ABSTRACT

HURRY, JARETTE JERALD. Investigating Fungicidal Seed Treatment Impact on Soybean Stand and Yield with Evolving North Carolina Production Practices (Under the direction of Dr. Rachel A. Vann).

Soybean producers across North Carolina are planting soybeans at earlier planting dates as a mechanism to increase soybean yields. As producers shift to earlier planting dates it is important to understand whether fungicide seed treatments are needed to protect soybean stand and yield. There has been previous research conducted in North Carolina evaluating fungicide seed treatment, but that research focused on later planting dates. Two experiments were conducted in 2019, 2020 and 2021 across various North Carolina environments to determine the impact of fungicide seed treatments on soybean stand and yield.

The first study focused on planting date, soybean maturity group, and fungicide seed treatment impact on soybean stand and yield. Experiments were conducted from 2019-2020 at four sites across North Carolina with planting dates ranging from late-March to mid-June using maturity group III, IV, and V, treated with a range of commercially available fungicide seed treatment compared to untreated controls at each environment.

Soybean stand was protected with the use of fungicide seed treatment however this was variable across environment and planting dates. There was a significant increase in soybean stand when used on maturity group 5. Fungicide seed treatment protected yield at 50percent of the environments in this study and provided considerable yield protection at planting dates mid-May and earlier.

The second study was unique as it was the result of the North Carolina Soybean On-Farm Trialing (OFT) Program which was initiated in 2020 as a collaborative effort between N.C. Cooperative Extension and the NC Soybean Producers Association to conduct on-farm research

in strip trials that synergizes research being conducted in small plots by the NC State Soybean Extension program. In 2020 and 2021, the OFT program investigated the value of using a fungicide seed treatment in 18 diverse production environments across North Carolina.

Across environments, fungicide seed treatment affected soybean stand variably, but on average, the use of a fungicide seed treatment protected stand by 9,187 plants/A. On average, fungicide seed treatment protected soybean yield by 1.3 bu/A. No interaction between planting date and seed treatment on soybean stand or yield was observed in this study. The results indicate that fungicide seed treatment can significantly protect yield in North Carolina.

Investigating Fungicidal Seed Treatment Impact on Soybean Stand and Yield with Evolving North Carolina Production Practices

by
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BIOGRAPHY

Jarette Hurry, son of Gerald Hurry and Bridget King, was born on March 4th in Arlington, Virginia. In the Spring of 2009, he graduated from Northwest Guilford Highschool in North Carolina. The following fall, he began attending the College of Agriculture and Environmental Sciences at North Carolina Agricultural and Technical State University. He graduated from North Carolina Agricultural and Technical State University in December of 2013 with a Bachelor of Science in Environmental Science. In the spring of 2014, he began his career with North Carolina Cooperative Extension as an Agriculture Agent in Bertie County. In the fall of 2017, he began taking graduate courses as a non-degree student at North Carolina State University, and in 2019 he was admitted into the Graduate school, where he began to pursue a Master of Science degree in Crop Science under Dr. Rachel A. Vann. Jarette served the citizens of Bertie County for seven and a half years before meeting his wife, Nettie, and moving to Pennsylvania in 2021. He continued his career in Extension as an Agriculture Agent in Frederick County with University of Maryland Extension for a short time before transitioning into his current role as a Technical Agronomist with Bayer Crop Science.

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ABSTRACT

Producers across the state of North Carolina are planting soybean at earlier planting dates as a mechanism to increase yield. As producers shift to earlier planting dates, discussion developed regarding whether fungicide seed treatments are needed at earlier planting dates to protect soybean stand and yield. Experiments were conducted from 2019-2020 at four sites across North Carolina. The locations were selected to represent a range of geographies and growing conditions commonly encountered in North Carolina soybean production. Planting dates evaluated included, early -April, mid to late April, mid-May, and mid-June. Maturity groups evaluated included three, four, and five. The seed treatments included in this study represent a range of the commercially available fungicide treatments and the various fungicidal seed treatments were compared to a nontreated control in each environment. Fungicide seed treatment impact on soybean stand was variable across environment, with considerable stand protection from using treated seed in one environment at the earliest planting date. Soybean maturity group also impacted the value of a fungicide seed treatment, which is likely a result of differing varietal resistance packages among the soybean maturity groups used in this study. Fungicide seed treatments provided considerable yield protection at planting dates mid-May and earlier. Results across these environments emphasize the variability in which fungicide seed treatment can protect soybean stand and yield across planting dates and environments

NOMENCLATURE

Seed treatment, stand, soil moisture, planting date, maturity group, yield

KEY WORDS

Soybean, *Glycine max* (L) Merr.; Pythium spp., Fusarium spp., Rhizoctonia solani and Phytophthora spp.

INTRODUCTION

Soybean [Glycine max (L.) Merr.] is a vital crop for North Carolina producers. Soybean is the largest acreage row crop planted in North Carolina with 1,690,000 acres planted in 2022 (USDA Nass, 2022c). Soybean has numerous uses including human consumption, animal feed, biofuels, and industrial products (Raghuvanshi, 2010; Warrington et al., 2015). North Carolina has a significant livestock industry with poultry and swine production ranking second and third respectively in the US (USDA NASS, 2021a&b). The high volume of livestock creates a significant demand for soybean, driving producers to seek higher yields to meet this ever-growing demand.

North Carolina has a diverse geography that encompasses a variety of soil types, crop rotations and weather conditions. Soybean is the most flexible row crop with regards to planting date in the region, making it an ideal crop for North Carolina and the Southeast USA (Hare et al., 2020; Morris et al.,2021). Recent updates to the North Carolina soybean planting date recommendations now indicate the optimum planting period in this state is April 20-May 20, which is a shift in earlier planting dates historically used in the state (Vann, 2023).

It is well known through many years of research that planting date is a critical factor affecting soybean development and subsequent yield (Zhang et al., 2010). Recent research from North Carolina has shown planting date coupled with optimal maturity group selection are critical factors for soybean yield in the state (Morris et al.,2021). Soybean yields can be optimized by using several maturity groups due to the diversity of cropping systems in North Carolina (Morris et al.,2021). Maturity group V and VI have been identified as the optimal maturity groups for normal planting dates across North Carolina based on recent maturity group models (Mourtzinis and Conley, 2017). Cultivars from maturity groups III–VII are also grown by North Carolina soybean producers in an effort to increase soybean yield (Salmeron et al., 2014). A recent study found that in high yield environments, early April planting dates achieved the highest yields (Morris et al., 2021). Additionally, Maturity group III and IV provided the highest yields when planted before mid-May in high yield environments. The same study found that mid-April through mid-May planting dates resulted in the highest yield for low yield environments with maturity groups V through VII (Morris et al.,2021).

Eighteen years of data from the NC soybean yield contest has shown producers are shifting to earlier maturing varieties; mirroring Mid-South USA producers as a means to increase yield and reduce risk (Mengistu and Heatherly, 2006; Vann et al.,2021). As producers have shifted to earlier soybean planting dates, the use of fungicide seed treatments has increased (Esker and Conley, 2012). Early planting dates can expose seedlings to diseases that potentially reduce stands and delay emergence (Hamman et al., 2002). Major pathogens known to reduce seedling emergence in soybean include Pythium spp., Fusarium spp., Rhizoctonia solani and Phytophthora spp. (Dean 2018). Fungicide seed treatment research across the United States has shown no yield increase when compared to the nontreated control (Mourtzinis, Krupke, et al., 2019). Furthermore, a study evaluating the effects of fungicidal seed treatment on soybean found yield increases were only observed in 3 of 16 site years (Schulz and Thelen 2008).

A similar study conducted from 2014-2016 in South Dakota conflicts with observations from (Schulz and Thelen 2008) finding fungicide seed treatments increased soybean yield in 23 out of 32 instances; concluding that fungicide seed treatments increased soybean yield independent of planting date and are beneficial to South Dakota soybean producers (Nleva et al., 2020). This study only evaluated yield and did not investigate the economic impact fungicide seed treatment has on the cost of soybean production.

