**Closing the Yield Gap in Soybean *(Glycine max)***
**with Combined Improved Management Practices**

by

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## Abstract

Food demand is expected to increase by 35% to 56 % by 2050. According to projections by the United Nations Food and Agricultural Organization, global food and feed production needs to increase by 70% by that time to meet the world's growing food needs. Prior researchers identified planting date and foliar fungicide and insecticide as factors that increase yield and theorized that combining these practices would have the greatest potential for increasing yield and profit. The objective of the current study was to empirically examine this postulation and compare the combined "improved" management practice (CIMP) to standard management practices (SMP). A randomized complete block design with 3-4 replications per field trial was conducted to compare the yield and partial economic return of the CIMP and SMP conditions. The CIMP condition included planting from April 6 through May 25, using a reduced seeding rate of 130,000 seeds per acre and the applications of foliar fungicide and insecticide in a tank mix at the R3 growth stage. The SMP system included a plant date at a minimum of 3 weeks after the CIMP plant date, a seeding rate of 160,000 seeds per acre and no foliar applications. Yield (4.9 bu/acre) and partial economic return (gross return minus costs = $65.47) in the CIMP condition compared to the SMP condition, but these differences were not significantly different. However, despite the lack of statistically significant differences, the practical benefits of a lower seeding rate, larger planting window, and protection from potential crop diseases afforded by the CIMP conditions support the recommendation for use of this system over standard practices as delineated in the discussion section of this paper.

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**Table of Contents**

## Chapter 1:

## Literature Review

### History of Soybean Production

In 1765 soybeans (*Glycine max* L.) were introduced by Samuel Bowen to the United States in Savannah Georgia, from China (Hymowitz and Harlan, 1983). Soybeans were used to manufacture soy sauce and vermicelli (soybean noodles) (Hymowitz and Harlan, 1983). Most soybean production was done in Asia, including China, Indonesia, Japan, and Korea, until the 1930's (Hymowitz, 1970)." The soybean is one of the oldest of cultivated crops" and "The soybean has been known to man for over 5000 years" are statements repeated from one agronomic publication to another without citation or explanation (Hymowitiz, 1970). In 1924, The USDA started compiling statistics on soybeans, including the area planted and seed yield (Specht et al., 2014). Compared with corn *(Zea mays*), wheat (*Triticum*), and some other crops, soybeans were a minor U.S. crop until after the Second World War, when demand for vegetable oil and meat consumption rose rapidly with increasing incomes and population (Ash et al., 2006). Today, soybeans account for about 90 percent of U.S. oilseed production. In 2005, planted soybean acreage was 72.1 million acres and farm production value were nearly $17 billion, trailing only corn in U.S. crop area and production value (Ash et al., 2006). Soybean yield has quadrupled from 11 bu/acre in 1924 to 44 bu/acre in 2009 (Specht et al., 2014). The United Nations Food and Agricultural Organization (FAO) projects that food and feed production will need to increase by 70% by 2050 to meet the world's food needs. However, predicting food needs and supplies decades into the future involves a lot of uncertainty and estimates can vary substantially (Hofstrand, 2014). The main soybean-producing area is the Corn Belt and lower Mississippi Valley. The North-

Central United States accounts for about one third of global soybean production (Rattalino Edreira et al., 2017). Currently Ohio's average soybean yield for 2021 was 56.5 bu/acre, up 1.5 bushels from 2020 (NASS-USDA V11 no. 1).

Soybeans are a short day, trifoliate legume. Soybeans have a facultative photoperiod development, meaning they grow according to day length and temperature, with two growth stages, a vegetative stage, and a reproductive stage. The vegetative stage is from germination to first flower and the reproductive stage is from flower to full maturity. The flowering stage is triggered when daylength grows shorter.

Planting before optimum dates is restricted mainly due to cool soil temperatures (Hu and Wiatrack, 2012). In the north, central, and southern zones of Iowa the soil temperature at 4 inches soil depth was more than 50°F and was adequate for planting by the last week of April (DeBruin and Pedersen, 2008). Suitable temperature ranges for soybean are 59-71°F at emergence, 68-77°F at flowering and 59-71°F at maturity (Mourtzinis et al., 2015). Heat stress for a prolonged period in early stages of vegetative growth can substantially influence crop growth, development and yield. (A heat wave is described here as air temperature equal to or greater than 90°F for 7-10 days or longer.) This effect is especially true if the heat stress is coupled with soil water deficit and/or an increase in soil temperature (Irmak, 2016).

Temperature and drought stress have a negative effect on plant development and yield (Hu and Wiatrak, 2012). Saturated soils after soybean planting can cause uneven emergence and stand reductions of varying extent depending on the stage of the soybean plant and other environmental factors including temperature and duration of saturated conditions. Additionally, increased disease incidence may further reduce plant stand (Lindsey and Lindsey, 2019). Soybeans require approximately 15 inches to over 25 inches of water per year depending on planting date, maturity group, location, and weather conditions (Kranz and Specht, 2012). The most important time to avoid water stress is during the mid- to late-reproductive stages. Soybeans in general need about an inch of rain per week during pod filing, stresses at stages R3 and R4 can cause yield reductions (Ellsworth Christmas, 2002).

Soybean should be planted in soil with an adequate moisture level (enough for the soybean to absorb 50% of its weight in water) and warm temperatures (mid-50°F or higher) to allow rapid germination and emergence. Rapid germination occurs when soil temperatures are above 65°F (Ciampitti et al., 2016). When Soybeans flower in the summer, they can produce up to 80 pods per plant. Each pod contains two to four pea-sized beans. Soybeans are grown primarily for processing into meal and oil (Ohio Soybean Farmers, 2020; NASS USDA).

**Soybean Production Systems and Challenges in the United States**

In 2020 the United States planted 83.8 million acres of soybeans, 0.3 million acres more than 2019. The US harvested approximately 4 billion bushels, averaging 50.2 bu/acre, 2.8% higher than 2019 (LMC International, 2019). The soybean industry had an economic impact of $115.8 billion per year (LMC International, 2019).

Of the foliar diseases that were surveyed by Savary et. al., (2019, as cited in Bradley et. al., 2021), frogeye leaf spot contributed to a loss of 119,393,000 bushels of soybeans and Septoria brown spot 74,203,000 bushels between 2015 through 2019. From 2015 through 2019 Septoria brown spot ranked in the top 10 most yield limiting diseases based on estimates of loss by disease or disease type from states in the Northern United States and Ontario, Canada. Frogeye leaf spot ranked (ninth in 2016 third in 2018 and sixth in 2019) in the top ten most yield-limiting fungal diseases (out of 28 diseases) in three of the five years. In 2018 frogeye leaf spot contributed to a loss of 47,187,000 bushels in soybean production, making it the third largest contributor in 2018.

Over this five-year survey Septoria brown spot contributed to a loss of 52,000,000 bushels, and 65,000,000 bushels caused by frogeye leaf spot (Bradley et. al., 2021). The increased presence of these foliar disease in the Northern United States and Ontario, Canada leads to the need for further investigation into in season foliar applications of fungicide.

Soybean invertebrate pests annually reduce yield and require economic investment to manage in the United States (Sisson et. al., 2021). In 2021, invertebrate pests reduced soybean yield by 2.5% across the 18 states reporting data. Additionally, overall management costs were estimated at $753.6 million USD (Sisson et. al., 2021). Overall, the stink bug complex (Hemiptera: Pentatomidae) was the costliest insect pest in soybean during 2021 in terms of lost yield (0.8%) and management costs ($2.48/ac), comprising 28% of all combined insect costs + losses (Musser et. al., 2022) In this survey corn earworm, Helicoverpa Zea (Llepidoptera: Noctuidae), was the second most damaging pest during 2021, comprising 16% of all insect costs and losses. Total management costs were $18.53 per acre, with estimated crop losses to insects at $17.83 per acre, making 2021 total costs plus losses $36.37 per acre (Musser et. al., 2022).

