Seeding Rate Effect on Soybean Grain Yield

by

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List of Abbreviations

ANOVA	Analysis of Variance
AOFS	Agronomic Optimum Fall Stand
AOI	Acres of Interest
AOSR	Agronomic Optimum Seeding Rate
EOSR	Economic Optimum Seeding Rate
NWARS	Northwest Agricultural Research Station
OSU	The Ohio State University
WARS	Western Agricultural Research Station

Chapter 1: Literature Review

1.1: Introduction

Soybean (*Glycine max*), also referred to as soya, is a leguminous crop that originated as a wild crop in East Asia. The crop was domesticated and produced large-scale before the 17th century in Asia. However, its numerous economic and health benefits have made it extremely popular across the globe, with soya being extensively adopted across the western world and Asia. According to Johnson et al. (2015), soybean is among the most economically important crops across the globe. Over half the oilseed production in the world comes from soybeans. When comparing among vegetable oils, only palm oil is produced in greater quantities than soybean oil (Johnson et al., 2015). It is high in protein, making it significantly useful to humans and farm animals.

Johnson et al. (2015) state that soybeans are a major crop in the United States not only due to their nutritional value but also due to the country's status as the largest producer of soybeans in the world followed by China, Argentina, and Brazil. The crop presents significant economic value to its growers and increasing demand for oil facilitating improvements in the production process. Ohio economy is highly dependent on the cultivation of soybean. These legumes are Ohio's top agricultural export with an economic impact of $107 billion (Ohio Soybean Council, 2021). Ohio's railroad connectivity gives it a significant advantage in exporting as it improves bulk transportation efficiency due to the north/south and east/west railroad crossing. Additionally, Ohio's soybean crush plant serves the dual purpose of extracting oil for processing into condiments and salad dressings for fast food restaurants as well as reselling the crushed soybean stock to livestock owners for feed. These factors along with a large and diverse livestock population in Ohio allows producers to receive competitive pricing, creating thousands of jobs and generating billions of dollars for the Ohio economy. Most of the soybeans that leave Ohio go to grain elevators on the East Coast, Gulf Coast, and Louisiana or are exported to other countries (Our Soy Checkoff, 2012). To continue to compete in the global market, it is important to find more efficient ways to grow and transport soybeans (Denicoff et al., 2014).

Soybeans undergo extensive research pertaining to their genetics, breeding, and production process in the United States to ensure maximum yield and efficiency in production (USDA, 2017). With everchanging technology such as variable rate seeders, auto-steer, GPS, new seed trials and varieties, it is important to be aligned with current research for seeding rate recommendations. Also, the price of seed has increased, and Ohio farmers are looking to reduce their seed costs by planting the minimum number of seeds that maximizes financial return. Numerous studies have been conducted in the past to define the optimal farming practices that would guarantee increased soybean yields. Two factors that play a major role in soybean production are row width and seeding rate.

1.2: Tillage

The discussion on soybean production is incomplete without the mention of the various farming operations, more specifically, tillage. According to the National Agricultural Statistics Service 2017 Census of Agriculture, 37% of the total cropland in Ohio was no-till, 35% was conservational tillage, and 28% was conventional tillage. Dr. Laura Lindsey, OSU Associate Professor and small grains expert estimates 40-60% of soybeans produced in Ohio are no-till soybeans. Tillage has considerable effects on row width, planting populations and optimal yields as it eliminates some of the main biotic factors that influence the process of cultivation (Jeschke and Lutt, 2016). Farmers till the land to remove weeds that hinder the growth of plants while providing the best soil sizes that crop roots can penetrate, facilitating the process of growth. Soils with a dense, firm, or a crust layer over the top, are not as conductive to the growth of soybean plants as compared to soft, healthy soil (Christmas, 1993). A study published by Moraru et al. (2011) showed that decreased root growth due to inadequate penetration and crop residues result in lowering the surface soil temperature, which decreases the rate of successful germination when looking at conservation management systems. Knezevic et al. (2012) state that the cultivation of soybean is affected by conventional tillage because these processes reduce the strain of root penetration. Additionally, conventional tillage is considered advantageous as it decreases weed pressure by 85% relative to disc harrowing and 15% when compared to chisel ploughing.

As previously stated, the germination success of crops such as soybeans is highly dependent on the rate of root growth (Moraru et al., 2013). In no-till environments, soil temperatures are usually lower, especially in heavy residue fields. Roots grow slowly in lower soil temperatures as compared to warmer soils, reducing the plant's access to basic nutrients and water from the ground. Tillage allows farmers to loosen the soil, which increases soil aeration that positively influences the growth of crops. Another pivotal significance of tillage is that it incorporates harvest residue into the soil, creating humus which facilitates the growth of soybeans. However, Knezevic et al. (2012) state that tillage has both positive and negative implications on the cultivation of soybeans. In a study conducted by Morrison et al. (2017), results showed the negative implications of tillage in soybean production include the destruction of soil aggregates, the loss of nitrogen and other soil nutrients, reduced microbial activity, and the facilitation of chemical runoffs. Most farmers in Ohio and the Mid-western areas have resorted to using no-till farming to eliminate the potential adverse effects of tillage on soybean crop yields.

No-till farming refers to a technique used by agronomists and farmers to grow crops without disturbing the soil structure. The significance of this form of crop production is that it enhances the retention of soil moisture. According to Ferrari et al. (2018), the primary rationale for the no-till farming approach, is its ability to enhance the biological fertility of the land, making soils more resilient to pests. Additionally, no-till methods have been widely used because they eliminate or reduce soil erosion which conserves the amount of organic matter in the soil structure while eliminating the soil erosion caused by frequent tillage. No-till farming became popular as farmers adopted the use of herbicides to kill weeds without ploughing or causing any forms of interference to the soil structure. This increased labor efficiency as farmers could now undertake other non-labor demanding activities yet attain the same results in each planting season. Despite its numerous benefits, no-till farming includes the usage of herbicides in the cultivation of crops such as soybeans, which leads to increased interference with microbial activity within the soil. This is a significant main downside of the no-till technique.

According to Carver et al. (2017) soybean farmers across the world have adopted the use of no-till practices due to its advantages in labor efficiency and the associated high yields. Carver et al. (2017) conducted a three-year study aimed at establishing the various implications of fertilizer management and cover cropping on the loss of soil nutrients such as phosphorus. They determined that good fertilizer management and cover cropping were essential in protecting water and soil resources while at the same time maximizing soybean yields. The primary challenge cover cropping had on soybean farming was that it decreased the nitrogen content of the crop's residues, unless the cover crop is also leguminous in nature, even though cover cropping may provide other benefits such as breaking up soil compaction and inducing water infiltration. Islam and Reeder (2014) examined the differences between no-till and conventional agricultural approaches in Ohio establishing that unlike conventional agricultural approaches in Ohio, no-till agriculture has the potential of decreasing carbon loss while improving soil health and increasing yields. Edreira et al. (2017) found in one region of Ohio there was no effect of tillage versus no-till, while a second region showed a small yield increase when the fields were tilled. They concluded the effect of tillage versus no-till is variable and depends on the drainage of the field. According to Islam and Reeder (2014), no-till agriculture was first introduced in Ohio in 1962. Ohio farming pioneers such as Bill Richards and David Brandt adopted the practice and provided crucial information proving that no-till agriculture had the potential of revolutionizing soybean production if elements such as seeding rates and row widths were considered. Row width is defined as the distance between rows of seeds (Garcia et al., 2018). Although tillage was not a main component of this study, it is important to note that this is relevant because there are differences in seeding rate in tilled fields verses no-tilled soybean fields.

1.3: Seeding Rate for Fall Stand

High seeding rates directly affect soybean farming as they influence the amount of capital needed for planting. Thai et al. (2017) published that soybean production in the southern regions of Alberta, Canada would significantly yield higher when planted in high densities. However, high planting densities or seeding rates would also increase production costs (Thai et al., 2017). Results from studies conducted by Suhre et al. (2014) also found that higher seeding rates produced a higher yield. Despite seeding rate being the most important element of a production system, the outcome is also influenced by abiotic and biotic factors, such as seasonal events and weather conditions, machinery or equipment breakdown, soil crusting, and seedling diseases. Therefore, farmers who want to obtain high yields by adopting increased seeding rates should adopt a system that would account for the listed abiotic and biotic factors of production.

Seeding rates vary by farm and recommendations can vary based on county, state, country, soil type, and many other factors so it is important to conduct a stand count before harvest to determine “Fall Stand” or “Final Harvest Stand.” Dr. Lindsey et al., (2017) recommends 100,000 to 120,000 plants per acre as a final stand if the crop was planted before May 20, 130,000 to 150,000 if planting Mid-June, and over 180,000 plants per acre as a final stand for double cropped, early July plantings. This guide also stated that 60% to 80% of the seeding rate survives to final harvest stands and similar results were found in a study by Walker, et al. (2010) suggesting 50 to 80% of soybeans will survive to final stand. The loss is attributed to disease, seeds that are dead when planted, insects, poor vigor during emergence, and plants that are outcompeted for nutrients and do not survive (Lindsey et al., 2017). As seeding rates increase, soybeans will have to compete with neighboring plants for water, nutrients, and sunlight (Christmas, 1993; Liu et al., 2007). Also, it is important to ensure uniform plant-to-plant spacing to decrease the possibility of competition among plants and weeds. If there are gaps or skips among the soybean plants, the yield potential may be lower because the canopy of the soybean plant needs to be completely developed before flowering to reach optimal yield. The gaps within the rows may not allow the canopy to close completely, thus impeding the yield (Roberson, 2014).

Research from Yunusa and Ikwelle (1989) and Ikeda et al. (1994) shows that yield increases with planting density. A study by Schutte and Nleya (2018) took the previous results a step further by showing populations. They published that a soybean plot having a rate of 204,930 seeds per acre had a higher yield as compared to plots with 100,035, 135,067, and 170,000 seeds per acre, establishing that seed yield increased with seeding rates. Results from a study by Mourtzinis et al. (2019) were that although the yield may increase with seeding rate, the increase is less than 0.10 bushels per acre.

A higher seed rate will result in taller plants with fewer pods and branches per plant (Christmas, 1993). Additionally, the lowest pod on the plant is higher compared to lower seed rates. It is important to measure the height of the lowest soybean pod because loss can occur at harvest if the pods are too close to the ground, causing the combine to miss them (Caliskan et al., 2007). Soybeans planted on a narrow row width, which is usually between 7.5 and 15 inches, have shown to have a higher height of the lowest pod (Palmer and Privette, 1992; Caliskan et al., 2007). According to the University of Wisconsin (2015), 5% of the soybean crop is found at or below a height of 3.5-inches and 12% at or below 6.5-inches.

Marquardt et al. (2012) explained that soybeans and other leguminous crops have broad leaves that provide an excellent ground cover which suppresses weeds. However, a very high seeding rate results in crops with narrow leaves and fewer seeds per pod. Bellaloui et al. (2015) assert that even though seeding rates are an essential determinant of overall yields, a high number of seeds planted within a given area will have an adverse effect on the mineral composition of the soybeans. In a trial comparing seeding rates of four, five and six plants per square foot, Bellaloui et al. (2015) reported that the lowest plant density, i.e., four plants per square foot, had the highest concentrations of seed minerals, sugars, and protein. Accordingly, they concluded that soybean farmers should focus on planting fewer seeds per unit area for them to get the highest quality soybean seeds. Bajaj et al. (2008) published that seed germination rate increased with wide row width but did not study the overall effect on yield. Marquardt et al. (2012) recommended that soybean farmers should adopt farming practices characterized by average seeding rates to reduce competition and enhance both the quality of the crops and the quantity of the output.

El-Zeadani et al. (2014) contend that soybean yield was substantially influenced by plant density and number of seeds per plant. They state that the number and yield of seeds per plant has a negative correlation with increased plant density, i.e., the yields decreased with an increase in density. Consequently, farmers who increase plant populations experience decreased productivity per plant.

The reviewed studies confirm that soybean farmers planting more seeds per unit area with narrow width rows are likely to harvest higher yields per a given surface area. Soybean production processes vary significantly between regions. Crops can be planted under different climatic conditions represented by different parts of Ohio and will respond differently to weather conditions and the chemical characteristics of the soil. Hence, there is a need for further research to assess optimal row width and seeding rates to maximize soybean yields in Ohio.

1.4: Economics of Seeding Rate

Any economic activity aims at minimizing the cost of inputs while maximizing output to generate greater revenue. In farming, this would translate to using low-cost inputs that give a greater yield and have a competitive market price. To maximize profit and minimize labor, farmers use the latest technologies such as precision planting equipment, GPS, yield monitors and numerous data collecting sensors. Increased revenue from the sale of soybeans has inadvertently contributed to an increase in the price of soybean seeds. This affects seeing rates, forcing farmers to design strategies that minimize the cost of inputs while increasing output to enhance revenue.

According to Cox et al. (2010), the costs of soybean seeds have tripled over the past decade. Therefore, high seeding rates are expensive forms of insurance against uncertain climatic conditions and pest damage. Additionally, if the crop is protected from environmental adversities, high seeding rates can result in significantly high yields. However, Cox et al. (2010) suggests that the economic value of high seeding rates is moderate because there is a risk that most crops may be damaged before they attain full maturity.

The economics of soybean production-based farming operation can be further gauged by the machinery used from land preparation to harvest. Planting width is limited to the width of the planter but allow adjustable seeding rates make them one of the most important machineries at the farm. The high cost of the equipment makes having 2 separate planters for corn and soybeans unaffordable to small scale farmers. Large scale farmers usually have separate planters for 30-inch corn spacing and 15-inch soybean spacing in Ohio and can justify the cost of 2 for increased acreage. Results from Mirsky et al. (2013) showed that there are numerous tradeoffs when using drills versus planters. Planters are highly efficient as they provide accurate and consistent planting populations due to their low cutting resistance as compared to drills.

