobalt II (Nuseed, Breckenridge, MN) was used and all seeds, including the untreated control were treated with mefenoxam (Apron XL, Syngenta Crop Protection, Basel Switzerland) at labeled rate, for disease control.

**Stand counts.** Stand counts were collected from each plot 14 days after emergence. To determine stand counts for each plot, plants present in 3.0 m of each of the middle two rows were counted. Stand counts were converted to live plants per hectare and then averaged between the two rows in each plot.

**Root ratings.** Root ratings were determined by gathering the roots from 10 plants from the outer two rows of each plot (i.e., five plants from each of the two outer rows). Root samples were collected 28 d post emergence. Plants were selected using a random number generator. Roots were brought back to the lab and washed to remove excess soil. After the roots were cleaned, each one was examined and rated using a one to ten scale (1 being a dead plant, 10 being no evidence of feeding).

**Yield.** For all location years in South Dakota, yield was determined by combining the center two rows of each plot using a combine outfitted with a scale. Moisture content, weight per plot, and total plot length were used to determine kg of seed produced per ha. North Dakota yield data was collected from one location in 2017. Other North Dakota years and locations were not harvested due to drought, stalk lodging, or black bird damage.

**Statistical Analysis**

Data were analyzed using the PROC MIXED procedure with SAS statistical software version 9.4 (SAS Institute, Cary, NC). Multi-year and multi-location analysis was used to determine effects of seed and in-furrow treatment on plant stand and yield. Year, field location, and treatment, along with all interactions, were considered fixed effects. Replication within each field and overall error term were considered random effects. The level of significance used was 95% and comparisons were conducted using least-squares mean test. Non-transformed data was used for making graphs.

To reduce heteroscadacity, the stand counts taken on day 14 and yield were natural log transformed. Significant effects were separated using F-protected least-squares mean test. Analysis of the stand count data determined that year was significant. Yield data analysis indicated that again year was always significant. The main model analysis was performed in PROC MIXED (SAS Institute, Cary, NC).

When determining root injury feeding rating, we determined that the North Dakota ($W$=0.9639; $P$<0.0045) and South Dakota ($W$=0.9458; $P$<0.0001) were not normally distributed by using a Shapiro-Wilk test for normality in PROC UNIVARIATE procedure with SAS statistical software version 9.4 (SAS Institute, Cary, NC). When data was found to not be normally distributed, we then analyzed it using the Kruskal-Wallis test with the PROC NPAR1WAY procedure (SAS Institute, Cary, NC) to determine differences among the mean ratings for each treatment. If differences were observed, root ratings were then evaluated using a Wilcoxon two-sample test within the PROC NPAR1WAY procedure.

## Results

### Efficacies of Seed and In-Furrow Treatments in Sunflower

#### Stand counts

We rejected our hypothesis that in-furrow insecticides would provide improved stand counts when compared to insecticide seed treatments. Stand count data were analyzed by state due to significant differences between South Dakota and North Dakota across years ($F$=81.71; df=1, 284; $P$<0.0001).

***North Dakota.*** In North Dakota, there were significant differences in stand counts between 2015, 2016, and 2017 ($F$=7.25; df=2, 123; $P$<0.0011). Stand counts in 2016 were significantly greater than 2015 and 2017. As a result, we evaluated stand counts by year.

We next evaluated the multiple locations within a year when applicable. Significant differences in stand counts between fields were only observed in 2015 ($F$=84.06; df=1, 34; $P$<0.0001). Linton, ND had significantly lower stand counts than Rogers, ND in 2015; however, neither location had significant differences among treatments (Fig. 1). In 2016, significant differences among treatments were observed for the Mohall, ND location ($F$=30.7; df=5, 24; $P$<0.0280) (Fig. 2). For this location, zeta-cypermethrin ($t$=2.82; df=1,24; $P$<0.0094), bifenthrin ($t$=3.22; df=1,24; $P$<0.0036), thiamethoxam 0.375 mg a.i./seed ($t$=2.52; df=1,24; $P$<0.0186), and bifenthrin plus biological ($t$=3.33; df=1,24; $P$<0.0028) had significantly greater stand counts than the untreated control. In 2017, both Mohall (1) ($F$=2.02; df=5, 24; $P$<0.1121) (Fig. 3a) and Mohall (2) ($F$=2.76; df=5, 24; $P$<0.0417) (Fig. 3b) locations had significant differences among treatments. At Mohall (1) the thiamethoxam 0.25 mg a.i./seed treatment had significantly greater stand counts than in the zeta-cypermethrin ($t$=2.20; df=1,24; $P$<0.0381) and the untreated control ($t$=2.83; df=1,24; $P$<0.0093) (Fig. 3a). At Mohall (2) the bifenthrin ($t$=2.99; df=1,24; $P$<0.0063), thiamethoxam 0.25 mg a.i./seed ($t$=3.31; df=1,24; $P$<0.0029), thiamethoxam 0.375 mg a.i./seed ($t$=2.15; df=1,24; $P$<0.0421), and zeta-cypermethrin ($t$=2.62; df=1,24; $P$<0.0150) had significantly greater stands than the untreated control (Fig. 3b).

***South Dakota*.** In South Dakota, stand counts were significantly greater in 2016 than in 2017 ($F$=124.68; df=1, 149; $P$<0.0001). We next evaluated the two fields within each year to determine if differences existed between them. There was no significant difference between the two fields each year. For South Dakota, stand count data for fields was combined for each year for analyses. We then evaluated South Dakota stand counts among treatments by year and field separately. In both South Dakota fields for 2016 and 2017, there were no significant difference in stand counts among the treatments (Fig. 4 and Fig. 5).

**Root ratings**

We rejected our hypothesis that in-furrow insecticides would provide additional root protection (i.e., higher root rating values) when compared to insecticide seed treatments. A root injury rating scale that went from 1-10 was used to analyze the data, where 1 indicated maximum root injury and 10 indicated no root injury. Because the data are not normally distributed it was analyzed using a Kruskal-Wallis test to determine if the mean ratings of treatments were the same between states. We discovered that there were significant differences in ratings by state ($H$=117.6585; $P$<0.0001). For this reason, data were next analyzed by state.

***North Dakota*.** For North Dakota, we next determined that year significantly affect root injury ratings ($H$=78.3147; $P$<0.0001) (Table 2). In 2015 and 2016, data were not analyzed to determine differences between fields as only one field with wireworm presence existed for each year. In 2017, the root injury ratings were significantly different between Mohall (1) and Mohall (2) ($H$=7.1021; $P$<0.0077). Root ratings were significantly different among treatments at the 2015 Linton location ($H$=11.7041; $P$<0.0085), 2016 Mohall location ($H$=18.4790; $P$<0.0024), and 2017 Mohall (2) location ($H$=13.2977; $P$<0.0207).