In another study, it was found that soybean fungicide seed treatments provided partial return over untreated soybean seed in a three-year study in Arkansas (Poag et al., 2005). Fungicide treated soybean seed enhanced profitability by an average of $17.69/A over untreated soybean seed making the input cost of $3.50/A for a fungicide seed treatment a minimal cost of overall soybean production (Poag et al., 2005)

A study in Michigan failed to find an interaction between planting date and seed treatment (Siler et al., 2022). The use of seed treatment did improve soybean stand at one location however yields were not improved over the control. Another study had similar findings, reporting that seed treatment did not consistently increase yield, although soybean stand was improved over controls in some environments (Rossman et al., 2018). Additional studies evaluating the effect of seed treatment on soybean yield did not find an interaction between planting date and seed treatment (Cox et al., 2008; Vosberg et al., 2017).

The objective of this study was to evaluate the impact of fungicide seed treatment on soybean stand and yield across the diverse maturity groups and planting dates used in North Carolina.

MATERIALS AND METHODS

Experiment Sites and Management

Experiments were conducted over two soybean growing seasons (2019 and 2020) at two sites across North Carolina annually. The combination of year and location comprises an environment. These locations were selected to represent a range of geography and growing conditions commonly encountered by soybean producers in NC. Plot size was 25 ft. by five ft. Plots were planted on 15-inch row spacing and a seeding rate of 120,000 seeds/A.

Treatment Description

The experiment was designed in a split-split plot design with the main plot as planting dates, sub-plot as maturity group, and sub-sub plot as seed treatment (Table 2). There were four to six replications per treatment combination depending on space availability at each environment. In 2019, three planting dates were targeted from late-March through mid-May (Table 3). In 2020, four planting dates were targeted from early-April through mid-June (Table 3). These planting dates were selected to target ultra-early planting situations (before mid-April), early planting dates (mid to late-April), moderate full season soybean planting dates (mid-May), and double crop soybean planting dates behind small grains (mid-June). Three soybean maturity groups were evaluated annually (maturity group III, IV, and V). In 2019 the varieties included: maturity group III (Show me Soy: 3901C), maturity group IV (MO4901D GT), and maturity group V (NC-Miller). In 2020 the varieties included: maturity group III (Asgrow 35X9), maturity group IV (Asgrow 45X8), and maturity group V (Asgrow 53X9). These maturity groups were selected because growers in North Carolina using earlier planting dates are generally interested in using an earlier maturing variety at these planting dates. The seed treatments selected for inclusion in this study represent a range of the commercially available fungicide treatments at the time of study employment (Table 2.). The various fungicide seed treatments were compared to a non-treated control in each environment. In 2019, all treated seed included Cruiser (Thiamethoxam) insecticide seed treatment to ensure consistency across the various seed treatments.

Data Collection

Soybean emergence was visually assessed across the main factor (planting date) in individual environments daily after planting to determine the number of days needed for soybean germination across planting dates. Soil temperature and soil moisture were captured at planting using a FieldScout TDR 350 soil moisture meter calibrated to measure soil moisture and soil temperature at a 12 cm depth. Average of five soil moisture and five soil temperature measurements were obtained at each main plot across all environments at planting. Soybean stand was measured between soybean growth stage V1-V3 by placing a meter stick randomly beside rows two and three of each subplot and counting the number of plants. Two measurements were taken per subplot and then averaged and converted into a population per acre. Plots were harvested timely using a small-plot combine and yields were adjusted to 13% moisture content.

Statistical Analysis

Analysis of variance was conducted using PROC GLIMMIX in SAS 9.4 (SAS Institute Cary, NC). Planting date, maturity group, seed treatment, environment and their interactions were considered fixed effects and replication nested within environment and planting date and maturity group nested within replication and environment were considered random factors. Degrees of freedom were calculated using the Kenward Rodger method and Tukey adjustment was used to adjust for multiple comparisons at $P \leq 0.05$. Data was scouted for normality and data transformations were not needed. When deciding about combining data over environments or presenting results by individual environments, the highest-order interaction was used to determine the appropriate method for data presentation.

RESULTS AND DISCUSSION

Seedling Disease Pressure

Seeding disease pressure was not evident across research sites, however it is assumed based on results that some disease pressure was present and reduced plant vigor. Conditions of the planting environment can have a significant impact on seed performance. Soybean plant vigor can be reduced by early planting dates which can expose seedlings to diseases that potentially reduce stands and delay emergence (Hamman et al., 2002). Major pathogens known to reduce seedling emergence in soybean include Pythium spp., Fusarium spp., Rhizoctonia solani and Phytophthora spp. (Dean 2018). The presence of pathogens in soil can have a negative effect on emergence and delay emergence (Hamman et al., 2002).

Soybean Days to Emergence

Several environmental factors may influence the time of emergence of soybeans seed (Hatfield et al.,1974). As soybean seeds make the transition from a dormant state to a metabolically active state, soil temperature at planting time is crucial (Horst 2003). Regardless of soil moisture, days to emergence decreased as soil temperature increased with the exception of Beaufort 2019 (April) and Rowan 2020 (late-June) (Table 3). Soybeans emerged within 11 days or less of planting in 2019 and within 10 days or less of planting in 2020 regardless of planting date (Table 3). In 2019 the greatest number of days to emergence was observed at the earliest planting date (late-March) in Beaufort and Sampson. Similarly in 2020 the greatest number of days to emergence were observed at the earliest planting date (late-March) in Beaufort and Rowan. As expected, the lowest soil temperatures were recorded at both early planting dates at

Beaufort 2020 and Sampson 2019 resulting in the greatest delay in emergence (Table 3). Planting conditions at early planting dates tend to be more adverse due to cooler soil and air temperatures and often abundant soil moisture resulting in delayed seed emergence (Cox et al., 2008) Alternatively, the fewest days to emergence was five days after planting in some environments (Table 3). As planting is delayed there is generally a decrease in the number of days to emergence (Morris et al.,2021). This is likely due to the increase in soil temperature at later planting dates creating a more favorable condition for emergence (Morris et al.,2021). An increase in soil temperature was observed in this study as planting date was delayed (Table 3). Previous research found that the optimum temperature for soybean germination is 82 degrees Fahrenheit (Tyagi et al.,1983) and additional research found that the optimum temperature range for soybean emergence is between 75- and 90-degrees Fahrenheit (Egli et al., 1973).

Fungicide Seed Treatment Product.

Four to five fungicide seed treatments were compared to an untreated control annually (Table 2). To ensure we could combine over fungicide seed treatment for our analysis, the untreated control was removed to determine the impact of the various fungicide seed treatments on soybean stand and yield. Across sites, fungicide seed treatment products generally did not impact soybean yield or stand and therefore for the remaining analyses the impact of fungicide seed treatment on stand and yield was combined over fungicide seed treatment to compare to the untreated control (Table 5). In general, fungicide seed treatments were selected for inclusion in this study that had multiple modes of action and therefore it is unsurprising that specific fungicide seed treatment did not impact yield. Comparisons of fungicide seed treatments in field settings are often inconsistent, somewhat due to low disease pressure. (Urrea et al.,2013). In previous research, it was reported that responses to fungicide seed treatments in one year of a study but did not have differences in stands compared with the untreated control in the year prior (Bradley2001 et al.,). (Poag 2005 et al.) reported that metalaxyl was the most economically effective seed treatment; however, in a subsequent study using metalaxyl was not better than the control, but the broad-spectrum seed treatments were effective (Popp et al,.2010). All the fungicide seed treatments included in this study contained the active ingredient metalaxyl or mefenoxam with the exception of Emesto Silver (Table 2). Metalaxyl and mefenoxam are PhenylAmides FRAC Code group 7(FRAC 2022) that have specific control of Oomycetes which is important in the management of Pythium spp. and Phytophthora spp. (Cocker 2010 et al., Knezevic 2017 et al.,). While the other broad spectrum active ingredients included in the other seed treatments provide control of other soil borne pathogens such as Fusarium spp. and Rhizoctonia solani (Knezevic 2017 et al.,)

Soybean Stand.