The most recent published soybean disease loss estimates from the United States and Ontario, Canada, were determined by university and extension plant pathologists and ranged from 369.6 million bushels to 511.6 million bushels from 2010 to 2014 (Allen et al., 2017b; Bradley et al., 2021). Estimated soybean yield losses from 2010 through 2014 were valued at nearly US$26 billion (Bradley et.al., 2021). Prior to this, Koenning and Wrather (2010) reported average estimated losses in the United States to be approximately 412.6 million bushels annually from 2006 through 2009. Additionally, Hartman et al. (2015) estimated the average annual yield losses due to soybean diseases in the United State to be approximately 11%. A survey conducted by

Savary et al. (2019, as cited in Bradley et. al., 2021) estimated soybean yield losses as a result of plant diseases in the Midwestern United States and Canada to be approximately 25%.

### Soybean Production in Ohio

According to the USDA-NASS, in 2022, Ohio farmers planted 5.08 million acres of soybeans, up 4% from 2021. Ohio harvested 282 million bushels and averaged 55.5 bu/acre, 1.5 bu/acre from 202021. The economic impact of the soybean market on Ohio's economy was $5.3 billion (Ohio Soybean Council, 2013).

In Ohio, soybeans are typically planted April through June then harvested in October. In southern Ohio, Soybeans should be planted any time after April 15 when soil conditions are suitable (Lindsey et al., 2017). In northern Ohio, Planting should begin the last few days of April if soil conditions are satisfactory (Lindsey et al., 2017).

Currently, the most common foliar disease of soybeans in Ohio is brown spot caused by *Septoria glycines* and the yield impact from this lower canopy pathogen can range from 3 to 6 bu/acre (C. Cruz 2008). Frogeye leaf spot (*Cercospora sojina*) was a serious pathogen on highly susceptible varieties in Ohio during 2006 and 2007 (Cruz and Dorrance, 2009). Bradley et. al. (2021) found that the average production loss in Ohio due to disease in soybean from 2015 through 2019 was approximately 13%, almost 4% higher than the average of the northern United States and Ontario, Canada. The total average loss in Ohio in Bradley's study was approximately 40,000,000 bushels. Bradley et al. (2021) evaluated the economic impact of the losses attributed to disease for the northern United States and Ontario, Canada. In US dollars more than $15 Billion was lost over the five-year study. Ohio's estimated loss to soybean diseases from 2015 through 2019 was $1.8 Billion. Ohio experienced a total loss of over $74.90 per acre during this study.

Spring planting coincides with the cooler temperature and higher humidity favored by slugs, putting seeds, cotyledons, and new foliage at risk. This can cause decreased emergence, plant stand losses, and/or reduced yields (Raudenbush et al., 2021). Ohio falls in the Great Lakes Region of the insect survey collected by Musser et. al. (2022). This region represented 11.2% of the soybean production in the U.S. in 2021. The overall loss due to invertebrate pests in the Great Lakes region in 2021 was 2.3%, or 11.8 million bushels. Japanese beetle caused the greatest estimated yield reduction. Slugs, seedcorn maggot, spider mites and the armyworm complex caused the next greatest losses, in descending order (Sisson et. al., 2023). Ohio's total costs plus losses increased from $21.24 per acre in 2020 to $38.81 per acre in 2021 (Musser et. al., 2021) Much of this increase was due to slugs, armyworms, and Japanese beetles, three pests that caused no losses in 2020, but together cost growers $15.75 per acre in management costs and yield losses in 2021 (Musser et. al., 2022)

**Yield Gap**

Most soybean varieties have genetic yield potentials well over 100 bu/acre (Lindsey et al., 2017). A variety's adaptability to the environment and production system where it will be used sets the yield potential of the production system. The quality of the weather during the growing season and the stress from weeds, diseases and insects determine what the crop yield will be (Lindsey et al., 2017). Growth, development, and yield of soybean are not only affected by the cultivar's genetic potential, but also by planting date and environmental conditions (Chen and Wiatrak, 2010). Yield potential is the yield of a crop cultivar when grown in an environment to which it is adapted, with non-limiting water and nutrient supplies, and with pests, weeds, and diseases effectively controlled (Rattalino Edreira et al, 2017). In these optimal conditions, crop growth is determined by solar radiation, temperature, atmospheric $CO_2$ concentrations and management practices which influence crop cycle duration and light interception, such as sowing date, cultivar maturity and plant density (Rattalino Edreira et al., 2017).

The yield gap is the difference between the potential yield and the farm yield. Closing the yield gap via a fine-tuning of current management practices provides an opportunity to increase crop production on existing cropland (Rattalino Edreira et al., 2017). The most common approach for assessing the magnitude and causes of a yield gap in localized areas involves conducting controlled research trials in which researchers experimentally evaluate various input levels or management practices to identify whether a particular input or practice improves yield, and if the degree of yield improvement justifies input costs (Rattalino Edreira et al., 2017). Recent studies using producer data identified planting date as the most important management practice explaining field-to-field variation across regions with similar weather and soil condition in the north-central United States (Mourtzinis et al., 2018; Rattalino Edreira et al., 2017; Matcham et. al., 2020). In regions where planting date was the most important factor influencing soybean yield, additional factors that explained a large percentage of field-to-field yield variation were topographic wetness index, subsoil pH, row width, foliar fungicide, and foliar insecticide (Mourtzinis et al., 2018; Matcham et. al., 2020).

**Planting Dates**

Planting date is an important factor affecting soybean growth and development, grain yield (Zhang et al., 2010), and grain quality (Rahman et al., 2005). Choosing the optimum planting date is an effective way to improve soybean growth and development, and close the yield gap (Hu and Waitrak, 2012). Timely planting of soybeans is extremely important to maximize seed yield in the north-central United States (Matcham et al., 2020). Planting dates have shifted in the last 34 years to earlier dates at a rate of 0.5 day per year (Ciampitti et al., 2016). The change in planting date may be attributable to changes in genetics (e.g., improved germination and cold tolerance of modern soybean varieties); environmental conditions (e.g., warmer temperatures in spring); and management practices (e.g., tillage system, rotation, fertility, inoculation, and machinery) (Ciampitti et al., 2016). Soybean planting typically begins when corn planting is complete but can be further delayed based on the recommendation that planting should begin after soil temperatures reach 50°F (Hoeft et al., 2000).

One early planting date study for soybean, as a grain and forage, was done in Knoxville, TN in 1907 and 1908, showed that planting around the first week of June returned the most favorable grain yields (Mooers, 1908). In 1963, Cartter and Hartwig reached the conclusion that no single cultural factor was more important to soybean production than planting date (Egli and Cornelius, 2009). Planting Dates have consistently shifted to earlier plantings when soil conditions are favorable.

Photoperiod and in-season temperature are the primary factors that dictate the region where a soybean variety is adapted (Mourtzinis and Conley, 2017). Soybean seed yield is correlated with length of flowering and pod set (Egli and Bruening, 2010), and seed filling (Andrade, 1995). Photoperiod is one of the most important environmental factors, because it regulated the whole development process of soybean plants (Hu and Waitrak, 2012). Short vegetative and reproductive stages, due to changes in photoperiod with delayed planting, contribute to yield loss (Hu and Wiatrak, 2012). Lower temperatures later in the season could reduce yield by reducing photosynthesis, but only when temperature drops below about 68°F in fall (Boote et al., 1998).

The first study that defined hypothetical maturity group (MG's) zones across the US was 45 years ago, and the most recently used data up to 2003 (Mourtzinis and Conley, 2017). Time of flowering and maturity in soybeans are important agronomic characters that determine its geographical adaptation. Based on these traits, soybean has been classified into 13 maturity groups (Zhang et al., 2007). Scott and Aldrich (1970) defined hypothetical zones of adaptation for 10 soybean MGs in the US and has been the most widely referenced document regarding the area of adaptation for specific soybean maturity groups (Zhang et al., 2007). Maturity Group numbers indicate the date in September that the plant is expected to be physiologically mature. Group 0 begins on September 1. The group numbers cover a 10-day span, with the sub-groups being the individual days, for instance Group 1.8 would be expected to mature on September 18$^{th}$. Overall, the regions of adaption for early-maturing cultivars (MG0-III) have not changed; however, the adapted zones for MGs IV, V and VI are much broader than previously thought. Groups VII and VIII, which dominated production areas in the South decades ago are now planted on a limited basis in the deep south (Zhang et al., 2007).

