Planting Date and Relative Maturity Effects on Soybean Grain Yield

Thesis

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By

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Abstract

In Ohio, soybean [*Glycine max* (L.) Merr.] yield has been greatly impacted by in-season weather variations. High temperatures during the month of July have been shown to cause the largest reduction in grain yield. Over the past twenty years, for every degree Fahrenheit increase in temperature, soybean yield decreased by one bu ac^{-1}. To reduce this effect, planting soybean early may help to extend the growing season and allow for earlier canopy closure.

Rate of canopy closure is a useful way of monitoring crop productivity. Canopy closure has typically been measured by percent light interception, but a faster, more accurate method may have been discovered. The objective of the first study was to determine the relationship between soybean canopy closure measurements using a mobile device application, Canopeo, and measurements of percent light interception using a line quantum sensor and light meter (referred to here on as "light meter"). This study was conducted in 2017 at the Northwest Agricultural Research Station (NWARS) in Custar, Ohio, the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio, and the Western Agricultural Research Station (WARS) in South Charleston, Ohio using a split plot randomized complete block design, with four replications. The main plot factor was planting date (mid-May and early-June) and sub-plot factor was relative maturity (2.2-4.4 RM). Beginning at the V2 soybean growth stage, canopy closure was evaluated using Canopeo and the light meter on a biweekly basis. Canopy closure

measurements using Canopeo and the light meter were linearly related. The linear relationship held true regardless of planting date and relative maturity. These results suggest that Canopeo is a viable alternative to using a light meter for measuring canopy closure in soybean.

The objective of the second study was to evaluate the effect of planting date and relative maturity on soybean canopy closure rate and yield. During the 2016 and 2017 growing season, the same sites and measurements were used as described for the first study. Canopy closure measurements were taken on a biweekly basis. The main effects of planting date and relative maturity significantly impacted the rate of canopy closure. In 2016, the second planting date reached 90% of the maximum closure in 12, 17, and 28 days fewer than the first planting date at NWARS, OARDC, and WARS, respectively. In 2017, the second planting date reached 90% of the maximum closure in 12, 14, and 20 days fewer than the first planting date at NWARS, OARDC, and WARS, respectively. Despite the reduction in days for reaching canopy closure, the first planting date closed at an earlier calendar date. The effect of planting date on soybean yield was inconsistent among the site-years. At three of the six site-years, planting in May produced higher yield than planting in June. The main effect of relative maturity was also significant for yield. In northern Ohio, the relative maturity with the highest yield ranged from 3.1-3.6. In southern Ohio, the relative maturity with the highest yield ranged from 3.6-4.1.

Dedication

Dedicated to my late grandpa Carl Fulton, for always believing in me, and helping to instill me with a passion for agriculture.

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Chapter 1: Literature Review

1.1 Soybean History and Description

Soybean [*Glycine max* (L.) Merr.] originated from China (Hymowitz and Harlan, 1983). Soybean was first introduced to the U.S. by Samuel Bowen in 1765 (Hymowitz and Harlan, 1983; Hymowitz and Shurtleff, 2005). In Savannah, Georgia, soybean was used to manufacture soy sauce and vermicelli, which were exported to England. Even though soybean was introduced to the U.S. in 1765, the majority of soybean production was done in Asia, including China, Indonesia, Japan, and Korea, until the 1930's (Hymowitz, 1970). In the late 1940's and early 1950's, the U.S. surpassed China, and eventually the rest of Asia in soybean production. In 2017, more than half of the U.S. soybean production was grown in Illinois, Indiana, Iowa, Minnesota, and Nebraska (USDA-NASS, 2018). Another one-quarter of production came from Kansas, Missouri, North Dakota, Ohio, and South Dakota.

In 1924, the USDA started compiling statistics on soybeans, including the area planted and seed yield (Specht et al., 2014). From 1929 to 1939, soybean production area quadrupled. Soybean was first grown primarily as a forage crop, but in 1941, the U.S. switched to mostly harvesting soybean seed (Probst and Judd, 1973). Due to this switch in production, total soybean seed production more than doubled between 1942 and 1949. From then on, area harvested for soybean seed increased until 1979 when it peaked at

71.4 million acres. That peak was then exceeded in 1998 and continued to increase. In 2007, there was a significant dip in harvested area due to a shift from soybean to corn production, in hopes that corn-derived ethanol production would increase corn prices. Since then, soybean has continued to increase in acres harvested. In 2017, 89.5 million acres of soybean were harvested in the U.S (USDA-NASS, 2018). Soybean yield in the U.S. has quadrupled from 11 bu ac^{-1} in 1924 to 44 bu ac^{-1} in 2009 (Specht et al., 2014). In 2017, the average soybean yield in the U.S. was 49 bu ac^{-1} (USDA-NASS, 2018).

1.2 Soybean Production in Ohio

Soybean is the number one produced crop in Ohio, with an annual economic impact of $5.3 billion from soybean production (Ohio Soybean Council, 2014). In 2017, 5.1 million acres of soybean were planted in Ohio (USDA-NASS, 2018). According to a survey done by Grassini et al. (unpublished), in the northern and western part of Ohio, most farmers plant during the third week of May. In central Ohio, most farmers plants during the second week of May. The survey also showed that in the western and central part of Ohio, farmers tend to plant maturity group 3 varieties and in the northern part of Ohio, farmers plant maturity group 2 varieties.

According to the Ohio Agronomy Guide, 15th edition (Lindsey et al., 2017), the recommendation for planting date in southern Ohio is any time after 15 April when soil conditions are suitable. In northern Ohio, planting can begin the last few days of April if the soil conditions are appropriate. The proper soil conditions for planting soybean are a soil temperature of at least 50 degrees Fahrenheit, and the presence of soil moisture in the upper 1 to 1.5 inches. Significant yield losses generally start to occur when the planting date is after the first week of May. For every 10-day delay of planting in May, maturity is delayed by three to four days (Lindsey et al., 2017). Planting soybean too early, or when soil conditions are inadequate, can result in adverse effects. Some possible risks are late-spring frost damage, susceptibility to disease, and bean leaf beetle damage (Lindsey et al., 2017).

The current recommendations for relative maturity range from 3.1 – 4.1 depending on planting date and location in Ohio (Lindsey et al., 2017). During the first three weeks of May, relative maturity has little effect on yield. Relative maturity has a larger effect on yield when planting late. In the first half of June, a four-day delay in planting can cause physiological maturity to be delayed by approximately one day. If soybean is planted late, then the yield potential decreases. This raises concern on whether a late maturing variety can mature before a fall frost. According to the Ohio Agronomy Guide, 15th edition (2017), the latest maturing variety that will reach physiological maturity before the first killing frost should be used when planting late. This allows the soybean plants to grow as much vegetation as possible before flowering and pod formation begins. Regardless of management practices involving planting or relative maturity, soybean plants should develop a closed canopy prior to flowering or before July (Lindsey et al., 2017).

The effects of planting date and relative maturity have not been studied together in Ohio in over 10 years. No published planting date x relative maturity studies from Ohio were found. Changes in weather patterns and soybean cultivars have created the need to re-evaluate planting date and relative maturity recommendations to maximize soybean grain yield.

1.3 Planting Date

Planting date has the largest impact on soybean grain yield than any other production practice (Cartter and Hartwig, 1963). Hankinson et al. (2015) conducted a study on planting date and starter fertilizer in 2013 and 2014. This study was conducted at two locations in Ohio with three to four planting dates per location, ranging from May 1 to July 2. At the Clark county location, grain yield significantly decreased by 0.58 bu ac^{-1} day^{-1} from the first to the last planting date. In Ohio, the greatest chance of consistently maximizing soybean yield and profitability is when soybean is planted in early May (Hankinson et al., 2015).

Planting soybeans early can extend the growing season and allows for earlier canopy closure. Chen and Wiatrak (2010) reported that grain yield is generally greater when soybean is planted earlier because the plants have a longer duration of vegetative and reproductive stages. Since the 1970s, producers have been planting soybean one to three weeks earlier because the length of the growing season has increased (Conley and Santini, 2007; Kucharik et al., 2010). Many studies have shown results where early May planting dates have yielded the highest (De Bruin and Pedersen, 2008; Gaspar and Conley, 2015; Marburger et al., 2016). If a producer delays planting after the first week in May, it is possible to incur a 0.33 bu ac^{-1} day^{-1} yield decrease (Gaspar and Conley, 2015).

1.3.1 Risks of Planting Early

Planting soybean early may result in risks that would be less if planting was delayed to mid-late May. One risk to consider is that planting early can expose plants to a late spring frost (Meyer and Badaruddin, 2001). A spring frost can cause soybean seedlings to die if the growing point is damaged. A soybean plant's tolerance to freezing temperatures can vary with growth stage, duration of freezing temperatures, soil moisture, and acclimation or declamation periods (Meyer and Badaruddin, 2001). According to the Ohio Agronomy Guide, 15th edition (2017), the median date of the last spring freeze ranges from 15 April in southern Ohio to 25 April in northern Ohio. However, the last freeze date is often not reached until early May in far northwest and northeast Ohio.

Another risk to consider is the exposure to early season insects, such as bean leaf beetle (*Cerotoma trifurcata*). Bean leaf beetles can reduce soybean yield by feeding on soybean pods (Pedigo and Zeiss, 1996). In one growing season, adult bean leaf beetles produce two generations. The first generation will defoliate soybean seedlings and the second generation will feed on the pods during grain fill. Pedigo and Zeiss (1996) studied the effect of soybean planting date on bean leaf beetle abundance and pod injury. Their results showed that planting soybean at the end of May reduced the seasonal densities and colonization of bean leaf beetle than when planting at the beginning of May. The reduced populations resulted in fewer feeding days during pod development.

1.4 Relative Maturity

Soybean varieties are classified to a specific maturity group based on the length of time from planting to maturity. Soybean maturity is classified into groups ranging from 000 to 10 (Boerma and Specht, 2004). The groups can then be broken down further by adding a decimal to the maturity group number to designate the relative maturity. The major difference among varieties of different maturity groups is the length of vegetative growth stages (planting to R1) (Heatherly, 2005). The primary factors used to decide where a soybean variety is adapted to are photoperiod and in-season temperature (Mourtzinis and Conley, 2017). Photoperiod for a specific time period and location is a value that remains constant from year to year, but climate is variable. Based on photoperiod, Scott and Aldrich (1970) were able to outline hypothetical maturity group zones using empirical data that were available at the time.

Zhang et al. (2007) conducted a study on modifying the optimum adaptation zones for soybean maturity groups. The objective was to analyze the distribution of soybean maturity groups adapted to the U.S. and create regions for them. For this experiment, they used 28 soybean-producing states variety trial data from 1998 to 2003. Their results showed that the adaptation regions for maturity groups 0 to 3 have not changed since Scott and Aldrich's study but the regions for maturity groups 4 to 6 have become wider. It was suggested that the maturity groups move North to South along convex, parallel latitude lines.

Mourtzinis and Conley (2017) conducted a study to delineate soybean maturity group adaptation zones across the U.S. In this study, they used soybean maturity group-specific yield data from variety performance trials conducted in 27 states. The results of this process are pictured in Figure 1.1, which shows that relative maturity does not follow latitude lines as was suggested by Zhang et al. (2007). Their results suggest that maturity group 3 varieties were better adapted for the major soybean-producing states, which includes the entire state of Ohio. With changing weather patterns, soybean genetics, and management practices, Zhang et al. (2007) concluded that the adaptivity of new soybean varieties should be routinely evaluated. This study also suggests that planting date effects on location-specific maturity group selection needs to be evaluated.