The 2016 Soybean Production Enterprise Budget created by The Ohio State University Extension assumes a farm size planting 1,000 acres of Roundup Ready soybeans – common within Ohio, a fixed machinery cost of $108 per acre, a fixed land charge of $187 per acre, and a fixed labor and management cost totaling $57 per acre (Table 1). The assumed variable rate is $188 which includes the cost of fertilizer and interest rates. Barry Ward, the creator of the enterprise budget, suggested to expect a $30 loss per acre when planting soybeans in 2016. The table shows that seed costs for 1,000 acres greatly affect the bottom-line profit. Even though there are other ways to reduce costs and improve efficiency in the farming operation, producers in Ohio have not put enough importance on seed costs and seeding rates.

Table 1. Cost attributed to planting and harvesting soybeans within Ohio in 2016 (Ward, 2017).

SEEDS PER ACRE	COST PER 1000 SEEDS	TOTAL COST PER ACRE	TOTAL COST OF SEEDS TO PLANT 1000 AC OF SOYBEANS	TOTAL COSTS	2016 PRICE PER BUSHEL OF SOYBEANS	TOTAL RETURN AT 55 BU/AC AND $10.25 SOYBEANS SELL PRICE	PROFIT OR LOSS
50,000		$20.50	($20,500)	($560,500)			$3,260
100,000		$41.00	($41,000)	($581,000)			($17,250)
150,000	$0.41	$61.50	($61,500)	($601,500)	$10.25	$563,750	($37,750)
200,000		$82.00	($82,000)	($622,000)			($58,250)
250,000		$102.50	($102,000)	($642,000)			($78,250)

The key gap is the inconsistencies in the examined studies that hinder the process of defining the optimum seeding rate, fall stand, row width, and yields in soybean production. However, the studies suggest that moderate seeding rates at optimal spacing can result in increased yield while controlling weeds, pests, and diseases. In this research, I focus on the gaps in information pertaining to the optimal rates needed to increase yields on farms in Ohio.

1.5: Advantages of Narrow Row Widths

A goal for soybean farmers is to ensure canopy closure before flowering to ensure maximum plant potential. Canopy closure in Ohio occurs from roughly June 20 to July 10 (Lindsey et al., 2017). During the reproductive growth stage, plant density does not influence the growth rate or the pod filling of soybeans but increasing plant density negatively affects the seed number per plant (El-Zeadani et al., 2014).

Research from The Ohio State University shows that optimal soybean yields are achieved at narrow row widths of 7 to 10-inches (Beuerlein, 2001). Research conducted by Virginia Tech confirmed narrow soybean rows planted at 7.5-inches apart have 10% to 20% higher yields compared to rows planted 9, 15, or 18-inches apart (Roberson, 2014). Although Roberson (2014) did not mention a seeding population, he did state the importance of seed uniformity. One study did show a seeding rate. Cherney (2011) established that soybean yield is optimized when a total of 130,000 seeds were planted per acre with a row width of 7.5-inches. For a third example of high yields in narrow rows, Andrade et al. (2018) conducted a study across 16 agronomic departments and extension agencies in 15 states. Their results showed that the yield from 15-inch rows was higher in 92% in the Southern U.S., 68% in the Central U.S., and 84% of the trials in the Northern U.S. as compared to the yield from 30-in rows.

Row width can only affect the population of the crops when rainfall and other factors are consistent. Andrade et al. (2018) found that irrigated areas produced up to 75 bushels per acre compared to the short season rainfed areas that only produced 40 bushels per acre. Schutte and Nleya (2018) conducted a study that examined the performance of soybean based on row width by examining the seeding rates across row widths that ranged from 7.5 to 30-inches. They published plants grew taller at 7.5-inch rows compared to 30-inches, as all the soybeans competed for sunlight.

Row width also determines the survival rates of soybean as it defines access to essential soil elements such as moisture and nutrients. When the canopy closes (earlier in narrow rows), there is less evapotranspiration and cooler soils (Mourtzinis et al., 2015). Mirsky et al. (2013) asserted that narrow soybean row width reduces the time taken for the crops to form canopies by increasing planting population, suppressing weed growth as canopies assist in weed control.

According to Lenssen (2013) weed competition is among the primary factors that decrease the yields of soybeans in Iowa and other Mid-western states.

1.6: Disadvantages of Narrow Row Widths

Narrow row widths have their disadvantages. Studies of De Souza Jaccoud-Filho et al. (2016) and Marquardt et al. (2012) showed that air circulation may be limited in narrow widths. Farmers can advance the potential crop growth rate by providing wider spaces to allow air flow within the plants. Wider row widths also allow better distributed moisture, sunlight, and soil nutrients to all plants, enhancing their germination and growth success.

Many management decisions are associated with wider row width. Mid-season applications will be a challenge for a sprayer if the row widths are under 30-inches as there will be no way to spray the soybeans without running over plants unless aerial application methods are used. Producers will have to estimate the yield loss from running over plants compared to the yield gain from making the application.

A combination of very high seeding rates and narrow row width has been associated with an increased risk for bacterial and fungal infections, as well as a greater risk of competition within the plants, reducing yield (Hu and Wiatrak, 2012; Marquardt et al., 2012; Zeng et al., 2012). Stem rots among soybean plants have been attributed to a combination of narrow row widths and increased seeding rates. Row width is a significant factor that influences the emergence of Sclerotinia stem rot, a pathogenic fungus that infects soybeans, and is characterized by visible white molds (Zeng et al., 2012). It is favored by full canopies and wet soils. The pathogen results in stand loss and is capable of surviving over several planting seasons, reducing cumulative plant density. Therefore, Zeng et al. (2012) recommend that the most appropriate way of dealing with the Sclerotinia stem rot is reducing the number of seeds planted within a given surface area while increasing the row widths to ensure that the fungus does not spread between rows. Another common fungus highly influenced by row width, planting population and seeding rates is the brown stem rot caused by *Phialophora gregata* (Hu and Wiatrak, 2012). Brown stem rot has the potential to significantly reduce soybean yields. It spreads quickly when the crop population is high. Both Zeng et al. (2012), and Hu and Wiatrak (2012) demonstrate that higher seeding rates at narrow widths can facilitate the spread of diseases, therefore, reduce soybean yields. Fifteen-inch rows maximize yield by allowing for enough air flow in most conditions to avoid mold issues and canopy closure before flowering.

In a perfect environment, all crops would grow best at equal distances from each other in all directions. Ikeda et al. (1994) conducted a study testing a square and zigzag (equilateral) planting pattern. As expected, the plants were taller in higher densities with less branches and seed pods. Results showed that low densities yielded higher in two of the three years, while the higher density out yielded the lower density in one of the years. The zigzag pattern out yielded the square pattern in all three years, except for one plot that exhibited poor seed establishment. Additionally, the zigzag pattern fared better during the heavy rainfall that occurred over two of the three years during the study. One reason the zigzag pattern is not used in traditional soybean farming practices is due to the use of machinery and tools. Again, if a mid-season application is needed, there would be no path for tractor or sprayer tires and significant yield loss would occur. Also, when scouting during the growing season, it is faster and easier to walk in the spacing between rows.

1.7: Objective

Foyer et al. (2019) stated that the rareness of studies on optimum soybean conditions is the primary cause of losses in many farms across the world. Soybean production processes vary significantly among regions. Additionally, soybean treatments and varieties have changed over the years, and it is important to address these differences. Moreover, crops planted under different climatic conditions in different parts of Ohio and will respond differently to weather conditions as well as the chemical characteristics of the soil. Therefore, the rationale for conducting this research was to determine how two essential elements of soybean production (planting population and row width) affect the overall yield, while focusing on Ohio.

According to Chessman et al. (2017), seed is the most essential, if not singularly expensive input for soybean farmers where seeding rates, plant spacing, and plant populations are closely tied. This study was conducted to fill the gaps in knowledge regarding row width and seeding rates needed to increase yields. It aims to address these gaps by determining the effects of row width and planting population on yield while presenting recommendations that will maximize yield and profits. Finding from this study will be used to make recommendations on row width and fall stand for soybean farmers in Ohio.

Chapter 2: Small Plot Research

2.1: Abstract

Increasing costs of soybean seed as well as new varieties, seed treatments, and production practices required a reevaluation of seeding rate recommendations. Previously recommended seeding rates do not account for new varieties, improved cultural practices, improved seed treatments, and precision planting equipment. Also, a recommended seeding rate does not account for changes between regions, soil types, or even across a field; therefore, the need for a fall stand recommendation. Chapter 5, the Soybean Production section of the Ohio Agronomy Guide (Lindsey et al., 2017) suggests Ohio farmers should have a fall stand of 100,000 to 120,000 plants per acre if planted before May 20. The objectives of this research were to test this recommendation and evaluate the effect of row width and seeding rate in small-plot research trials. Stand counts were taken at the V4 and R8 stages to note whether desired planting populations were achieved and compared to plant population at harvest to recorded yields. Ten plant samples were taken from the field to measure plant height, lowest pod height, nodes per plant, branches per plant, number of pods, and seed weight on branches and main stems. Seeding rate influenced yield at 5 out of 6 site-years. Row width and seeding rate had a significant effect on branches per plant, pods per plant, and seeds per main stem and seeds per branch. The results were very close to the Ohio State University recommendations and showed ideal agronomic optimal fall stand (AOFS) was 123,000 plants per acre. Plants compensated for low seeding rate by producing more branches and seeds per plant.

2.2: Introduction

Climatic and soil properties vary across Ohio and can influence soybean growth. Hence, there is a need for further research to assess optimal row width and seeding rates for fall stand to maximize soybean yield in different regions of Ohio. Current research shows that narrower row width is associated with higher yields. These benefits could be 10 to 20% higher at 7.5 to 9-inch rows compared to 15-18-inch row widths (Roberson 2014).

To show how variable recommendations can be based on climate and soil properties, Schutte and Nleya (2018) conducted a study in South Dakota showing that a soybean plot having a rate of 204,930 seeds per acre had a higher yield compared to plots with 100,035, 135,067, and 170,000 seeds per acre. On the other hand, Gaspar et al. (2015) recommended a seeding rate within the range of 93,960 to 105,705 seeds per acre for optimum yields using soybeans treated with CrusierMaxx seed treatments in Wisconsin.

Many factors contribute to a soybean plant’s ability to survive until harvest such as planting conditions, weather, soybean cultivar, pests, diseases, and soil type, making a standard seeding rate recommendation next to impossible. An easy comparable value is to look at the soybean population before harvest, also known as the fall stand. The recommended final stand of soybeans in Ohio is 100,000 to 120,000 plants per acre if planted before May 20 (Lindsey et al., 2017). This value has shown to be fairly consistent across the fields but the number of seeds to plant is extremely variable. It is important for farmers to conduct a stand count in the fall before harvest and adjust their seeding rate accordingly in the following years.

Small research plots allow researchers to analyze the results from different inputs, management styles, and rotations (White, 2019). Mueller (2017) conducted a study in Iowa in 2015 and 2016. One data set was from on-farm trials while the other was from small plot trials.

The yield results were similar between the two with agronomic optimum final stand (AOFS), meaning the plant stand required to maximize grain yield, of the small plots being lower than the large plots. However, the variation of the yield based on location was larger on the on-farm plots, which could be attributed to the larger sample size and different soil types. The objectives of this research were to test this recommendation and evaluate the effect of row width and seeding rate in small-plot research trials.

2.3: Materials and Methods

Figure 1 Small plot research locations in Ohio in 2015 and 2016.

This research was conducted on three Ohio State University research farms, Western Agricultural Research Station (WARS), Northwest Agricultural Research Station (NWARS), and Wooster Campus (Figure 1). The soybean variety planted was ASGROW AG3334, with a relative maturity level of 3.3. This cultivar was chosen by ASGROW, who donated seed for soybean research plots. The Ohio State University requested a commercially available cultivar recommended for this region and ASGROW AG3334 is what they donated. Plot sizes measured 28 ft by 6.25 ft. and the only fungicide and insecticide would have been in the seed

treatment. The treatments in this experiment consisted of five seeding rates and three row widths. The design of this study was a split-plot factorial, randomized complete block with four replications of treatments. The main plot factor was row width, and the subplot factor was seeding rate. A grain drill was used to plan row widths of 7.5-inches, and a plot planter was used to plant 15-inches and 30-inch rows. The seeding rates were 50,000, 100,000, 150,000, 200,000, and 250,000 seeds per acre.

Stand counts were taken twice during the growing season around the V4 and R8 growth stages. Ten randomly selected plants were manually harvested at the R8 stage for additional measurements. The number of pods were counted to estimate the average number of pods per plant. Average plant height was determined by measuring from the top node to the bottom of the main stem averaging them together per plot. Branches per plant, lowest pod height, pod number and seed weight were also noted. Yields were collected at harvest using a Hege 140 plot combine with a 4.6-ft header utilizing yield monitor data and weigh scales. To obtain a better representation of field production, the two outside rows and end-rows were removed before harvest. Two rows were harvested in the 30-inch, four rows in the 15-inch, and eight rows in the 7.5-inch row width plots. Yield was adjusted to 13% moisture by subtracting actual moisture from 100 and dividing the result by 100 minus 13.

Information pertaining to the location of the farms, soil type, average percent slope, acres of interest, and percent of acreage was notated (Table 2). At the Northwest location, we were unable to plant 30-inch rows at 250,000 plants per acre due to planter limitations. In 2015, one of the 7.5-inch row width plots at 50,000 plants per acre had half of the plot missing, possibly due to rainfall washing out the plot at the Northwest location. At the Western Agricultural Research Station (WARS) location, the 7.5-inch populations of 50,000, 100,000, and 200,000 plants per acre had three to four feet of area that was washed out, due to rainfall. In 2016, three plots planted using 15-inch rows also had a large area washed out due to rainfall in the 250,000, 150,000, and 200,000 plants per acre plots. A smaller area was harvested and compensated in the calculation of the plot yield.

Data from the Web Soil Survey (2020) shows all plots had a slope between 0 and 6 percent (Table 2). Each of the research sites consisted of a study area totaling 2 to 3.5 acres. The plots in 2015 and 2016 were planted from mid- to late May, except for the plots in Wooster in 2015 which were planted in early June (Table 2). This table also shows that all plots were harvested in October, except for the 2015 Western which were harvested in late September. The previous crop in all plots was corn.