Climate change appears to have reduced crop yields in some countries (Lobell, Schlenker, and Costa-Roberts, 1980). And these effects are expected to continue (Tubiello et al., 2007). Crop management strategies could help to mitigate the potential negative impacts of climate change on crop yields (Mourtzinis et al., 2015). Strategies include the development of new cultivars and hybrids, the use of altered maturity groups, changes in planting dates, the use of cover crops, and greater management of crop residues from the previous year (Mourtzinis et al., 2015). In Mourtzinis' et al. (2015) research from 1994-2013 in May through September showed a collective US warming trend. State-specific climate-yield models based on monthly cumulative precipitation and average temperature accounted for a large amount (53-95%) of the variability in soybean yield

(Mourtzinis et al., 2015). Mourtzinis et al. estimated that soybean yield fell by around 2.2% per Celsius degree increase in temperature and precipitation combined over the study period. Crop planting dates control the yield and cropping intensity of rainfed agriculture, and modifying planting dates can be a major adaptation strategy under climate change (Zhang et. al., 2021). According to Southward et. al. (2002) planting dates must shift earlier in northern and central regions to obtain maximum yields.

According to Egli and Cornelius (2009) maximum yield (planting date with the highest yield in each experiment) varied among experiments and regions, with the Midwest having the highest average yield (44.06 bu/acre, range 32.42 to 52.95 bu/acre), followed by the Upper South (39.27 bu/acre, range 23.2 to 52.64 bu/acre), and the Deep South (37.31 bu/acre, range 21.44 to 50.56 bu/acre). The response of relative yield to delayed planting was remarkably similar across the three regions with a rapid decline in yield beginning on 30 May in the Midwest, 7 June in the Upper South and 27 May in the Deep South (Egli and Cornelius, 2009). In the Upper Midwest planting soybean 1 May compared with 15 May has increased yield to 7.35 bushels in Minnesota (Lueschen et al., 1992), and 11.02 bushels in Wisconsin (Grau et al., 1994).

Planting dates in May resulted in yield in the Midwest and Deep South, but yield declined steadily when planting was delayed after early June, (Egli and Cornelius, 2009). According to Siler and Singh (2022) planting by mid-May resulted in the greatest seed yield but was not different from seed yield in the late April plant date for three of four site-years. However, there is a potential for yield loss from planting earlier than mid-May. When planting was delayed beyond mid-May, soybean yield decreased by an average of 1.95 bu/acre per week between the mid-May and early June plant dates and by 4.85 bu/acre per week between the early June and late June plant dates (Siler and Singh, 2022).Several works suggested recently that April and early-May plantings may produce higher yields in Midwestern soybean production areas (Egli and Cornelius, 2009). Robinson et al. (2009) reported that optimum planting dates for soybean grown in Indiana are from April to early May and yields would be lower for planting before or after that critical time.

A U.S.-wide study estimated a 10% increase in yield and approximately $9 billion in monetary gains could be realized if soybean was planted at the optimal time across the United States (Mourtzinis, Specht, & Conley, 2019b).Specific knowledge of planting date responses at different locations is necessary to determine whether early planting should be a general recommendation (Bruin and Pedersen, 2008). Planting date is a management factor that we continue to push back in an effort to increase yield. Common practice is to plant in the Midwest in May, Early planting would refer to Mid-April.

Planting too early comes with risks such as seedling disease and seed rot, frost or freeze damage along with affecting growth, development, and yield. Magnitude of the response to early planting can be year (Pedersen and Laur, 2003), location (Lueschen et al., 1992), and cultivar specific (Elmore, 1990; Grau et al., 1994). Probability for spring frost does limit how early planting can occur and requires region-specific recommendations (DeBruin and Pedersen, 2008). Cool and wet soil conditions during much earlier plantings may delay the soybean seed emergence (Andales et al., 2000), reduce the canopy development and grain yield (Kane et al., 1997a; Steele and Grabau, 1997). Moreover, early planted soybean may be exposed to late spring frost (Meyer and Badaruddin, 2001) and early season insects such as bean leaf beetles (*Cerotoma trifurcata)* (Lam et al., 2001), which may also adversely affect soybean yields (Hu and Wiatrak, 2012). The probability of a killing frost event in Iowa during the spring is less than 25% after 25 April for areas south of 42-degrees latitude (south and central) and after 1 May for the area north of that latitude (DeBruin and Pedersen, 2008). Interactions between cultivar, poor early season growing conditions that limit seedling emergence and growth, and soilborne pathogens may reduce any benefit to planting earlier in the season (Grau et al., 1994).

Grain yields are generally greater from earlier planted soybean due to longer duration of vegetative and reproductive stages (Chen and Wiatrak, 2010). In Egli and Conrelius' (2009) work, an analysis of April and early-May planting dates showed an increase in yield in only 23% of the comparisons and the average increase was only 7%. According to DeBruin and Pedersen (2008) early planting consistently improved yield through an increase in seed per foot, rather than improvements in seed mass. Varying crop planting dates is a particularly effective and affordable strategy, allowing farmers to better control the weather conditions experienced by growing plants (Zhang et. al., 2021).

Delayed planting often results in shorter vegetative, and flowering/pod set periods (Egli and Cornelius, 2009), decreased seed germination, root function, crop growth rate, plant height, duration of growth stages, radiation use efficiency, and thus grain yield (Hu and Wiatrak, 2012). According to Egli and Cornelius (2009) simulations with SOYGRO suggested that declining solar radiation was a major cause of the lower yields from delayed plantings. Heatherly (2005) reported that late planting date reduced duration of both vegetative and reproductive growth stages of MG IV through VI soybean. Yield loss resulting from delayed planting ranges from ¼ bushel to more than 1 bushel per acre per day, depending on the row width, date of planting, and plant type (Lindsey et al., 2017). Weaver et al. (1991) found that the duration of seed filling (R5-R7) was reduced in later planting dates for both indeterminate and determinate soybean. Response of primary soybean yield components to planting dates and seeding rates for the Upper Midwest would be useful for identifying primary yield limitations at late planting dates (Bruin and Pedersen, 2008). Delaying planting beyond the critical time seems to produce a plant that may not have the yield potential of those from earlier plantings, and it also tends to shift reproductive growth into a less favorable environment (Egli and Cornelius, 2009), that is, lower temperatures and solar radiation and possible precipitation, thereby reducing yield (Egli and Cornelius, 2009). In Nebraska and Ohio, delayed planting after 1 May resulted in yield declines that ranged from -0.73 to -1.47 bu/day (Bastidas et al., 2008; Hankinson, Lindsey, & Culman,2015; Matcham et al., 2019). Temperature was responsible for lower yields in late plantings in simulation studies with cultivars that matured in late October and early November when temperatures were low (Egli and Bruening, 1992) and in field experiments in a low temperature environment in Argentina (Calvino et al., 2003).

**Fungicide Uses in Soybean Production**

In the North Central region there are few foliar fungal diseases that annually limit yield. Of these diseases, *Septoria glycines* and frogeye leaf spot caused by *Cercospora sojina* are the most common (Kandel et al., 2016). Foliar pathogens reduce the photosynthetic activity in infected leaves by reducing green leaf area and affecting photosynthesis in the asymptomatic area of diseases infected (Bassanezi et al., 2001). These diseases can lead to reduced yield and economic penalties.

Foliar fungicide treatment increased soybean yield at 4 out of 12 site-years with most yield responses occurring in 2015 (Ng et al., 2018) when applied at the flowering growth stage. Producers are interested in practices that could improve yield and reduce production risks (Swoboda and Pedersen, 2009), from diseases like soybean rust and frogeye leaf spot. Interest in fungicide use on soybeans has increased since 2004 when soybean rust first was confirmed in the United States (Swoboda and Pedersen, 2009). In research performed by Kyveryga et al. (2013) average soybean yield response to fungicide ranged from 1.7 to 3.7. The average yield response was 2.4 bu/acre. This is slightly higher than the breakeven yield response of approximately 2 bu/acre (Kyveryga et al., 2013). This trial was a strip trial with half treated and the other half non-treated.