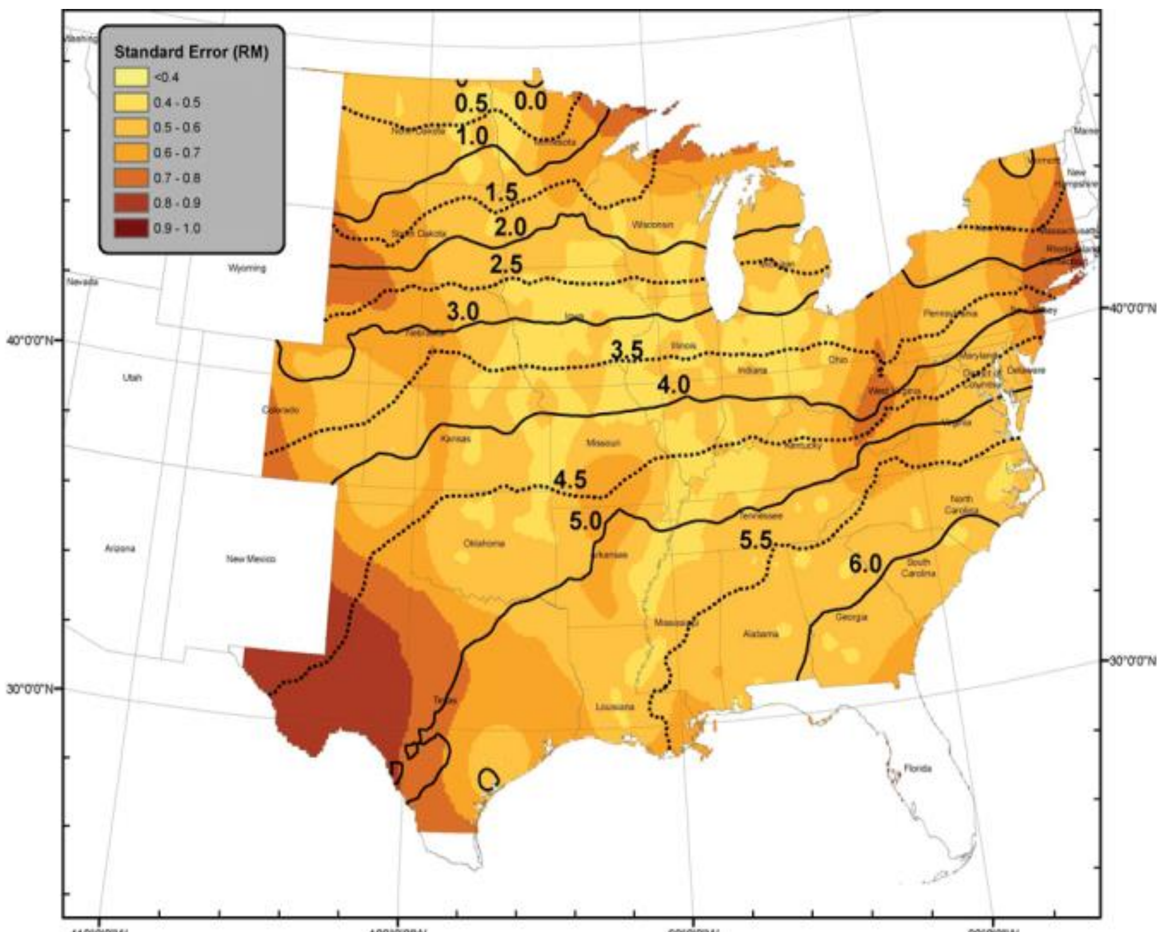

Figure 1.1 Soybean maturity group zones across the U.S. (Mourtzinis and Conley, 2017)

In southern regions of the U.S., an early soybean production system (ESPS) is used to avoid drought stress. The combination of planting early maturing cultivars (Maturity Groups 3 through 5) in April has increased yield over traditional systems (Maturity Groups 5 through 7) planted in May and June (Heatherly, 1999; Heatherly and Elmore, 2004). The ESPS has been successful in producing high yields because the reproductive growth stages occur before the late summer droughts (Heatherly, 1999). The ESPS has not been evaluated in northern regions, but has been promoted in northwest Ohio (Poston and Jeschke, 2015).

More vegetation leads to more nodes and pods, therefore a higher yield. Mourtzinis et al. (2017) results showed that the highest soybean yield came from planting early (late April- early May) and using the latest maturing soybean that will not be killed in a frost. However, many producers in Ohio may be planting soybeans with relative maturities that are shorter than optimum (Grassini et al., unpublished).

1.5 Temperature

Temperature can have a major impact on soybean grain yield. High temperatures in July have been attributed to cause the largest reduction in soybean grain yield (Mourtzinis et al., 2015). For every degree Fahrenheit increase in temperature over 85°F in July, soybean grain yield decreased by one bu ac^{-1}. If mid- to late-summer temperatures continue to rise, there is concern that the high temperatures will significantly compromise soybean reproductive development and increase flower, pod, and seed abortion (Specht et al., 2014). Planting date and relative maturity may be able to be adjusted so that the sensitive reproductive stages do not occur during high temperature months (Mourtzinis et al., 2015). Early planting can result in warmer average air temperatures between soybean growth stages R5 and R8 (Mourtzinis et al., 2017). These warmer air temperatures were more favorable for yields of late-maturing varieties.

Mourtzinis et al. (2015) conducted a study that assessed the effect of in-season weather trends on soybean yields in the U.S. between 1994 and 2013. To assess this effect, they used field trial data, meteorological data, and information on crop management practices. Between 1994 and 2013, in-season temperature trends had a greater impact on soybean yields than in-season precipitation trends. This response varied significantly among individual states and with the month of the year when the warming occurred. They estimated that the U.S. average yield gain was suppressed by about 30% due to elevated temperatures, which led to a loss of about $11 billion over the 20-year time period.

High temperatures are often associated with low rainfall and high evapotranspiration rates (Hoeft et al., 2000), which may lead to water stress. Figure 1.2 shows that Ohio had the second highest economic loss associated with rainfall variability and high temperatures (Mourtzinis et al., 2015). Over the 20-year period, Ohio producers lost an estimated $2.9 billion due to changes in monthly precipitation and temperature.

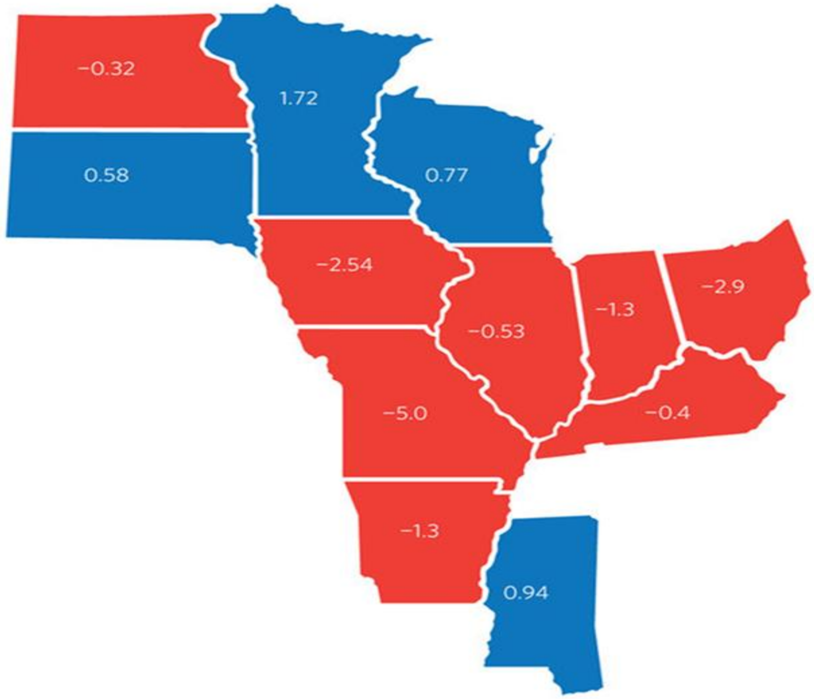

Figure 1.2. Monetary impacts associated with the effects of changes in monthly precipitation and temperature (Mourtzinis et al., 2015)

1.6 Canopy Closure

Canopy photosynthesis is maximized when the canopy has reached its maximum closure as the plants are intercepting the most light and absorbing the most photosynthetic radiation (Wells, 1991). Canopy closure is an important factor related to soybean yield at the R2 (full bloom) and R5 (beginning seed) stages (Steele and Grabau, 1997). Studies have shown that seed number per area had a significant correlation to growth rate during the flowering (R1-R3) and pod set (R3-R5) stages (Egli and Bruening, 2000; Vega et al., 2001). This can impact the number of seeds and pods per plant, which also impacts yield. With early canopy closure, more sunlight can be intercepted and increase yield. Earlier canopy closure reduces soil temperature and minimizes in-season water loss due to evaporation (Mourtzinis et al., 2015).

1.6.1 Fractional Green Canopy Cover

Fractional green canopy cover (FGCC) is a measurement that can be used to estimate canopy development, light interception, and evapotranspiration partitioning (Patrignani and Ochsner, 2015). It is a nondestructive and relative easy-to-measure parameter that has become widely used in measuring active vegetative land cover. Purcell (2000) examined the relationship between FGCC digital images analyzed by SigmaScan Pro and light interception with a line quantum sensor. The FGCC and light interception measurements had a very close one-to-one relationship, meaning these two methods produced very similar values of canopy closure. Purcell (2000) also made note that the amount of time to analyze the digital images was comparable to the time required for taking light interception measurements using the line quantum sensor. Canopy cover measurements, using digital images, can be made any time during the absence of direct beam radiation which is one limitation to light interception measurements.

1.6.2 Canopeo

Canopeo is a mobile device application that can rapidly analyze FGCC from images and videos (Patrignani and Ochsner, 2015). It is an automatic color threshold (ACT) image analysis tool that uses color values to classify all the pixels in the image. Analysis of the pixels is based on the red to green (R/G) and blue to green (B/G) color ratios and an excess green index (2G-R-B). The resulting image is a binary image where the white pixels are the pixels that satisfied the selection criteria (green canopy) and the black pixels are the pixels that did not meet the criteria (not green canopy). Fractional green canopy cover ranges from 0 to 1, where 0 equals no green canopy cover and 1 equals 100% green canopy cover. Patrignani and Ochsner (2015) compared Canopeo with SamplePoint and SigmaScan Pro, both popular methods used for analyzing FGCC. Their comparison results showed that Canopeo was accurate and faster at quantifying FGCC than SamplePoint and SigmaScan Pro. However, literature comparing Canopeo to a line quantum sensor and light meter has not been published.

1.7 Summary

Changing crop management strategies could help alleviate potential negative impacts of climate change on soybean yield. This includes using varieties with different relative maturities and altering planting dates. This study will evaluate soybean planting date and relative maturity recommendations for Ohio. Planting soybeans early can extend the growing season and allows for earlier canopy closure. Early canopy closure reduces soil temperature and minimizes in-season water loss due to evaporation.

The objectives of this research were to: a) evaluate planting date and relative maturity combinations to promote early canopy closure and maximize yield and b) determine the relationship between soybean canopy closure measurements using the mobile device application, Canopeo, and measurements of percent light interception using a line quantum sensor and light meter.

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Chapter 2: Mobile Device Application, Canopeo, Produces Similar Soybean Canopy Closure Measurements as a Line Quantum Sensor and Light Meter

2.1 Introduction

Canopy closure is a useful way of monitoring crop productivity. Canopy photosynthesis is maximized when the crop has reached its maximum closure value because the plants are intercepting the most light and absorbing the most photosynthetic radiation (Wells, 1991). One common method for measuring canopy closure is by measuring light interception with a line quantum sensor and light meter (Hankinson et al., 2015). However, the cost of these systems can be cost prohibitive, and the measurements can be time-consuming and variable due to ambient light conditions. Another method for measuring canopy closure is fractional green canopy cover (FGCC). Fractional green canopy cover can be used to assess canopy development, light interception, and evapotranspiration partitioning (Patrignani and Ochsner, 2015). Purcell (2000) examined the relationship between FGCC digital images analyzed by SigmaScan Pro and light interception with a line quantum sensor. The FGCC and light interception measurements had a very close one-to-one relationship, meaning these two methods produced very similar values of canopy closure. Purcell (2000) also made note that the amount of time to analyze the digital images was comparable to the time required for taking light interception measurements using the line quantum sensor. Canopy cover measurements, using digital images, can be made any time during the absence of direct beam radiation which is one limitation to light interception measurements.

A more recently developed method for measuring FGCC is Canopeo (Oklahoma State University, Stillwater, OK). Canopeo is a mobile device application that can rapidly analyze FGCC from images and videos (Patrignani and Ochsner, 2015). Canopeo is an automatic color threshold (ACT) image analysis tool that analyzes pixels based on the red to green (R/G) and blue to green (B/G) color ratios and an excess green index. Patrignani and Ochsener (2015) found Canopeo to be accurate and faster at quantifying FGCC than other widely used software. Canopeo can process images 75 to 2500 times faster than SamplePoint and 20 to 130 times faster than SigmaScan Pro (Patrignani and Ochsner, 2015). Soybean canopy closure measured using Canopeo and a line quantum sensor and light meter has yet to be reported. The objective of this study was to determine the relationship between soybean canopy closure measurements using Canopeo and measurements of percent light interception using a line quantum sensor and light meter.

2.2 Materials and Methods

2.2.1 Locations and Experimental Design

In 2017, a study was established at the Northwest Agricultural Research Station (NWARS) near Custar, Ohio, the Ohio Agricultural Research and Development Center (OARDC) near Wooster, Ohio, and the Western Agricultural Research Station (WARS) near South Charleston, Ohio. The study was conducted using a split-plot, randomized complete block design with four replications of treatments. The main plot factor was target planting dates of mid-May and early June. The actual planting dates for each site are reported in Table 2.1. The sub-plot factor was soybean relative maturity. At the NWARS and OARDC locations, eight soybean relative maturities of 2.2 through 3.8 were evaluated. At the WARS location, ten soybean relative maturities of 2.2 through 4.4 were evaluated.