Data were next analyzed using Wilcoxon two sample test to determine differences among treatments. All treatment comparisons were made for the individual fields within a given year. At the 2015 Linton location, the untreated control had a significantly lower root injury rating than the thiamethoxam 0.25 mg a.i/seed ($W$=40.0; $P$<0.0040), thiamethoxam 0.375 mg a.i./seed ($W$=39.5; $P$<0.0079), and zeta-cypermethrin ($W$=40.0; $P$<0.0040) treatments. For the 2016 Mohall location, the untreated control had a significantly lower root injury ratings than the thiamethoxam 0.25 mg a.i/seed (W=40.0; P<0.0040), thiamethoxam 0.375 mg a.i./seed ($W$=40.0; $P$<0.0040), and zeta-cypermethrin ($W$=40.0; $P$<0.0040) treatments. At the 2017 Mohall (1) location the untreated control had a significantly lower root injury rating than the bifenthrin ($W$=40.0; $P$<0.0040), thiamethoxam 0.25 mg a.i/seed ($W$=37.0; $P$<0.0238), thiamethoxam 0.375 mg a.i./seed ($W$=40.0; $P$<0.0400), bifenthrin plus biological ($W$=40.0; $P$<0.0040), and zeta-cypermethrin ($W$=37.5; $P$<0.0198) treatments. For the 2017 Mohall (2) location, the untreated control ($W$=40.0; $P$<0.0040), bifenthrin ($W$=16.5; $P$<0.0119), had significantly lower root injury ratings than the thiamethoxam 0.25 mg a.i./seed treatment (Table 2).

***South Dakota***

For South Dakota, year significantly affected root injury ratings ($H$=4.6372; $P$=0.0313). Data were next analyzed to determine if differences in root injury ratings existed between fields within each year. We determined that in 2016, Volga (1) had significantly lower root injury ratings than Volga (2) ($H$=47.9474; $P$<0.0001). There were no differences observed between fields in 2017, however, data were still analyzed by field (Table 2). Root ratings were significantly different among treatments at the 2017 Volga location ($H$=16.448; $P$<0.0116).

Using the Wilcoxon two sample test, comparisons were made for treatments within individual fields each year. For the 2016 Volga (1) location, the thiamethoxam 0.25 mg a.i./seed had a significantly higher root injury rating when compared to the bifenthrin plus biological ($W$=28.0; $P$<0.0411). At the 2016 Volga (2) location the bifenthrin ($W$=28.0; $P$<0.0433) and thiamethoxam 0.25mg a.i./seed ($W$=28.0; $P$<0.0433) treatments had a significantly higher root injury ratings than the untreated control. At the 2017 Volga location the thiamethoxam 0.25 mg a.i./seed ($W$=27.5; $P$<0.0335), thiamethoxam 0.375 mg a.i./seed ($W$=27.5; $P$<0.0400), zeta-cypermethrin ($W$=24.5; $P$<0.0119), and bifenthrin ($W$=26.5; $P$<0.0249) had significantly higher root injury ratings than the untreated control. For the 2017 Volga location, the thiamethoxam 0.25 mg a.i./seed ($W$=27.0; $P$<0.0314), thiamethoxam 0.375 mg a.i./seed ($W$=24.0; $P$<0.0108), zeta-cypermethrin ($W$=55.5; $P$<0.0043), and bifenthrin ($W$=25.5; $P$<0.0108) had significantly higher root injury ratings than the bifenthrin plus biological treatment. No significant differences in root injury ratings were observed at the 2017 Onida location.

**Yield**

We rejected our hypothesis that in-furrow insecticides would provide improved yield when compared to insecticide seed treatments. We determined that South Dakota had significantly greater yield when compared to North Dakota ($F$=434.31; df=1, 169; $P$<0.0001). Data were next analyzed by state.

***North Dakota.*** The only yield data collected in North Dakota was from the 2017 Mohall (2) location. Yield was significantly greater for the bifenthrin ($t$=2.27; df=1,24; $P$<0.0325), thiamethoxam 0.25 mg a.i./seed ($t$=2.94; df=1,24; $P$<0.0072), thiamethoxam

0.375 mg a.i./seed (*t*=2.64; df=1,24; *P*<0.0144) and zeta-cypermethrin (*t*=2.75; df=1,24; *P*<0.0111) treatments when compared to the untreated control. However, no differences were observed among the insecticidal treatments.

***South Dakota.*** Yield was collected from all South Dakota locations each year. We first evaluated yield by year and determined that the yield between 2016 and 2017 was significantly different (*F*=39.73; df=1, 139; *P*<0.0001). The 2016 yield (*t*=6.30; df=1, 139; *P*<0.0001) was significantly greater than 2017. We next evaluated yield for each year to determine if yield was different among fields. For 2016, there were no significant difference between. However, in 2017 there were significant differences between the fields in South Dakota for yield (*F*=33.23; df=1, 67; *P*<0.0001). In the 2017 growing season, the Volga location (*t*=5.76; df=1, 67; *P*<0.0001) yielded significantly greater than the Onida location. We then evaluated yield by field for each year for significant differences among treatments.

For the 2016 Volga (1) location, there were no significant differences among treatments (Fig. 7a). Significant differences in yield were observed among treatments for the 2016 Volga (2) location (*F*=3.76; df=5,30; *P*<0.0092) (Fig. 7b). For this location, the thiamethoxam 0.375 mg a.i./seed (*t*=3.48; df=1,30; *P*<0.0016), bifenthrin (*t*=2.72; df=1, 30; *P*<0.0107), zeta-cypermethrin (*t*=3.45; df=1,30; *P*<0.0017), and untreated control (*t*=3.45; df=1, 30; *P*<0.0017) had significantly greater yields when compared to the bifenthrin plus biological treatment. No significant differences among yield were observed at the 2017 Volga location (Fig. 8a). However, significant differences among treatments were observed from the 2017 Onida location (*F*=5.22; df=6, 24; *P*<0.0015) (Fig. 8b). For this location, the bifenthrin (*t*=2.78; df=1, 24; *P*<0.0103), zeta-cypermethrin (*t*=3.82; df=6,24; *P*<0.0008), and untreated control (*t*=2.56; df=1, 24; *P*<0.0170) had significantly greater yields when compared to the bifenthrin plus biological treatment. The bifenthrin (*t*=3.39; df=1, 24; *P*<0.0024), zeta-cypermethrin (*t*=4.48; df=1,24; *P*<0.0002), thiamethoxam 0.25 mg a.i/seed (*t*=2.17; df=1, 24; *P*<0.0400) and untreated control (*t*=3.18; df=1, 24; *P*<0.0041) also had significantly greater yields when compared to the thiamethoxam 0.375 mg a.i/seed treatment.