Research on applications of strobilurin fungicides on various field crops has suggested that there are benefits beyond disease management (Grossman and Gunter, 1999), which may come from affecting various metabolic pathways (Koehle et al., 2002). The potential fungicidal effects on these pathways may lead to various outcomes, including increased drought tolerance and induced systemic resistance to disease (Kyveryga et al., 2013). Therefore, foliar fungicide applications are often promoted for their potential non fungicidal physiological effects or improved "plant health". The overall idea is that the preventive application of strobilurin fungicide will protect the plant from harmful foliar diseases and potential stress, both possibly resulting in greater yields (Kyveryga et al., 2013).

A survey of soybean growers during 2014 through 2016 indicated that approximately 33% of soybean fields in Ohio received foliar fungicide application (Lindsey, unpublished). Matcham et. al. (2020) found that foliar fungicides were associated with increased yield in early-planted fields in Eastern Nebraska and Ohio, and late-planted fields in Eastern Iowa. Dorrance et al (2010) noted that the preventive applications of fungicides reduced the incidence and severity of brown spot and frogeye leaf spot in Ohio. More studies are needed to determine the specific action thresholds for brown spot and frogeye leaf spot at various growth stages of soybean and the environmental conditions necessary for continuation of disease development (Dorrance et al., 2010).

**Insecticide Use in Soybean Production**

In Ohio there are several insects that can cause issues for soybean producers. Bean Leaf Beatle and Mexican Bean Beetle show up after the first of May and will be around until mid to late September. Around the middle of June Green Clover worm and Grasshoppers come on the scene and hang around through the end of August and early September. Near the end of June Japanese Beetle, Two-spotted Spider Mite ad Soybean Aphid and again they will be around until the end of August. There are pests of economic importance that should be discussed. The Soybean Aphid (*Aphis glycines* Matsumura) a native of Asia, has been in the Midwest since 2000 and has quickly become the most serious pest of soybeans in much of Indiana (Krupe et. al., 2010). Soybean aphid control is based on factors such as number per plant, growth stage, and stress factors according to Krupe et. al. (2010). Soybean Aphids can cause yield loss up to the late R5 to early R6 growth stage (Michel and Tilmon, 2021). Feeding injury due to soybean aphids can lead to yield losses of up to 40% (Joshi et. al., 2021). The economic impact can be estimated to $3.6-4.9 Billion USD every year (Hill et. al., 2012, Joshi et. al., 2021). This data supported previous studies which indicated insecticide application was economical when soybean aphids reach damaging levels in fields (Ragsdale et al., 2007). Damaging levels of Aphids is 250 aphids per plant and 80% of plants infested.

Pest interference (including disease, weeds, and insects etc.) may also influence plant growth, development, and yield (Hu and Wiatrak, 2012). Early season insects such as bean leaf beetles (BLB) (*Cerotoma trifurcata*) (Lam et al., 2001), which may also adversely affect soybean yields (Hu and Wiatrak, 2012). BLB larva feed on the root system and then the adults feed on the soybean foliage. BLB can have two generations in Ohio,

Most foliar applications of insecticide in Ohio are tank mixed with fungicide. For soybean, insecticide application is advised when defoliation levels reach 30% in pre-bloom stages, 10% in bloom, and 15% during pod fill to harvest (Laura Lindsey, Andy Michel, and Horacio Lopez-Nicora 2022). This would be over the whole plant, not just one leaf. Treatment of insecticide at the R3 soybean growth stage (late July) was too early to be effective against bean leaf beetle which generally appear during late August through early September in Ohio (Hammond et al., 2014; Ng et al., 2018).

**Tank-Mix Application of Fungicide and Insecticide in Soybean Production**

Farmers aim to minimize the number of applications in soybean since equipment tracks across emerged soybeans can cause a reduction in yield due to compaction (Hanna et al., 2007) and multiple applications result in increased fuel, labor, and application costs. Therefore, farmers may combine pesticides such as fungicides and insecticides to minimize the number of applications that occur in soybeans (Kandel et al., 2016). The economic threshold for application of fungicides and insecticides can vary quite widely as the price per bushel fluctuates between and within years (Dorrance et al., 2010). Due to the relatively low cost of foliar insecticide, farmers frequently tank-mix insecticide with fungicide (Ng et al., 2018). In Ohio, among the 33% of fields sprayed with foliar fungicide, 65% of applications were tank-mixed with foliar insecticide (Ng et al., 2018).

Despite the low cost of tank-mixing insecticide with fungicide, this practice is not recommended unless insect pests and/or leaf defoliation is at the economic threshold due to concerns of insecticide resistance and risk to beneficial insects (Hodgson et al., 2012; Nelson et al., 2016; Ng et al., 2018). Widespread fungicide and insecticide applications may eliminate beneficial insects and fungi (Nelson et al., 2016; Wise and Mueller 2011) and increase the risk of secondary problems, such as the resurgence of target pests and pesticide poisoning to humans, wildlife, honeybees, livestock etc. (Pimentel 1993). Widespread fungicide use also increases the risk of fungicide resistance development (Kandel et al., 2016).

Currently, several soybean pathogens have been reported as less sensitive or resistant to QoI (quinone outside inhibiting) fungicides in the North Central region, including *C. soling*, in Illinois and Tennessee (Zhang et al., 2012) and Mississippi (Standish et al., 2015). The causal fungus of Cercospora leaf blight (C. kikuchii) has been reported to be resistant to QoI fungicides (Price et al., 2015) indicating that resistance issues are more widespread across soybean production areas in the United States (Price et al., 2015; Standish 2015; Zeng et al., 2015; Kandel et al., 2016)

Using an integrated management approach to manage soybean foliar diseases, including planting cultivars with resistance to frogeye leaf spot, implementing crop rotation to reduce soybean residue, and scouting soybeans prior to R3 to determine if foliar diseases and insects are at levels that warrant applications (Kandel et al., 2016). Use products with mixed modes of action to reduce the speed at which fungicide resistance will develop (Kandel et al., 2016).

**Research Objectives**

States in the North Central Region collected survey data to determine the major causes of yield gap in soybeans in 2019, surveying over 9,000 fields across the north-central United States, including Ohio. Their data showed that soybean planting date is the most consistent management factor explaining the current yield gap. Delay in planting date after late April leads to a yield penalty of about 1/4 bushel per acre per day in both dryland and irrigated fields (Grassini, Rattalino Edreira and Andrade, 2019). Prophylactic use of fungicides and insecticides has recently been advocated to optimize plant health and increase yields (Henry et al., 2011). The ability to use a tank mix application of fungicide and insecticide allow for greater economic benefits. In this trial we are going to test a combination of earlier planting date, with a reduction in seeding rate and the application of foliar fungicide and insecticide. This trial will use standard management practices (SMP) of planting three weeks after the early planting date, using a standard seeding rate with no foliar applications as the control portion of the experiment. Therefore, the SMP condition is also referred to as the control condition.

Therefore, the objectives of this thesis are as follows.

Objective 1. Investigate the effectiveness of planting date and foliar pesticide applications on yield.

Objective 2. Evaluate the economic impacts on planting date and foliar pesticide applications.