Table 2.1. Planting dates at the Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) in 2017.

Site/year	Target Planting Date	Actual Planting Date
NWARS 2017	May 15	May 16
	After June 1	June 6
OARDC 2017	May 15	May 17
	After June 1	June 9
WARS 2017	May 15	May 16
	After June 1	June 8

2.2.2 Cultural Practices

At all locations, plots were planted at a seeding rate of 150,000 seed ac^{-1} and at a depth of 1.5 inches. Pioneer brand soybean seed treated with fungicide and insecticide was used (Johnston, IA). Each plot was 10 ft wide and consisted of seven 15-inch rows of soybean. The length of each plot was 34 ft at NWARS, 25 ft at OARDC, and 40 ft at WARS. No fertilizer was applied during the growing season as the soil test P, K, and pH were adequate for soybean production according to the Tri-State Fertilizer Recommendations (Vitosh et al., 1995).

2.2.3 Field Measurements

At each location, canopy closure measurements were collected on a bi-weekly basis, beginning at the V2 soybean growth stage until a closure value of 90% was reached. The first replication at each location was used to compare the line quantum sensor and light meter to Canopeo. The LI-191R line quantum sensor and LI-250A light meter (LI-COR®, Lincoln, NE) were used to measure the amount of light above and below the canopy in $\mu mol\ s^{-1}\ m^{-2}$ (LI-COR®, 2004). For each plot, one reading was taken above the canopy and three readings, spaced out evenly within the plot, were taken on the ground below the canopy. For the above canopy reading, the line quantum sensor was held approximately 2-ft above the canopy, parallel to the ground. For the below canopy readings, the line quantum sensor was placed diagonally in the plot between two of the center rows of soybean plants. The three below canopy readings were then averaged together. To calculate canopy closure, the following equation was used:

$$C = [1 - (BA/A)] * 100$$

Where,
C is the canopy closure as a percent (%)
BA is the average of the below canopy readings in $\mu mol\ s^{-1}\ m^{-2}$
A is the above canopy reading in $\mu mol\ s^{-1}\ m^{-2}$

The mobile device application, Canopeo, was used to determine the percent canopy cover. Pictures and videos were taken using the Canopeo app on an iPad (Apple, Cupertino, CA). The iPad was held approximately two feet above the canopy of the same two rows of soybean plants used for the light meter measurements, three pictures were taken per plot in the same areas as the below canopy light meter measurements. The canopy closure values from the app were averaged for each plot. One video was also taken per plot by walking the entire length of the plot.

2.2.4 Statistical Procedures

Proc REG, in SAS 9.4 (SAS Institute Inc., Cary, NC), was used to determine the relationship between soybean canopy closure using pictures and videos taken with the Canopeo application and light meter. Significance of the relationship was assessed using $\alpha = 0.05$.

2.3 Results and Discussion

At all three locations, canopy closure was measured six times for the first planting date and five times for the second planting date during the growing season (n = 285). Percent canopy closure measurements using Canopeo pictures were highly correlated with percent canopy closure estimates from the light meter ($R^2 = 0.9404$; $p = < 0.0001$; Figure 2.1). Percent canopy closure measurements using Canopeo videos were also highly correlated with the light meter percentages ($R^2 = 0.9216$; $p = < 0.0001$; Figure 2.2).

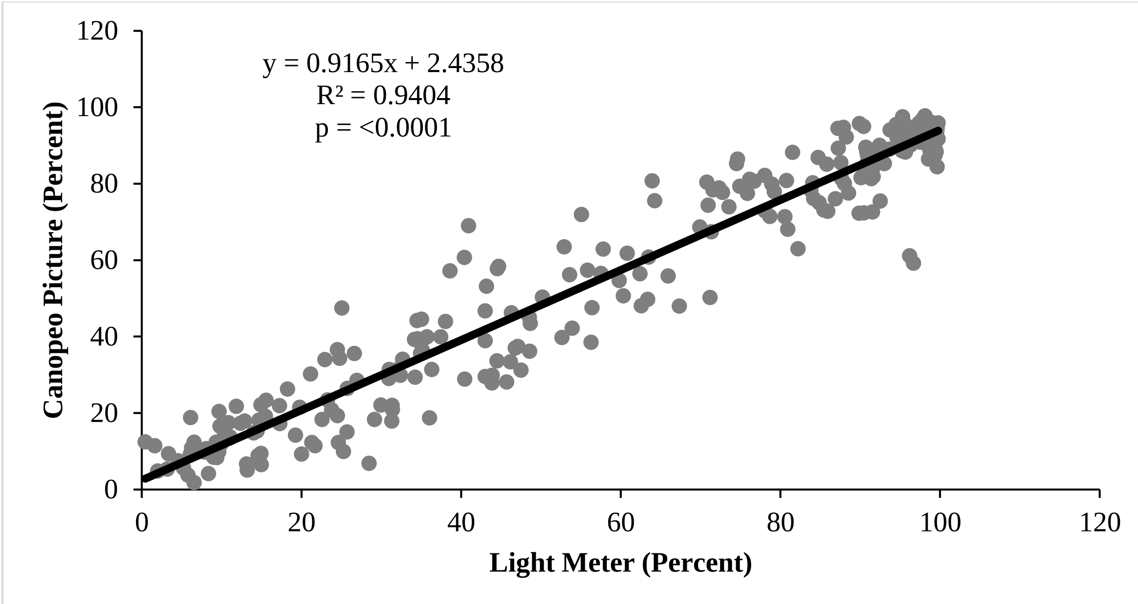

Figure 2.1. Relationship of percent canopy closure from Canopeo pictures vs. percent canopy closure measured using a line quantum sensor and light meter (n = 285).

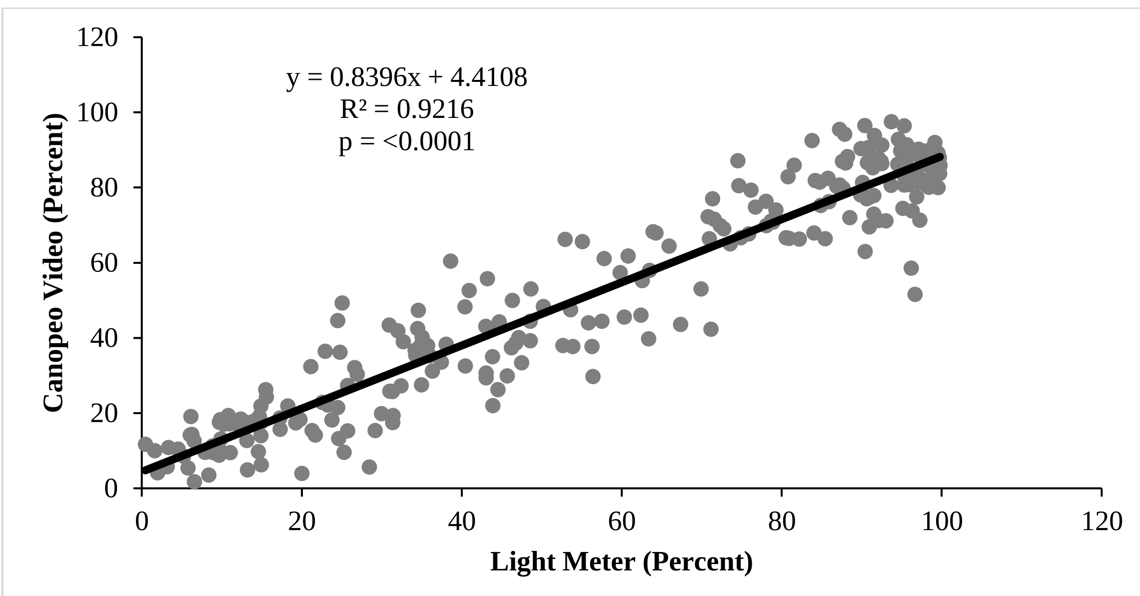

Figure 2.2. Relationship of percent canopy closure from Canopeo video vs. percent canopy closure measured using a line quantum sensor and light meter (n = 285).

Figures 2.1 and 2.2 show a linear relationship of Canopeo and light meter canopy closure measurements ranging from the V2 growth stage through the R5 (beginning seed) reproductive stage. The linear relationship held true regardless of planting date and soybean variety.

The Canopeo app and light meter methods both have advantages and disadvantages. Canopeo is faster at calculating a canopy closure percentage while standing in the field. It took less than a minute to take three pictures or one video per plot to get the measurement of percent canopy closure. With the light meter, data collection time per plot varied due to cloud cover. It is crucial to collect the light meter measurements in full sun to minimize the effect of changing ambient sunlight levels. If a cloud passes over the sun, then a new ambient value may need to be collected to ensure accurate canopy closure measurements. With the Canopeo app, there is an adjustment that can help fine-tune its sensitivity for defining green pixels. This feature can help provide accurate measurements, however very dark green plants cannot be detected no matter what setting is used. In contrast, the light meter method can be used no matter what color the plants are and with no adjustments necessary.

2.4 Conclusion

This study showed a strong linear relationship between the Canopeo measurement for canopy closure and a line quantum sensor and light meter. Using Canopeo to take pictures or videos to estimate canopy closure are viable alternatives to using a light meter. Canopeo can calculate a percentage for canopy cover in the field and is faster than having to calculate the percentage of canopy closure using light meter values. Currently, Canopeo is free to download and this research suggests it is comparable to alternative methods to measure canopy closure.

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Chapter 3: Planting Date and Relative Maturity Effects on Soybean Grain Yield

3.1 Abstract

In Ohio, soybean [*Glycine max* (L.) Merr] should be planted after 15 April in southern Ohio and at the end of April in northern Ohio. Depending on planting date and location, it is recommended to use a relative maturity from 3.1-4.1. In-season variation in weather has greatly impacted soybean yield with high temperatures during the month of July, causing the largest reduction in grain yield. To reduce this effect, soybean planting date and maturity group selection may need to be adjusted so that the sensitive reproductive stages occur when temperatures are lower. The objective of this study was to evaluate the effect of planting date and relative maturity effects on soybean canopy closure rate and yield. In 2016 and 2017, an experiment was conducted at the Northwest Agricultural Research Station (NWARS), the Ohio Agricultural Research and Development Center, and the Western Agricultural Research Station (WARS). The experiment was a split-plot randomized complete block design with four replications. The main plot factor was planting date (mid-May and early June) and subplot factor was cultivar varying in relative maturity (2.2-4.4). The first planting date reached canopy closure at an earlier calendar date, while the second planting date reached canopy closure in the fewest number of days from planting. The effect of planting date on yield was inconsistent. At three of the six site-years, the early planting date yielded more than the

second planting date. The highest yields were obtained with relative maturities ranging 3.1-3.6 for northern Ohio and 3.6-4.1 for southern Ohio.

3.2 Introduction

Over the past twenty years, the largest weather-related reduction in soybean grain yield has been caused by high temperatures during the month of July (Mourtzinis et al., 2015). For every degree Fahrenheit increase in temperature, soybean grain yield decreased by one bu/acre. Over a 20-year period (1994-2013), it was estimated that the Ohio soybean industry lost $2.9 billion due to adverse weather conditions (Mourtzinis et al., 2015). Ohio had the second highest economic loss in the Midwest associated with rainfall variability and high temperatures. To minimize yield reductions associated with high temperature, recommendations for planting date and relative maturity need to be re-evaluated to reduce soybean stress and preserve yield (Mourtzinis et al., 2015).

Planting date has a larger and more consistent impact on soybean grain yield compared to other production practices (Rattalino et al., 2017; Cartter and Hartwig, 1963). Planting soybeans early can extend the growing season and allows for earlier canopy closure (Steele and Grabau, 1997). Chen and Wiatrak (2010) reported that grain yields are generally greater when soybean is planted earlier because the plants have a longer duration of vegetative and reproductive stages. Soybean plants should develop a closed canopy prior to flowering or before July (Lindsey et al., 2017). Canopy closure is an important factor related to soybean yield at the R2 (full bloom) and R5 (beginning seed) stages (Steele and Grabau, 1997). Studies have shown that seed number per area has a significant correlation to growth rate during the flowering (R1-R3) and pod set (R3-R5) stages (Egli and Bruening, 2000; Vega et al., 2001). Seed and pod number can have a major impact on yield. Earlier canopy closure reduces soil temperature and minimizes in-season water loss due to evaporation (Mourtzinis et al., 2015). In Ohio, the greatest chance of consistently maximizing soybean yield and profitability is when soybean is planted in early May (Hankinson et al., 2015).