The highest order interactions for soybean stand were planting date and environment and maturity group and seeding rate (Table 4).

Planting date and fungicide seed treatment interacted with environment to affect soybean stand (Table 4, P=0.006). Therefore, the impact of these factors on soybean stand is explored within each specific environment.

At the Beaufort 2019 environment, there was a large impact of fungicide seed treatment on soybean stand at the early and late-April planting dates, but not at the mid-May planting dates (Figure 1). At the early-April planting date, stand was protected by approximately 30,000 seeds/A from the use a fungicide seed treatment. At the late-April planting date, stand was protected by approximately 10,000 seeds/A.

At the Beaufort 2020 and Rowan 2020 environments, there was no impact of fungicide seed treatment on stand across planting dates (Figure 1).

At the Sampson 2019 environment it was interesting to note that the non-treated seed actually increased stand at the late-April and mid-May planting dates compared to the treated seed (Figure 1). There was no impact of fungicide seed treatment on stand at the early-April planting date at this environment (Figure 1).

Results across these environments underscore the variability in which fungicide seed treatment can protect soybean stand across planting dates. Although planting date was not as robust in a North Dakota study, soybean treated with fungicide seed treatment had significantly improved stands over the non-treated seed across sites in one year of a two-year study (Bradley 2008). A study conducted in New York found that fungicide seed treatment improved soybean stand at mid-May planting dates. This may be due to extended periods of wet soil conditions potentially leading to a more conducive environment for soil borne pathogens (Cox and Cherny 2011). Stand analysis from a study conducted in four Midwest states and Canada evaluating soybean stands found fungicide seed treatment affected early-season plant stands in each data set except for the location in Indiana (Gaspar et al., 2017). Interestingly enough, the Indiana location had a late-May planting date compared to the early-May plating dates at the other environments in this study. This correlates well with what we found in Beaufort 2019 when fungicide seed treatments protected stand at early planting dates but not at mid-May planting dates. Seed treatments are more likely to increase soybean stand over untreated soybean seed when planting date occurs before May 10th (Vossenkemper, et al., 2015) This study also found that seed treatments increased early season soybean stands by 4,200 plants/A compared with non-treated soybean seed.

Maturity group and fungicide seed treatment interacted to impact soybean stand (Table 5). In the maturity group III and IV varieties, there was no impact of fungicide seed treatment on soybean stand (Figure 2). However, fungicide seed treatment significantly protected stand in the maturity group V varieties (Figure 2), providing about 10,000 plants/A of stand protection.

Selection of soybean cultivars genetically resistant to disease is regarded as the best means of crop protection and this method is often the most economical and efficient option (Morton 1992). Fungicide seed treatments protect soybean seedlings from Phytophthora spp. prior to the onset of the tolerance mechanism present in tolerant cultivars (Morton 1992). Previous research demonstrated the potential benefits of fungicide seed treatment with higher plant emergence, plant height, fresh whole plant weight, and root weight for soybean cultivars with partial resistance to Phytophthora spp. (Dorrance & McClure 2001). Other research found soybean seed treatments can be a cost-effective component of soybean production however environment and cultivar are important factors that need to be considered (Esker and Conley 2012). A study in North Dakota found that soybean fungicide seed treatments could prevent stand losses, although some cultivars may not respond to seed treatments in the same manner (Bradley 2008). It is likely that the difference in response among maturity groups to seed treatment in this study is a result of differing levels of disease resistance among the maturity groups evaluated. It is interesting to note that maturity group 5 varieties should be more widely used in North Carolina and may generally be perceived to have more robust seedling disease tolerance in our environment than an earlier maturing variety

Soybean yield

Fungicide seed treatment and environment interacted to impact soybean yield (Table 5). At the Beaufort and Sampson 2019 environments, fungicide seed treatment protected yield by 6-

7 bu/A (Figure 3). This interaction could be due to six days of low temperatures being 10 degrees Fahrenheit cooler than average following the late- March planting date (NOAA 2022). There was no impact of fungicide seed treatment on yield at the Beaufort 2020 and Rowan 2020 environments (Figure 3). In 2020 both sites received adequate timely rainfall through the growing season leading to adequate soil moisture (NOAA 2022). It is well known that soil moisture stress throughout the growing season can results in reduced leaf area, leaf duration, number of seed per pod, crop growth rate, and the number of pods per plant (Pandey et al., 1984; Cox and Jolliff 1986). Under such ideal growing conditions, regarding soil moisture, soybean plants likely over-came any of the aforementioned yield reduction components related to soil moisture stress and compensated for any early season stress. It was also observed in previous work that environment was a major factor in determining when soybean treated with fungicide seed treatments produced a greater yield than non-treated trials (Bradley 2008).

Planting date and fungicide seed treatment also interacted to impact soybean yield (Table 5). At the early-April, mid-April, and mid-May planting dates, fungicide seed treatment protected yield but did not affect yield at the mid-June planting dates (Figure 5). Earlier planting dates typically results in soil conditions that are cooler and wetter where a fungicide seed treatment could provide protection against early season diseases caused by Pythium spp., Phytophthora sojae, Fusarium spp., and Rhizoctonia solani (Esker and Conley 2012). Depending on the year the diseases rank second to sixth in suppressing soybean yields across the U.S. (Wrather and Koenning 2009). Research in Michigan found that soybean fungicide seed treatment only protected yields at 3 of the 16 site years throughout the trial (Schulz and Thelen 2008). However, one Michigan location in 2004 and 2005 experienced yield increase from the use of fungicide seed treatment over the untreated control. Both years this location had the earliest planting dates in the study at late- April and early-May respectively. These two locations experienced below normal temperature as well as above average precipitation which may have caused more early soil-borne disease pressure (Schulz and Thelen 2008).

Planting date and maturity group interacted with the environment to impact yield (Table 5), therefore the impact of these production practices on soybean yield is discussed for each specific environment. At the 2020 environments, we observed the general trend we would expect in that yield declined as planting date was delayed (Figure 5). At the Beaufort 2020 environment, the Maturity group III variety maximized yield at the earliest planting date and there were less pronounced differences in soybean yield across maturity groups as planting date was delayed. The maturity group V variety performed more optimally at the Sampson 2020 environment at the earlier planting dates and there again was minimal differences in yield across maturity groups at the later planting dates (Figure 5).

Interestingly in 2019, the Maturity group IV was the highest performer across both environments at the early-April and late-April planting dates (Figure 5). The Maturity group III variety did better at later planting dates. The 2019 earliest planting dates were slightly earlier than those in 2020, which may explain why we did not see a linear decline in yield as planting date was delayed in 2019. Previous literature has documented a yield penalty of planting before mid-April at many environments in North Carolina (Morris et al., 2021).

The results of this study align with previous studies in North Carolina. In this study across maturity groups soybeans typically emerged within 11 days or less of planting in 2019 and within 10 days or less of planting in 2020 regardless of planting date. The greatest number of days to emergence was observed at the earliest planting date late- March in Beaufort and Sampson in 2019. These results align with findings from Morris et al. (2019). At the earliest planting date in that study, which was mid- March, soybean required 26 days to emerge. Planting conditions at early planting dates tend to be unfavorable due to cooler soil and air temperatures and adequate soil moisture resulting in delayed seed emergence (Cox et al., 2008). Alternatively, as planting was delayed there was a decrease in the number of days to emergence with the fewest days to emergence being 5 days in Rowan 2020 at a late-June planting date. Once again, this result correlates with (Morris et., al 2021) finding that as planting was delayed in that the fewest days to emergence was reduced to 4 days in some environments at June and July planting dates. This is likely due to higher air temperatures that resulted in warmer soil temperatures at or close to the optimum temperature for soybean germination of 82 degrees Fahrenheit (Tyagi et al.,1983).