## Discussion

Results from this experiment across locations in both North Dakota and South Dakota indicate that for the examined performance metrics including stand counts, root injury ratings and yield there are no clear benefits of using an in-furrow insecticide when compared to a neonicotinoid seed treatment. However, the data from North Dakota indicate that there is a clear benefit associated with the use of insecticides for early season insect pest management for establishing sunflower stands (Fig. 2 and Fig. 3). However, this trend wasn't observed at each location in North Dakota. In South Dakota, statistical differences were not observed, however, numerical differences between insecticide treatments and the untreated control do exist (Fig. 4). Similarly, the root injury ratings from a majority of the locations and years from both North Dakota and South Dakota indicate that both in-furrow treatments and neonicotinoid seed treatments resulted in healthier roots (Table 2 and Table 3). Lastly, yield from North Dakota indicated that both in-furrow and seed treatments provide improved yield when compared to the untreated control. Yield data from South Dakota did not have a clear indication to the benefit of insecticide treatments, however, this could be partly due to seasonal growing conditions (e.g., adequate precipitation and temperatures).

The average yield improvements observed in North Dakota between pooled insecticide treatments and the untreated control accounted for an approximate 411 kg/ha increase in yield or $70/ha increase in revenue (i.e., based on the three-month average price per hundred-weight of sunflower in Fargo, ND of $17.36). For South Dakota, yield differences between the untreated control and pooled insecticide treatments across all location years accounted for an approximate 122 kg/ha decrease in yield or $21/ha decrease in revenue. On a field by field basis, however, there are instances where the in-furrow bifenthrin and zeta-cypermethrin treatments in South Dakota provided a slight yield benefit (Fig. 7a, Fig. 8b). This shows that numerical differences in yield should be taken into consideration on a case by case basis to determine if the yield increase gained will be greater than treatment price, depending upon the market. Yield data from both states across multiple years indicate that the use of the in-furrow treatments of bifenthrin and zeta-cypermethrin resulted in improved yields. Yield data for both thiamethoxam rates was more variable and may be more dependent on growing conditions.

Although our study did not observe a benefit associated with the use of in-furrow insecticides when compared to neonicotinoid seed treatments there is still the potential for a benefit to exist. Although not explored in this study, there is evidence that insecticides that act as deterrents may result in increased selection pressure to the target pest (Van Rozen et al. 2013). In addition, when the pest population is not reduced by a treatment it will persist for subsequent crops and may cause additional injury. In the case of wireworms, the target insect of this study, populations may persist in the soil for 2-3 years depending on the species (Vernon et al. 2009). For these reasons, the use of a broad-spectrum insecticide with known efficacy toward the targeted pest (i.e., wireworms) would be recommended over the use of a neonicotinoid seed treatment. However, the prophylactic use of the neonicotinoid seed treatment thiamethoxam in sunflower originated from its successful use for the management of early season population outbreaks of the palestriped flea beetle (Knodel et al. 2015).

In sunflower, the lack of management recommendations is in part due to the year-to-year and field-to-field variation of key pest populations (i.e., palestriped flea beetles and wireworms). Our results suggest that early season management should be conducted based on the potential presence of these pests. Although historically an economic pest of sunflower, the palestriped flea beetle has not an issue in recent years. Based on this evidence, the transition of early season management to in-furrow insecticides may be beneficial for wireworm management. However, these insecticides should also be used based on thresholds and not as prophylactics. Wireworm scouting should be done following protocols established by Kirfman et al. (1986), where bait stations are placed in the field prior to planting to determine the presence of wireworms. This early season scouting can determine whether insecticides are necessary at planting. Future work should evaluate additional products to determine their efficacy towards wireworm populations and determine if wireworm populations have any detectable levels of resistance to the commonly used in-furrow and seed treatment active ingredients.

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Table 1. Previous crop and planting date for all location years.

| State | Year | Location | Previous Crop | Planting Date |
|---|---|---|---|---|
| North Dakota | 2015 | Linton | Corn | 1 June |
| | | Rogers | Corn | 21 May |
| | 2016 | Mohall | Barley | 24 May |
| | 2017 | Mohall (1) | Barley | 23 May |
| | | Mohall (2) | Barley | 23 May |
| South Dakota | 2016 | Volga (1) | Spring wheat | 23 June |
| | | Volga (2) | Winter wheat | 23 June |
| | 2017 | Onida | Corn | 21 June |
| | | Volga | Spring wheat | 20 June |

Table 2. 2015, 2016 and 2017 North Dakota root rating injury.

| Year | Field | Treatment | Root Rating |
|---|---|---|---|
| 2015 | Linton | Untreated | 7.4±0.2*b* |
| | | Thiamethoxam 0.25 mg | 8.2±0.1*a* |
| | | Thiamethoxam 0.375 mg | 8.1±0.1*a* |
| | | Zeta-cypermethrin | 8.3±0.1*a* |
| 2016 | Mohall | Untreated | 6.6±0.1*b* |
| | | Thiamethoxam 0.25 mg | 7.5±0.1*a* |
| | | Thiamethoxam 0.375 mg | 7.6±0.1*a* |
| | | Bifenthrin | 7.4±0.0*ab* |
| | | Bifenthrin plus biological | 7.4±0.1*ab* |
| | | Zeta-cypermethrin | 7.5±0.1*a* |
| 2017 | Mohall (1) | Untreated | 5.0±0.3*b* |
| | | Thiamethoxam 0.25 mg | 5.8±0.2*a* |
| | | Thiamethoxam 0.375 mg | 6.2±0.2*a* |
| | | Bifenthrin | 6.4±0.3*a* |
| | | Bifenthrin plus biological | 6.4±0.2*a* |
| | | Zeta-cypermethrin | 6.4±0.4*a* |
| | Mohall (2) | Untreated | 4.7±0.3*b* |
| | | Thiamethoxam 0.25 mg | 6.0±0.3*a* |
| | | Thiamethoxam 0.375 mg | 5.5±0.*6ab* |
| | | Bifenthrin | 4.9±0.2*b* |
| | | Bifenthrin plus biological | 5.1±0.*4ab* |
| | | Zeta-cypermethrin | 5.9±0.4*ab* |

*Lettering denotes significant differences between treatments with each field.