Soybean cultivars, management practices, and climate continually change and impact the region, so studying soybean relative maturity is also necessary. Soybean varieties are classified to a specific maturity group based on the length of time from planting to maturity. Soybean maturity is classified into groups ranging from 000 to 10 (Boerma and Specht, 2004). The major difference among cultivars of different maturity groups is the length of vegetative growth stages (planting to R1) (Heatherly, 2005). The maturity designation can be further clarified through adding a decimal to the maturity group number. The primary factors that determine where a soybean variety is adapted to are photoperiod and in-season temperature (Mourtzinis and Conley, 2017). Photoperiod for a specific time of year and latitude is a constant value from year to year, but climate is always variable. It was once suggested that the optimum adaptation zones for soybean maturity groups moved North to South along the convex, parallel latitude lines (Zhang et al., 2007). Mourtzinis and Conley (2017) have since then found that relative maturity does not follow the latitude lines. They concluded that the adaptivity of new soybean varieties should be routinely evaluated since weather patterns, genetics, and management practices are constantly changing. They also suggested that planting date effects on location-specific maturity group selection needs to be evaluated.

The objective of this study was to evaluate the effect of planting date and relative maturity combinations on soybean canopy closure and yield.

3.3 Materials and Methods

3.3.1 Locations and Experimental Design

In 2016 and 2017, a study was established at the Northwest Agricultural Research Station (NWARS) (41° 11' 49.29" N, 83° 45' 53.71" W) near Custar, Ohio, the Ohio Agricultural Research and Development Center (OARDC) (40° 45' 32.316" N, 81° 54' 10.842" W) in Wooster, Ohio, and the Western Agricultural Research Station (WARS) (39° 51' 45.21" N, 83° 40' 20.66" W) near South Charleston, Ohio. At all locations, a different field was used each year.

The study was a split-plot, randomized complete block design with four replications of treatments. The main plot factor was target planting dates of mid-May and early June. The actual planting and harvest dates for each site-year are given in Table 3.1. The sub-plot factor consisted of soybean relative maturity. At the NWARS and OARDC locations, eight relative maturities of 2.2 through 3.8 were evaluated. At the WARS location, ten relative maturities of 2.2 through 4.4 were evaluated. The specific varieties (Pioneer brand, Johnston, IA) and relative maturities used in the study are in Table 3.2.

Table 3.1. Planting and harvest dates at the Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) in 2016 and 2017.

Site-year	Target Planting Date	Actual Planting Date	Harvest Date
NWARS 2016	May 15	23 May	14 Oct
	After June 1	13 Jun	14 Oct
NWARS 2017	May 15	16 May	17 Oct
	After June 1	6 Jun	17 Oct
OARDC 2016	May 15	19 May	18 Oct
	After June 1	9 Jun	18 Oct
OARDC 2017	May 15	17 May	20 Oct
	After June 1	9 Jun	20 Oct
WARS 2016	May 15	7 May	26 Oct
	After June 1	1 Jun	26 Oct
WARS 2017	May 15	16 May	19 Oct
	After June 1	8 Jun	19 Oct

Table 3.2. Seed varieties and relative maturity used in 2016 and 2017 at the Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS).

Variety	Relative Maturity	Variety	Relative Maturity
P22T69R	2.2	P33T72R	3.3
P24T05R	2.4	P36T14R2	3.6
P26T76R	2.6	P38T42R	3.8
P28T62R	2.8	P41T33RR*	4.1
P31T11R	3.1	P44T63R*	4.4

* Varieties only planted at WARS.

3.3.2 Cultural Practices

The previous crop at all locations was corn. In 2016 at NWARS, the field was chisel plowed and disked in the fall. In 2017 at NWARS, the field was disk chiseled followed by a disc and field cultivated in the fall. In 2016 and 2017, the fields at OARDC were chisel plowed in the fall. In 2016 and 2017 at WARS, a chisel plow followed by a finishing tool were used in the fall.

Prior to planting, ten soil cores were collected from each trial location at a depth of eight inches and then combined for a composite sample. Soil texture and chemical properties were measured and are shown in Table 3.3. At all locations, plots were planted at a seeding rate of 150,000 seed ac^{-1} and a depth of 1.5 inches. Planting equipment used at each location is as follows: NWARS used a White 8104 planter with splitter (AGCO, Duluth, GA), OARDC used a Great Plains 10 ft grain drill (Great Plains Ag, Salina, KS), and WARS used a Kinze 2000 (Kinze, Williamsburg, IA). Each plot was 10 ft wide and consisted of seven 15-inch rows of soybean. The length of each plot was 34 ft at NWARS, 25 ft at OARDC, and 40 ft at WARS. No fertilizer was applied during the growing season because the soil test P, K, and pH levels were adequate for soybean production according to the Tri-State Fertilizer Recommendations (Vitosh et al., 1995). Pre-emergence and post-emergence herbicides were applied as necessary to control weeds.

Table 3.3. Soil texture and chemical properties for 2016 and 2017 at Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) including soil texture classification, organic matter (OM) content, plant available phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), and cation exchange capacity (CEC).

Site-year	Soil texture	Soil pH	OM	P	K	Mg	Ca	CEC
			%	-----------------ppm-----------------				meq $100g^{-1}$
NWARS 2016	Clay	6.7	3.8	63	189	536	2939	20.8
NWARS 2017	Clay	6.5	3.7	59	191	496	2980	21.9
OARDC 2016	Silt loam	6.7	2.1	44	113	197	1334	9.8
OARDC 2017	Silt loam	6.8	2.2	45	136	255	1313	9.3
WARS 2016	Clay loam	5.9	3.3	55	173	453	2228	19.0
WARS 2017	Silty clay	6.1	4.4	84	198	771	3851	31.0

3.3.3 Field Measurements

At each location, canopy closure measurements were taken on a bi-weekly basis, beginning at the V2 soybean growth stage until maximum closure was reached. The mobile device application, Canopeo (Patrignani and Ochsner, 2015) (Oklahoma State University, Stillwater, OK), was used to determine the percent canopy cover. Pictures were taken using the Canopeo app on an iPad (Apple, Cupertino, CA). In each plot, three pictures, spaced out evenly within the plot, were taken and then averaged. For each plot, the iPad was held approximately two feet above the canopy of two center rows of soybean plants. For comparing canopy closure across plots, 90% of the maximum value recorded for each plot was used to determine the date for canopy closure.

Temperature readings were taken in each plot on a bi-weekly basis on the same day as the canopy closure measurements. Temperature was measured using a handheld infrared thermometer (Extech 42510, Nashua, NH). In each plot, three soil temperatures, spaced out evenly within the plot, were taken below the canopy on the soil surface. The thermometer was held approximately six inches above the soil surface. Three canopy temperatures were taken in the same locations as the soil temperature readings. For the canopy readings the thermometer was held approximately six inches above the canopy to ensure that the temperature was being read from the very top trifoliates of the canopy.

Starting at the R7 reproductive stage (beginning maturity, one pod on the main stem is mature in color), soybean maturity dates were determined by evaluating soybean pod color every three days until 95% of pods were the mature color. Days to maturity was determined by calculating the number of days it took each plot to go from planting date to the maturity date. Just prior to harvest, lodging and plant heights in each plot were measured. Lodging was based on a 0-100% scale where zero equals no plants lodged. At NWARS and WARS the center five rows from each plot were harvested and reported for yield. At OARDC the center four rows were harvested. Yields were adjusted to 13.0% moisture prior to data analysis. Harvesting equipment used at each location is as follows: NWARS used a Kincaid 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS), OARDC used a Hege 140 plot combine (Hege Company, Waldenburg, Saxony), and WARS used a Kincaid 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS).

Weather data were obtained from the Ohio Agricultural Research and Development Center (OARDC) weather stations located at NWARS, OARDC, and WARS. This data included monthly average temperature and cumulative precipitation from April through October for each location and were compared to the 30-year average (1988-2017).

3.3.4 Statistical Procedures

All statistical procedures were done using SAS 9.4 (SAS Institute Inc., Cary, NC). Analysis of variance was conducted using the Proc Mixed procedure. The Least Significant Difference (LSD) at $\alpha = 0.10$ was used to identify differences in treatment means. The Proc NLIN procedure was used to find the equation for each plot's canopy closure curve. The Proc Reg procedure in SAS was used to perform regression analysis. The polynomial regression model's derivative, when set to equal zero, was used to find the relative maturity that resulted in the highest grain yield.

3.4 Results and Discussion

3.4.1 Weather

In 2016 and 2017, the monthly air temperatures were similar to the 30-year average at all three locations (Figures 3.1, 3.2, and 3.3). In 2017, NWARS had above average air temperature in April and May while OARDC and WARS only had above average air temperature in April. At NWARS in 2016, precipitation was below the 30-year average by 1.60 and 2.19 inches in May and July, respectively, while September had above average precipitation by 1.43 inches (Figure 3.4). In 2017, NWARS had below average precipitation in April and September and received above average precipitation by 1.46, 1.88, 2.14, and 1.14 inches in May, June, July, and August, respectively. For 2016, OARDC received below average precipitation in April, May, June, July, and September, and above average precipitation in August and October (Figure 3.5). In 2017 at OARDC, June, August, and September were below the 30-year average by 3.53, 1.97, and 1.69 inches, respectively, and May and July had above average precipitation. In the month of June 2017, OARDC only received 0.13 inches of precipitation. In 2016, WARS had below average precipitation in April, May, June, July, and October, and above average precipitation in August and September (Figure 3.6). At WARS in 2017, precipitation was below average in September and above average in May and July by 1.47 and 2.70 inches, respectively.

Overall, the 2016 and 2017 growing seasons were close to the 30-year average for air temperature at all locations. No location experienced a very cool or very hot season. When comparing precipitation, 2016 was more of a dry year whereas 2017 was more of a wet year. In both years, OARDC experienced abnormally low precipitation rates in July.

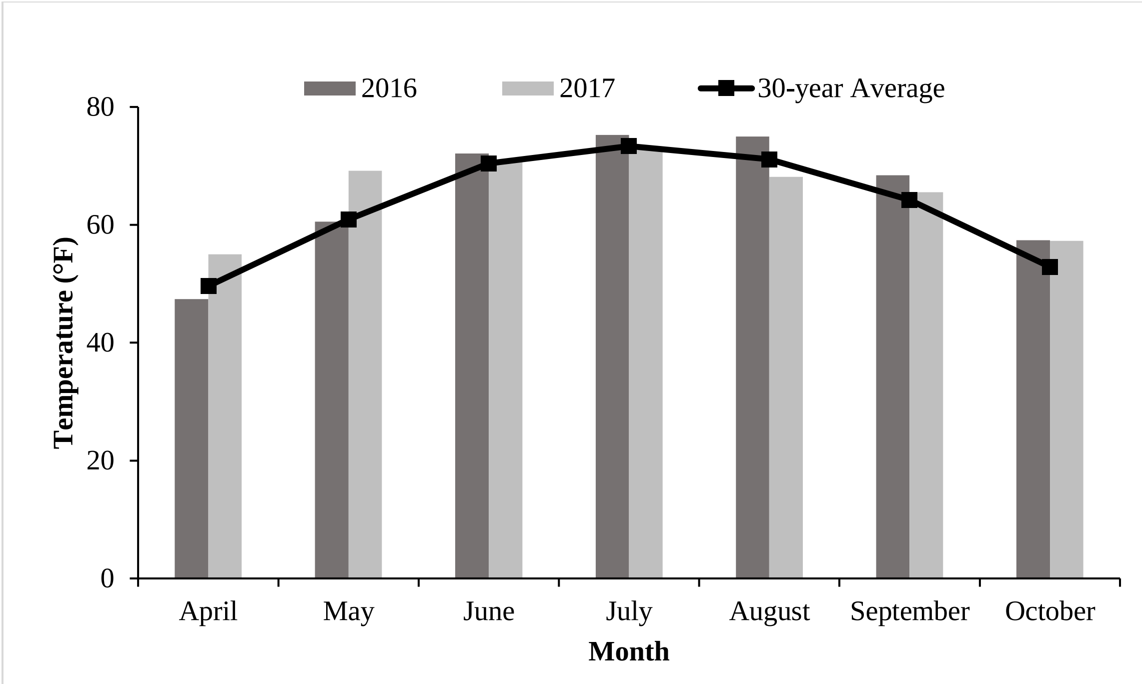

Figure 3.1. Monthly average air temperature at the Northwest Agricultural Research Station (NWARS) in 2016 and 2017, compared to the 30-year average (1988-2017).