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## Chapter 2:

## Combined Improved Management Practices Compared to Standard Management Practices in Soybean Production in Ohio

### Abstract

There are several studies looking at management practices. In these studies, planting date, tillage, and in-season foliar fungicide and/or insecticide were identified as explanatory causes for yield increases. In this study a combined improved management practices (CIMP) system of planting date and foliar applications of insecticide and fungicide at the R3 stage and seeding rate of 130,000 seeds/acre based on the results of Mourtzinis' survey of producer practices was used. We compared this to a standard management practices (SMP) system based on survey data of planting date at least 3 weeks later with no foliar applications and 160,000 seeds/acre. The sites were all located in the technology extrapolation domain's (TEDs) established by Rattalino Edreira et. al., according to soil, climate, and water regime. All the sites in this study were on-farm field plots. Each trial was a randomized complete block design with 3-4 replications. Each replication was planted to the width of three passes of the producer's equipment and at least 300 feet long. Out of the 25 locations, only four of the CIMP plots had a higher stand count than the control. There are three locations that showed a statistical partial economic return difference when using the CIMP system, which were \$253.16, \$158.57, and \$113.39 larger return per acre when compared to the SMP. There were two plots that showed a statistical difference in yield at 20 bu/acre and 12 bu/acre more than the SMP system. Even with limited statistically significant differences, the trend in the data shows that the CIMP system does show benefits over the SMP system in yield and partial economic return in good growing conditions. Despite the lack of statistically significant differences, the

practical benefits of a lower seeding rate, larger planting window, and protection from potential crop diseases afforded by the CIMP management support the recommendation for use of this system over standard practices.

## Introduction

There are 7.9 billion people on the planet as of January 1, 2023 (US Census Bureau, 2023), with a growth rate of 1 percent per year according to Roser et al. (2013). It has been said that agricultural production would need to increase in order to be able to feed the growing population (Pilbeam, 2015). Agriculture has become more efficient, and production has increased, but not at a rate that food production can keep up with the rate of population growth. The need is to grow more food on less land than ever before. There is promise in this thought. Between 1960 and today, world population more than doubled, global food production more than tripled, and agriculture land use increased by less than 15 percent (OECD, 2021) Average crop yields will need to increase substantially during the next 33 years to meet expected food demand increase while avoiding massive expansion of cropland area (Mourtzinis et. al., 2018).

Yield potential is the genetic potential of a crop to produce maximum yields in a certain growing environment while farm yield is the actual amount of yield obtained with normal management practices (Rattalino Edreira et. al., 2017). There are four major constraints to closing the yield gap which are: sowing date, tillage, drainage, and in-season foliar fungicide and/or insecticide applications. The data suggest that planting date and in-season foliar fungicide and/or insecticide are the largest contributing factors for Ohio (Conley et. al., 2019). The yield gap of a crop grown in a certain location and cropping system is defined as the difference between the yield under potential conditions and the average yield achieved by farmers (Ittersum et al., 2013). Management practices can be used to reduce the size of the yield gap (Rattalino Edreira et al., 2017).

Closing the yield gap is integral to finding ways to produce enough food to feed the growing population. There are several studies looking at management practices. These studies have focused on individual management strategies over broader geographical locations. However, focus on individual geographical areas and their requirements and specific management practices allows for larger producer yields and smaller yield-gaps. Thus, in Ohio, earlier planting dates combined with the use of in-season foliar fungicide and insecticide and a reduced seeding rate may improve soybean yield compared to the standard planting date and no use of foliar fungicide and insecticide products and a standard seeding rate.

According to NOAA's Ohio State summary, annual average temperature in Ohio has risen more than 1.5° F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. Extreme heat is a concern for Ohio agriculture because plants in the region are very vulnerable to extreme weather. The ideal temperature for soybean growth is 85°F. When temperatures exceed this threshold, you can see accelerated maturity and early flowering (Vann, 2020). Vann (2020) states that heat stress has the most adverse impact on soybeans in the R5 growth stage. Getting the soybean in the ground earlier in the year may help to prevent some of the negative effects of the annual average temperature. Although annual precipitation projections are uncertain, winter and spring precipitation is projected to increase. In addition, extreme precipitation is projected to increase, potentially causing more frequent and intense floods. Heavier precipitation and higher temperatures increase the risk of springtime flooding, posing a threat to Ohio's agricultural industry by delaying planting and resulting in a loss of yield (Frankson et. al., 2022). Wet springs can also lead to increased foliar disease in soybean production (Matcham et. al., 2020). In any one year, yield potential can be reduced by several soybean diseases that can infect the crop. Growing conditions are an important factor when considering planting date. With spring weather becoming more wet and making it more difficult for producers to get into the field to plant, we need to evaluate if earlier planting is possible given the need to take advantage of good field conditions versus good planting conditions.

Soybeans are typically planted in Ohio after April 15th, or when soil conditions are suitable (soil temperatures reach 50 degrees Fahrenheit and moisture is present at seed depth) (Ohio Agronomy Guide, 2017). Timely planting of soybeans is extremely important to maximize seed yield in the north-central United States (Matcham et al., 2020). Early planted soybeans may reach V1 growth stage earlier in the season resulting in an earlier flowering date, and potentially a longer growing season. Earlier flowering in turn increases the length of the seed-fill period (Elmore et. al., 2014). And this in turn can lead to larger yields. Planting dates have shifted in the last 34 years to earlier dates at a rate of 0.5 day per year (Ciampitti et al., 2016). The change in planting date may be attributable to changes in genetics (e.g., improved germination and cold tolerance of modern soybean varieties); environmental conditions (e.g., warmer temperatures in spring); and management practices (e.g., tillage system, rotation, fertility, inoculation, and machinery) (Ciampitti et al., 2016).

When soybeans are planted in May, a final (harvest) population of 100,000 to 120,000 plants/acre is generally adequate for maximum yield. Final soybean population depends on germination, emergence, disease and insect pressure, competition from other plants, etc. (Ohio Agronomy Guide, 2017). In most situations, 140,000 seeds per acre should result in at least 100,000 plants/acre at harvest (Lindsey et al., 2018). For the first half of June, seeding rate should be between 150,000 to 180,000 seeds/acre. For the second half of June, increase seeding rate to 170,000 to 200,000 seeds/acre (Colet and Lindsey, 2023). In the CIMP system we used a seeding rate of 130,000 seeds per acre which can reduce cost.

Most producers in Ohio apply foliar insecticides in a mixed application with foliar fungicides (Lindsey, Michel, and Lopez-Nicora, 2022). This is to reduce the cost of application and reduce the effects on soil compaction that comes with multiple trips across the field. The economic threshold for application of fungicides and insecticides can vary quite widely as the price per bushel fluctuates between and within years (Dorrance et al., 2010). Matcham et al. (2020) found that foliar fungicides were associated with increased yield in early planted fields in Eastern Nebraska and Ohio, and late-planted fields in Eastern Iowa. Dorrance et al (2010) noted that the preventive applications of fungicides reduced the incidence and severity of brown spot and frogeye leaf spot in Ohio. More studies are needed to determine the specific action thresholds for brown spot and frogeye leaf spot at various growth stages of soybean and the environmental conditions necessary for continuation of disease development (Dorrance et al., 2010). Planting date, tillage, and in-season foliar fungicide and/or insecticide were identified as explanatory causes for yield variation, with planting date the most consistent management factor that influenced soybean yield (Rattalino Edreira et.al., 2017). Schmitz and Kandal (2021) found that when stacking management practices there are some synergistic effects that could improve yield. This study chose to use planting date and foliar applications of insecticide and fungicide at the R3 stage based on the results of Mourtzinis (2018) survey results of producer practices.

The objective of this research was to study the effect of the combination of three specific management practices, early planting combined with a lower seeding rate and the use of foliar fungicide and insecticide in a mixed application compared to not using these practices on soybean yield and partial economic return. The region used in this research was taken from the US North Central Region previously evaluated by Moutzinis et. al. (2018). This study has addressed the following question. Will improved management practices reduce the yield gap in soybeans compared to standard management practice and result in an increased partial economic return for farmers?

## Materials and Methods

### Site Description and Cultural Practices

From 2019 to 2021, a study was conducted across Ohio examining planting date of soybeans with in-season foliar treatments of fungicide and insecticide with a reduced seeding rate. The sites were all located in the technology extrapolation domain's (TEDs) established by Rattalino Edreira et. al. (2017) according to soil, climate, and water regime. All of Ohio fell into the same TED. All the sites in this study were on-farm field plots, and therefore had management practices that varied beyond what was manipulated in this study. Self-reported on-farm management practices and pre-planted soil parameters that differed across plots are provided in Table 1 for descriptive purposes. Table 2 shows the seed and pesticide commercial names and varieties used by each producer annually.