Table 3. 2016 and 2017 South Dakota root rating injury.

| Year | Field | Treatment | Root Rating* |
|---|---|---|---|
| 2016 | Volga (1) | Untreated | 7.2±0.2*ab* |
| | | Thiamethoxam 0.25 mg | 7.4±0.1*a* |
| | | Thiamethoxam 0.375 mg | 6.7±0.1*ab* |
| | | Bifenthrin | 7.6±0.2*ab* |
| | | Bifenthrin plus biological | 6.0±0.2*b* |
| | | Zeta-cypermethrin | 7.4±0.1*ab* |
| | Volga (2) | Untreated | 4.3±0.2*b* |
| | | Thiamethoxam 0.25 mg | 4.3±0.2*ab* |
| | | Thiamethoxam 0.375 mg | 4.8±0.2*a* |
| | | Bifenthrin | 4.9±0.3*a* |
| | | Bifenthrin plus biological | 4.5±0.3*ab* |
| | | Zeta-cypermethrin | 4.3±0.1*ab* |
| 2017 | Volga | Untreated | 5.0±0.3*b* |
| | | Thiamethoxam 0.25 mg | 6.8±0.9*a* |
| | | Thiamethoxam 0.375 mg | 6.5±0.6*a* |
| | | Bifenthrin | 6.8±0.7*a* |
| | | Bifenthrin plus biological | 4.5±0.2*b* |
| | | Zeta-cypermethrin | 7.3±0.7*a* |
| | Onida | Untreated | 5.3±0.7 |
| | | Thiamethoxam 0.25 mg | 5.2±1.0 |
| | | Thiamethoxam 0.375 mg | 5.8±1.0 |
| | | Bifenthrin | 7.5±0.8 |
| | | Bifenthrin plus biological | 6.3±0.8 |
| | | Zeta-cypermethrin | 7.2±0.7 |

*Lettering denotes significant differences between treatments within each field.

## Figure Captions

**Figure 1. 2015 North Dakota sunflower stand counts.** Note that the top graph (a) is data from Linton, ND and the bottom graph (b) is data from Rogers, ND. Data were analyzed by insecticide treatment. There were numerical differences among treatments but no significant differences were found

**Figure 2. 2016 North Dakota stand counts.** Note that there was only one North Dakota location during 2016. Data were analyzed by insecticide treatment, and capital letters indicates significant differences among treatments ($P$<0.05).

**Figure 3. 2017 North Dakota stand counts.** Note that two separate fields were planted near Mohall in 2017. Mohall 1 (a) and Mohall 2 (b) stand counts were analyzed by insecticide treatment, and capital letters indicates significant differences among treatments ($P$<0.05).

**Figure 4. 2016 Volga, South Dakota stand counts.** Note that two separate trials were planted near Volga in 2016. Volga 1 (a) and Volga 2 (b) stand counts were analyzed by insecticide treatment. No significant differences were found.

**Figure 5. 2017 South Dakota stand counts.** Note that the top graph (a) is stand count data from Volga, SD and the bottom graph (b) is data from Onida, SD. Stand counts were analyzed by insecticide treatment. No significant differences were found.

**Figure 6. 2017 North Dakota sunflower yield.** Note this was the Mohall 2 field, which was the only North Dakota location where yield data was collected. Data were analyzed by insecticide treatment. Capital letters indicate significant differences in yield among treatments ($P$<0.05).

**Figure 7. 2016 South Dakota sunflower yield.** Note that yield was collected separately for Volga 1 (a) and Volga 2 (b). Data were analyzed by insecticide treatment. There were no significant differences found in Volga 1, but Volga 2 had significant differences in yield among treatments. Capital letters indicate significant differences in yield among treatments lettering ($P$<0.05).

**Figure 8. 2017 South Dakota sunflower yield.** Note that yield data was collected from Volga (a) and Onida (b). Data were analyzed by sunflower treatment. There were no significant differences found at the Volga location, significant differences were observed among treatments at the Onida location. Capital letters indicate significant differences among treatments ($P$<0.05).

Figure 1.

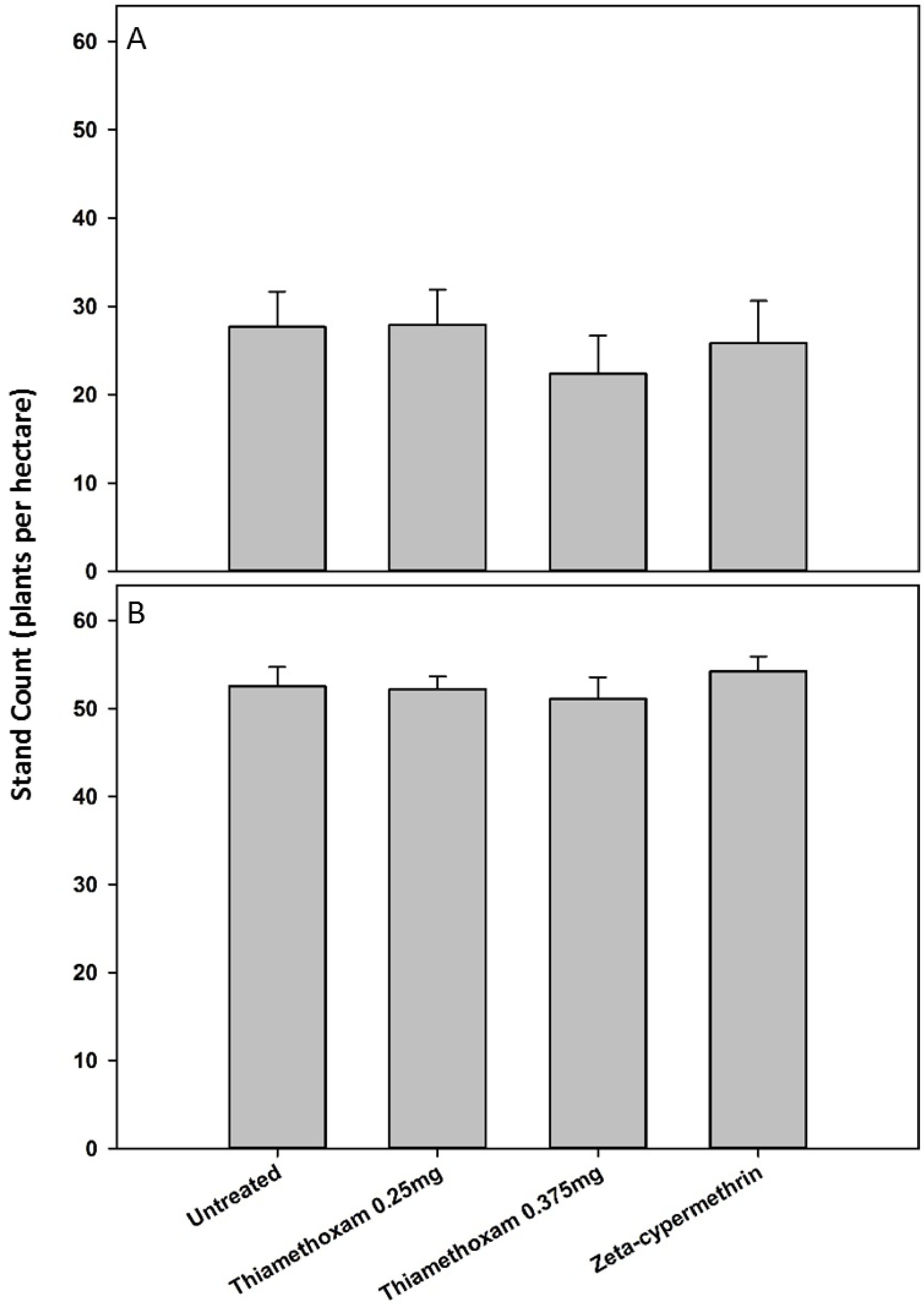

A
B
Stand Count (plants per hectare)
0
10
20
30
40
50
60
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Zeta-cypermethrin

Figure 2.