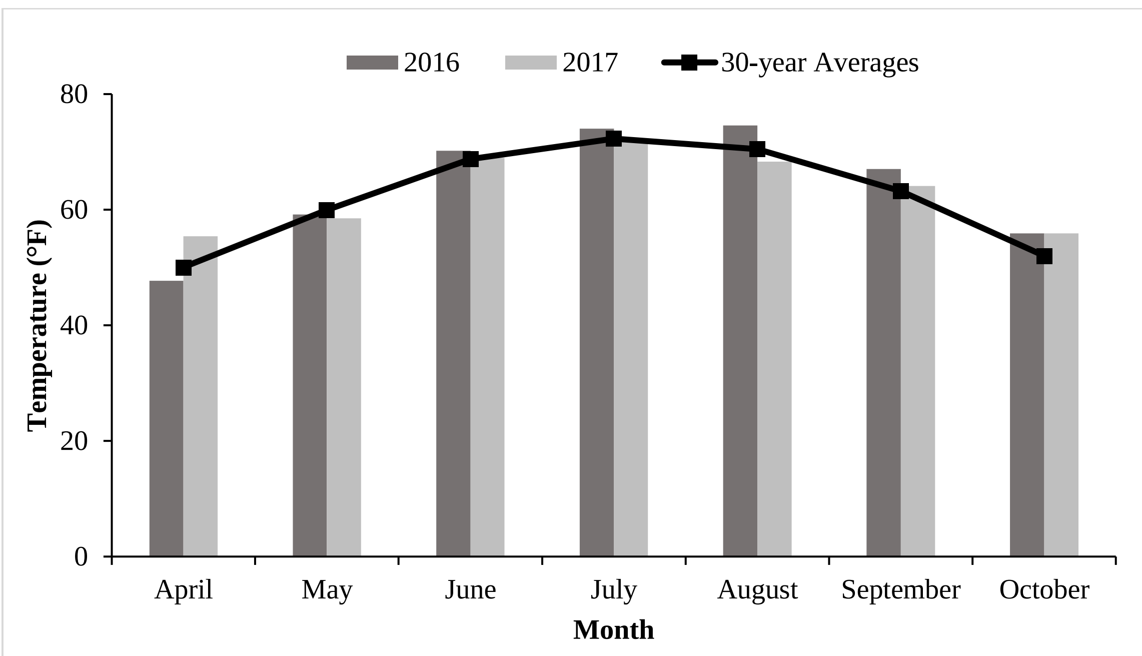

Figure 3.2. Monthly average air temperature at the Ohio Agricultural Research and Development Center (OARDC) in 2016 and 2017, compared to the 30-year average (1988-2017).

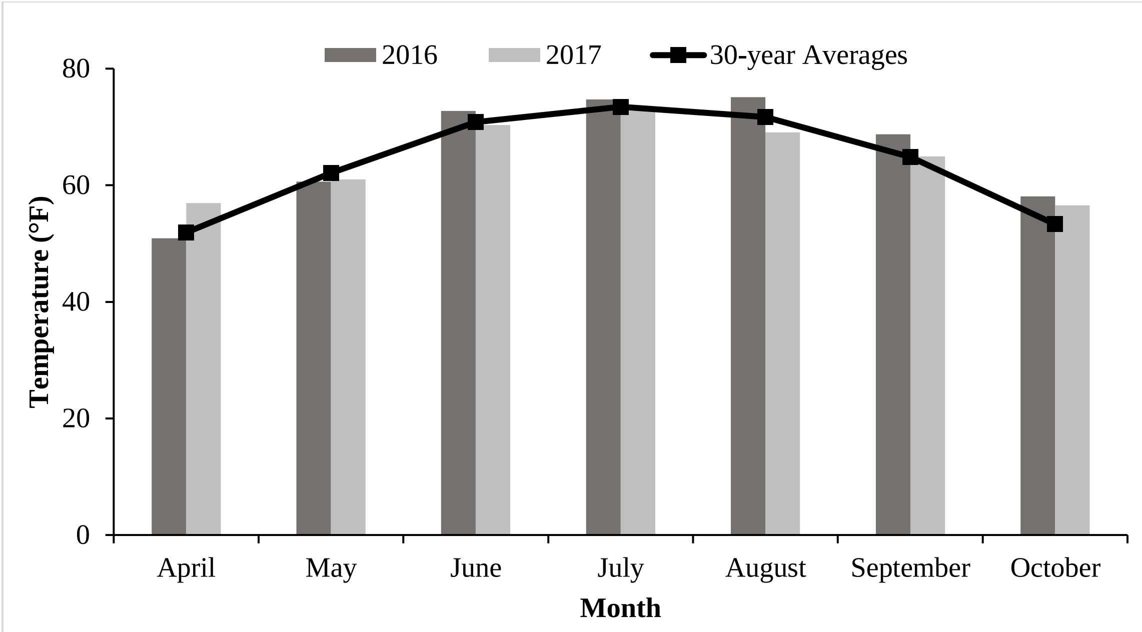

Figure 3.3. Monthly average air temperature at the Western Agricultural Research Station (WARS) in 2016 and 2017, compared to the 30-year average (1988-2017).

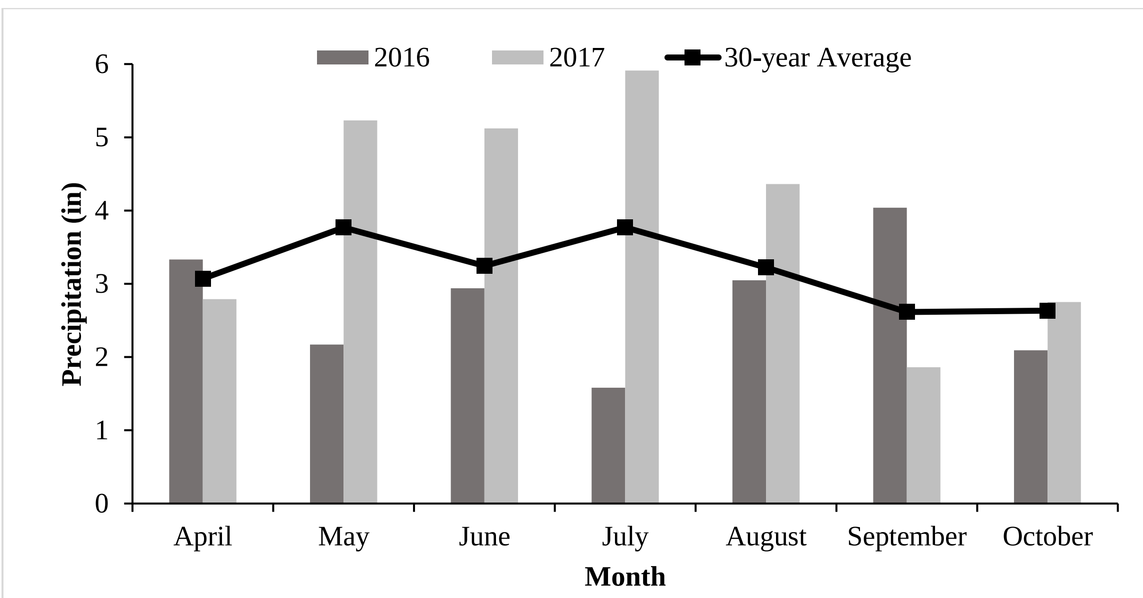

Figure 3.4. Monthly precipitation at the Northwest Agricultural Research Station in 2016 and 2017, compared to the 30-year average (1988-2017).

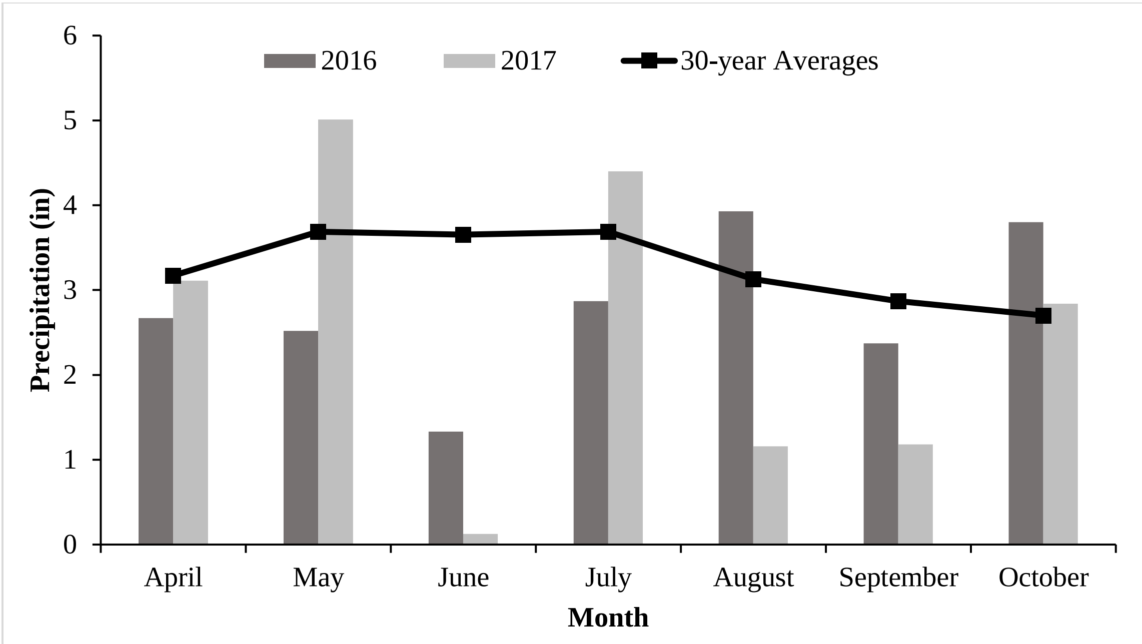

Figure 3.5. Monthly precipitation at the Ohio Agricultural Research and Development Center (OARDC) in 2016 and 2017, compared to the 30-year average (1988-2017).

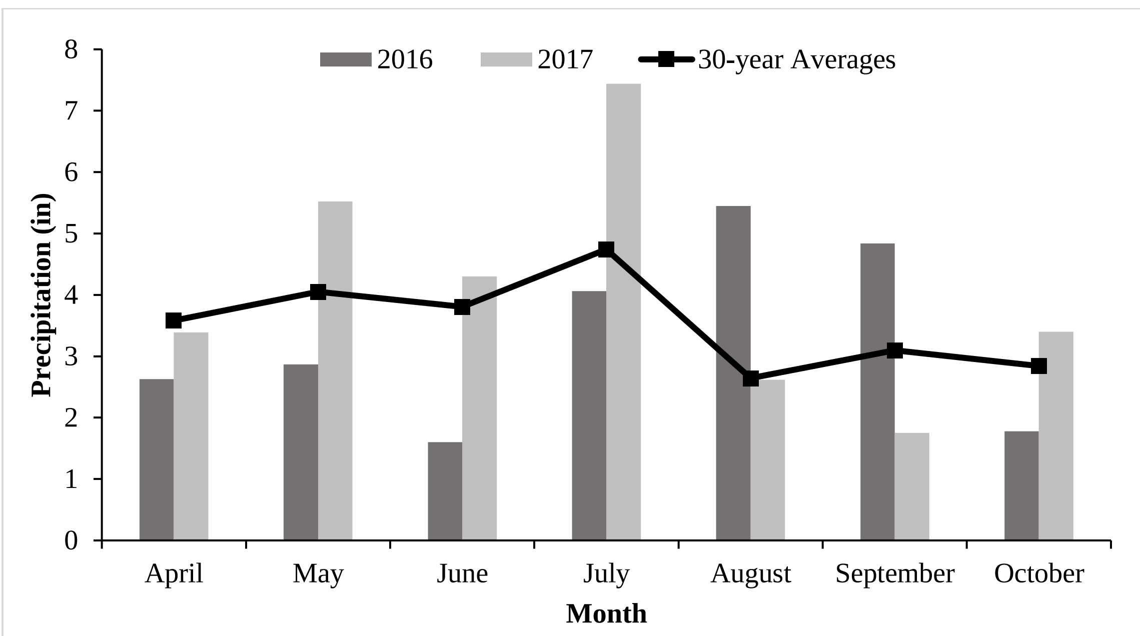

Figure 3.6. Monthly precipitation at the Western Agricultural Research Station (WARS) in 2016 and 2017, compared to the 30-year average (1988-2017).

3.4.2 Field Measurement Results

The analysis of variance results for the field measurements are shown in Table 3.4. Canopy closure was impacted by both planting date and relative maturity, but there was no interaction between planting date and relative maturity for canopy closure at any of the site-years. The first July soil surface temperature measurement was used to draw conclusions for yield differences at NWARS, OARDC, and WARS because the second July soil surface temperature measurements were not significant at any of the site-years. For all six site-years, a significant planting date by relative maturity interaction was observed for days to maturity, and a significant planting date by relative maturity interaction for yield was measured at three of the six site-years.