A mixed procedure in SAS 9.4 (SAS Institute, Cary, NC), was used to analyze grain yield and plant data utilizing the analysis of variance (ANOVA) test. For the GLIMMIX test and random ANOVAS (TABLES), row width, seeding rate, and row width x seeding rate were the fixed effects. Width, rate, and width times rate were means tested. SAS was also used to produce a linear and quadratic response curves by regressing the seeding rate against the yield and partial return. The agronomic optimum seeding rate (AOSR) was maximum point in the response curve when regressing seeding rate versus grain yield. The economic optimal seeding rate (EOSR) was determined the same way when regressing the seeding rate by the partial return. To get exact numbers, the AOSR and EOSR were calculated by solving the quadratic formulas. When the trendlines were concave, the lowest seeding rate at that site-year was used for the AOSR.

Gross return was calculated by multiplying yield by $10.25, the market price of soybeans sold in 2015, at Cargill in Sidney, Ohio. Partial return was calculated by subtracting seed cost from the gross return. The seed cost was calculated by multiplying rate times $0.41, the recommended cost for 1,000 seeds from the 2014 Ohio Soybean Production Budget (Loux, 2014). Yield was adjusted to 13% moisture by subtracting actual moisture from 100 and dividing the result by 100 minus 13.

Table 2. Field operation dates and site description from the Western Agricultural Research Station (WARS), Northwest Agricultural Research Station (NWARS), and Wooster Campus. Soil series from USDA NRCS Web Soil Survey.

LOCATION	WARS	WOOSTER	NWARS	WARS	WOOSTER	NWARS
YEAR	2015	2015	2015	2016	2016	2016
PLANT DATE	05/28/2015	06/03/2015	05/19/2015	05/26/2016	05/17/2016	05/27/2016
HARVEST DATE	09/29/2015	10/15/2015	10/07/2015	10/25/2016	10/18/2016	10/12/2016
* SOIL TYPE(S)	Kokomo silty clay loam (Ko); Strawn-Crosby complex (SuA)	Canfield silt loam (CdB)	Hoytville clay loam (HoA)	Kokomo silto clay Loam (Ko); Strawn silty clay loam (StB2); Strawn-Crosby complex *SuB)	Canfield silt loam (CdA); Wooster-Riddles silt loams (WuB)	Hoytville clay loam (HoA)
AVERAGE PERCENT SLOPE	0-2; 0-2	2-6	0-1	0-2; 2-6; 2-6	0-2; 2-6	0-1
ACRES OF INTEREST (AOI)	0.6; 2.3	2.6	2.5	2.7; 0.5; 0.3	0.1; 0.9	2.2
PERCENT OF ACREAGE	21.1; 78.9	100	100	77.8; 14.4; 7.8	8.7; 91.3	100
LONGITUDE/ LATITUDE	83° 45’21” W 41° 13’22” N	81° 54’6” W 40° 45’30” N	83° 45’28” W 41° 13’22” N	83° 39’46” W 39° 51’33” N	81° 54’29” W 40° 46’16” N	83° 45’27” W 41° 13’11” N

* Soil types, slope, AOI, acreage, longitude and latitude from NRCS Web Soil Survey.

2.4: Results and Discussion

2.4.1: Effect of Row Width on Grain Yield

At WARS 2015, WARS 2016 and Wooster 2016, the main effect of row width influenced soybean grain yield (Table 3) and can be seen by the p-values of 0.0016 and 0.0057 respectively. At WARS 2015, soybean yield was 68.7 and 74.0 bu/acre when grown in 7.5- and 15-inch row width, respectively, while soybean yield decreased to 55.9 bu/acre when grown in 30-inch row width (Table 4). At Wooster 2016, soybean yield was greatest in 7.5-inch row width (75.8 bu/acre) and significantly decreased to 64.9 and 64.0 bu/acre in 15 and 30-inch row width, respectively. There was a significant row width x seeding rate interaction (<0.0001) at WARS in

2016 (Table 3). At this location, soybean yield was greatest (108.2 bu/acre) when grown in 7.5-inch row width at 250,000 seeds/acre. At the remaining 3 site-years, there was no significant effect of row width on soybean grain yield (Table 3). Interaction can also be discussed when looking at the yield spreads between the lowest and highest seeding rates of the different row widths. The yield spread at 7.5-inch row width was 31.6 bushels per acre, 9.8 at 15-inch rows, and 7.6 bushels per acre at 30-inch rows. This means 7.5-inch rows provide a bigger response to seeding rate compared to 15 and 30-inch rows and would have a steeper slope if graphed. The letters denoting statistical differences (Table 5) show 7.5-inch rows have letters A-E where 15 and 30-inch rows only have B-C and D-E respectively.

Overall, soybean grain yield tended to be greater in narrow rows (7.5-inch and 15-inch) compared to wide rows (30-inch). Previously-conducted studies have seen similar results such as Beuerlein (2001) who calculated optimal results at 7 to 10-inches. Also, the study by Andrade et al. (2018) across 15 states showed increased yields in 68% to 92% depending on region in the United States. These narrow rows help ensure canopy closure before flowering (Lindsey et al., 2017) and suppress weed growth (Mirsky et al., 2013) allowing maximum sunlight exposure while minimizing competition.

Table 3. ANOVA p-values indicating the probability that the means are significantly different for the fixed effects of row width (RW), seeding rate (SR), and RW x SR interaction on the dependent variables of grain yield, partial return, soybean height, lowest pod height, number of nodes per plant, and number of branches per plant by site-year.

SITE & YEAR	SOURCE	GRAIN YIELD	PARTIAL RETURN	PLANT HEIGHT	LOWEST POD HEIGHT	NODES PER PLANT	BRANCHES PER PLANT
NWARS 2015	RW	0.0980	0.0976	0.5941	0.5884	0.0981	0.2366
	SR	<0.0001	<0.0001	0.9142	0.0183	0.0105	0.0107
	RWxSR	0.3456	0.3450	0.3085	0.4942	0.3845	0.5143
NWARS 2016	RW	0.3034	0.3034	0.0089	0.5952	0.0518	0.0410
	SR	<0.0001	<0.0001	0.3427	0.0086	<0.0001	<0.0001
	RWxSR	0.0620	0.06020	0.0043	0.343	0.0006	0.5441
WOOSTER 2015	RW	0.7900	0.7879	0.0081	0.4773	0.0413	0.2371
	SR	<0.0001	0.0054	<0.0001	0.0009	<0.0001	<0.0001
	RWxSR	0.3300	0.3271	<0.0001	0.0228	<0.0001	0.0448
WOOSTER 2016	RW	0.0057	0.0057	0.0177	0.6026	0.2348	0.6373
	SR	0.2680	0.3765	0.7463	0.0003	<0.0001	<0.0001
	RWxSR	0.7500	0.7499	0.4770	0.1026	0.0832	0.1834
WARS 2015	RW	0.0016	0.0016	0.1098	0.0629	0.5790	0.4525
	SR	0.8500	0.0699	0.4473	<0.0001	0.1836	0.4498
	RWxSR	0.7300	0.7344	0.0418	0.0708	0.1478	0.5238
WARS 2016	RW	0.0006	0.0006	NA	NA	NA	NA
	SR	<0.0001	0.0092	NA	NA	NA	NA
	RWxSR	0.0024	0.0024	NA	NA	NA	NA

*RW = Row Width, SR = Seeding Rate, RWxSR = Row Width by Seeding Rate Interaction

There was a significant row width by seeding rate interaction (Table 3) in one site-year, WARS 2016, which resulted in a p-value of 0.0006, if considering 5% probability. If considering 10%, NWARS 2016 would be added as well, with a p-value of 0.0620. The yields from the site-years that did not have a significant row width by seeding rate interaction ranged from 50.1 to 75.8 across the 5 site-years. Since it was the only site-year of significance, the results were removed from Table 4 and more detail is shown in Table 5. WARS 2015 had the biggest spread of grain yield increase based on row width, with an increase of 12.8 bushels per acre. Wooster 2016 plots spread was the second biggest spread of 11.8 bushels per acre. This explains the difference in letters showing the statistical differences in Table 4 where WARS 2015 and Wooster 2016 have A-B letters. This shows planting at 7.5-inch rows resulted in a much higher yield compared to the 15 and 30-inch rows. The last 3 spreads were much smaller with NWARS 2015 at 5.4, NWARS 2016 at 4.6 and Wooster 2015 at 2.3 bushels per acre. The lettering of these also show they have similar yield values as seen with only "A" lettering. The SAS report did not give a yield value for the NWARS 2015 30-inch row width. The 250,000 plants per acre plots at 30-inch row widths could not be planted due to planter limitations. Periods were inserted in the SAS data for analysis, which should have still given a yield as resulted in NWARS 2016.

Table 4. Soybean grain yield by the main effect of row width for each site-year.

Site-year	Row width (inch)	Grain yield (bu/acre)
NWARS 2015	7.5	50.1 A[a]
	15	55.5 A
	30	Non-Est
NWARS 2016	7.5	64.5 A
	15	68.0 A
	30	69.1 A
WARS 2015	7.5	68.7 A
	15	74.0 A
	30	55.9 B
Wooster 2015	7.5	62.1 A
	15	60.5 A
	30	59.8 A
Wooster 2016	7.5	75.8 A
	15	64.9 B
	30	64.0 B

[a]Means not sharing common letters within a site-year denote statistical differences among row width treatments ($\alpha = .05$).

There was a significant interaction between row width and seeding rate at the WARS location in 2016 (Table 5). Grain yield increased as seeding rate increased at all 3 row widths. The 7.5-inch row width resulted in a 31.6 bushel increase between the lowest and highest seeding rate. The 7.5 and 15-inch row widths resulted in higher yields at all seeding rates, compared to the 30-inch row width. The yield spread between the different row widths and site-years was also an effective way at analyzing the data. At 7.5-inch rows, the yield spread was 31.6 bushels per acre between the 50,000 and 250,000 seeds per acre seeding rate. The spread was 9.8 at 15-inch rows and 7.6 at 30-inch rows. This means 7.5-inch rows not only had the highest yield at the highest seeding rate but also had the largest bushel increase as seeding rate increased.

Table 5. Soybean grain yield at the Western Agricultural Research Station (WARS) in 2016 as affected by row width and seeding rate.

Row width (inch)	Seeding rate (1,000 seeds/acre)	Grain yield (bu/acre)
7.5	50	76.6 ED[a]
	100	96.2 BC
	150	93.8 BC
	200	101.4 BC
	250	108.2 AB
15	50	87.5 C
	100	88.9 C
	150	93.4 BC
	200	93.7 BC
	250	97.3 B
30	50	69.9 ED
	100	68.9 E
	150	72.6 ED
	200	75.7 ED
	250	77.5 D

[a]Means not sharing common letters denote statistical differences among row width treatments ($\alpha = .05$).

2.4.2: Effect of Seeding Rate on Grain Yield

The main effect of seeding rate was highly significant (p=<0.0001) at four site-years, including NWARS 2015, NWARS 2016, Wooster in 2015, and Western in 2016 (Table 3), meaning yield increased as seeding rate increased. This correlates with the research from El-Zeadani et al. (2014) showing that soybean yield was substantially influenced by plant density. The interaction of row width and seeding rate was significant at WARS in 2016 with a p-value of 0.0024 (Table 3). The relationship of soybean grain yield based on seeding rate at the small plot research sites was evaluated (Table 6). WARS 2015 was the only site-year to not have any relationship differences and WARS 2016 varied the most. The lowest yield of 43.5 bu/ac was at the NWARS 2015 location, planted at 50,000 seeds per acre. The highest yield was 94.3 bu/ac at the WARS 2016 location, planted at 250,000 seeds per acre. The highest spread was Wooster 2015 with an 18.2 bushel per acre increase from 50,000 to 250,000 seeds per acre seeding rate. The next highest spread was WARS 2016 with 16.3 bushels per acre, NWARS 2016 with 13.8, NWARS 2015 with 12, followed by Wooster 2016 with 5.4 bushels per acre. WARS 2015 had a spread of 0 from the lowest to the highest seeding rate. This data means an average of an 11-bushel increase is expected when increasing the seeding rate to 250,000 seeds per acre, compared to 50,000 seeds per acre.

Table 6. Soybean grain yield by the effect of seeding rate for each site-year.

Location	Seeding rate (1,000 seeds/acre)	Grain yield (bu/acre)
NWARS 2015	50	43.5 C
NWARS 2015	100	51.1 B
NWARS 2015	150	54.2 A
NWARS 2015	200	55.5 A
NWARS 2015	250	N/A
NWARS 2016	50	61.0 C
NWARS 2016	100	65.6 B
NWARS 2016	150	66.4 B
NWARS 2016	200	68.3 B
NWARS 2016	250	74.8 A
WARS 2015	50	67.1 A
WARS 2015	100	67.5 A
WARS 2015	150	64.7 A
WARS 2015	200	64.4 A
WARS 2015	250	67.1 A
WARS 2016	50	78.0 D
WARS 2016	100	84.7 C
WARS 2016	150	86.6 BC
WARS 2016	200	90.3 BA
WARS 2016	250	94.3 A
WOOSTER 2015	50	49.3 C
WOOSTER 2015	100	58.7 B
WOOSTER 2015	150	63.8 BA
WOOSTER 2015	200	64.7 BA
WOOSTER 2015	250	67.5 A
WOOSTER 2016	50	65.2 B
WOOSTER 2016	100	67.4 AB
WOOSTER 2016	150	69.0 AB
WOOSTER 2016	200	69.0 AB
WOOSTER 2016	250	70.6 A

[a]Means not sharing common letters within a site-year denote statistical differences among row width treatments ($\alpha = .05$).

2.4.3 Plant Characteristics

Row width did not have a significant effect on plant height, lowest pod height, nodes per plant, or branches per plant (Table 3). Seeding rate did have a significant effect (p=<0.0001) on nodes per plant and branches per plant at NWARS 2016, Wooster 2015, and Wooster 2016. The number of nodes per plant decreased as seeding rate increased. Looking at the spreads, at 7.5-inches, the number of nodes between the lowest and highest seeding rate was 2.5. The spread at 15-inch rows as 9 and 5.1 at 30-inch rows.