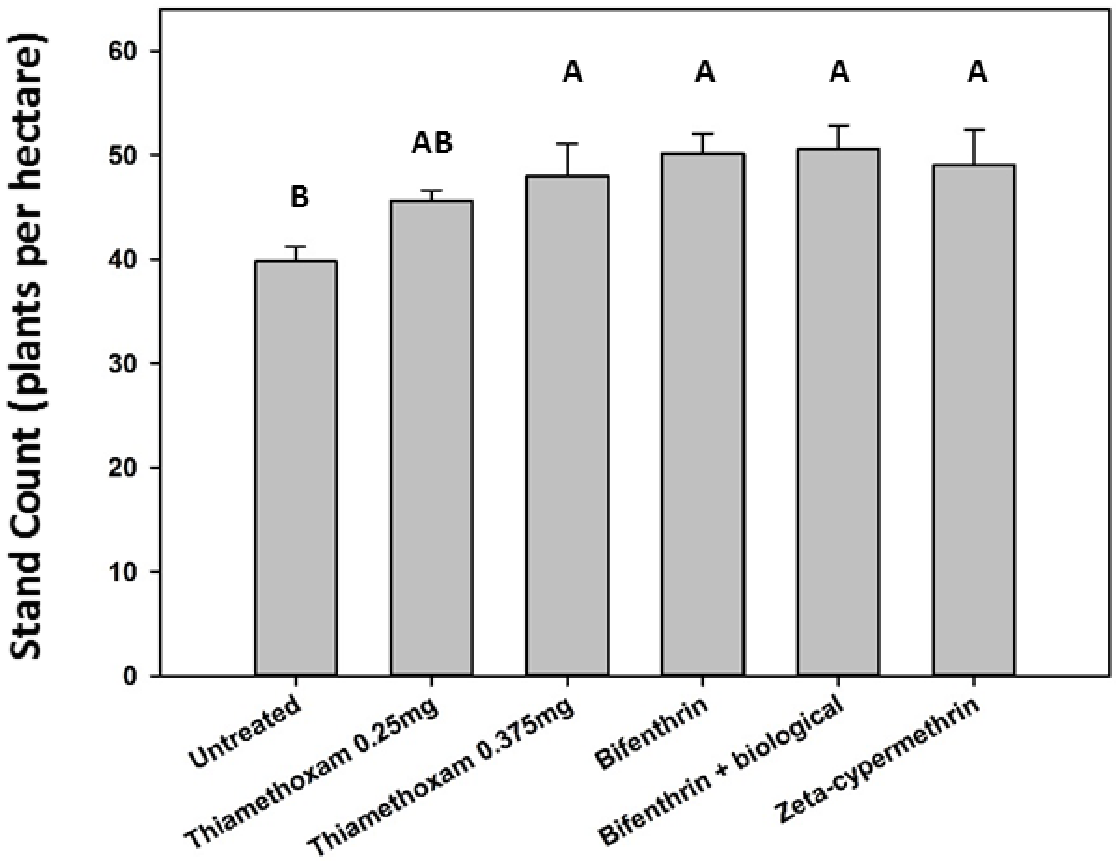

Stand Count (plants per hectare)
60
50
40
30
20
10
0
B
AB
A
A
A
A
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 3.

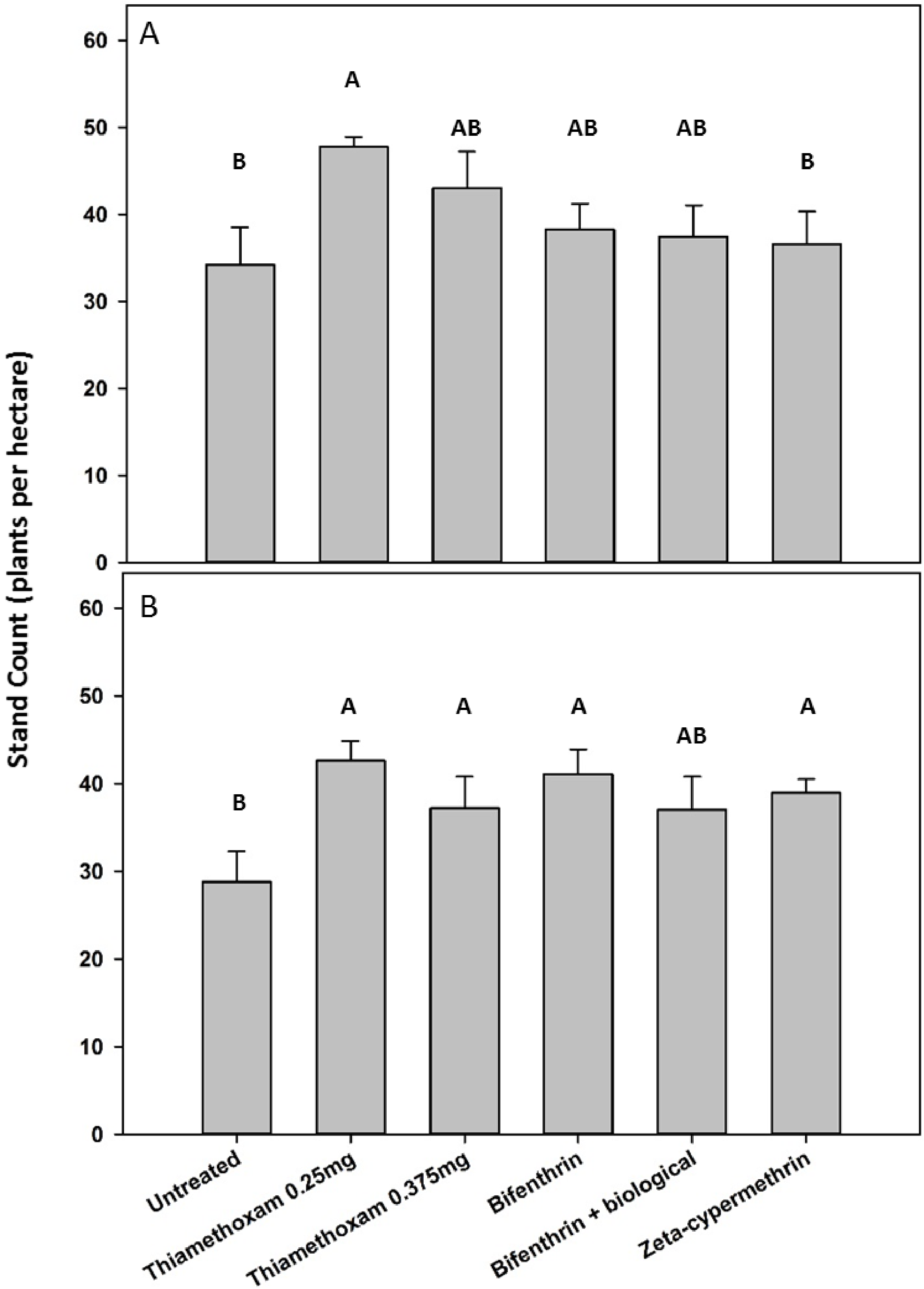

A
B
Stand Count (plants per hectare)
0
10
20
30
40
50
60
B
A
AB
AB
AB
B
A
A
A
AB
A
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 4.