Table 3.4. Analysis of variance for effects of planting date (PD), relative maturity (RM), and planting date by relative maturity interaction (PD x RM). ($\alpha = 0.10$).

Site-year	Source	Canopy Closure	1st July Soil Temp.	Days to Maturity	Yield
NWARS	PD	0.0009	0.0256	0.0013	0.9374
2016	RM	0.0643	0.9238	<0.0001	<0.0001
	PD x RM	0.2148	0.0070	<0.0001	0.0937
NWARS	PD	0.0528	0.0180	0.0003	0.0548
2017	RM	0.0520	0.5778	<0.0001	0.0011
	PD x RM	0.3805	0.5740	<0.0001	0.5320
OARDC	PD	0.0014	0.2113	0.0041	0.0853
2016	RM	0.6353	0.2440	<0.0001	0.0080
	PD x RM	0.1717	0.1519	0.0082	0.0375
OARDC	PD	0.0191	0.4549	0.0002	0.0665
2017	RM	0.0654	0.5048	<0.0001	0.3332
	PD x RM	0.1510	0.0999	0.0151	0.6649
WARS	PD	<0.0001	0.0733	0.0002	0.2535
2016	RM	0.0353	0.0148	<0.0001	<0.0001
	PD x RM	0.1930	0.0055	0.0076	0.7666
WARS	PD	0.0003	0.1380	<0.0001	0.2141
2017	RM	0.0051	0.0186	<0.0001	<0.0001
	PD x RM	0.6924	0.1530	0.0061	0.0005

3.4.3 Canopy Closure

There was no significant planting date by relative maturity interaction for canopy closure at any of the site-years (Table 3.4). Canopy closure was significantly influenced by planting date at all three locations in 2016 and 2017 (Table 3.5). All locations reached 90% of the maximum canopy closure in the fewest number of days after planting when soybeans were planted later. In 2016, the first planting date reached 90% of the maximum closure in 61, 67, and 71 days at NWARS, OARDC, and WARS, respectively, while it took the second planting date 12, 17, and 28 days fewer to reach 90% of the maximum canopy closure at NWARS, OARDC, and WARS, respectively. In 2017, the first planting date reached 90% of the maximum closure in 75, 64, and 74 days at NWARS, OARDC, and WARS, respectively, while it took the second planting date 12, 14, and 20 days fewer to reach 90% of the maximum canopy closure at NWARS, OARDC, and WARS, respectively. Even though the second planting took the fewest number of days to reach canopy closure, the first planting date for five site-years reached 90% of the maximum closure at an earlier calendar date. In 2016, the first planting date reached 90% of the maximum closure on 22 July and 24 July at NWARS and OARDC, respectively, and the second planting date reached this closure 9 and 4 days later at NWARS and OARDC, respectively. In 2017, the first planting date reached this closure on 29 July, 19 July, and 28 July at NWARS, OARDC, and WARS, respectively, and the second planting date reached this closure 9, 10, and 3 days later at NWARS, OARDC, and WARS, respectively. The WARS 2016 site-year, was the only site-year that showed the second planting date reaching 90% of the maximum closure on 13 July and the first planting date reaching this closure 3 days later.

Soybean growth and development increases as temperature increases (Van Schaik and Probst, 1958). Another contributor to this effect is the number of growing degree days (GDDs). At all six site-years, the second planting date had fewer GDDs when it reached 90% of the maximum canopy closure than the first planting date. In 2016, the planting date differences in accumulative GDDs on the day when closure was reached at each location were 206, 243, and 376 GDDs at NWARS, OARDC, and WARS, respectively (Table 3.5). In 2017, the accumulative GDD differences were 182, 100, and 340 GDDs at NWARS, OARDC, and WARS, respectively. These differences in accumulative GDDs show that the first and second planting dates were very close to having the same number of accumulative GDDs, even though there was a 3-week difference in planting dates. This also explains why the second planting date may have had an accelerated growth and development rate.

Canopy closure was also significantly influenced by the main effect of relative maturity at NWARS in 2016 and 2017, OARDC in 2017, and WARS in 2016 and 2017 (Table 3.4). At NWARS in 2016 and 2017, the 2.8 relative maturity reached 90% of the maximum canopy closure in the fewest number of days (Table 3.6). In 2017 at OARDC, the 2.2 relative maturity had the fewest number of days to canopy closure. In 2016 and 2017 at WARS, the 4.1 relative maturity reached 90% of the maximum closure in the fewest number of days. The differences in relative maturity may be caused by the varieties' growth habits. It is possible that the relative maturities that closed in the fewest number of days could have a more bush-like growth habit. These plants could have had bigger leaves and longer branches which would cause the canopy to close faster.

In 2017 at NWARS and WARS, all of the relative maturities took longer to reach 90% of the maximum canopy closure than in 2016. This could have been due to an increase in precipitation. In 2017, NWARS and WARS both received almost twice the amount of precipitation in May, June, and July than the amount received in 2016 (Figure 3.4 and 3.6). Too much rain in a short amount of time could have potentially slowed down growth and development. This trend may not have affected OARDC because in

2017 this location only received 0.13 inches of precipitation in the month of June (Figure 3.5). Air temperature for both years was similar to the 30-year average. Also, the total accumulated GDDs at NWARS and WARS for 2016 and 2017, on the day when 90% of the maximum closure was reached, were very similar so the increased precipitation is a more probable cause for the differences between site-years.

Table 3.5. Number of days after planting to 90% of the maximum canopy closure and growing degree days (GDDs) at Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) by planting date in 2016 and 2017.

Site-year	Planting date	Days to 90% closure	GDDs
NWARS	23-May	60.7 a*	1403.0
2016	13-Jun	48.5 b	1197.5
NWARS	16-May	75.3 a	1537.3
2017	6 Jun	63.3 b	1355.6
OARDC	19-May	67.1 a	1376.0
2016	9-Jun	50.2 b	1132.9
OARDC	17-May	64.4 a	1205.4
2017	9-Jun	50.8 b	1105.2
WARS	7-May	70.9 a	1351.0
2016	1-Jun	42.7 b	974.6
WARS	16-May	74.3 a	1532.0
2017	8-Jun	54.4 b	1192.1

*Values followed by the same letter in a column within a site-year are not significantly different from each other ($\alpha = 0.10$)

Table 3.6. Number of days after planting to 90% of the maximum canopy closure at Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) by relative maturity in 2016 and 2017.

Relative Maturity	NWARS 2016	NWARS 2017	OARDC 2016	OARDC 2017	WARS 2016	WARS 2017
2.2	53.1 bc*	66.9 bc	59.6 a	55.1 d	59.3 a	64.0 bcd
2.4	57.1 a	71.6 a	60.5 a	58.1 abcd	58.1 ab	65.3 bc
2.6	53.5 bc	71.1 a	58.6 a	55.4 cd	56.3 bcd	61.9 cd
2.8	52.5 c	66.1 c	58.4 a	57.3 bcd	55.3 cd	61.3 cd
3.1	54.0 bc	71.8 a	59.7 a	61.1 a	58.0 ab	63.5 bcd
3.3	55.4 ab	68.6 abc	57.5 a	59.1 ab	58.0 ab	65.0 bc
3.6	57.0 a	68.4 abc	57.6 a	58.5 abc	56.0 bcd	65.1 bc
3.8	54.8 abc	70.0 ab	57.1 a	56.4 bcd	57.4 abc	67.0 ab
4.1	-**	-	-	-	54.5 d	60.9 d
4.4	-	-	-	-	55.3 cd	69.6 a

*Values followed by the same letter in a column within a site-year are not significantly different from each other ($\alpha = 0.10$).
**The 4.1 and 4.4 relative maturities were not planted at NWARS or OARDC because both locations do not have a long enough growing season.

3.4.4 Days to Maturity

All site-years had a significant planting date by relative maturity interaction for days to maturity (Table 3.4). The first planting date matured earlier than the second planting date (Table 3.7). Also, the maturity group 3 varieties took longer to mature than the maturity group 2 varieties. The average number of days between the first and second planting dates was 21, 22, and 24 days at NWARS, OARDC, and WARS, respectively. Even though there was approximately a 20-day difference between planting dates, the average difference between days to maturity for the two planting dates was 9, 13, and 15 days for NWARS, OARDC, and WARS, respectively. This shows that second planting date had an accelerated growth and development because for each relative maturity the number of days to maturity was not equal to number of days between the first planting date and the second planting date. The accelerated growth and development for the second planting date could be caused by the warmer temperatures at the beginning of growth in June and July. The results of Van Schaik and Probst (1958) supports this claim. Their study showed that soybean growth and development increased as temperature increased. When temperature was increased from 60-90°F, this caused earlier and more profuse flowering to occur.

Table 3.7. Number of days after planting to maturity at Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) with a planting date by relative maturity interaction in 2016 and 2017.

Site/year	Planting Date	Relative Maturity	Days to Maturity	Planting Date	Relative Maturity	Days to Maturity
NWARS 2016	23-May	2.2	117.3 g*	13-Jun	2.2	106.5 i
		2.4	119.0 f		2.4	107.0 i
		2.6	120.8 ef		2.6	115.3 h
		2.8	122.3 e		2.8	116.7 gh
		3.1	125.0 d		3.1	117.0 g
		3.3	128.5 c		3.3	119.5 f
		3.6	128.8 b		3.6	120.0 f
		3.8	136.0 a		3.8	122.0 e
NWARS 2017	16-May	2.2	119.3 g	6-Jun	2.2	112.8 i
		2.4	119.5 fg		2.4	114.3 i
		2.6	123.8 cd		2.6	116.5 h
		2.8	125.0 c		2.8	116.4 h
		3.1	128.3 b		3.1	118.5 g
		3.3	129.0 b		3.3	120.8 ef
		3.6	134.5 a		3.6	121.8 de
		3.8	135.0 a		3.8	122.0 de
OARDC 2016	19-May	2.2	119.5 fg	9-Jun	2.2	109.3 j
		2.4	119.3 fg		2.4	110.8 j
		2.6	122.3 de		2.6	114.0 i
		2.8	123.3 d		2.8	115.3 hi
		3.1	127.0 c		3.1	117.5 gh
		3.3	130.5 b		3.3	118.5 g
		3.6	131.3 b		3.6	119.8 efg
		3.8	136.8 a		3.8	121.3 def
OARDC 2017	17-May	2.2	122.0 f	9-Jun	2.2	106.3 m
		2.4	124.5 e		2.4	107.8 l
		2.6	125.8 e		2.6	110.0 k
		2.8	127.3 d		2.8	109.3 k
		3.1	129.8 bc		3.1	111.8 j
		3.3	129.0 c		3.3	113.5 i
		3.6	130.8 b		3.6	116.0 h
		3.8	132.5 a		3.8	118.5 g

WARS 2016	7-May	2.2	122.0 f	1-Jun	2.2	107.0 j
		2.4	122.0 f		2.4	110.0 i
		2.6	125.8 e		2.6	115.3 h
		2.8	132.5 d		2.8	116.8 gh
		3.1	134.3 cd		3.1	116.5 gh
		3.3	135.5 bc		3.3	117.8 g
		3.6	137.3 b		3.6	121.3 f
		3.8	142.8 a		3.8	127.3 e
		4.1	143.5 a		4.1	127.8 e
		4.4	143.0 a		4.4	128.0 e
WARS 2017	16-May	2.2	123.3 fg	8-Jun	2.2	107.3 l
		2.4	124.5 ef		2.4	107.8 l
		2.6	125.5 e		2.6	111.0 k
		2.8	127.8 d		2.8	113.0 j
		3.1	128.0 d		3.1	114.8 ij
		3.3	128.8 d		3.3	115.0 i
		3.6	131.0 c		3.6	119.0 h
		3.8	133.3 b		3.8	122.0 g
		4.1	137.8 a		4.1	122.0 g
		4.4	139.5 a		4.4	122.8 fg

*Values followed by the same letter within a site-year are not significantly different from each other ($\alpha = 0.10$)

3.4.5 Yield

At NWARS in 2016, there was a significant interaction between planting date and relative maturity on soybean yield (Table 3.4). Both planting dates, 23 May and 13 June, had similar yields for all relative maturities except for 3.8 where yield was reduced by 7.9 bu ac^{-1} in the 13 June planting date compared to the 23 May planting date (Figure 3.7). The highest yield for the 23 May planting date was calculated to occur at a higher relative maturity than was used in the study (>3.8 RM). For the 13 June planting date, the highest yield was calculated to occur with a 3.1 relative maturity. In 2017, there was no significant planting date by relative maturity interaction at NWARS (Table 3.4). However, the main effect of planting date and relative maturity had a significant effect on yield. The first planting date, 16 May, had an average yield of 58 bu ac^{-1} (across relative maturity) and the second planting date, 6 June, had an average yield of 50.7 bu ac^{-1} (across relative maturity) (Figure 3.8). The highest yield was calculated to occur with a 3.3 relative maturity across planting dates (Figure 3.9).