Regardless of environment and fungicide seed treatment, higher plant stands were achieved with maturity group V verses maturity group III and IV. Maturity group V treated with fungicide seed treatment did achieve higher stands than non-treated maturity group V. (Morris et al.2021) had similar findings realizing that later maturing cultivars, maturity groups ≥V achieved higher plant stand regardless of environment across planting dates and seeding rates. This could be the result of later maturity groups being more adapted to the Southeast U.S. (Morris et al.2021)

Conclusions

Soybean fungicide seed treatments can provide yield and stand protection however this is highly dependent on planting date and environment. Fungicide seed treatment protected yield at 50 percent of the environments in this study. Fungicide seed treatments provided considerable yield protection at planting dates mid-May and earlier in this study. Soybean fungicide seed treatment did not provide any yield protection at mid-June planting dates. Results across these environments emphasize the variability in which fungicide seed treatment can protect soybean stand and yield across planting dates and environments. The research solidifies our knowledge of fungicide seed treatments impact on stand and yield before mid-May planting dates and earlier. The results showing the significant increase in stand when using a fungicide seed treatment on a maturity group V merits further investigation.

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Table 1. Planting date by environment and soil type

Environment	Soil Type	Planting Date 1	Planting Date 2	Planting Date 3	Planting Date 4
Beaufort 2019	Cape Fear fine sandy loam	3/30	4/12	5/15	-
Sampson 2019	Norfolk loamy sand	3/30	4/11	5/13	-
Beaufort 2020	Cape Fear fine sandy loam	4/6	4/29	5/26	6/24
Rowan 2020	Lloyd clay loam	4/7	4/28	6/3	6/26

Table 2. Fungicide seed treatment common name and active ingredients investigated in research plots in 2019 and 2020.

Year	Fungicide Seed Treatment Common Name	Fungicide Active Ingredient
2019	Allegiance + Cruiser	Metalaxyl, (Thiamethoxam)
2019	Acceleron + Cruiser	Fluxapyroxad, Metalaxyl, Pyraclostrobin, (Thiamethoxam)
2019	Emesto Silver + Cruiser	Penflufen, Prothioconazole, (Thiamethoxam)
2019	Vibrance Trio + Cruiser	Fludioxonil, Mefenoxam,Sedaxane, (Thiamethoxam)
2019	CruiserMaxx + Vibrance	Fludioxonil, Mefenoxam, Sedaxane, (Thiamethoxam)
2020	Acceleron	Fluxapyroxad, Metalaxyl, Pyraclostrobin
2020	Obvius Plus	Metalaxyl
2020	Saltro+Vibrance Trio	Pydiflumetofen,Fludioxonil, Mefenoxam, Sedaxane
2020	Vibrance Trio	Fludioxonil, Mefenoxam, Sedaxane

Table 3. Planting date, soil moisture at planting, soil temperature at planting and days to soybean emergence across environments.

Environment	Planting Date	Soil Moisture at Planting	Soil Temperature at Planting	Days to Soybean Emergence
Beaufort 2019	3/30/19	29.4	72.9	11
	4/12/19	31.0	70.8	10
	5/15/19	21.3	81.6	6
Sampson 2019	3/30/19	13.0	57	11
	4/11/19	13.6	75.7	9
	5/13/19	7.6	82.2	7
Beaufort 2020	4/6/20	46.5	67.6	10
	4/29/20	23.1	72.1	8
	5/26/20	28.1	73.1	8
	6/24/20	34.6	85.9	6
Rowan 2020	4/7/20	51.3	72.0	10
	4/28/20	46.3	75.7	8
	6/3/20	33.7	83.3	5
	6/26/20	32.2	89.3	10

Table 4. Summarized ANOVA results for the impact of fungicide seed treatment product on soybean stand and yield across environments

Environment	Stand	Yield
	P>F	
Beaufort 2019	0.05	0.61
Beaufort 2020	0.16	0.44
Sampson 2019	0.89	0.83
Rowan 2020	0.77	0.87

Table 5. Summarized ANOVA results for the effect of fungicide seed treatment, planting date, maturity group, and environment and the relevant interactions on soybean stand and yield

Dependent Variable	Source	Combined (P>F)
Soybean Stand	Planting Date (PD)	0.0250
	Maturity Group (MG)	<0.001
	Seed Treatment (ST)	0.02
	Environment (E)	<0.001
	PD*E	0.008
	ST*E	<0.001
	PD*MG	0.045
	PD*ST	0.002
	MG*ST	0.02
	PD*PD	<0.001
	MG*MG	<0.001
	PD*ST*E	<0.001
	PD*PD*E	<0.001
	MG*MG*ST	0.02
Yield	PD	0.05
	MG	<0.001
	ST	<0.001
	E	<0.001
	PD*E	<0.001
	MG*E	<0.001
	ST*E	<0.001
	PD*MG	0.06
	PD*ST	0.05

Table 5. (continued)

	PD*PD	0.40
	MG*MG	<0.001
	PD*MG*E	<0.001
	PD*PD*E	0.002
	MG*MG*E	<0.001

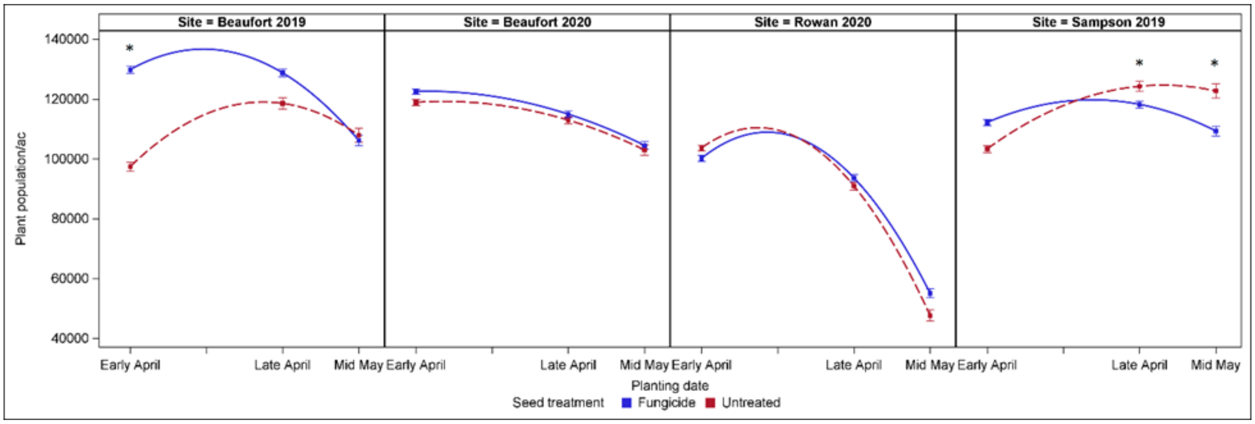

Figure 1. The impact of fungicide seed treatment on stand across planting dates and individual environments combined over maturity groups.

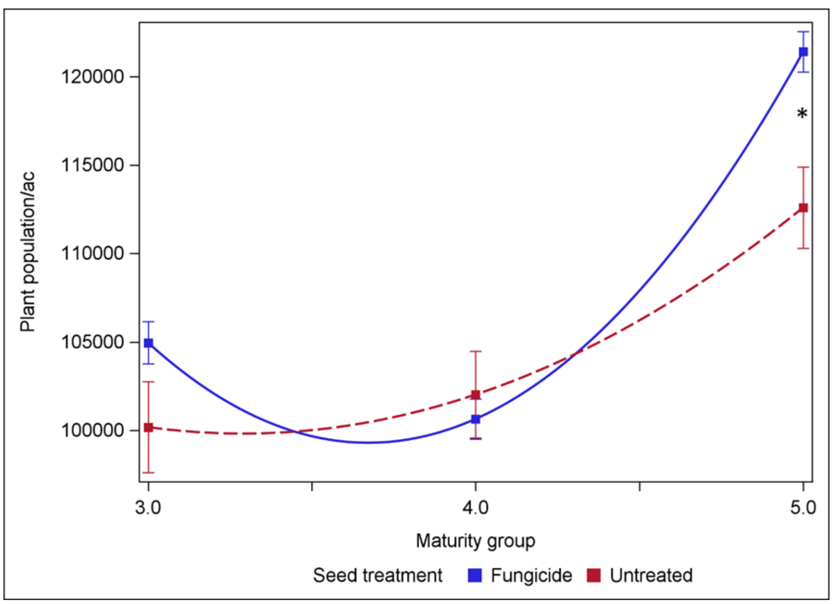

Figure 2. The impact of fungicide seed treatment on soybean stand across maturity groups combined over planting dates.