The study had two treatments: 1) combined improved management practices (CIMP) and 2) standard management practices. The CIMP system included an early planting date, with a foliar fungicide and insecticide application at the R3 growth stage with an intermediate seeding rate of approximately 130,000 seeds per acre. The standard management practice was planted at least 3 weeks after the improved one with no foliar application and a seeding rate of 160,000 seeds per acre. Each trial consisted of a randomized complete block design with 3-4 replications of each treatment depending on the location. Each replication was planted to the width of three passes of the producer's equipment and was a minimum of 300 feet long. Figure1 shows the relative locations of each research plot across Ohio. Figure 2 shows the field layout for the research plots.

Each replication had three passes with the planter to allow for a clean single pass with the harvesting equipment down the middle of the replication (Fig. 2).

**Field Measurements**

The soil samples were collected using a probe at 6-8 inches deep in each field area. The cores were pulled from each plot using a "w" pattern of 15 cores in each section. Table 1 shows the soil test results for each location and year. Fertilization was performed following the recommendations of the Ohio State University Extension (Culman et al., 2020).

Soybean stand counts were taken during the V2-V3 soybean growth stage (Ferh, 1971) and calculated by counting seedlings at 3 locations per test strip. The counts were done at the front, middle, and back of each strip. To obtain the counts, researchers counted plants on each side of the row for 17.5 feet in a 15-inch row and then multiplied by 1000 to get plants/acre.

Percent emergence was calculated by first using the stand count to determine the ratio of plants to seeding rate. The stand count was then divided by the seeding rate and the product multiplied by 100 to convert this value to a percentage.

Plots were harvested by taking a central section from each strip. The size of the harvested swath was dependent upon the producer's equipment. The yield data were taken from the combine yield monitors or weigh wagons used by each producer. Harvest date and equipment varied from producer to producer. Grain yield was adjusted to a standard 13% moisture.

**Partial Economic Return**

In order to examine whether there was a difference in the economic impact of using the combined improved management practice versus the standard cropping method, economic Impact was measured by calculating the partial return of soybean production. To determine partial return the following equation was used:

$$Partial\ Return = Gross\ Return - Costs$$

Gross return was calculated using yield multiplied by soybean price of $13.30/ per bushel, from the Ward 2023 enterprise budget). Partial return was calculated by subtracting costs from gross returns.  For the calculation of costs for each system, only expenses that varied across production systems were considered (Lindsey et. al., 2020). Cost values came from Ward's 2022 Custom Rates Survey (Table 3). The cost for the control system was comprised entirely of the seed cost ($0.435/1000 seeds). The CIMP system also included seed cost but due to a lower seeding rate and therefore a lower cost for seed/acre ($18.65/acre less than SMP). This system also included costs for foliar treatments and application. These costs were determined by using the 2022 Ohio Farm Custom rates per acre for fungicide ($10), insecticide price ($3), application cost ($8.40), and seed cost ($0.435/1000 seeds).

**Statistical Procedures**

Data were analyzed using SAS 9.4 (SAS Analytical Systems, Cary, North Carolina). A series of mixed model ANOVAs for stand count, yield, and partial economic return were conducted with condition (CIMP verses Control) as the fixed factor and replications as a random factor. Analyses were performed for the treatment effect overall as well as for individual plots using $\alpha = 0.05$. Results with a p-value less than or equal 0.05 were therefore considered statistically significant. Additionally, a descriptive analysis for percent emergence was performed. Refer to the Appendix for output of abbreviated statistical results of the ANOVAs.

## Results and Discussion

**Effects of Combined Improved Management Systems on Stand Counts, Percentage of Emergence, and Seeding Rate**

Planting date affected the seeding rate. The later in the year that planting is delayed the higher the seeding rate will need to be to get an economically viable yield. According to the Ohio Agronomy Guide (2017), the final harvest stand is usually 60-80 percent of the seeding rate. Final populations of mid-June plantings should have a harvest population in the range of 130,000 to 150,000 plants/acre. Final populations for early July plantings should be greater than 180,000 plants/acre. It is important to remember that the CIMP plots had an earlier plant date and therefore a lower seeding rate of 130,000 seeds/acre compared to the Control plots that were planted three weeks later and a corresponding seeding rate of 160,000 seeds/acre.

Although seeding rates were greater in the SMP compared to the CIMP system, emergence averages showed that the percentage emergence in plants/acre were similar across both conditions (Fig. 5). Figure 6 shows that both the CIMP and the SMP systems had a stand count that ranged from 90,000 to 145,000 plants/acre and produced a yield of 40-80 bu/acre. This finding shows that despite the lower seeding rate in the CIMP system, the stand count produced an economically viable yield comparable to the SMP system. When examining the emergence by year it can be seen that in 2019 and 2020 the control showed a higher percentage of emergence than the CIMP system by 1% and 4% respectively, and in 2021 the CIMP had a higher percentage by 6% but none of these were statistically significant. The study total showed no difference in percentage emergence at 73% average emergence in both conditions (Fig. 11).

The evaluation of stand count showed an expected outcome of a lower stand count in the CIMP plots than in the SMP condition. On average the control had 22 more plants/acre than the CIMP and this difference was statistically significant. Figure 4 shows this overall difference (from the statistical analysis) as well as the means of stand count (plants/acre) by year for descriptive purposes. The stand count difference by year were 6, 28, and 30 plants/acre per year for 2019, 2020, and 2021 respectively. A descriptive analysis that further breaks down stand count by year and plot showed that out of the 25 locations, only four of the CIMP plots had a larger stand count than the control (Fig. 3). The stand count differences could be due to weather conditions that caused the control plots to have a reduced stand count (Table 1). It can be seen that two producers reported drought conditions after planting the control system affecting this condition more than the CIMP system due to that condition's advanced growth stage which is more tolerant of drought conditions. Pirasteh et. al. (2011) found that drought stress during the imbibition phase of germination is the primary reason for both inhibition or delayed seed germination and seedling establishment. In the current experiment the CIMP was not likely affected by drought in that location as it was planted three weeks earlier than the control and therefore still had moisture in the soil, whereas the control experienced dry conditions during planting. Another weather condition experienced during this study was a snow event. Specifically, plot H21 experienced four inches of snow (before the SMP sections were planted) reducing the stand count of the CIMP.

In regard to the planting date, Figure 7 shows that the yield of the plots planted in April (earlier planting) did not significantly differ from the plots planted in June (later planting). However, as noted earlier, the later planted soybeans had a higher seeding rate. This similar yield despite differences in seeding rate lends support to the guidelines provided in the Ohio Agronomy Guide that a target population should be between 100,000-120,000 plants/acre for crops planted before May 20. Stand counts from June 1 through June 15 should be in the range of 130,000-50,000 plants/acre according to the Ohio Agronomy Guide.

**Effects of Combined Improved Management Systems on Soybean Yield**

This evaluation of soybean planting date has shown that you can plant earlier in April and still get good yields. The CIMP plantings showed no significant difference from the SMP plantings in yield produced. This means that producers have a larger window of opportunity to plant soybeans in the spring without a yield penalty. Although our data did not show a statistical improvement in yield by using an improved system, we did conclude that soybeans can be planted earlier in April than previously believed. In the yield comparisons of year 1 of this research trial, we had two locations show a statistical difference in the yield, and both of those locations had a statistical difference in stand count as well (Fig. 8). The yield differences in the plots that had a statistical difference were at 20 bushels and 12 bu/acre more than the control.

There was a total of 13 out of 22 fields (59.1%) that showed a yield response to the CIMP system; however, this difference was not statistically different. In 2019 there were 5 fields (22.3%) that showed an increase over the standard system. On average in 2019 there was a 7.4 bushel per acre benefit. In 2020 there were 6 fields (27.3%) that showed an improved yield. 2020 had an average of 4.2 bu/acre improved yield over the standard practices. In 2021 the CIMP treatment also showed an increase in 2 fields (9.1%) at 1 bushel per acre. There was an overall yield increase of 4.9 bu/acre using the CIMP system when compared to the standard system with a range from 1 to 20 bu/acre. The range of 1.0 to 7.4 bu/acre yield advantage of the CIMP treatment is slightly greater than other studies. For example, Conley et. al. (2022) found the improved management treatment netted soybean producers an average that ranged from 3.2 to 5.5 bu/acre yield increase in a three-year study. However, the current findings for the overall average of 4.2 bu/acre yield increase (average over three years) is consistent with Conley et. al. at (2022) 4.1 bu/acre. Michigan State University Extension performed a similar research trial and received similar results of average yield increases of 2.6, 1.2, and 3.4 bu/acre from 2019 through 2021.