In 2016 at OARDC, there was a significant planting date by relative maturity interaction (Table 3.4). The first planting date, 19 May, overall had higher yields for all relative maturities except for the 2.2 relative maturity (Figure 3.10). The 2.2 relative maturity soybean had the same yield regardless of planting date. For the 19 May planting date, the highest yield was calculated to occur at a higher relative maturity than what was tested (>3.8 RM). For the 9 June planting date, there was no significant difference in yield among the relative maturities. At OARDC in 2017, yield responded to the main effect of planting date, but not relative maturity (Table 3.4). There was no planting date by relative maturity interaction. The first planting date, 17 May, had an average yield of 62.6 bu ac^{-1} (across relative maturity) and the second planting date, 9 June, had an average yield of 56.9 bu ac^{-1} (across relative maturity) (Figure 3.11).

In 2016 at WARS, there was a significant yield response to relative maturity (Table 3.4). There was no significant planting date by relative maturity interaction. The highest yield was calculated to occur with a 3.6 relative maturity (Figure 3.12). In 2017 at WARS, a significant planting date by relative maturity interaction occurred (Table 3.4). Unlike the previous interactions, the second planting date, 8 June, had the highest yields for all relative maturities except for the 4.1 and 4.4 relative maturities (Figure 3.13). The 8 June planting date was likely higher yielding than the 16 May planting dates because of precipitation rates in May. Western Agricultural Research Station received 4.15 inches of precipitation in 12 days after the first planting date, 16 May, compared to the 1.83 inches of rain in the 12 days after the 8 June planting date. The highest yield for 16 May was calculated to have occurred with a higher relative maturity than was used for this study (>4.4 RM). For the second planting date, 8 June, the 3.6 relative maturity resulted in the greatest yield.

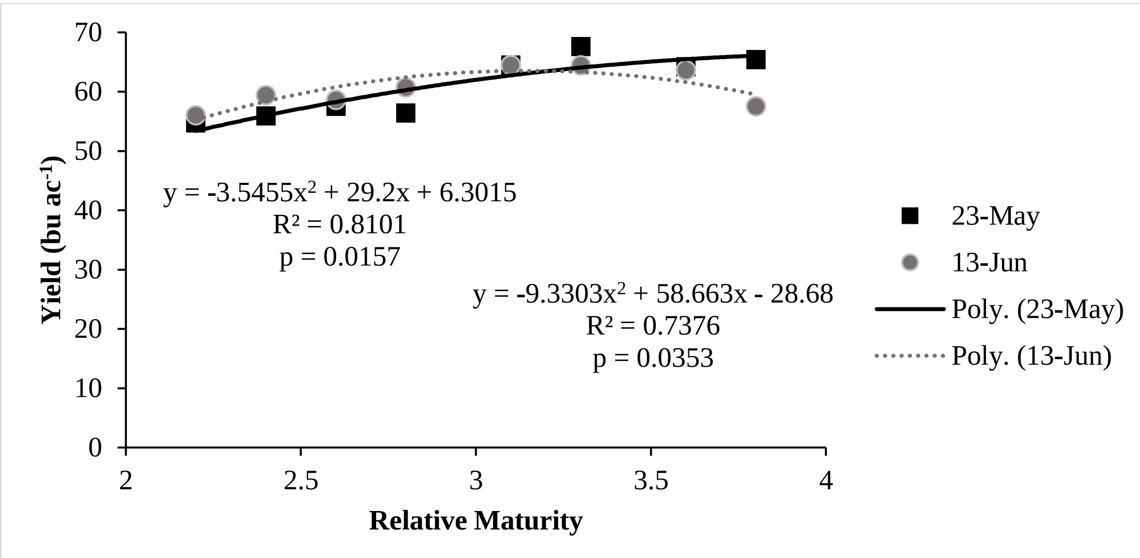

Figure 3.7. Grain yield at the Northwest Agricultural Research Station in 2016.

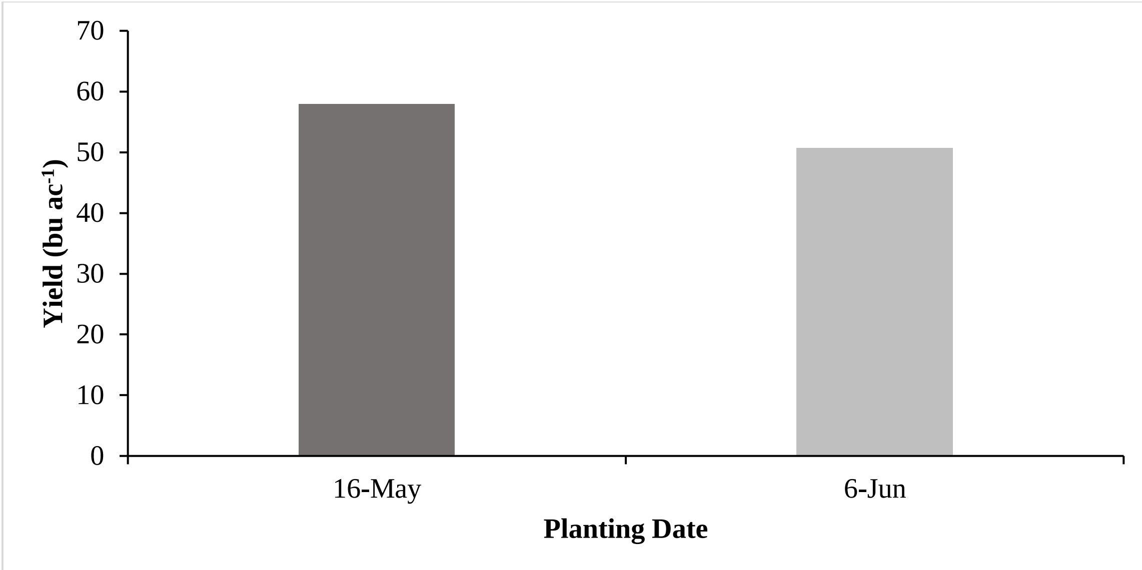

Figure 3.8. Grain yield by planting date at the Northwest Agricultural Research Station in 2017.

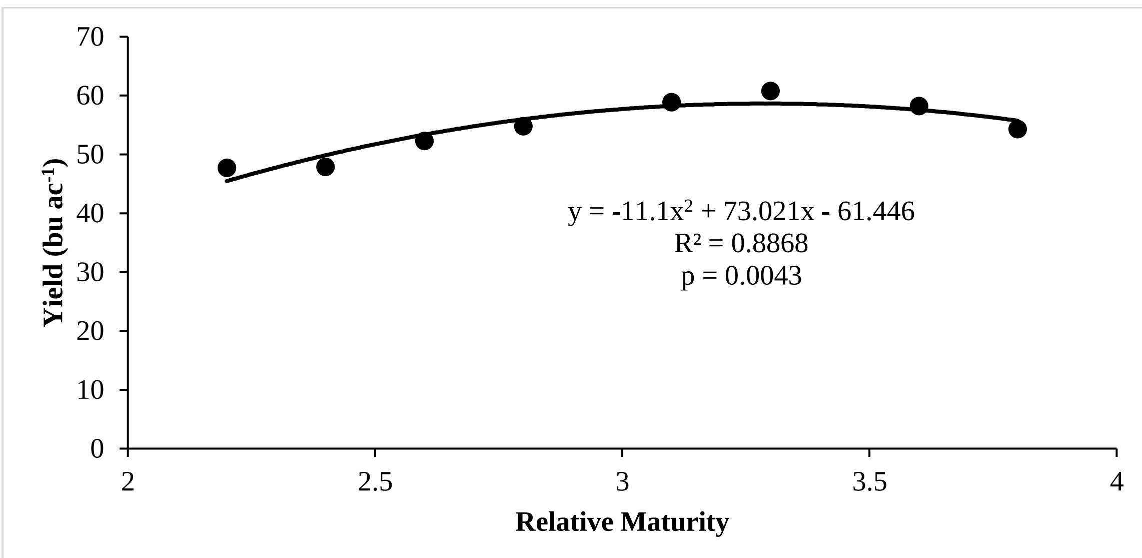

Figure 3.9. Grain yield by relative maturity at the Northwest Agricultural Research Station in 2017.

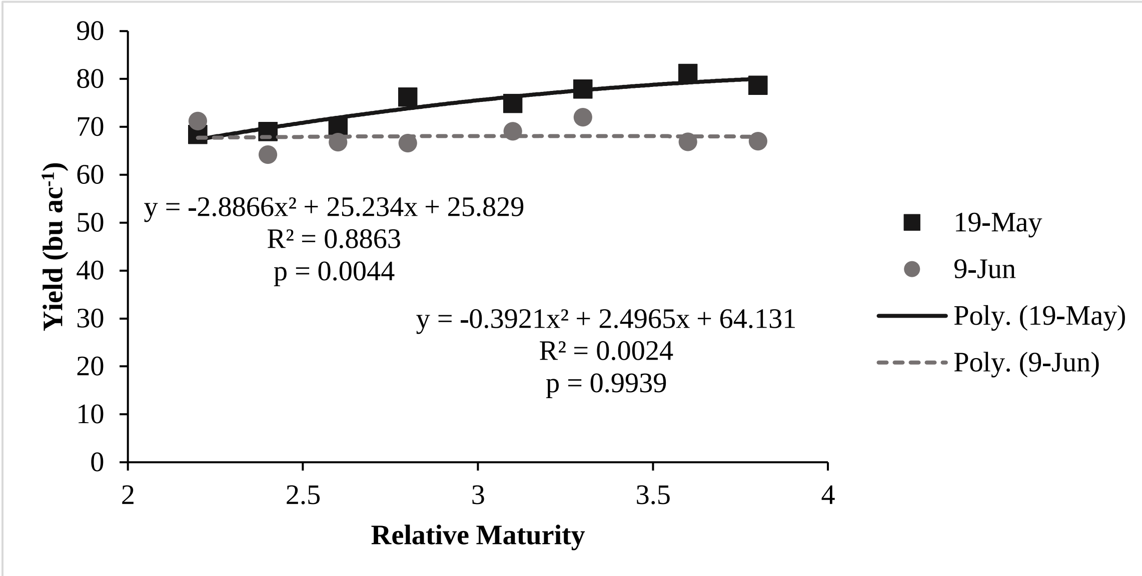

Figure 3.10. Grain yield at the Ohio Agricultural Research and Development Center in 2016.

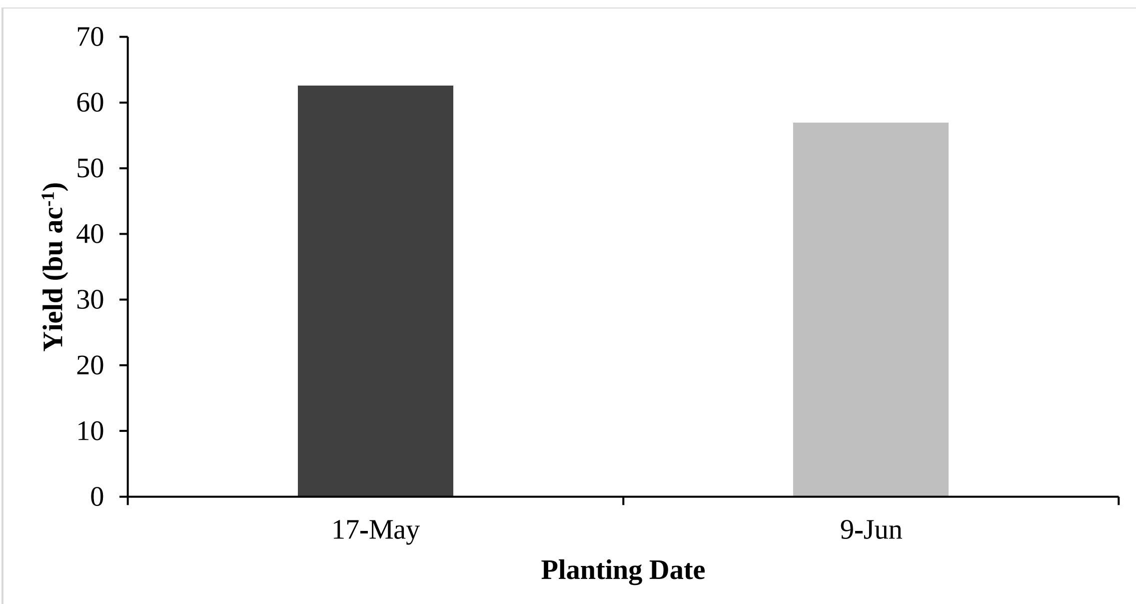

Figure 3.11. Grain yield at the Ohio Agricultural Research and Development Center in 2017.