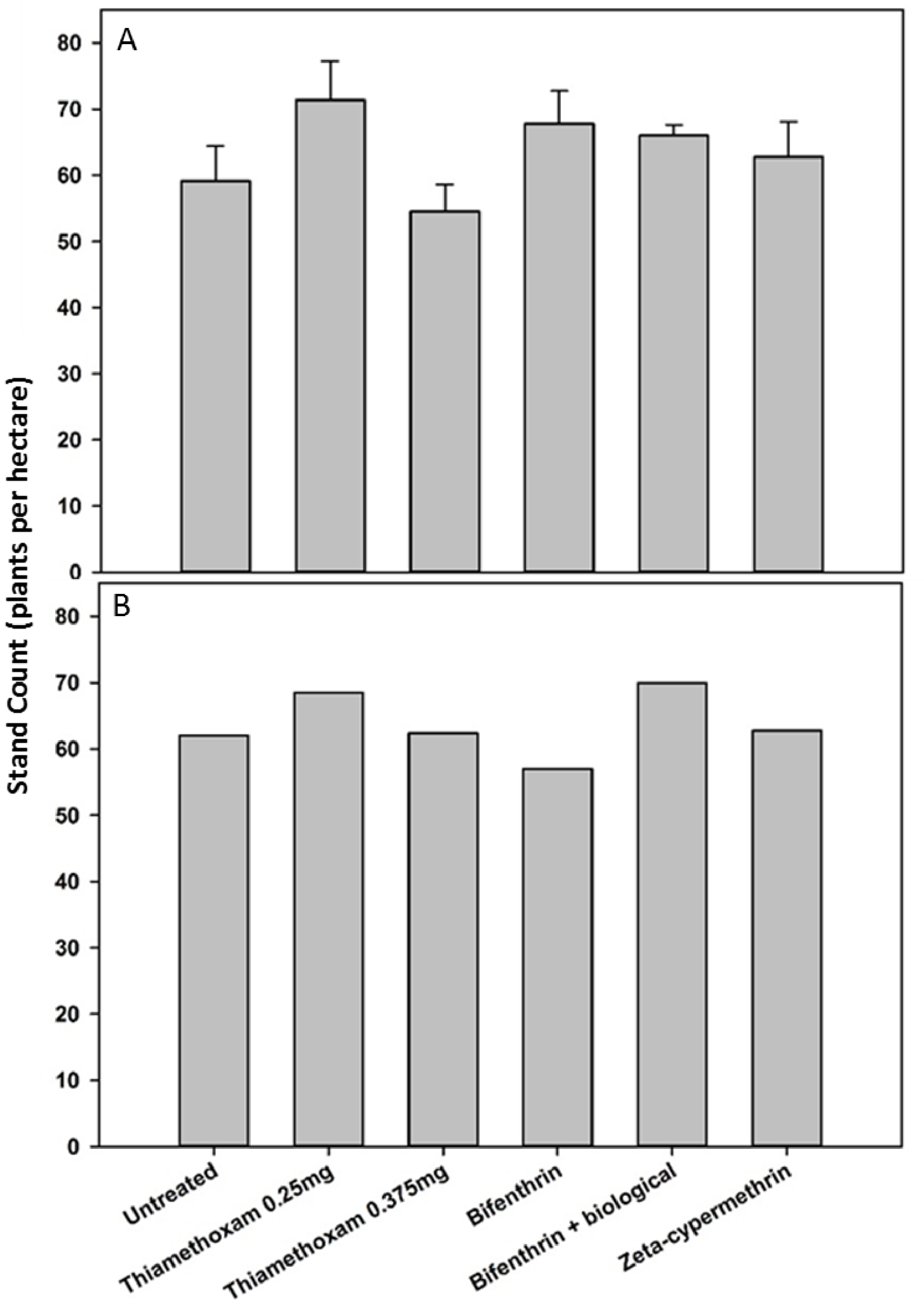

A
B
Stand Count (plants per hectare)
80
70
60
50
40
30
20
10
0
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 5.