The lowest pod height was affected by seeding rate at Wooster 2015 (p=0.0009), Wooster 2016 (p=0.0003), and WARS 2015 (p=<0.0001). As the seeding rate increased, the lowest pod grew higher off the ground. The largest spread difference between the seeding rates at the different row widths was the 7.5-inch rows with a 6-inch spread. There was a 0.5-inch spread at 15-inch rows and 3.6 inch spread at 30-inch rows. This means the seeding rates at 7.5-inch rows had a much higher effect on the lowest pod than the 15 or 30-inch rows. These results were similar to results as Caliskan et al., (2007) and Palmer and Privetter (1992), who found that soybean planted between 7.5 and 15 inches have shown to have a higher height of the lowest pod compared to 30-inch rows.

Row width x seeding rate only showed an effect on nodes per plant in NWARS 2016 (p=0.0006) and Wooster 2015 (p=<0.0001) (Table 3). The number of nodes per plant decreased as planting population increased (Table 7). Table 3 and Table 7 results differ from Christmas (1993) stating a higher seed rate will result in taller plants with fewer pods and branches per plant. This was seen in some instances within the seeding rates and row widths, but not all.

The mean plant characteristics from the 10 plants collected just before harvest from each plot at each site year were evaluated (Table 7). Plant height was the lowest at 48.7 inches when planted at 250,000 seeds per acre at a row width of 15 inches. It was the highest at 72.1 inches at a seeding rate of 250,000 seeds per acre and a 7.5-inch row width. The 48.7 inches was questionable, so the original data was checked for confirmation. Within just the 250,000-seeding rate, there were 9 of 20 entries that were between 40 and 49 inches with heights down to 24, 25, and 32 inches. There is no clear explanation for this, and it did not follow the expectation of being the tallest height in the 15-inch rows since it was at the highest seeding rate.

The shortest lowest pod height was 3.1 inches, planted at 50,000 seeds per acre and a 15-inch row width. The tallest lowest pod height was at 13.2 inches, planted at 200,000 seeds per acre and a 7.5-inch row width. The number of nodes per plant ranged from 13.3 to 23.5. The number of branches per plant ranged from 1.9 to 5.3. The number of pods per main stem and pods per branch ranged from 18.5 to 41.0 and 7.6 to 66.2 respectively. The plants produced more branches and more pods per plant were seen at the lower seeding rates and wider rows. The seeds per main stem ranged from 46.3 to 100.6 and the number of seeds per branch ranged from 22.6 to 161.7. Again, the number of seeds increased as the seeding rate was lower and the row width was wider. The seed weight on the main stem ranged from 0.26 oz. to 0.54 oz. and the seed weight on the branches ranged from 0.12 oz to 0.85 oz. It is interesting that there were more seeds on the branches and more weight on the branches compared to the main stem.

Table 7. Average plant characteristics of 10 plants collected before harvest at NWARS, WARS, and Wooster in 2015 and 2016.

Mean Plant Characteristics											
Row width (in)	Rate (1,000 seeds per acre)	Plant Height (in)	Lowest Pod Height (in)	Nodes Per Plant	Branches Per Plant	Pods Per Main Stem	Pods Per Branch	Seeds Per Main Stem	Seeds Per Branch	Seed Wt Main Stem (oz)	Seed Wt Branches (oz)
7.5	50	62.7	7.3	17.3	5.3	41.0	66.2	100.6	161.7	0.54	0.85
7.5	100	66.4	9.2	15.4	4.1	31.8	38.2	78.1	87.3	0.43	0.49
7.5	150	70.4	10.1	18.8	3.3	27.5	22.3	66.3	51.5	0.37	0.29
7.5	200	70.1	13.2	19.8	3.3	33.4	22.2	63.1	47.4	0.36	0.26
7.5	250	72.1	11.6	16.0	2.4	23.0	15.1	54.3	35.7	0.30	0.19
15	50	61.7	3.1	23.5	5.2	34.5	54.3	93.0	130.7	0.53	0.73
15	100	65.2	3.5	22.2	3.9	31.2	35.1	65.7	84.5	0.38	0.46
15	150	63.8	3.5	17.9	3.4	25.9	20.7	67.3	49.4	0.38	0.26
15	200	64.2	4.2	14.5	3.0	23.1	20.3	52.3	43.0	0.29	0.22
15	250	48.7	3.3	14.6	1.9	18.5	7.6	46.3	22.6	0.26	0.12
30	50	63.9	7.9	22.1	4.4	40.4	55.4	97.8	142.0	0.54	0.76
30	100	57.6	8.7	16.0	4.2	33.1	34.3	87.3	89.2	0.43	0.48
30	150	63.6	10.6	17.1	2.7	26.0	20.3	68.9	47.7	0.37	0.25
30	200	67.8	10.8	13.3	3.1	28.5	23.6	74.4	53.5	0.45	0.30
30	250	67.7	10.6	16.2	2.8	24.1	20.0	62.5	49.4	0.39	0.30

Seeding rate had a significant effect (p=<0.0001) on pods per main stem, pods per branch, seeds per main stem, seeds per branch, seed weight on the main stem, and seed weight on the branch at all site years (Table 8). The numeric effects are derived from the data in Table 7 where it shows they all increased as seeding rate decreased. In each of these, other than the seed weight on the main stem, the 7.5 and 15-inch rows had higher values compared to the 30-inch rows. The seeds per branch had the greatest variation and although all were significant, seemed to have the most significant changes among the row widths.

The number of seeds per main stem showed 4 out of 6 significant p-values (Table 8) when looking at row width. The effect is shown in Table 7 showing the number of seeds decreased as seeding rate increased. This agrees with the work published by Marquardt et al.

(2012) explaining that a very high seeding rate results in crops with narrow leaves and fewer seeds per pod. These results are also supported by work published by El-Zeadani et al. (2014) which stated the number and yield of seeds per plant has a negative correlation with increased plant density. There are no results for the WARS 2016 because these plots were harvested before final stand counts and 10 plants per plot could be collected.

Table 8. ANOVA p-values indicating the probability that the means are significantly different for the fixed effects of row width, seeding rate, and row width and seeding rate interaction on the dependent variables of grain yield and partial economic return.

SITE & YEAR	SOURCE	PODS MAIN STEM	PODS PER BRANCH	SEEDS MAIN STEM	SEEDS PER BRANCH	SEED WT MAIN STEM	SEED WT BRANCH
NWARS 2015	RW	0.0836	0.1099	0.0423	0.1453	0.0873	0.1519
	SR	0.0019	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	RWxSR	0.6497	0.2428	0.6528	0.3744	0.5398	0.2700
NWARS 2016	RW	0.0252	0.0611	0.0088	0.0783	0.0500	0.0474
	SR	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	RWxSR	0.0876	0.6796	0.0850	0.2564	0.0003	0.4041
WOOSTER 2015	RW	0.1228	0.6799	0.0092	0.4269	0.0224	0.4140
	SR	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	RWxSR	0.5095	0.5910	0.2017	0.5857	0.9606	0.2411
WOOSTER 2016	RW	0.7458	0.6521	0.7459	0.5185	0.6889	0.6083
	SR	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	RWxSR	0.1915	0.6456	0.1646	0.6721	0.2308	0.5832
WARS 2015	RW	0.1905	0.0358	0.0322	0.0280	0.1160	0.0477
	SR	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	RWxSR	0.1454	0.0847	0.3193	0.3741	0.0935	0.2943
WARS 2016	RW	NA	NA	NA	NA	NA	NA
	SR	NA	NA	NA	NA	NA	NA
	RWxSR	NA	NA	NA	NA	NA	NA

*RW = Row Width, SR = Seeding Rate, RWxSR = Row Width by Seeding Rate Interaction

2.4.4 Agronomic Optimum Seeding Rate

The agronomic optimum seeding rate (AOSR) is the seeding rate where soybean yield is maximized. The higher quadratic values were used, determined by the higher r-squared value, compared to the linear values. The p-values less than $\alpha = 0.05$ were determined significant. The highest AOSR was greater than 250,000 seeds per acre at 7.5, 15, and 30-inch rows at all locations (Table 9). The lowest AOSR was 83,000 seeds per acre at 7.5-inch row width at the Western plot location. The Average AOSR was 193,000 seeds per acre in 2015, and 241,000 seeds per acre in 2016.

Table 9. Soybean agronomic optimum seeding rate and the economic optimum seeding rate based on row width for each site-year.

LOCATION	ROW WIDTH (IN)	AOSR 2015 (1,000 SEEDS/AC)	AOSR 2016 (1,000 SEEDS/AC)	EOSR 2015 (1,000 SEEDS/AC)	EOSR 2016 (1,000 SEEDS/AC)
NWARS	7.5	>250	>250	216	203
NWARS	15	>250	>250	186	178
NWARS	30	170	155	149	99
WARS	7.5	83	>250	192	>250
WARS	15	164	>250	<50	<50
WARS	30	132	<50	<50	135
WOOSTER	7.5	>250	247	240	84
WOOSTER	15	205	172	178	128
WOOSTER	30	229	>250	<50	<50

At the Northwest Research station in 2015, soybean yield increased quadratically with seeding rate (Figure 2). In 2015, the AOSR for 7.5 and 15-inch rows were over 250,000 seeds per acre and at 30-inch rows was 170,000 seeds per acre. At the same location in the following year, 2016 (Figure 3), yield increased quadratically with seeding rate. The AOSR’s at 7.5 and 15-inch rows were over 250,000 seeds per acre and 155,000 seeds per acre at 30-inch rows.

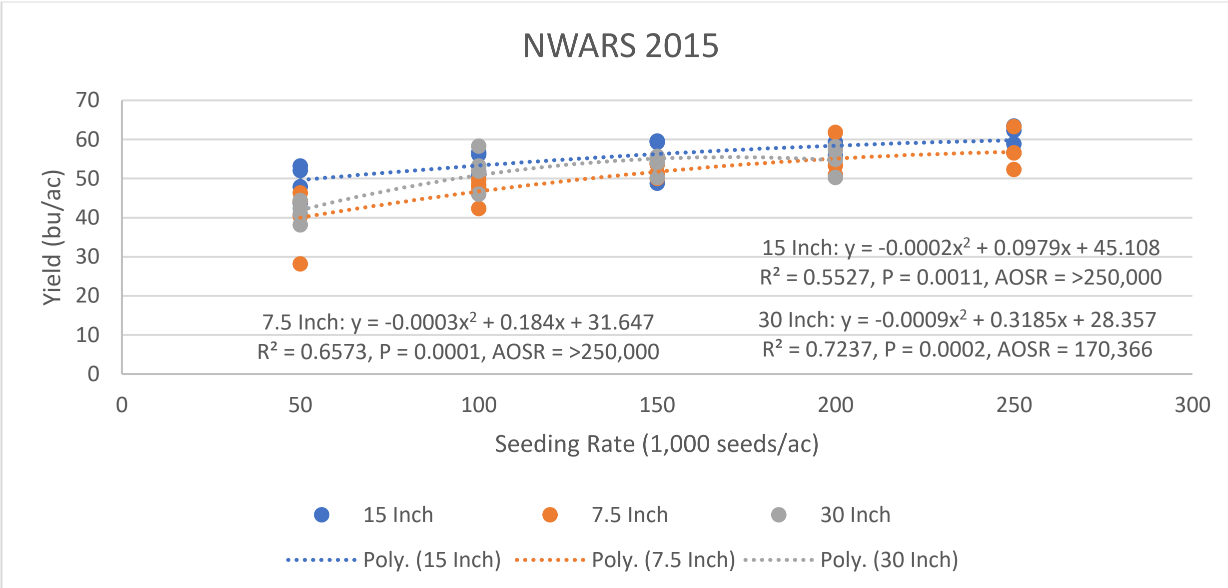

Figure 2: Regression of soybean yield on seeding rate at Northwest Agricultural Research Station (NWARS) in 2015.

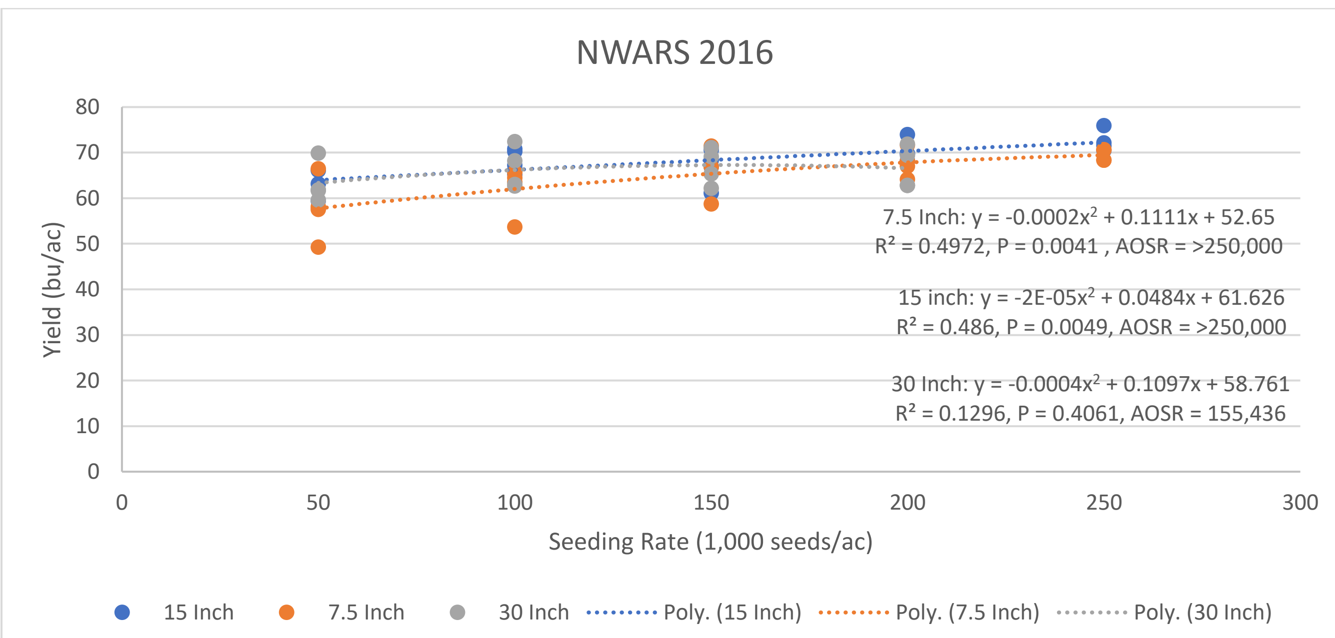

Figure 3: Regression of soybean yield on seeding rate at Northwest Agricultural Research Station (NWARS) in 2016.