However, stand count statistical difference did not necessarily indicate a statistical difference in yield. You can see in plot D19 in Figure 8, stand count had a statistical difference but had no yield difference. In plot Ha19 in Figure 8, there was a statistical difference in both yield and stand, however, the control stand had a much higher stand count and a lower yield. Figure 8 also shows that plot C19 had a statistical difference in stand, but the yield was only one bushel different. The data analysis showed there is not a significant correlation between yield and stand count. Lee, Egli, and Tekrony (2008) also found that soybean yield is relatively insensitive to plant population with a wide range in seeding rates usually producing the same yield. The results of the current study are therefore consistent with prior research; stand counts have little correlation with yield.

Yield and stand count gave us results that we expected to find and align with the Ohio Agronomy Guide recommendations for crops planted before May 20 in narrow rows, final populations of 100,000 to 120,000 plants/acre are generally adequate (Ohio Agronomy Guide, 15$^{th}$ Edition). Figure 6 shows that as the stand count approaches 100,000 up to 140,000 plants/acre the yield clusters between 40 and 80 bu/acre, showing less risk than populations lower than 100,000 plants/acre and populations above 140,000 plants/acre did not necessarily return a more economically higher yield. Studies throughout the Midwest have pointed toward lower seeding rates because lower stand counts can potentially achieve similar yields and provide a higher return on investment (De Bruin and Pedersen, 2008; Epler and Staggenborg, 2008; Lee et al., 2008; Gasper, Mitchell, and Conley, 2015).

The earliest planted fields did see a slightly lower yield, but as we passed April 10$^{th}$ the yield was between 40 and 80 bushels through the first week in June. However, there was a slight drop in yield after June 4$^{th}$ (Fig. 9). This demonstrates that early planting may not necessarily give a higher yield, but it opens a larger window of opportunity to get the seed in the ground. Planting soybeans early can help producers increase yields, extend the planting window, and reduce soil erosion and sedimentation (Stanton, 2011). Crop Insurance has also adjusted their replant date, allowing producers in Midwest Ohio to get into the field a full 9 days earlier than before, going from April 24$^{th}$ to April 15$^{th}$.

Between April 18$^{th}$ and June 4$^{th}$ (Fig. 9) we have consistent yields, After June 4$^{th}$ there is a drop in yield. Yield reduction as a result of late planting ranges from 0.25 to 1 bushel/acre/day depending on row width, date of planting, and variety (Lindsey, 2017). The earlier planted soybeans can also experience yield reductions due to weather events such as frost and freezing temperatures. This research leads to the conclusion that the opportunity to plant earlier in Ohio can lead to sufficient yields for producers even with lower emergence and stand counts.

**Effects of Combined Improved Management Practices on Partial Economic Return**

The partial return across the full study for the combined improved management practices ($M$=\$801.87 per acre) did not statistically differ from the partial return using the standard cropping method ($M$=\$779.72 per acre), $p = .16$. The overall study showed that the CIMP partial return was \$21 higher than the control. When evaluating the cost of the treatments the CIMP total cost was \$77.95, and the control was \$96.60. This included the foliar treatments and application cost for the CIMP system. The economic values per year of this study showed two years that the CIMP was more profitable at circa \$62 and \$26 per acre (Fig. 11).

There were 4 locations that showed significant economic differences (Fig. 10). In one of those fields the control was more profitable than the CIMP. When looking at the individual plots there is a larger partial economic return on 12 of the plots ranging from \$2.82 through \$253.16.

There are 3 locations that showed a statistical difference when using the CIMP system, they were \$253.16, \$158.57, and \$113.39 larger return when compared to the standard system. The fields during 2020 showed a large portion with higher partial economic returns than the standard system (Fig. 17). It appeared that the financial risk for planting date, using both the CIMP system and the control, was small across all plots. The planting date from April 18$^{th}$ through June 4$^{th}$ had little variation (Fig. 7). Singh and Siler (2022) found that maximum net income was achievable using lower seeding rates for all planting dates from mid-April through late-June.

This leads to the conclusion that if you can plant after April 18$^{th}$ the economic risk may be low. The planting dates for this study had a range for the CIMP of April 6$^{th}$ through May 25$^{th}$, the Standard planting date ranged from May 9$^{th}$ through June 28$^{th}$. Extremely Early planting dates may cause yield reductions (Lindsey, 2018), but those extremes were not tested in this study. From this data I have concluded that CIMP and Control practices showing relatively similar partial economic returns allows for a wider planting window and added benefits to farmers to plant when conditions are good for planting.

While planting date has consistently been shown to be a primary factor in accounting for yield differences with early planting dates showing a yield advantage, the findings for the effect of foliar application of fungicide and/or insecticide and partial economic return, on the other hand, have produced mixed results. Researchers have posited that these applications only provide a yield and economic advantage when threat conditions exceed a certain threshold (determined by prior research). Agronomists have developed models to predict the main threats to crops in a given year to help determine the risk of fungus and insects to soybean and other plants. The management practice of combing an earlier planting date with application of a foliar fungicide and insecticide was based on the findings of the Mourtzinis et al. (2018) study which identified early planting and in-season foliar fungicide and/or insecticide application as two of the main factors that accounted for variation in yield. A key difference between the current study and the Mourtzinis et al. study that served as the foundation for the current research is that the reference study used survey data whereas the current study was experimental. The decision to use a foliar fungicide and/or insecticide application was made by the producers in the Mourtzinis study. In the current study, producers grew soybean crops under both the CIMP and SMP conditions; all producers grew their crops under both conditions. A possible reason for the lack of a statistically significant difference in yield and partial economic return between conditions in the current study that were found in the references study is the role of the producers. Specially, experienced growers are likely to forego the expense of the foliar applications when perceived risk of threat to the crops is low. In other words, their use of the applications was likely based on the need whereas in the current study it was assigned to all producers regardless or risk/threat. Future research should examine the decision to use or forego such applications as a function of producer experience.

This study also combined seeding rate, planting date, and use of a fungicide/insecticide tank mix (i.e., spray) at the R3 growth stage into a single factor that comprised the experimental condition. It was therefore not possible to assess unique interaction effects of these variables on crop yield and partial economic return. Similarly, prior research has shown the effects of seeding rate, planting date, and use of a fungicide/insecticide tank mix independently but has yet to experimentally examine the interactive effects of these factors. Future experimental studies that manipulate these three variables separately would allow researchers to assess if there are unique combinations that maximize yield and profit for producers. For example, such research could be conducted to determine if early planting with less seed but without sprays could result in an partial economic return similar to the CIMP condition or standard practices or whether it would result in a decrease in yield due to crop loss from fungal and insect threats.

This study did not look at ultra-early planting dates. Planting too early may be a detriment to both yield and partial economic return. A Michigan State University Extension Study by Singh and Siler (2022) reported significant yield loss from ultra-early planting (April 8), indicating potential risks associated with such plantings. More research should be pursued to determine the earliest date that soybeans can thrive.

## Conclusion

The effects of the combined improved management practices did not statistically differ from the control practices in the study as a whole. However, there were individual fields that showed a statistically significant difference in each of the areas that were observed with the majority favoring the CIMP system. Similarly, the overall trend in the data showed higher yield and partial economic return in the CIMP system when compared to the SMP system. The yield measurements showed statistical difference in three locations. When evaluating the partial economic return, there was no significant difference between the CIMP and the control practices for the whole study. Some plots showed significantly higher net return, three in the CIMP system and one in the standard system.