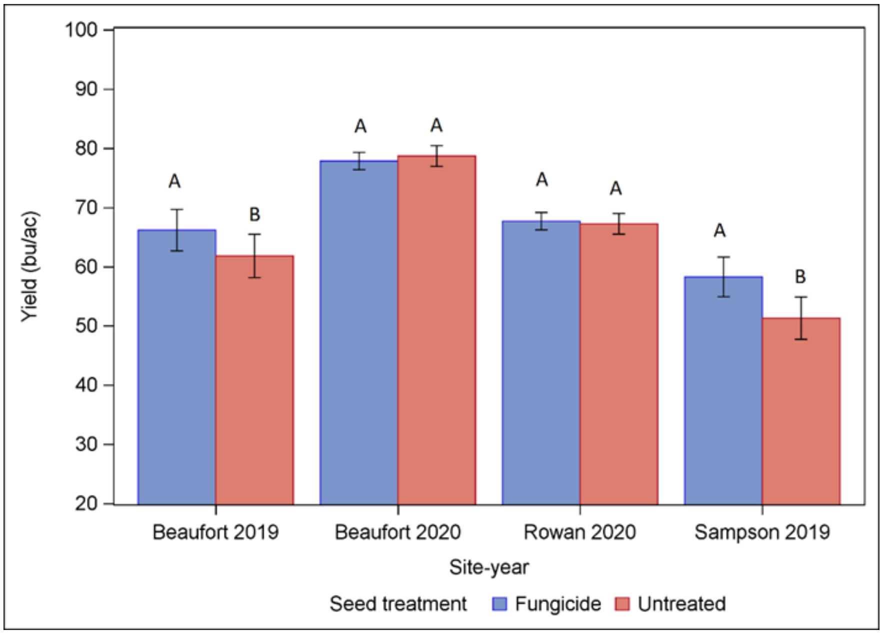

Figure 3. Fungicide seed treatment impact on soybean yield combined at maturity group at individual environments.

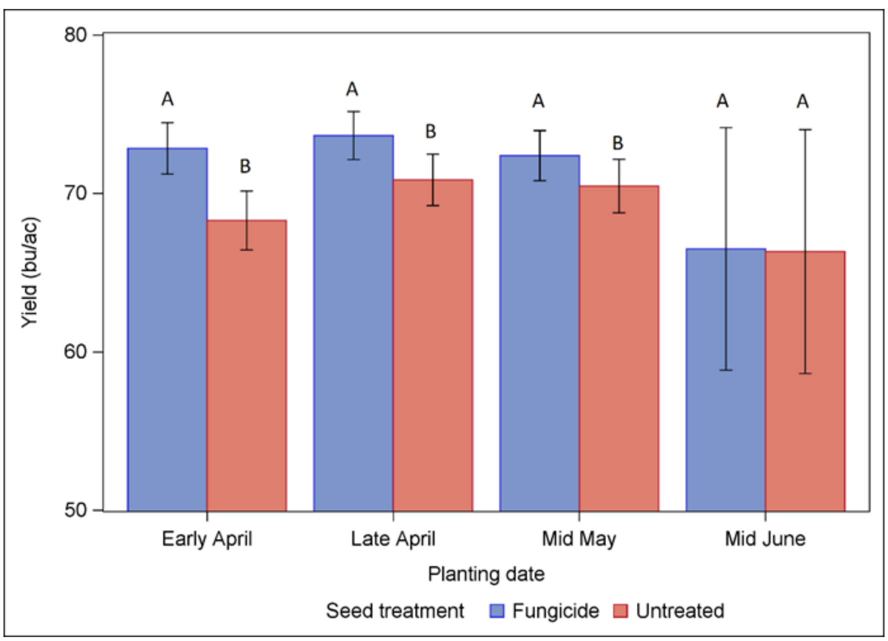

Figure 4. Seed treatment impact on yield in a combined analysis across environments

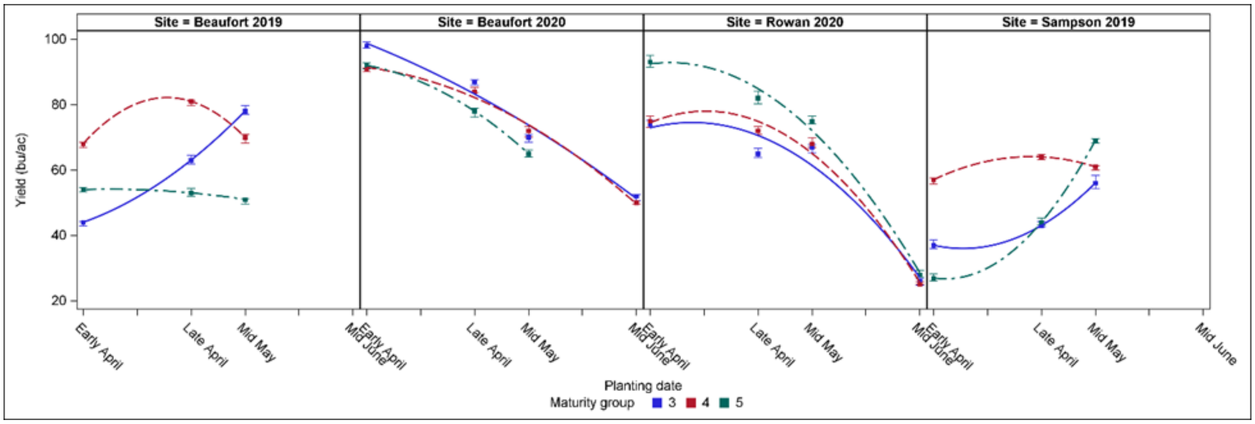

Figure 5. Soybean planting date and maturity group impact on soybean yield at individual environments.

CHAPTER 2
What is the Value of a Fungicidal Seed Treatment in North Carolina Soybean Production?

ABSTRACT

North Carolina soybean producers have shifted to earlier planting dates as a mechanism to increase soybean yields. As growers shifted to earlier planting dates soybean fungicide seed treatment usage has become more common. The NC State Soybean Extension program has been collaborating with the NC Soybean Producers Association and NC Extension Agents on a new initiative (OFT) where county agents work with local producers to run large strip-plot trials that complement data being generated from small plot research. In 2020 and 2021 the soybean OFT program focused on investigating the value of a fungicide seed treatment across the state. Experiments were conducted across 18 diverse production environments across North Carolina during that time period. Treatments included fungicide seed treatment compared to untreated seed. Data collected included soybean stand and soybean yield.

Fungicide seed treatment impacted soybean stand. The use of a fungicide seed treatment impacted stand variably, but when combined over environments, fungicide seed treated plots averaged 110,757 plants/A as opposed to untreated plots averaging 101,570 plants/A. When averaged across environments, fungicide seed treatment protected yield by 1.3 bu/A. As planting date was delayed yield decreased for both fungicide treated and untreated plots. Results from this trial indicate that fungicide seed treatments do provide protection of soybean yield and stand in North Carolina although protection provided may not provide a return on investment with current input prices on average.