In 2015, the Western Agricultural Research Station (WARS) shows soybean yield decreased for the 7.5-inch rows, increased quadratically for the 15-inch rows, and had very little change for the 30-inch rows (Figure 4). The AOSR for 7.5-inch rows was 83,887, 15-inch rows was 164,440 seeds per acre and at 30-inch rows was 132,090 seeds per acre. At the same location in the following year, 2016, the results show yield increased quadratically with seeding rate (Figure 5). 7.5 and 15-inch rows were again over 250,000 seeds per acre and 30-inch rows below 50,000 seeds per acre.

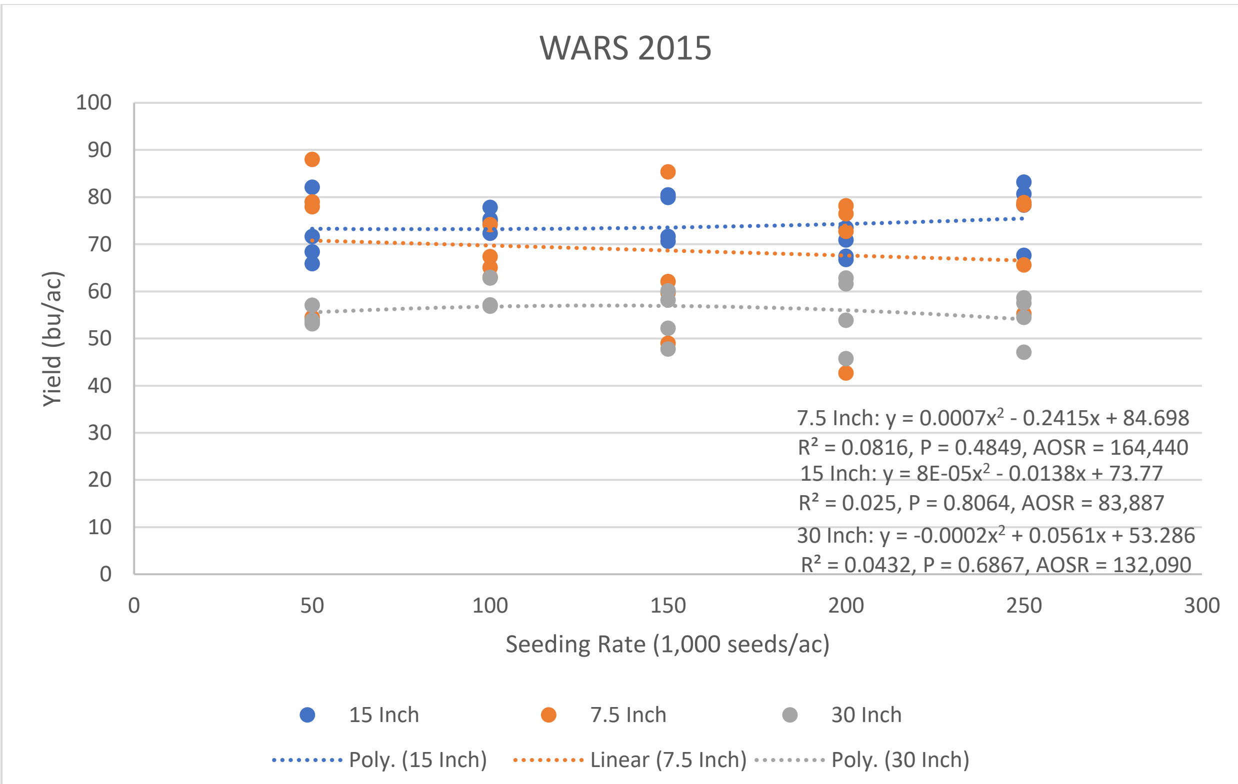

Figure 4: Regression of soybean yield on seeding rate at Western Agricultural Research Station (WARS) in 2015.

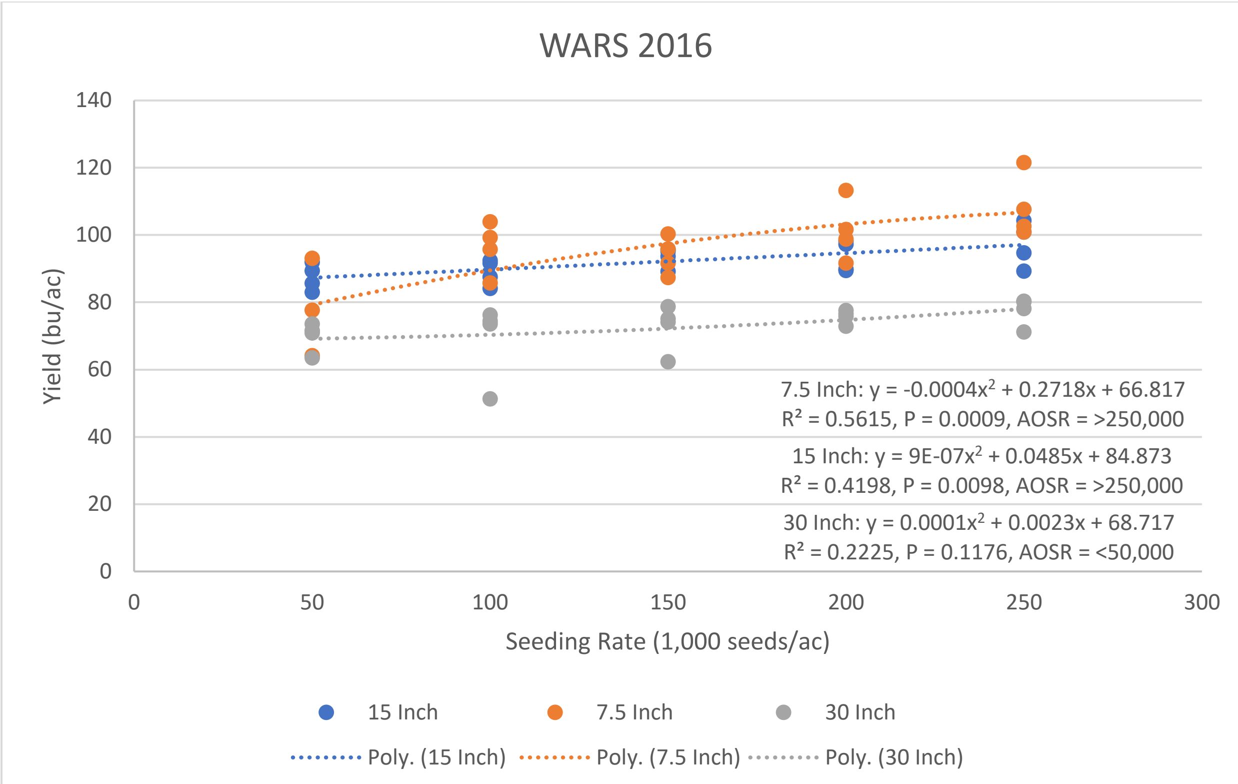

Figure 5: Regression of soybean yield on seeding rate at Western Agricultural Research Station (WARS) in 2016.

At the Wooster Research station in 2015, soybean yield increased quadratically with seeding rate (Figure 6). The AOSR for 7.5-inch rows was over 250,000 seeds per acre, 15-inch rows was 205,250 seeds per acre, and at 30-inch rows was 229,260 seeds per acre. At the same location in the following year, 2016 (Figure 7), yield increased quadratically with seeding rate. The AOSR for 7.5-inch rows was over 250,000 seeds per acre, and 15-inch rows was 172,970, and 30-inch rows was over 250,000 seeds per acre. The yield was higher in 2016 than in 2015. Again, there was not much of a yield response due to seeding rate, as seen by the mostly flat lines and high p-values.

Figure 6: Regression of soybean yield on seeding rate at Wooster Agricultural Research Station in 2015.

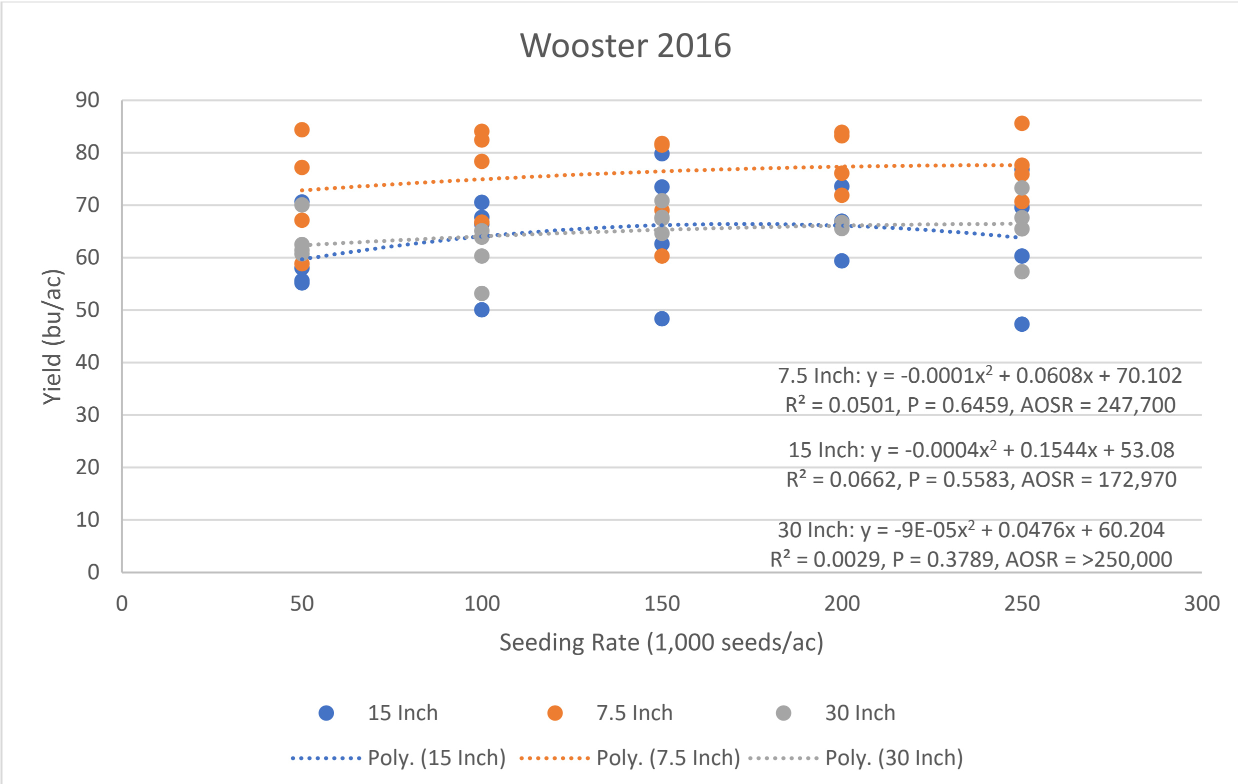

Figure 7: Regression of soybean yield on seeding rate at Wooster Agricultural Research Station in 2016.

2.4.5 Partial Return and Economic Optimum Seeding Rate

The main effect of seeding rate on partial return was significant at 4 site-years (Table 3), including NWARS 2015 (p=<0.0001), NWARS 2016 (p=<0.0001), and Wooster 2015 (p=0.0054) and WARS 2016 (p=0.0092). Row width also had a significant effect on partial returns at 3 site-years including Wooster 2016 (p=0.0057), WARS 2015 (p=0.0016), and WARS 2016 (p=0.0006). These site-years were averaged together to show partial returns (Table 10). The partial return ranged from $491.50 at the lowest seeding rate of 50,000 seeds per acre and narrowest row width of 7.5-inches to $681.57 at 250,000 seeds per acre at the 15-inch row width. The spreads of these partial returns were $189.70, $144.16, and $103.80 for 7.5, 15, and 30-inch rows respectively. At most seeding rates, the 15-inch row width had a higher partial return compared to the 7.5 and 30-inch row widths. At the 50,000, 100,000 and 150,000 seeding rates, the 30-inch row widths had a higher partial return than the 7.5-inch row width.

Table 10. Partial return from NWARS 2015, NWARS 2016, and Wooster 2015 based on row width and seeding rate.

Row Width (in)	Rate (x 1,000 Seeds/ac)	Yield (bu/ac)	Gross Return ($)	Seed Cost ($ per 1,000)	Partial Return ($ per acre)
7.5	50	48.0	$491.50	$20.50	$491.50
7.5	100	56.8	$581.88	$41.00	$581.88
7.5	150	59.4	$608.45	$61.50	$608.45
7.5	200	63.4	$649.80	$82.00	$649.80
7.5	250	66.5	$681.20	$102.50	$681.20
15	50	52.4	$537.41	$20.50	$537.41
15	100	60.9	$623.68	$41.00	$623.68
15	150	63.1	$646.43	$61.50	$646.43
15	200	63.3	$649.07	$82.00	$649.07
15	250	66.5	$681.57	$102.50	$681.57
30	50	52.9	$542.28	$20.50	$542.28
30	100	57.8	$592.50	$41.00	$592.50
30	150	61.5	$630.72	$61.50	$630.72
30	200	61.8	$632.89	$82.00	$632.89
30	250	63.0	$646.08	$102.50	$646.08

The economic optimal seeding rate (EOSR) is the amount of seed needed to maximize optimal return. The lowest EOSR was less than 50,000 seeds per acre at the Western and Wooster locations when planting 7.5, 15, and 30-inch rows (Table 9). The average EOSR was 146,000 seeds per acre in 2015, and 131,000 in 2016. Iowa State suggests an EOSR of 125,000 to 140,000 seeds per acre for 15 and 30-inch rows (Licht, 2021). The results of 2015 were just above this recommendation and the 2016 results fell within the suggested rates. The EOSR recommended by Iowa State University (2021) is slightly higher than the recommended agronomic optimal fall stand of 100,000-120,000 seeds per acre from the Ohio Agronomy Guide (Lindsey et al., 2017) but given the percentage losses between planting and harvest, it is reasonable that they could be within the same recommended levels.