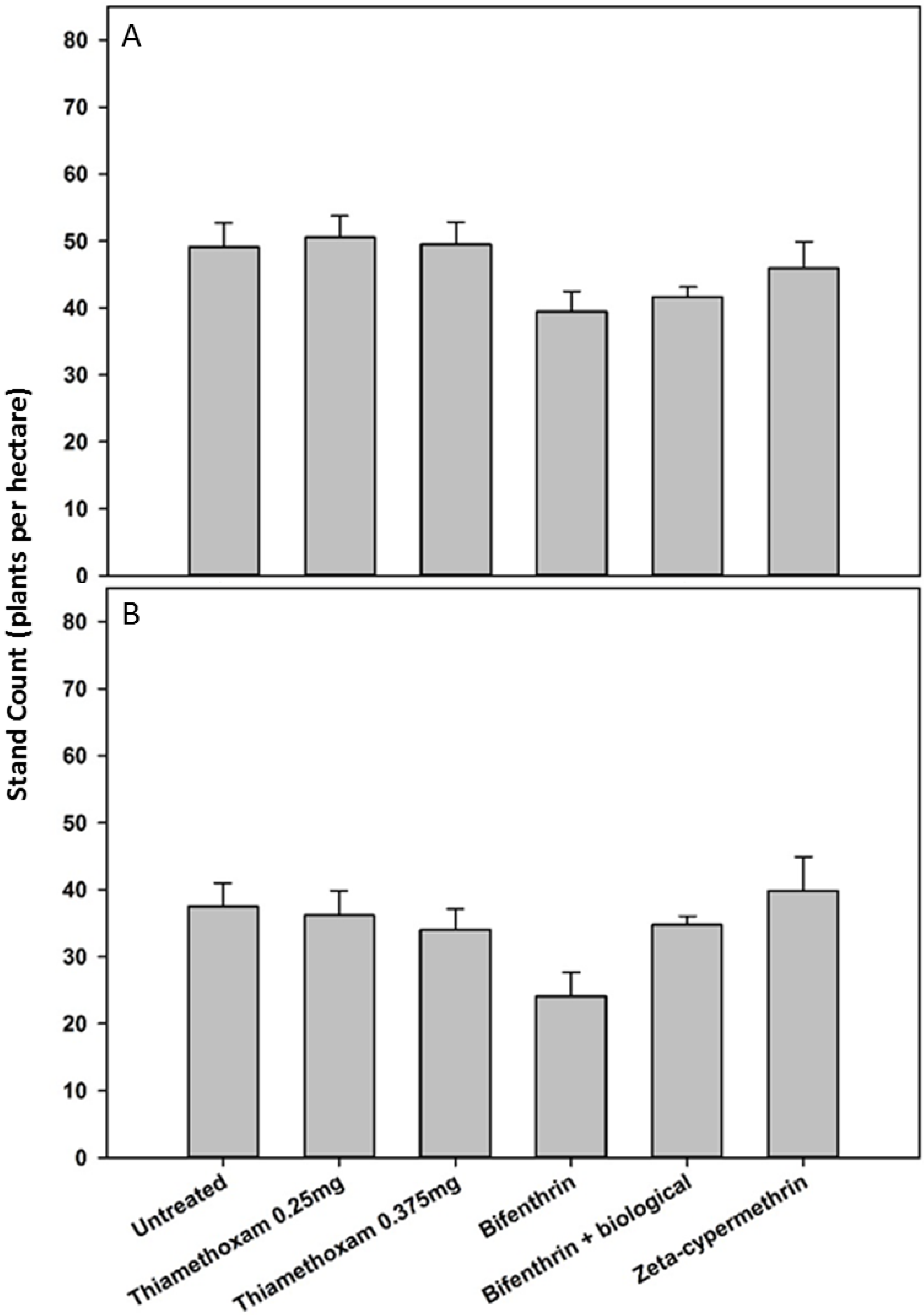

A
B
Stand Count (plants per hectare)
0
10
20
30
40
50
60
70
80
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 6.

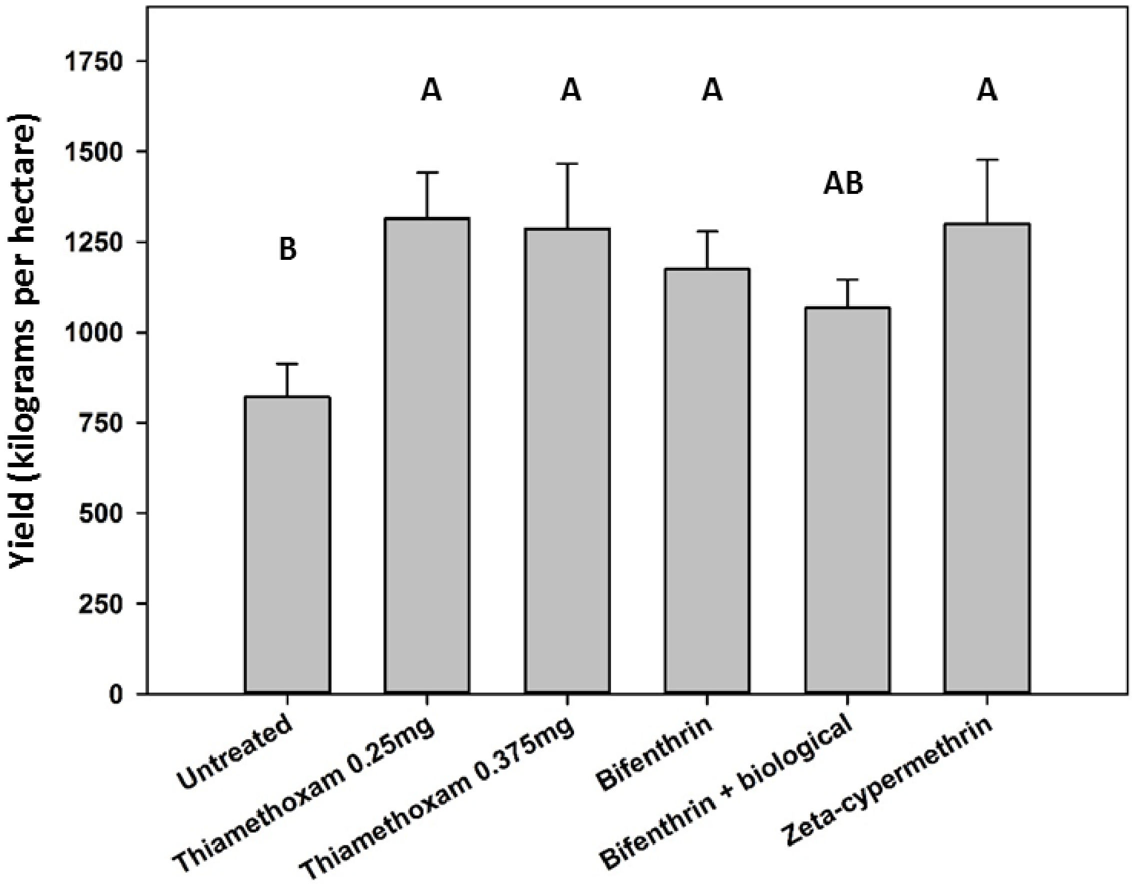

Yield (kilograms per hectare)
1750
1500
1250
1000
750
500
250
0
B
A
A
A
AB
A
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 7.