NOMENCLATURE Seed treatment, stand, yield

KEYWORDS

Soybean, *Glycine max* (L) Merr,

INTRODUCTION

Soybean [Glycine max (L.) Merr.] is among the most economically important crops in the United States. (USDA-FAS 2021). North Carolina is the number one soybean producing state in the southeast with 1.69 million acres planted in 2021 (USDA-Nass 2021). Moreover, soybean make up the largest portion of row crops planted in North Carolina in 2021 (USDA-NASS 2021) with the majority of soybeans acres located in the coastal plain (NCSPA 2019). Soybean has many desirable uses, particularly soybean meal for animal feed (SoyStats,2022). Soybean meal is a popular feedstuff derived from soybean for swine and poultry diets because of its high protein content when compared to other plant-based protein sources (Shelton et al., 200; Subth et al.,2002).

Planting date is an important predictor of soybean yield (Mooers,1908). Optimal planting dates for soybean in North Carolina have been identified as April 20-May 20 in recent years (Vann, 2023). However, North Carolina producers have recognized earlier planting dates as a method to increase soybean yields (Vann et al.,2021). Analysis of NC soybean yield contest entries over 18-years from 2002-2019 verifies that producers are also shifting from later maturity groups to earlier maturity groups as an additional method to increase soybean yield.

Further analysis of 877 entries in the NC soybean yield contest indicated that planting date and maturity group were the strongest predictors of high soybean yield in North Carolina. There was a definite trend in yield increase related to earlier planting and earlier maturity groups, with maturity group ≤ IV providing a yield advantage over later maturing varieties, and mid-May and earlier planting dates often leading to yield advantages (Vann et al.,2021; Morris et al.,2021). Additional studies over an 11-year span from 2006-2017 suggest that planting soybean 12 days earlier across the USA could have resulted in 10 percent greater soybean yield (Mourtzinis, Specht, et al.,2019; Knott et al., 2019). Increased yields can be achieved from earlier planting as this allows for longer vegetative growth prior to moving into reproductive development. Longer vegetative growth allows for a greater number of nodes to form prior to flower initiation increasing the probability of more fruiting sites per plant, and ultimately, more pods per plant (Bastidas et al., 2008). Furthermore, early planting allows soybeans to potentially reach full canopy earlier in the season and capture more sunlight (Salmeron et al., 2015).

Along with shifts in planting date and maturity group there has also been an increase in fungicidal seed treatment use on soybean. (Esker and Conley, 2012; Vann et al.,2021). The extended period of soybean planting in the southern U.S. contributes to potential for greater disease incidence due to favorable soil conditions. (Bandara et al.2020). The soil environment can impact the incidence of seedling diseases that result from extended periods of excessive soil moisture and planting into soils early in the season when marginal temperatures occur (Bowers et al .1999; Bandara et al.2020). Between 1996 and 2016, the estimated total economic losses due to soybean diseases in the U.S. was $95 billion (Bandara et al.2020). Among various yield-limiting disease categories, seedling diseases are of great importance. An array of soilborne pathogens can cause soybean seedling diseases, the major pathogens include Pythium spp., Fusarium spp., Rhizoctonia solani and Phytophthora spp. (Dean ,2018). Recent soybean seed treatment research summarized across the United States showed that on average there was no increase in yield from the use of a fungicidal seed treatment compared to the untreated control (Mourtzinis, Krupke, et al., 2019).

However, recent research conducted in North Carolina showed increased yield protection from fungicidal seed treatment usage at earlier planting dates, with 9.1, 5.9, and 2.4 bushel per acre yield protection compared to the untreated control with March, April, and May planting dates, respectively (Vann., 2020). An extensive data set over an 18-year period in North Carolina found that Fungicidal seed treatment usage was a moderately strong predictor of yield and it led to yield protection when used with earlier maturity groups (Vann et al., 2021)

In 2011 and 2012, 58 large strip plots with early and normal planting dates containing a full season cultivar maturity group 3.4-4.1 and short season cultivar maturity group 2.5-3.4 with and without fungicide seed treatments were conducted in Illinois and Indiana. This study found that cultivar maturity and seed treatment had a significant effect on grain yield. Seed treatments increased soybean yield by 1.2 bu/A and full season cultivars increased soybean yield by 3.8

bu/A. Seed treatments are more likely to increase soybean stand over untreated soybean seed when planting date occurs before May 10th (Vossenkemper, et al., 2015) This study also found that seed treatments increased early season soybean stands by 4,200 plants per acre compared with non-treated soybean seed. Earlier planting dates typically results in soil conditions that are cooler and wetter where a fungicide seed treatment could provide protection against early season diseases caused by Pythium spp., Phytophthora spp., Fusarium spp., and Rhizoctonia solani (Esker and Conley, 2012). Depending on the year the diseases rank second to sixth in suppressing soybean yields across the U.S. (Wrather and Koenning, 2009). In Michigan (Schulz and Thelen 2008) found that fungicide seed treatment only protected yields at 3 of the 16 site years throughout the trial. However, one Michigan location in 2004 and 2005 experienced yield increase from the use of fungicide seed treatment over the untreated control. Both years this location had the earliest planting dates in the study at late- April and early-May respectively. These two locations experienced below normal temperature as well as above average precipitation which may have caused more early soil-borne disease pressure (Schulz and Thelen 2008).

Currently the majority of soybean seed planted in North Carolina is not treated (Vann, Personal Communication), however as production practices shift to earlier planting and use of earlier maturing varieties, we need to understand the impact on soybean stand and yield. The objective of this research was to evaluate fungicide seed treatment effect on soybean yield and stand across diverse North Carolina environments to understand the influence on soybean stand and yield in the diverse production situations encountered across the state.

MATERIALS AND METHODS

North Carolina On-Farm Trialing Program

The North Carolina Soybean On-Farm Trialing (OFT) Program was initiated in 2020 as a collaborative effort between N.C. Cooperative Extension and the NC Soybean Producers Association. This program leverages the talent and resources that N.C. Cooperative Extension has at the local level to conduct on-farm research in strip trials that synergizes research being conducted in small plots by the NC State Soybean Extension program. This program amplifies the reach of the soybean checkoff by providing more touch points across North Carolina. Annually, the program runs on-farm research trials that complement the research being conducted in small-plot across the state. This was the first experiment conducted in the North Carolina On-Farm Trialing Program.

Experiment Sites and Management

Experiments were conducted in 2020 and 2021 across 18 locations in North Carolina. The combination of year and location comprises an environment. Environment descriptions are available in (Table 1). In 2020 the environments selected either AG 52X9 or AG 56X8 for variety use (Table 1). In 2021, AG59X9 was used (Table 1). Soybean varieties used in 2020 and 2021 are tolerant to the herbicides glyphosate and dicamba. Asgrow 52X9 is an indeterminate, maturity group 5.2 with average field tolerance to Phytophthora root rot, with gene specific susceptibility, above average tolerance to southern stem canker, sudden death syndrome, average tolerance to frogeye leaf spot, soybean cyst nematode resistance, and susceptibility to root knot nematode. Asgrow 56X8 is a determinate maturity group 5.6 with good field tolerance to phytophthora root rot with gene specific susceptibility, above average tolerance to southern stem canker, sudden death syndrome, and frogeye leaf spot, soybean cyst nematode resistance and resistance to southern root knot nematode. Asgrow 59X9 is a determinate maturity group 5.9

with average field tolerance to Phytophthora root rot, with gene specific susceptibility, above average tolerance to southern stem canker, sudden death syndrome, frogeye leaf spot, susceptibility to soybean cyst nematode and resistance to southern root knot nematode. These varieties were selected because they are widely grown across the state of North Carolina in our diverse production situations.

Treatment Description:

Treatments were arranged in a randomized complete block design with 3 to 5 replications at each environment depending on space availability. Treatments included fungicide seed treatment versus non-treated seed. The fungicide seed treatment was Vibrance TRIO (Syngenta USA) with the active ingredients Fludioxonil, Mefenoxam, and Sedaxane. The seed treatment was applied by the seed distributors using industry standard rates.