2.4.6 Agronomic Optimum Fall Stand

The agronomic optimal fall stand (AOFS) is the amount of plants recommended a producer to have just before harvest to maximize soybean yield. The AOSR and EOSR values were greater than expected but can be explained since only 60-80% of the plants survive to harvest (Lindsey et al., 2017). Therefore, the AOFS was calculated using the final stand rather than seeding rate. The highest AOFS was 163,000 plants per acre at 15-inch rows at the Northwest location (Table 11). The lowest AOFS was 73,000 plants per acre at 7.5-inch rows at the Western location. According to the Ohio Agronomy Guide (Lindsey et al., 2017), the recommended fall stand for soybeans planted before May 20 is 100,000 to 120,000 plants per acre. The results of the 7.5-inch rows were 60-73% lower and the 15-inch rows were 136-163% higher than the Ohio Agronomy Guide recommendation.

Table 11. Soybean agronomic optimum fall stand (AOFS) based on row spacing for each site-year.

LOCATION AND YEAR	ROW SPACING (IN)	AOFS (X 1,000 PLANTS PER ACRE)
NWARS 2015	7.5	160
NWARS 2015	15	163
NWARS 2015	30	105
WARS 2015	7.5	73
WARS 2015	15	137
WARS 2015	30	117
WOOSTER 2015	7.5	129
WOOSTER 2015	15	129
WOOSTER 2015	30	147
WOOSTER 2016	7.5	118
WOOSTER 2016	15	100
WOOSTER 2016	30	99

2.5 Conclusion

The results of this study show that the Agronomic Optimum Fall Stand is 123,000 plants per acre. This is only 3,000 plants per acre higher than the Ohio Agronomy Guide recommendation of 100,000 to 120,000 plants per acre (Lindsey et al., 2017). To back into a AOSR based on the AOFS by calculating 60-80% of the plants expected to survive to harvest, the recommended AOSR would be 154,000 - 205,000 seeds per acre. Based on this AOSR, farmers could expect to receive $608-$650 in partial returns. It is recommended that producers count populations after emergence and again before harvest to determine what seeding rate will accomplish the optimum populations for their soil types and equipment to maximize economic return. In conclusion, row width influenced grain yield in 3 of the 6 site-years at 5% probability, and 4 out of 6 site-years accepting 10%. Based on these results, row width can affect yield and 7.5 and 15-inch row widths can yield higher than the 30-in rows. Additionally, plants compensated for low seeding rate by producing more branches and more seeds per plant. The recommended fall stand results confirm the recommendation from the Ohio Agronomy Guide of 100,000 to 120,000 plants per acre.

Chapter 3: On-Farm Trials

3.1: Abstract

The purpose for this study is to recommend a seeding rate or fall stand for Ohio farmers. Trials were conducted in 2014 and 2015 on five farms in Fulton, Miami and Darke Counties in Ohio to assess optimal seeding rates and row width for soybean cultivation to maximize crop yield. These on-farm trials consisted of four to five seeding rates ranging from 60,000 to 235,000 seeds per acre with three to four replications of treatments. The experimental design for the on-farm research was a randomized complete block design with four replications of treatments. The main plot factor was seeding rate. Stand counts of soybean were conducted shortly after emergence and just prior to harvest. The agronomic optimum fall stand (AOFS) was 142,000 seeds per acre. Plants compensated for lower seeding rates by developing branches and producing more seeds per plant.

3.2: Introduction

The Ohio Agronomy Guide (Lindsey et al., 2017) suggests Ohio farmers should plant a seeding rate to achieve a fall stand of 100,000 to 120,000 plants per acre, if planted before May 20, to achieve maximum yield. Common row widths in Ohio range from 7-inches to 15-inches. Although most farmers in Ohio prefer a 15-inch row width, 30-inch row widths can be found on smaller farms or farms that use the same planter for corn and soybeans. Current research shows that narrower row width is associated with higher yields as benefits are substantially higher for farms with 7.5 to 15-inch rows (Roberson, 2014; Andrade et al., 2018). However, a combination of very high seeding rates and narrow row width has been associated with an increased risk for bacterial and fungal infections, as well as a greater risk of competition within the plants, reducing yield (Hu and Wiatrak, 2012; Marquardt et al., 2012; Zeng et al., 2012). This research aims to evaluate optimal soybean fall stand by conducting on-farm trials.

Small plot trials are complemented by on-farm large scale trials, as larger scale plots better mimics traditional farming practices, while allowing for comparison with the results of the small farm trial. Licht and Witt (2019) describe on-farm trials as a positive way for farmers to try new products, management styles, or equipment as it enables the testing of different varieties of plants, planting types – such as twin row or row width, or pre trials for transitioning to organic farming. Farmers and researchers have conducted on-farm trials for decades. Farmers may plant different row widths or strips of different plants and compare the results. These trials conducted on-farm trials are a great way for farmers to learn how different farming styles, equipment and products will work with their farming style. These trials along with the use of precision technology, including GPS, have further enabled farmers to conduct on-farm trials in easier ways.

On-farm trials are conducted to evaluate specific practices under normal farming growing conditions. They are designed to forecast responses to the different effects and confirm research conducted from small plots on a larger scale. There are different types of on-farm trials. Usually the researcher determines the treatments and sets certain parameters, while the farmer makes the rest of the management decisions. Extreme cases involve the farmer making all the decisions pertaining to the setting of treatments. Some trials are researcher managed, while others involve varying shares of management responsibilities between farmers and researchers. Nonetheless, on-farm trials are a sort of citizen science for farmers as the large scale of results from many site-years in a region provide a better understanding of how management decisions relate with weather and different soil types for improved farm profits (Licht and Witt, 2019).

3.3: Materials and Methods

Figure 8: Ohio 2014 & 2015 on-farm trial locations.

On-farm research trials were conducted on five farms across the western side of Ohio in Fulton, and Darke counties in 2014 and Miami county (Englewood) in 2015 (Figure 8). The preceding crop on all farms was corn. These on-farm trials consisted of four to five seeding rates ranging for 60,000 to 235,000 seeds per acre with 3 to 4 replications of treatments. The experimental design on each farm was a randomized complete block design with four replications of treatments and the treatment factor was seeding rate. The large-scale plots were planted using the farmers' own soybean planters, sprayers, and combines. Since the planters used by farmers do not have the capacity to quickly change planting populations and row width as was the case in the small plots, the soybeans were planted at the Ohio standard 15-inch row widths. This was done because row width cannot be changed without major hardware changes that would take hours of time. Even though sprockets can be changed to adjust the seeding population, they are not as exact as the plot planters. Stand counts were taken around the V4 and R8 stages by measuring 17.5 ft down the plot with a tape measure and counting the number of plants in two rows. This was conducted to ensure successful plots were established to obtain reliable data. Notes were taken about the plot establishments and any concern that could change the results were noted.

The 2014 plots were planted and managed by Sam Custar and Eric Richer, Extension Agents in Darke and Fulton County respectively. They both agreed I could use this data for my research to expand on the small plot research. I do not have the plot size, locations, or equipment used for these results. I was able to conduct a trial on one of our farms. In the Englewood 2015 plots in Miami County, there were a total of 20 plots. Ten of the soybean plots were no-till planted into corn stalks, and the other 10 were planted in the ground tilled with a chisel plow. Tillage was not a treatment factor. This section was plowed to reduce the soil ridges and create a uniform seedbed. These plots were harvested with a MacDon 40-foot FlexDraper combine head attached to a John Deere S770 Combine. At this site-year, the combine head plugged multiple times at the 200,000 and 250,000 plants per acre, causing the operator to shut down the machine in order to unplug the jammed plants. These plots were harvested at 1-1.5 mph instead of 3-3.5mph decrease the possibility of lodging. Although we can only confirm this occurred at one site-year, lodging should be a consideration when planting populations over 200,000 plants per acre. For the 2015 Englewood plots, the 40-foot combine head could have harvested 32 rows, but we chose to harvest 31 to ensure uniformity of harvest and reduce the risk of missing plants during harvest of long rows. This was taken into account when measuring yield.

A mixed procedure in SAS 9.4 (SAS Institute, Cary, NC), was used to analyze grain yield and plant data utilizing the analysis of variance (ANOVA) test. For the GLIMMIX test and ANOVAs (tables), yield was the dependent variable and replication as well as replication times width were the random effects. Width, rate, and width times rate were means tested. SAS was also used to produce a linear and quadratic response curves by regressing the seeding rate against the yield and partial return. The Agronomic Optimal Seeding Rate (AOSR) was maximum point in the response curve when regressing grain yield on seeding rate. The Economic Optimal Seeding Rate (EOSR) was determined the same way when regressing the seeding rate by the partial return. To get exact numbers, the AOSR and EOSR were calculated by solving the quadratic formulas.

Gross return was calculated by multiplying yield by $10.25. Partial return was calculated by subtracting seed cost from the gross return. The seed cost was calculated by multiplying rate times $0.41. Yield was adjusted to 13% moisture by subtracting actual moisture from 100 and dividing the result by 100 minus 13.

3.4: Results and Discussion

3.4.1 Weather

The weather in 2015 near Englewood, Ohio was advantageous for crops. March was too cool so planting occurred mostly in April and May. Although the area received five inches of rain in April (Table 12), less than two inches in May, and almost eight inches in June, it was not enough to drown out our on-crop plots nor cause a need for replant. On the contrary, the crops seemed to flourish in these conditions. The amount of rainfall began to drop in July and was down to below two inches in August. Rainfall was less than an inch in September allowing for major progress in harvesting crops. In 2016, much of the soybean planting occurred in April and May. Both months received less than 3 inches of rainfall allowing for dry planting conditions. Compared to 2015, the rainfall amount was less in Jun and July but was higher in August and September. October received less than 2 inches allowing for dry harvest conditions (Table 12).

Table 12. Monthly precipitation and temperatures for the Dayton, Ohio area.

Monthly Total Precipitation for Dayton Area, OH (ThreadEx)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	2.8	1.4	3.9	5.3	1.8	7.9	4.6	1.9	0.9	3.7	2.4	4.4
2016	1.5	3.3	5.5	3.0	3.0	3.6	3.0	3.7	3.3	1.9	1.1	3.0
Monthly Min and Max Temperature for Dayton Area, OH (ThreadEx)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015 Max	59	58	71	79	87	91	91	87	91	81	75	69
2015 Min	-7	-5	6	31	41	48	55	51	47	35	24	1
2015 Average	26.3	20.4	38.7	54.1	68.0	72.5	73.8	70.7	69.4	55.8	47.8	43.7
2016 Max	61	69	74	83	88	92	92	91	90	82	79	66
2016 Min	0	3	23	23	35	51	52	56	49	35	24	1
2016 Avg	27.9	33.4	47.4	51.2	61.1	72.7	75.5	76.8	69.7	59.3	47.3	30.3

NOAA Online Weather Data (NOAA, 2021).

3.4.2 Effect of Seeding Rate on Grain Yield

Yields were influenced by rate in three site-years, FultonA 2014 (p=0.0007), FultonC 2014 (p=0.0125), and FultonD 2014 (p=0.0098) (Table 13). These values came from SAS regression formulas. Since these are on-farm plots, they are all at 15-inch row widths. At the remaining 5 site-years, there was no effect of row width on soybean grain yield. These results differ from those of El-Zeadani et al. (2014) which showed soybean yield was substantially influenced by plant density.

Table 13. P-value of seeding rate's influence on soybean yield in Ohio in 2014 and 2015.

Location	p-value
DarkeA 2014	0.3873
FultonA 2014	0.0007
FultonB 2014	0.9060
FultonC 2014	0.0125
FultonD 2014	0.0098
Englewood 2015	0.7627

DarkeA, Englewood, and Fulton B did not show differences in significance relationships (Table 14). FultonA, FultonC, and FultonD plots did show relationship differences. The lowest yield was FultonC with 46.5 at 110,000 seeds per acre. Englewood had the highest two mean with 76.2 at 197,000 seeds per acre and 75.7 at 163,000 seeds per acre. The mean yields did not show a trend of increasing or decreasing with seeding rate. The FultonA with 9.2 bushels per acre, FultonC with 9.7 bushels per acre, and FultonD with 4.5 bushels per acre. All of these plots were at 15-inch row widths. FultonB 2014 was a scatterplot regression curve, and no data was concluded from this. Confirmation that FultonC having the highest spread is also shown by the significant relationshiop letters (Table 14).

Table 14. Rate and yield with significant relationships of 2014 and 2015 on-farm plots in Ohio.

Location	Seeding rate (1,000 seeds/acre)	Grain yield (bu/acre)
DarkeA 2014	60	63.0 A[4]
DarkeA 2014	95	62.4 A
DarkeA 2014	130	64.8 A
DarkeA 2014	165	66.5 A
DarkeA 2014	200	65.9 A
DarkeA 2014	235	66.5 A
FultonA 2014	140	57.7 C
FultonA 2014	160	63.7 B
FultonA 2014	175	66.6 A
FultonA 2014	200	66.8 A
FultonB 2014	115	49.6 A
FultonB 2014	140	50.0 A
FultonB 2014	165	50.1 A
FultonB 2014	190	51.1 A
FultonC 2014	110	46.5 C
FultonC 2014	135	49.6 BC
FultonC 2014	160	47.8 C
FultonC 2014	185	53.3 BA
FultonC 2014	210	56.2 A
FultonD 2014	107	51.2 C
FultonD 2014	131	52.9 BC
FultonD 2014	154	55.5 A
FultonD 2014	175	54.2 BA
FultonD 2014	200	55.7 A
Englewood 2015	101	73.4 A
Englewood 2015	131	74.4 A
Englewood 2015	163	75.7 A
Englewood 2015	197	76.2 A
Englewood 2015	229	71.4 A

[4]Means not sharing common letters denote statistical differences among row width treatments (α = .05).