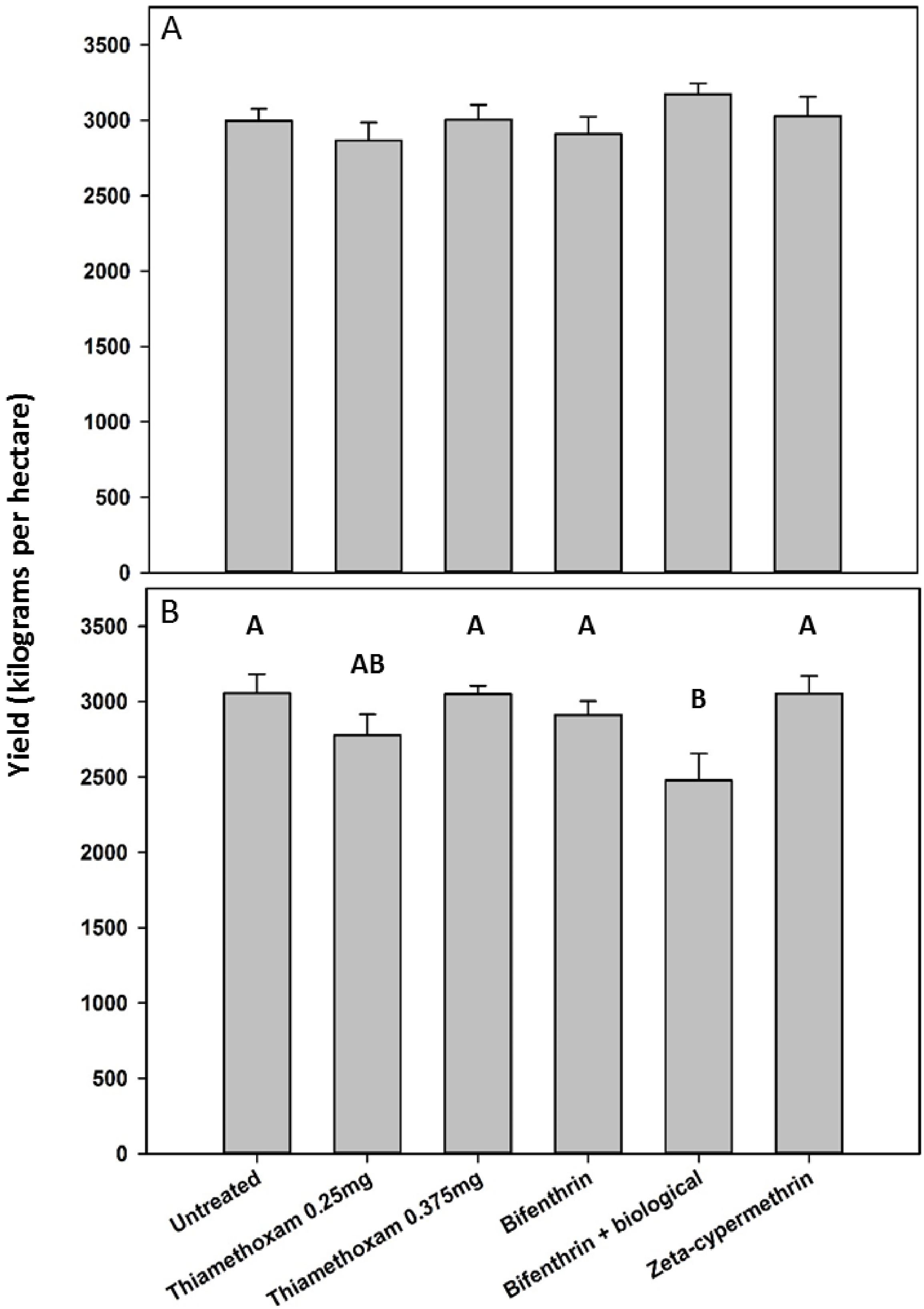
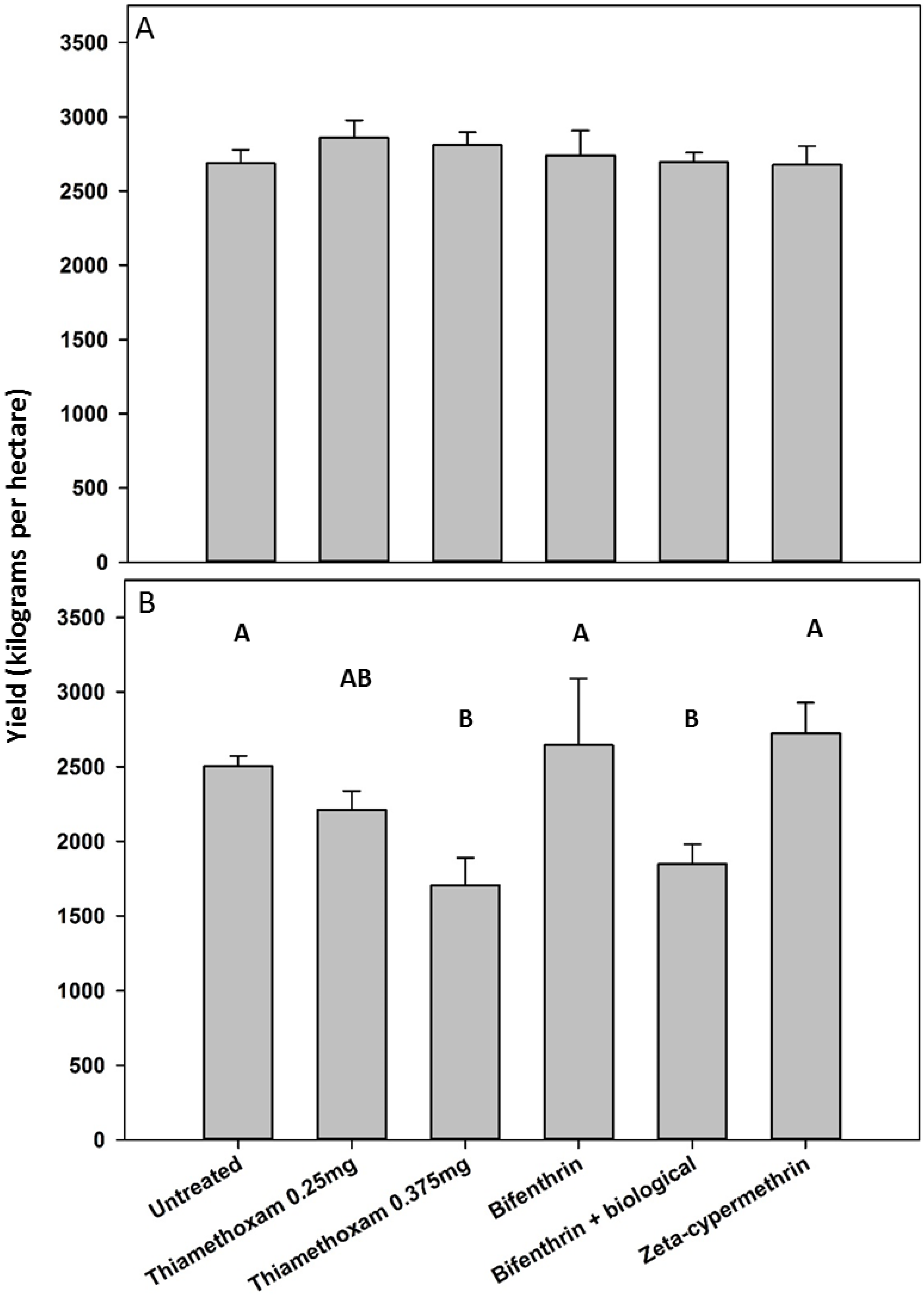

Yield (kilograms per hectare)
A
3500
3000
2500
2000
1500
1000
500
0
B
A
AB
A
A
B
A
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin

Figure 8.


A
B
Yield (kilograms per hectare)
0
500
1000
1500
2000
2500
3000
3500
A
AB
B
A
B
A
Untreated
Thiamethoxam 0.25mg
Thiamethoxam 0.375mg
Bifenthrin
Bifenthrin + biological
Zeta-cypermethrin