Data Collection

Soybean stand was measured between soybean growth stage V1-V3 by placing a meter stick randomly in each plot (excluding border rows) and counting the number of plants. Two measurements were taken per plot and then averaged and converted into a stand per acre. Soybean yield was obtained using either a Wintersteiger Model Quantum small-plot combine or a grower combine/weigh wagon combination. Soybean yield was corrected to 13 percent moisture content.

Statistical Analysis

Soybean stand and yield data were subjected to mixed model analysis of variance (ANOVA) using the ‘lme4’ package in R. For both stand and yield, fixed effects included treatment, environment, and treatment x environment. Random effects included replication nested within environment and the overall error term. Degrees of freedom for all analyses were calculated using the Kenward-Roger's method (Bell et al., 2013). Predictions and contrasts were generated with the 'emmeans' R package using a Bonferroni adjustment (Lenth, 2023).

To visually explore trend differences over a range of planting dates, both yield and stand by planting (DOY) was graphed and a linear regression for each treatment was plotted using the 'ggplot2' R package (Wickham, 2016) with the equation of the line and coefficient of determination shown for each treatment.

RESULTS AND DISCUSSION

Soybean Stand

Fungicide seed treatment interacted with environment to affect soybean stand (Table 2). When we investigated individual environments most trended towards having a protection of stand from the use of a fungicide seed treatment (Figure 1). The greatest stand protection from using a fungicide seed treatment was achieved at the Yadkin 2020 environment where the use of a fungicide seed treatment protected stand by 24,161 plants/A. There were four environments where the use of a fungicide seed treatment provided >20,000 plants/A of stand protection. On average when combined over the environment, fungicide seed treatment provided 9,187 plants/A of stand protection compared to using non-treated seed (Figure 1).

Planting date did not impact the soybean stand (P=0.34). This differs from (Morris et., al) and (Oplinger and philbrook 1992) where both studies found that soybean stand increased as planting date was delayed. While fungicide seed treatment did provide superior stand protection compared to non-treated seed across environments, there was no interaction with planting date (Figure 2) (P=0.84). This is interesting because other studies suggest that there is an interaction with plating dates and stand protection (Cox and Cherny 2011; Gaspar et al., 2017). Previous research indicated that seed treatments are more likely to increase soybean stand over untreated soybean seed when planting date occurs before May 10th, seed treatments increased early season soybean stands by 4,200 plants/A compared with non-treated soybean seed in Illinois and Indiana (Vossenkemper, et al., 2015).

Soybean yield

Fungicide seed treatment impacted yield (Table 2) ($P<0.001$). Averaged across environments, fungicide seed treated plots averaged 58.1 bu/A and untreated plots averaged 56.8 bu/A, providing a 1.3 bu/A yield protection. The largest impact on yield from the use of a fungicide seed treatment was observed at the Tyrell 2021 environment protecting yield by 4.68 bu/A (Figure 3). This increased yield protection at the Tyrell 2021 environment could be a result of Ponzer muck soil type which is classified as a very poorly drained, slow permeability organic soil (Dolman et al., 1967) and an early May planting date. There were four environments where fungicide seed treatment use provided >3 bu/A yield protection compared to untreated seed (Figure 3). Interestingly, none of these were the same sites where the use of a fungicide seed treatment provided considerable stand protection (Figure 1). Seed yield was likely not affected by the stand protection at these sites because stands were at or above the minimum required for acceptable yields according to previous work (Gaspar and Conley 2015, Vann 2022 et al)**.** We observed the general trend one would expect in that yield declined as planting date was delayed. As it is well known that planting date is one of the most important agronomic decisions affecting soybean yields (Mooers,1908). It is known that significant yield declines associated with delayed planting are due to the reduction of both the vegetative and reproductive periods (Bateman et al.,2020; Hu&Wiatrak,2012). Resulting in plants that are smaller and have fewer nodes and pods, leading to reduced yields. Conversely, planting early can result in increased yields as planting early allows for longer vegetative and reproductive periods (Knott et al.,2019). A longer vegetative stage will allow for a greater number of nodes to form prior to flowering, increasing the likelihood of more fruiting sites per plant, and thus more pods per plant (Bastidas et al.,2008).

Current fungicide treatment prices range from $13.50 to $16.75 per/unit of seed (140,000 Seed) (Agricultural Industry, personal communication). At the current soybean price of $12.58/Bu. for November 2023 contracts the average yield protection of 1.3 bu/A. would only slightly provide a return on the fungicide seed treatment investment or provide a negative return. In this study, only five of the 18 locations had planting dates in April with others ranging from early-May to late-June. If earlier planting dates were deployed in this study soybeans would be more likely to be planted in soil conditions that are cooler and wetter where a fungicide seed treatment could provide protection against early season diseases caused by Pythium spp., Phytophthora spp., Fusarium spp., and Rhizoctonia solani (Esker and Conley, 2012). In which case there is the potential to see a greater yield protection from a fungicide seed treatment and perhaps a greater return on investment. There was no interaction between seed treatment and planting date on soybean yield (P=0.64). However, yield declined as planting date was delayed across both seed treatments (P=0.07).

Conclusions

The North Carolina Soybean On-Farm Trialing (OFT) Program was initiated in 2020 as a collaborative effort between N.C. Cooperative Extension and the NC Soybean Producers Association to conduct on-farm research in strip trials that synergizes research being conducted in small plots by the NC State Soybean Extension program. In 2020 and 2021, the OFT program investigated the value of using a fungicide seed treatment in18 diverse production environment across North Carolina. Across environments, fungicide seed treatment affected soybean stand variably but on average the use of a fungicide seed treatment protected stand by 9,187 plants/A. On average, fungicide seed treatment use protected soybean yield by 1.3 bu/A. In 22 percent of the environments, fungicide seed treatment protected yield by >3 bu/A. There was no interaction between planting date and seed treatment on soybean stand or yield observed in this study. Our results indicate that fungicide seed treatment can significantly protect yield in North Carolina but as soybean seed treatment prices increase, the return on investment of this production practice could be very narrow.

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Table 1. Soybean planting date, harvest date, seeding rate, row spacing, variety, and number of replications for each environment

Environment	Planting Date	Harvest Date	Seeding Rate (seeds/A)	Row Spacing (in)	Variety	Replications
Beaufort 2020	5/26/2020	11/04/2020	125,000	30	AG52X9	4
Duplin 2020	5/11/2020	-	130,000	15	AG56X8	3
Onslow 2020	6/30/2020	12/03/2020	130,000	24	AG56X8	5
Wayne 2020	5/12/2020	-	135,000	15	AG56X8	5
Yadkin 2020	5/04/2021	11/03/2020	90,000	30	AG56X8	5
Bertie Harrell 2021	4/19/2021	10/19/2021	140,000	15	AG59X9	4

Bertie PB 2021	4/23/2021	11/03/2021	122,000	36	AG59X9	4
Davidson 2021	-	-	130,000	15	AG59X9	4
Gaston 2021	6/08/2021	11/16/2021	162,800	15	AG59X9	5
Onslow 2021	5/11/2021	12/01/2021	123,000	30	AG59X9	5
Johnston 2021	5/03/2021		140,000	30	AG59X9	4
Randolph 2021	5/06/2021	11/09/2021	165,000	15	AG59X9	4
Robeson 2021	4/30/2021	11/02/2021	110,000	30	AG59X9	5
Sampson 2021	5/18/2021	11/29/2021	120,000	15	AG59X9	5
Tyrell 2021	5/05/2021	11/11/2021	-	15	AG59X9	3
Washington 2021	4/29/2021	10/21/2021	100,000	30	AG59X9	3
Wayne 2021	5/05/2021	12/14/2021	120,00	15	AG59X9	5
Yadkin 2021	4/23/2021	11/11/2021	120,000	30	AG59X9	4

[a]AG: Asgrow

[b]-Information not available for these environments

Table 2. Summarized ANOVA results for the effect of fungicide seed treatment, environment, and their interaction on soybean stand and yield