3.4.3 Agronomic Optimum Seeding Rate

The agronomic optimum seeding rate (AOSR) is the seeding rate where soybean yield is maximized. Like with the small plot research, the higher quadratic values were used, determined by the higher r-squared value, compared to the linear values. The p-values less than 0.05 were determine significant. The mean AOSR and EOSR for the On-farm trials in Ohio during the

2014 and 2015 growing seasons were evaluated (Table 15). The mean AOSR was 148,000 seeds per acre. The DarkeA plots were within 15 miles of the Englewood plots and all of the Fulton plots were in the same county. A county location effect is not suggested but rather a field effect because of the vast differences in yields between the Fulton plots. The study from Mourtzinis et al. (2019) showed how varies across a field, which makes seeding recommendations difficult.

Table 15. Agronomic optimum seeding rate (AOSR) and economic optimum seeding rate (EOSR) by location and year in Ohio on-farm trials in 2014 and 2015.

LOCATION AND YEAR	**AOSR (1,000 PLANTS PER ACRE)**	**EOSR (1,000 PLANTS PER ACRE)**
DARKEA 2014	227	144
FULTONA 2014	127	140
FULTONB 2014	101	116
FULTONC 2014	>150	110
FULTOND 2014	120	60
ENGLEWOOD 2015	161	142

The AOSR on the DarkeA farm trial in 2014 was 227,000 seeds per acre (Figure 9). The slope of this line is mostly flat so the AOSR was expected to be closer to the highest or lowest seeding rate. The AOSR from the 2015 Englewood on-farm plot was 161,000, and although the p-value was unsignificant (0.7627), the slope of the line was as desired to obtain a measurable AOSR within the studied seeding rates (Figure 10).

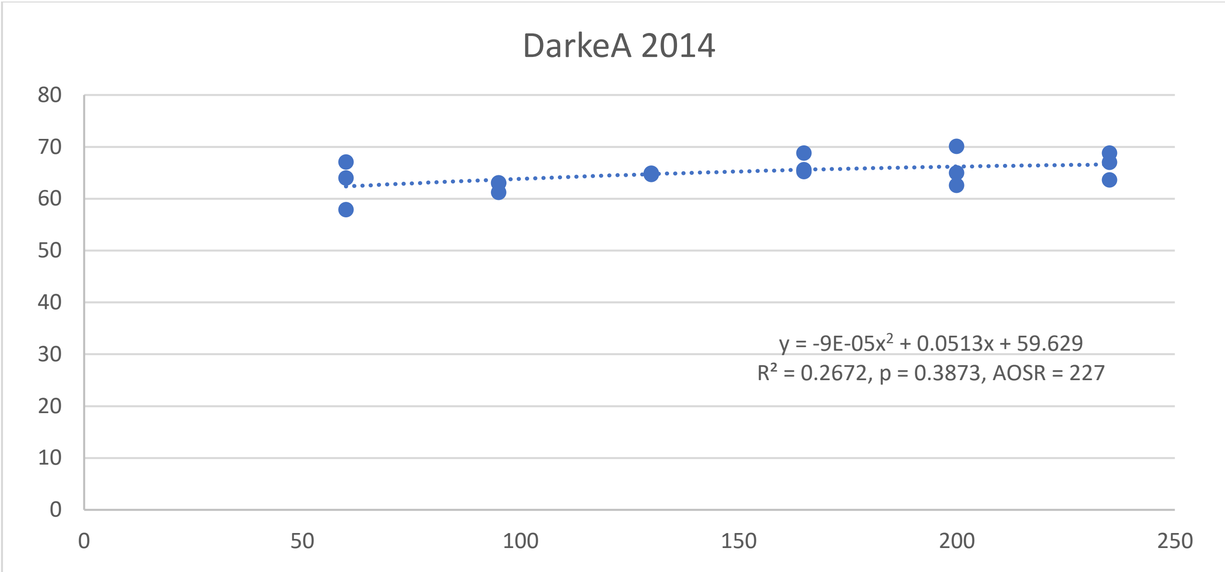

Figure 9: Regression of soybean yield on seeding rate at DarkeA in 2014.

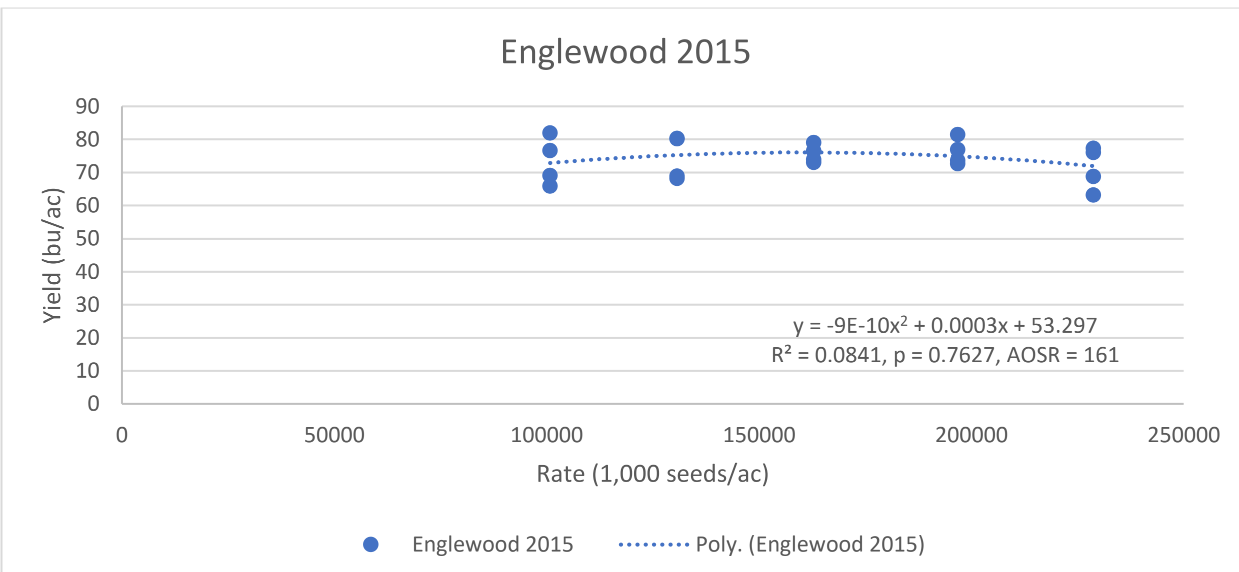

Figure 10: Regression of soybean yield on seeding rate at Englewood in 2015.

The FultonA plots in 2014 (Figure 11) show the soybean yield increased quadratically with seeding rate. The p-value was significant (0.0007) and the results showed yield increased as seeding rate increased (Table 13). The AOSR was 183,000 seeds per acre. The slope of the line does not begin to drop until getting close to the higher seeding rate, confirming the possibility of a correct AOSR. The FultonB 2014 plot (Figure 12) shows a lot of variation within the data. Although it appears the yield increases with seeding rate, no statistical analysis could be determined from these results.

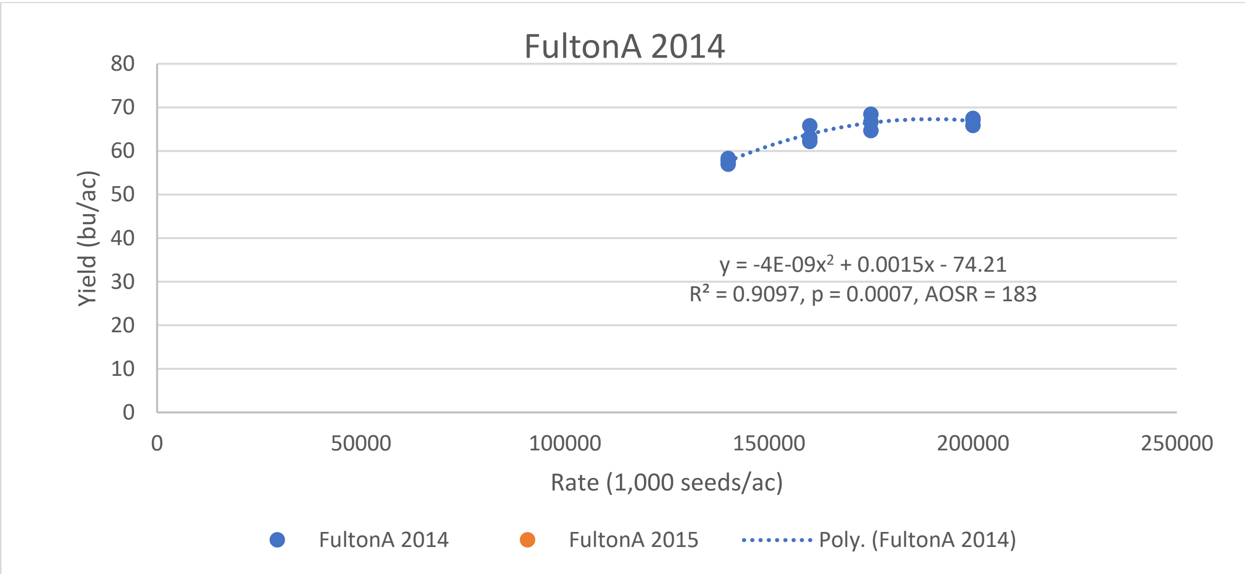

Figure 11: Regression of soybean yield and seeding rate at FultonA in 2014.

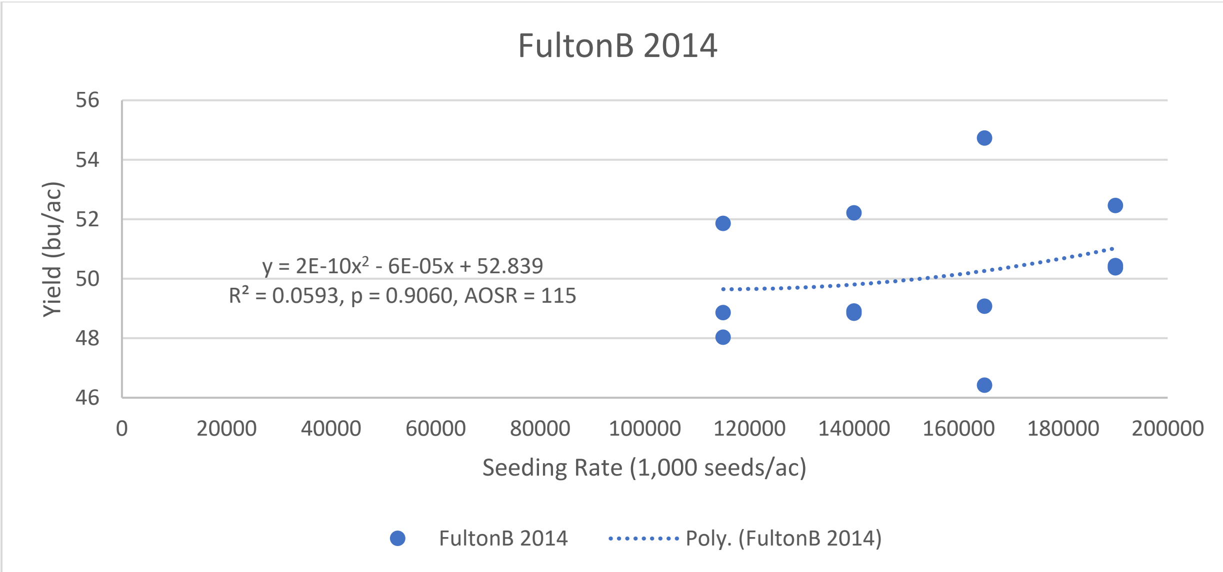

Figure 12: Regression of soybean yield on seeding rate at FultonB in 2014.

The FultonC plot in 2014 (Figure 13) shows the soybean yield increased quadratically with seeding rate. The p-value was significant (p=0.0125) and showed yield increased with seeding rate. The AOSR was 110,000 seeds per acre, the lowest seeding rate, since the slope was concave. In 2014, at FultonD, the AOSR was greater than 200,000 seeds per acre (Figure 14). This p-value was also significant (p=0.0098) and soybean yield increased with seeding rate.

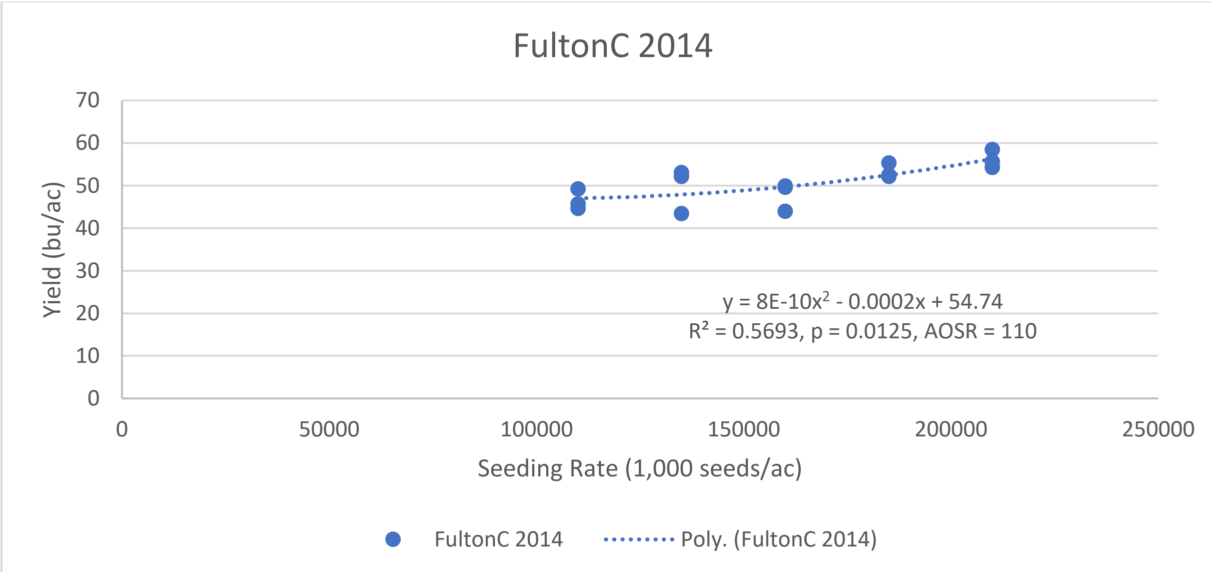

Figure 13: Regression of soybean yield on seeding rate at FultonC in 2014.