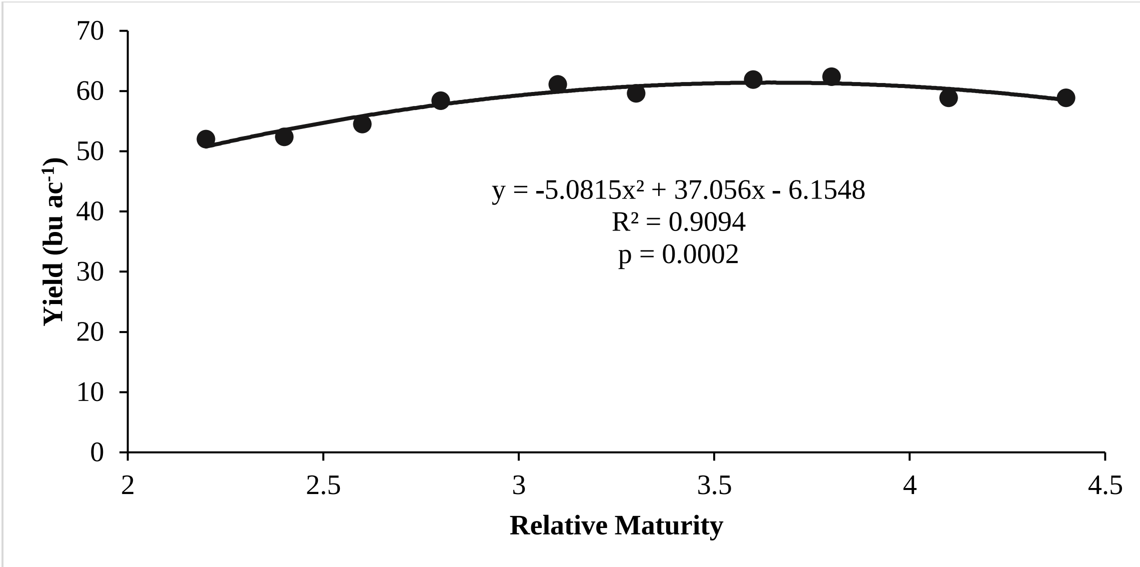

Figure 3.12. Grain yield at the Western Agricultural Research Station in 2016.

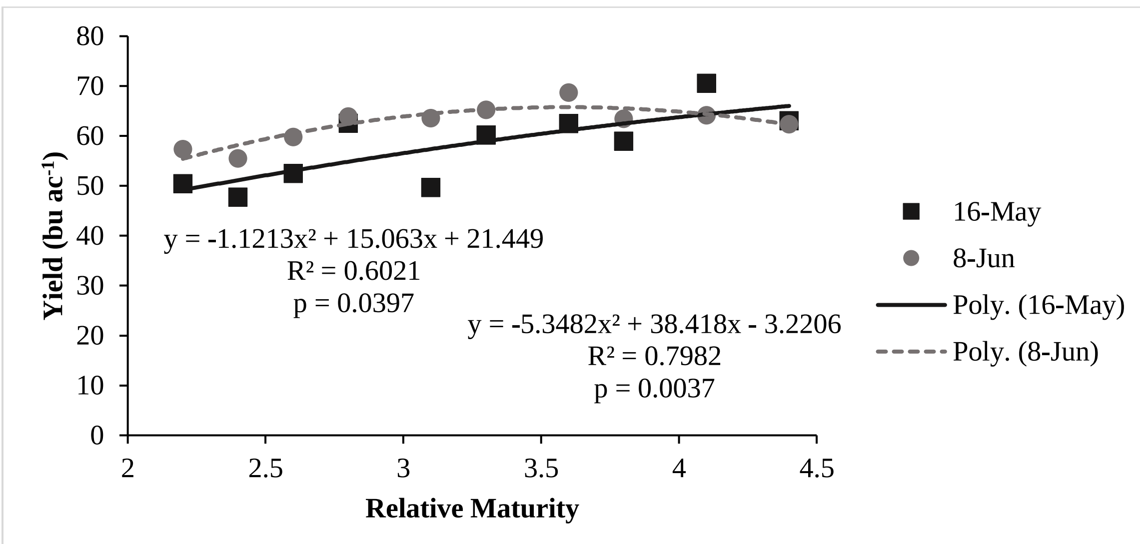

Figure 3.13. Grain yield at the Western Agricultural Research Station in 2017.

3.4.6 Influence of Soil Temperature on Yield

At NWARS in 2016, the first July soil surface temperature (measured on 5 July) had a planting date by relative maturity interaction (Table 3.4). This interaction could explain the planting date by relative maturity interaction for yield. The first planting date shows a significant relationship between soil surface temperature and yield (Figure 3.14). As the soil surface temperature increased, yield decreased. At the time when the soil surface temperatures were measured, the average air temperature was 77.1° F. The soil surface temperatures were higher than the average air temperature because the canopy had not reached full closure yet, allowing direct sunlight to reach the soil surface. At the time when the soil surface temperature measurements were taken, the maturity group 3 soybeans had a little more canopy cover than the maturity group 2 soybeans. The maturity group 3 soybeans ranged from 50 – 52.5% canopy closure while the maturity group 2 soybeans ranged from 44.7 – 54.8% canopy closure. The higher percent canopy cover helped keep the soil surface cooler. Soil temperature was greater for the second planting date and did not have a significant effect on yield.

The NWARS 2016 site-year, was the only planting date by relative maturity interaction to show a significant regression curve. For the remaining site-years, the regression models for the first July soil surface temperature and yield are shown in Table 3.8.

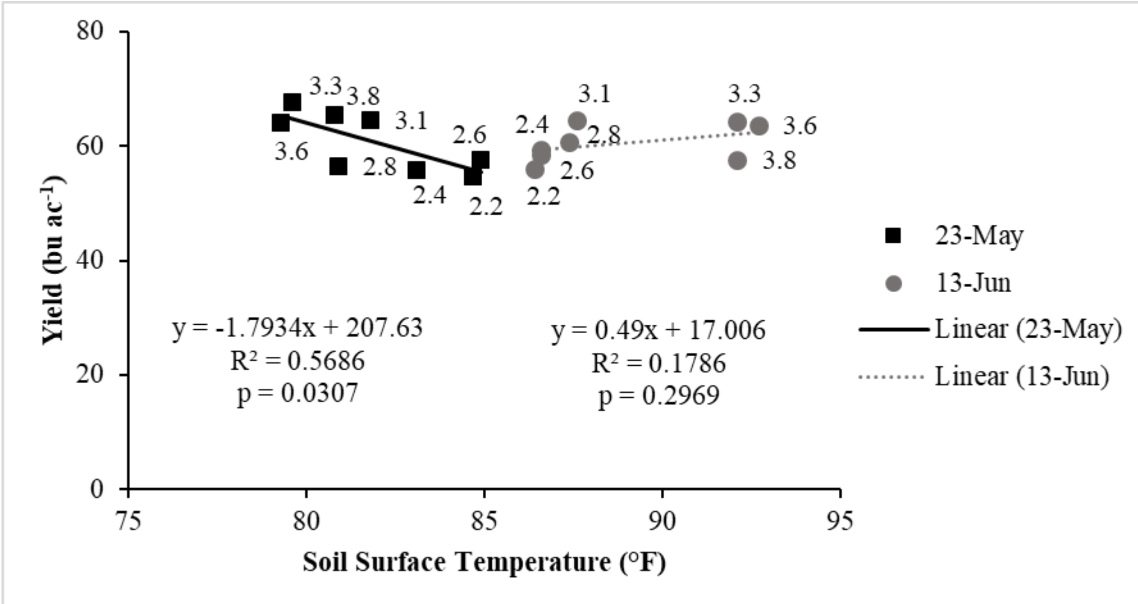

Figure 3.14. Yield (bu ac^{-1}) over soil surface temperature (°F) at the first July soil surface temperature measurement (5 July) at the Northwest Agricultural Research Station in 2016.

Table 3.8. Regression models fit yield over soil surface temperature at the first July soil surface temperature measurement at the Northwest Agricultural Research Station (NWARS), the Ohio Agricultural Research and Development Center (OARDC), and the Western Agricultural Research Station (WARS).

Site-year	Planting Date	Model	R^2	Model P-value
NWARS 2016	23-May	$y = -1.7934x + 207.63$	0.5686	0.0307
	13-Jun	$y = 0.49x + 17.006$	0.1786	0.2969
OARDC 2017	17-May	$y = 2.0676x - 95.145$	0.3734	0.1075
	9-Jun	$y = 2.5345x - 135.02$	0.2010	0.2653
WARS 2016	7-May	$y = -0.5779x^2 + 79.783x - 2694.2$	0.2054	0.4473
	1-Jun	$y = -0.5425x^2 + 79.027x - 2819.4$	0.0954	0.7041
WARS 2017	-*	$y = -0.9322x + 146.21$	0.1677	0.2399

*There was no planting date by relative maturity interaction at in WARS in 2017. Only a significant relative maturity effect.

3.5 Conclusions

Planting date and relative maturity both had a significant effect on yield. The effect of planting date in this study was not as consistent as other studies have shown (Rattalino et al., 2017; Hankinson et al., 2015; Cartter and Hartwig, 1963). In only three of the six site-years, planting in May produced higher yields than planting in June. To get a better understanding as to what the optimum planting date is, more than two planting dates should be examined. In northern Ohio, NWARS and OARDC, the relative maturity with the highest yield ranged from 3.1-3.6. In southern Ohio, WARS, the relative maturity with the highest yield ranged from 3.6-4.1. Three of the site years indicated that with planting early a higher relative maturity could have been used to reach the highest yield. These relative maturity ranges are similar to the recommendations found in the Ohio Agronomy Guide, 15th edition (Lindsey et al., 2017).

Growing conditions must be considered when deciding when to plant. Too much precipitation shortly after planting can significantly reduce yields when planting early. However, delayed planting can limit soybean growth and development when a full canopy is not reached by July. The warm temperatures can reduce the number of days to maturity and the maximum yield potential by accelerating the growth and development of the plant.

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Appendix A: Methods Tables

Table A.1. Chemical application date and rates used at the Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) in 2016 and 2017.

Site/year	Application Date	Product	Rate (oz ac^{-1})
NWARS 2016	May 18	Boundary	32
		Authority 1st	4
		2,4-d ester lv6	11
	Aug 3	Zeal	6
NWARS 2017	May 19	Boundary	32
		Authority XL	4
		2.4-d ester	16
		Mad dog gly	32
		Choice	6
OARDC 2016	May 25	Metribuzen 4L	8
		Linex 4L	10
		Classic DF	1.5
		Glystar Plus	32
		Dual II Magnum	26
	Jun 10	Scepter DF	2.8
		Dual II Magnum	26
		Glystar Plus	32
	Jul 21	Glystar Plus	32
OARDC 2017	Jun 2	Scepter DF	2.8
		First Rate	.3
		Dual II Magnum	26
		Glystar DF	32
	Jun 14	Scepter DF	2.8
		First Rate	.3
		Dual II Magnum	26
	Jul 18	Glystar Plus	32
WARS 2016		Glyphosate	32
		AMS 17 lbs/100 gal	
		Command 3ME	24
		Dual II Magnum	16
		Trivence	8
		Glyphosate	24
		AMS 17 lbs/100 gal	
		Select Max	12
		NIS 1 qt/100 gal	

WARS 2017	Glyphosate	32
	AMS 17 lbs/100 gal	
	Command 3ME	24
	Dual II Magnum	16
	Trivence	8
	Glyphosate	24
	AMS 17 lbs/100 gal	
	Select Max	12
	NIS 1 qt/100 gal	

Table A.2. Dates of canopy closure and temperature (Temp.) measurements at Northwest Agricultural Research Station (NWARS), Ohio Agricultural Research and Development Center (OARDC), and Western Agricultural Research Station (WARS) in 2016 and 2017.

NWARS 2016	OARDC 2016	WARS 2016
Jun 21	Jun 22	Jun 16
Jul 5	Jul 6	Jun 30
Jul 19	Jul 20	Jul 14
Aug 2	Aug 3	Aug 1
Aug 22	Aug 19	Aug 18
Sept 6 (Temp. only)	Aug 30 (Temp. only)	Sept 2 (Temp. only)
NWARS 2017	**OARDC 2017**	**WARS 2017**
Jun 12	Jun 19	Jun 13
Jun 27	Jul 6	Jun 29
Jul 18	Jul 21	Jul 17
Jul 27	Aug 2	Jul 28
Aug 7	Aug 14	Aug 8
Aug 21	Aug 30	Aug 23