Dependent Variable	Source	Combined Analysis (P>F)
Soybean Stand	Env	<0.001
	FST	<0.001
	FST*Env	<0.001
Soybean Yield	Env	<0.001
	FST	0.04
	FST*Env	0.90

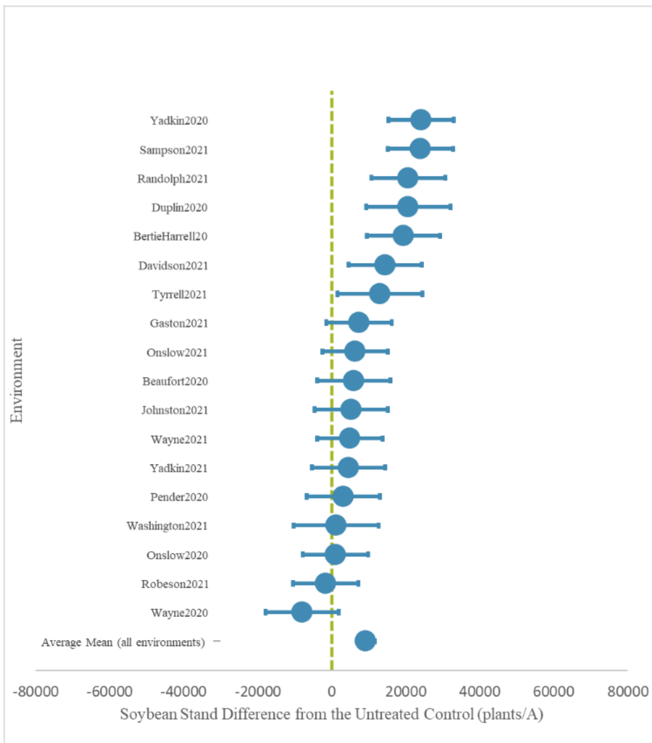

Figure 1. Fungicide seed treatment impact on soybean stand at individual environments and combined over environments. Bars indicate 95% confidence intervals.

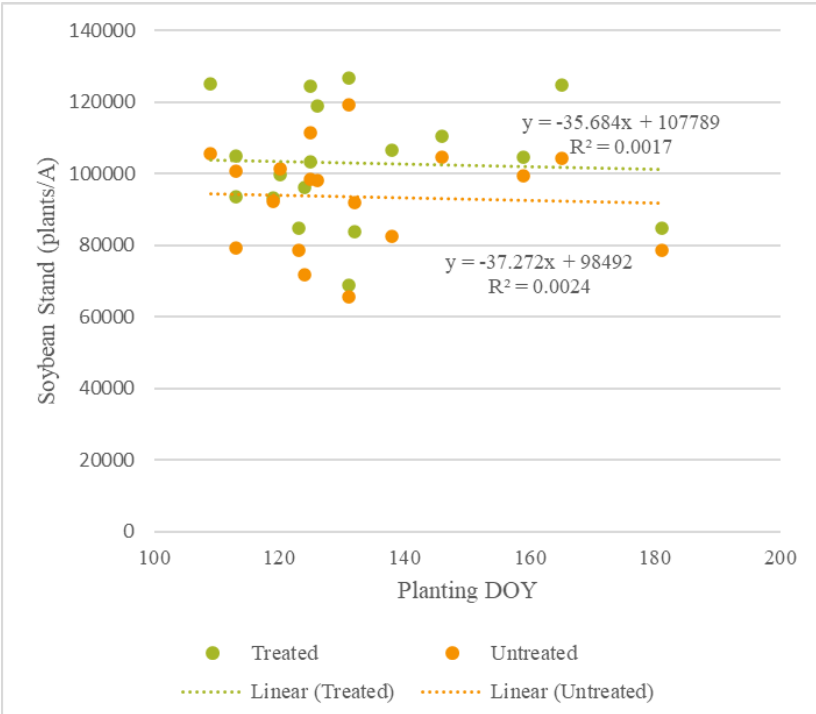

Figure 2. Planting date impact on soybean stand combined over environments for both the fungicide seed treatment and untreated seed

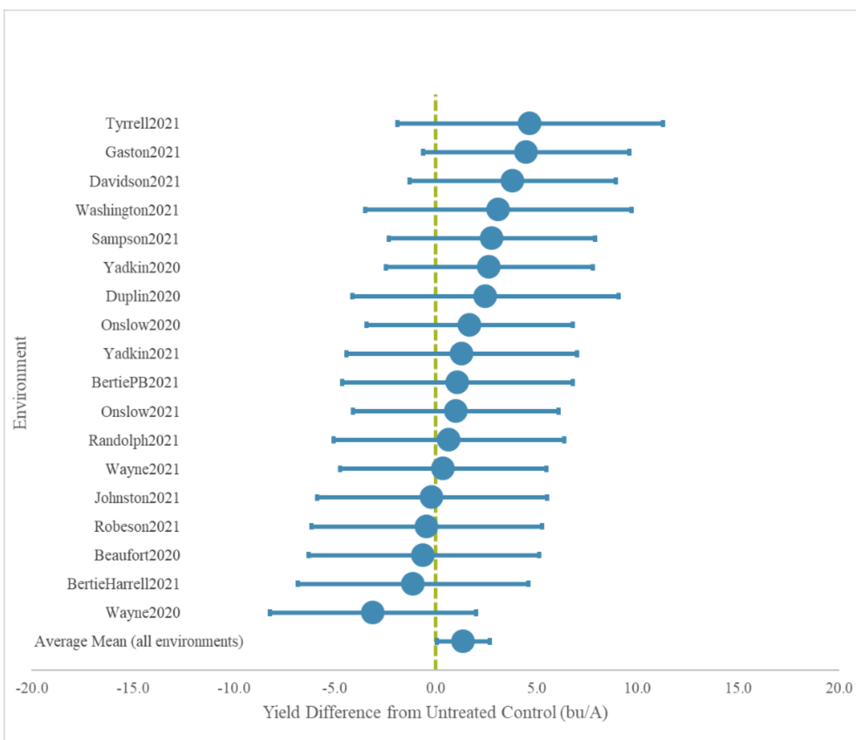

Figure 3. Fungicide seed treatment impact on soybean yield at individual environments and combined across environment. Bars indicate 95% confidence intervals.

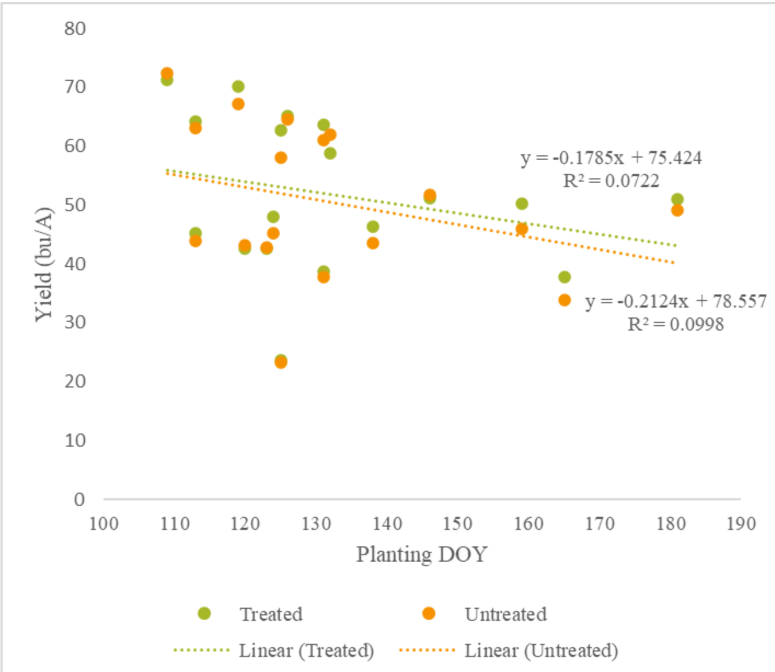

Figure 4. Planting date impact on soybean yield combined over environments for both the fungicide seed treatment and untreated seed