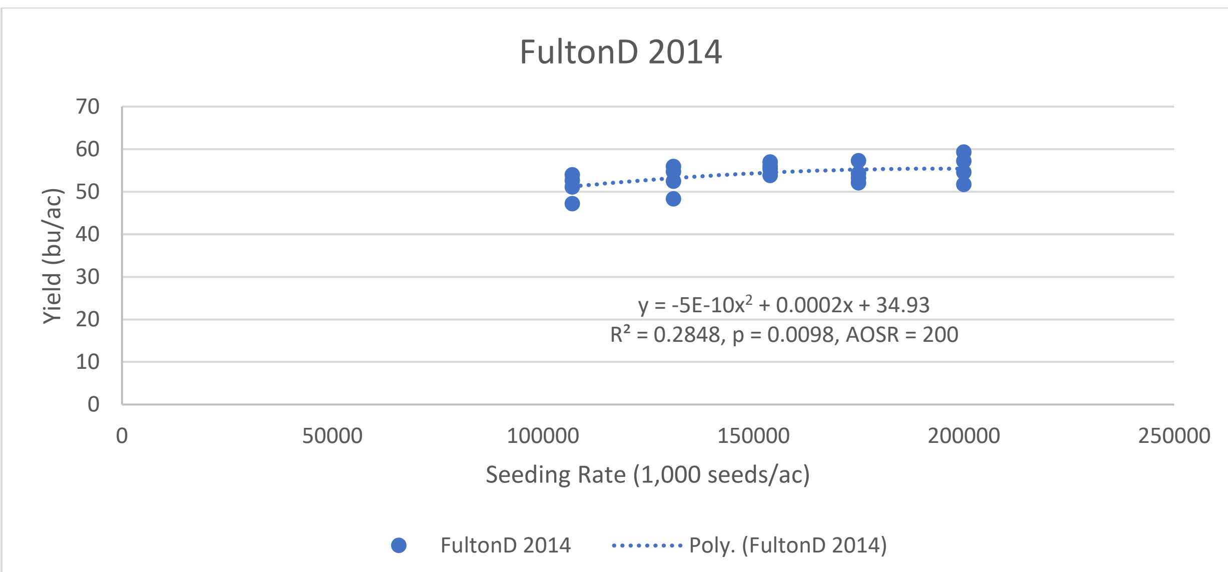

Figure 14: Regression of soybean yield on seeding rate at FultonD in 2014.

3.4.4 Partial Return and Economic Optimum Seeding Rate

Partial return was calculated by multiplying the yield by \$10.25 to get the gross return and subtracting the seed cost of \$0.41 per 1,000 seeds to get the partial return (Table 16). The only site-year showing seeding rate had a significant effect on partial return was FultonA 2014 with a p-value of 0.0024, which was determined from regression tests using SAS. If looking at 10% significance, FultonC 2014 (p=0.0991) and FuldonD 2014 (p=0.0575) would be included. The partial returns ranged from $424.56 at the FultonC 2014 site planted at 160,000 seeds per acre. The highest partial return was at Englewood 2015 with $711.04 (Table 17). DarkeA and Englewood site-years resulted in a partial return highest at the lowest seeding rate 60,000 and 101,000 seeds per acre respectively. The opposite was true for FultonA and FultonC, which were both the highest at the highest seeding rate, 200,000 and 210,000 seeds per acre respectively. The FultonD site-year was highest at the middle seeding rate of 154,000 seeds per acre. Partial returns increased as seeding rate and yield increased.

Table 16. P-values for the regression of seeding rate on partial return in Ohio in 2014 and 2015.

Location	p-value
DarkeA 2014	0.6642
FultonA 2014	0.0024
FultonB 2014	0.8654
FultonC 2014	0.0991
FultonD 2014	0.0575
Englewood 2015	0.3055

Table 17. Partial return from DarkeA, FultonA, FultonC, FultonD from 2014 and Englewood in 2015 Ohio on-farm research plots.

Location	Rate (1,000 Seeds per Acre)	Yield (bu/ac)	Gross Return ($)	Seed Cost ($)	Partial Return ($)
DarkeA 2014	60	63.0	$645.75	$24.60	$621.15
DarkeA 2014	95	62.4	$639.91	$38.95	$600.96
DarkeA 2014	130	64.8	$664.20	$53.30	$610.90
DarkeA 2014	165	66.5	$681.93	$67.65	$614.28
DarkeA 2014	200	65.9	$675.48	$82.00	$593.48
DarkeA 2014	235	66.5	$681.32	$96.35	$584.97
FultonA 2014	140	57.7	$591.08	$57.40	$533.68
FultonA 2014	160	63.7	$652.93	$65.60	$587.33
FultonA 2014	175	66.6	$682.65	$71.75	$610.90
FultonA 2014	200	66.8	$685.04	$82.00	$603.04
FultonC 2014	110	46.5	$476.63	$45.10	$431.53
FultonC 2014	135	49.6	$507.99	$55.35	$452.64
FultonC 2014	160	47.8	$490.16	$65.60	$424.56
FultonC 2014	185	53.3	$546.74	$75.85	$470.89
FultonC 2014	210	56.2	$575.54	$86.10	$489.44
FultonD 2014	107	51.2	$525.11	43.87	$481.24
FultonD 2014	131	52.9	$541.71	$53.71	$488.00
FultonD 2014	154	55.5	$569.18	63.14	506.04

FultonD 2014	175	54.2	$555.86	$71.75	$484.11
FultonD 2014	200	55.7	$570.93	$82.00	$488.93
Englewood 2015	101	73.4	$752.45	$41.41	$711.04
Englewood 2015	131	74.4	$763.01	$53.71	$709.30
Englewood 2015	163	75.7	$775.52	$66.83	$708.69
Englewood 2015	197	76.2	$781.15	$80.77	$700.38
Englewood 2015	229	71.4	$731.54	$93.89	$637.65

The EOSR from each site-year from the on-farm research trials in 2014 and 2015 was calculated (Table 15). The EOSR ranged from 60,000 to 144,000 seeds per acre and the mean EOSR was 119,000 seeds per acre. FultonA 2014's EOSR was 140,000 seeds per acre. It is important to single out this site year since it is the only significant seeding rate and yield interaction (0.0007). To give one recommendation, an EOSR of 130,000 seeds per acre is recommended.

3.4.5 Agronomic Optimum Fall Stand

The agronomic optimum fall stand (AOFS) is the amount of plants recommended at seeding to maximize soybean yield. Planting populations differ from harvest populations because only 60-80% of the plants survive to harvest (Lindsey et al., 2017). Since planting populations can differ so much based on numerous factors, fall stand was used to show higher quality data. The AOFS ranged from 117,000 to 176,000 seeds per acre and the mean AOFS was 142,000 seeds per acre (Table 18). The range of these results differ from the Ohio Agronomy Guide (Lindsey et al., 2017) seeding rate recommendations for soybeans planted before May 20 which is 100,000 to 120,000 plants per acre. If backing into an AOSR based on the AOFS and utilizing the 60-80% plant survival rate (Lindsey et al., 2017), the AOSR would be 178,000 to 237,000 seeds per acre, much higher than the AOSR recommended from this study of 148,000 seeds per acre.

Table 18. Location and year of Ohio on-farm trails showing AOFS in 2014.

LOCATION	AOFS (1,000 PLANTS PER ACRE)
DARKEA	176
FULTONA	127
FULTONB	121
FULTONC	117
FULTOND	169

3.5: Conclusion

The results of this on-farm show seeding rate had a significant effect on grain yield in 3 of the 6 site years (Table 13). This was the FultonA 2014 with the AOSR of 140,000 seeds per acre (Table 15), FultonC 2014 with the AOSR of >150,000 seeds per acre and FultonD 2014 with the AOSR of 120,000 seeds per acre. When averaging these together, it amounts to 137,000 seeds per acre. As with the small plot study, a standard seeding rate across Ohio cannot be recommended due to variables such as soil type, rainfall, seed variety, and management, therefore an optimum fall stand will be recommended. The ideal plant stand in the fall was 142,000 plants per acre, which is very close to the AOSR. By lowering the seeding rate, plants will have increased air flow, less competition among themselves, and the farmers will be saving money on seed costs. The mean EOSR was 119,000 seeds per acre and based on the seeding rate, farmers could expect to receive $452 to $709 partial return.

Chapter 4: Thesis Conclusion

4.1 Row Width Effect on Yield

Row width studies only occurred on the small plot research farms so there is no way to compare results to the on-farm results. On the small plot research plots, soybean grain yield was positively influenced by row width (Table 3) in 3 of the 6 site-years, accepting 5% level of probability and 4 of the 6 site-years if accepting 10%. The effect showed yield was greater in the 7.5 and 15-inch rows compared to the 30-inch rows. There was a significant row width x seeding rate interaction at WARS 2016 (Table 3), showing yield was the highest at the 7.5 and 15-inch rows and the yield increased as seeding rate increased. At this location, soybean yield was greatest (108.2 bu/acre) when grown in 7.5-inch row width at 250,000 seeds/acre. At 7.5-inch row spacing, the yield increase with higher plant density was greater than the yield increases with high density at the 30-inch row spacing. At the remaining site-years, there was no effect of row width on soybean grain yield. Overall, soybean grain yield tended to be greater in narrow rows (7.5-inch and 15-inch) compared to wide rows (30-inch).

4.2 Seeding Rate Effect on Yield

The main effect of seeding rate was significant at 4 of the 6 site-years of the small plot research (Table 3) showing yield increased as seeding rate increased. For the on-farm plots, the yields were influenced by rate in 2 of the 6 site-years at 5% probability and 3 of the 6 years if looking at 10% probability (Table 13). As with the small plots, yields increased as seeding rate increased. Overall, these results are enough significance to further study the seeding rate effects on yield. This is confirmed with the research from El-Zeadani et al. (2014) showing that soybean yield was substantially influenced by plant density.

4.3 Agronomic Optimum Seeding Rate

The average small farm AOSR was 217,000 seeds per acre (Table 9) and the average on-farm AOSR was 147,000 seeds per acre (Table 13). Optimum seeding rates will vary depending on variety, soil type, climate, and management techniques. If only evaluating the significant yield responses of small plot and on-farm results, NWARS 2015, NWARS 2016, Wooster 2015, Wooster 2016, FultonA 2014 and FultonD 2014 would be evaluated. The average small plot significant AOSR would be 225,500 and the on-farm would be 123,500 seeds per acre.

4.4 Economic Optimum Seeding Rate

The main effect of seeding rate on partial return was significant at 3 site-years (Table 3). The average EOSR was 146,000 seeds per acre for the small plots and 119,000 seeds per acre for the on-farm plots (Table 13). Therefore, a range of 119,000-146,000 would be the recommended seeding rate based on the EOSR. If looking specifically for one seeding rate, it would be 133,000 seeds per acre based on the economic optimum seeding rate, which is an average of the 2.

4.5 Agronomic Optimum Fall Stand

The results between the small plot and on-farm trails were not vastly different (Table 19). The AOFS of the small plots were lower compared to the on-farm plot. There was not a row width by seeding rate interaction on the small farm plots. Based on the results of this study, the recommended AOFS was 123,000 on the small plots to 142,000 plants per acre on the on-farm trials. These line up closely with the EOSR's of 119,000 for the small plot trials and 146,000 for the on-farm trials. This recommendation is possible because although seeding rate recommendations can vary based on variables already mentioned, Ohio farmers should target an optimum fall stand. This also aligns closely with the Ohio State Agronomy Guide's recommendations of 100,000-120,000 plants per acre if planting before May 20 and 130,000-150,000 if planting mid-June (Lindsey et al., 2017).

Table 19. AOFS in Ohio small plot and on-farm plot trials in 2014, 2015, and 2016.

LOCATION AND YEAR	SMALL PLOT VS. ON-FARM	ROW SPACING (IN)	AOFS (1,000 SEEDS PER ACRE)
NWARS 2015	Small Plot	7.5	160
NWARS 2015	Small Plot	15	163
NWARS 2015	Small Plot	30	105
WARS 2015	Small Plot	7.5	73
WARS 2015	Small Plot	15	137
WARS 2015	Small Pot	30	117
WOOSTER 2015	Small Plot	7.5	129
WOOSTER 2015	Small Plot	15	129
WOOSTER 2015	Small Plot	30	147
WOOSTER 2016	Small Plot	7.5	118
WOOSTER 2016	Small Plot	15	100
WOOSTER 2016	Small Plot	30	99
DARKEA 2014	On-Farm	15	176
FULTONA 2014	On-Farm	15	127
FULTONB 2014	On-Farm	15	121
FULTONC 2014	On-Farm	15	117
FULTOND 2014	On-Farm	15	169

4.6 Farmer Recommendation

This study confirms lower row widths of 7.5 and 15-inches tended to show higher yields. It is recommended to plant 133,000 seeds per acre (EOSR) or target a fall stand of 123,000-142,000 plants per acre. It is possible this recommendation will take years to achieve due to getting precision data to support the seeding rate, emergence, harvest stands, and yield data per field. Changes can be expected year to year based on weather, changing of seed variety, changes in equipment and/or settings and management techniques. This data is slightly higher than the

Ohio Agronomy Guide recommendation of 100,000 to 120,000 plants per acre as a fall stand, but my research does not take into consideration planting date as the Ohio Agronomy Guide does. My results fall within the Ohio Agronomy Guide's recommendations of a Mid-June planting with a fall stand of 130,000-150,000 (Lindsey et al., 2017).

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