Although not all plots showed a statistically significant difference on the dependent measures, there were several that showed higher return with the CIMP system than the Control: 13 plots in the yield and 12 in partial economic return. The research has shown that given an opportunity to plant in early April when you have good field conditions, it might be a good time to do so If planting is delayed until late into the spring soybeans have shown a yield penalty of

0.25 up to 1 bushel per acre per day (Lindsey, 2018). This research did show that the savings from a lower seeding rate covered the costs of foliar applications during the years of this study, However, Soybean seed cost and foliar application costs do fluctuate every year. The data from this research suggests that planting soybeans early with foliar fungicide and insecticide in a tank-mix can still produce a profitable crop even when limited by stand damage due to weather conditions such as snow and drought. This is important because of the climatic shifts in Ohio that have made spring rains more abundant and summer heat more extreme.

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## List of Tables

## List of Figures

# Tables

**Table 1**. On-Farm Management Practices and Pre-Planted Soil Parameters by Plot

| Field name | Maturity Group | Drainage | Tillage | Row Spacing | Previous crop | Soil parameters pH | P | K | OM |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *inch* | | | --- *ppm* | --- | *%* |
| C19[1] | 3.4 | Yes | No-till | 15 | Corn | 6.1 | 27 | 122 | 3.0 |
| D19[2] | 3.6 | Yes | Vertical | 15 | Corn | - | - | - | - |
| Du19 | 2.4 | No | No-till | 15 | Corn | 6.4 | 56 | 126 | 2.3 |
| Ha19 | 3.6 | Yes | No-till | 15 | Corn | 7.1 | 42 | 147 | 2.5 |
| L19 | 3.8 | Yes | Vertical | 15 | Corn | 6.2 | 75 | 182 | 1.7 |
| LV19[3] | 3.6 | Yes | Disk, Vertical | 15 | Corn | 6.3 | 22 | 85 | 3.1 |
| Mu19 | - | - | - | 7.5 | Corn | 6.6 | 51 | 137 | 2.6 |
| A20[4] | 3.1 | Yes | No-till | 15 | Corn | 6.6 | 20 | 105 | 3.6 |
| B20[5] | 3.4 | Yes | No-till | 15 | Corn | 6.8 | 19 | 122 | 2.8 |
| D20 | 3.6 | Yes | Vertical | 15 | Corn | 7.1 | 24 | 132 | 4.0 |
| He20 | 3.6 | No | | 15 | Prevent Plant | 6.9 | 27 | 127 | 3.3 |
| Mc20 | 3.6 | No | vertical | 30 | Soybean | 6.4 | 26 | 114 | 3.7 |
| Mo20 | 3.3 | - | DR/SF | 15 | Prevent Plant | 6.8 | 52 | 143 | 3.2 |
| Mu20[6] | 2.8 | No | No-till | 15 | Corn | 6.2 | 57 | 149 | 2.8 |
| O20 | 3.9 | No | No-till | 15 | Soybean | 5.3 | 46 | 135 | 3.2 |
| St20 | 2.7 | Yes | No-till | 15 | Corn | 7.4 | 64 | 129 | 2.9 |
| A21 | 3.1 | Yes | No-till | 15 | Corn | 6.1 | 30 | 68 | 2.3 |
| B21 | 3.3 | Yes | No-till | 15 | Corn | 6.8 | 19 | 101 | 2.4 |
| H21[7] | - | No | No-till | 15 | Corn | 6.7 | 46 | 140 | 2.4 |
| L21 | 3.1 | No | No-till | 15 | Soybean | 6.6 | 80 | 234 | 2.7 |
| M21 | 2.8 | Yes | No-till | 15 | Corn | 6.1 | 30 | 131 | 2.7 |
| O21 | 3.0 | Yes | No-till | 15 | Corn | 6.7 | 24 | 95 | 2.2 |
| S21 | 3.5 | Yes | No-till | 15 | Corn | 7.4 | 50 | 147 | 3.0 |
| Bo21 | 3.6 | Yes | No-till | 15 | Corn | 6.1 | 83 | 128 | 2.9 |

[1] Wet Early/Dry late
[2] Drought- July through September
[3] August 12 to harvest less than 2 inches of rain
[4] No rainfall in august
[5] Sudden Death
[6] Frost on early planted
[7] Snow and Frost on Early planted Stand

**Table 2**. Seed and Pesticide Commercial Names and Varieties Used by Each Plot Annually

| Plot | Seed Brand | Seed Variety | Insecticide | Fungicide |
|---|---|---|---|---|
| C19 | Pioneer | P36T36x | Fastac | Priaxor |
| D19 | Asgrow | AG36X6 | - | - |
| Du19 | Hubner | 24-38R2X | Fastac | Priaxor |
| Ha19 | Pioneer | P36T36X | Fastac | Priaxor |
| L19 | Pioneer | 38A98X | Fastac | Priaxor |
| LV19 | Becks | 3682FP | Fastac | Priaxor |
| Mu19 | - | - | - | - |
| A20 | Pioneer | 31A22Y | - | - |
| B20 | Pioneer | 34A24 | - | - |
| D20 | Pioneer | P36A83X | - | - |
| He20 | BA Genetics | BA36EN0 | Lambda | Gold Rush |
| Mc20 | Stine | 36EA02 | Fastac | Priaxor |
| Mo20 | Pioneer | P33A24X | - | - |
| Mu20 | Seed Consultants | SCS7280E | - | - |
| O20 | Becks | 3992FP | - | - |
| St20 | Golden Harvest | GH2727LG | Swager | TriviaPro |
| A21 | Pioneer | 31A95BX | - | - |
| B21 | Pioneer | P33A24 Xtend | Delta Gold | Delaro |
| H21 | - | - | - | - |
| L21 | Pioneer | B31T64E | - | - |
| M21 | Pioneer | P28A47 | Warrior | Priaxor |
| O21 | Becks | 3082FP | - | - |
| S21 | Golden Harvest | 3582E3 | - | Miravis Neo |
| Bo21 | Pro Harvest | 31A95BX | - | - |

*Note*. A "-" indicates product names and/or varieties were not provided by the producer.

**Table 3**. Costs ($/acre) of Combined Improved Management Practices (CIMP) and Standard Management Practices (Control)

| **Management Practice** | **CIMP ($)** | **Control ($)** |
|---|---|---|
| | *$/acre* | *$/acre* |
| Seeding Rate (0.435 per 1000) | 56.55 | 96.60 |
| Foliar Fungicide | 10.00 | - |
| Foliar Insecticide | 3.00 | - |
| Foliar Application | 8.40 | - |
| **Total Expense** | **77.95** | **96.60** |

**Table 4**. Plots with a Greater Positive Economic Return of Combined Improved Management Practices (CIMP) Verses Control Practices

| Plot | Positive Economic Return using CIMP System (CIMP-Control Difference) |
|---|---|
| | *$/acre* |
| D19 | 40.13 |
| *Ha19 | 113.39 |
| L19 | 43.18 |
| *Lv19 | 253.16 |
| A20 | 27.35 |
| D20 | 56.98 |
| He20 | 39.27 |
| Mc20 | 31.78 |
| Mo20 | 9.35 |
| O20 | 2.82 |
| *St20 | 158.57 |
| A21 | 9.62 |
| **Average Improvement** | **65.47** |

* $p \leq .05$ for CIMP-Control Difference

**Table 5.** Condition by Plot Means and Differences (Combined Improved Management Practices (CIMP)-Control) in Yield (bu/acre)

| Plot | CIMP | Control | Difference (CIMP-Control) |
|---|---|---|---|
| | | *bu/acre* | |
| C19 | 54 | 53 | 1 |
| D19 | 54 | 50 | 4 |
| Du19 | 62 | 67 | -5 |
| Ha19 | 57 | 48 | 9 |
| L19 | 60 | 56 | 4 |
| Lv19 | 74 | 54 | 20 |
| A20 | 58 | 55 | 3 |
| B20 | 56 | 59 | -3 |
| D20 | 69 | 64 | 5 |
| He20 | 62 | 59 | 3 |
| Mc20 | 64 | 67 | -3 |
| Mo20 | 97 | 96 | 1 |
| Mu20 | 47 | 49 | -2 |
| O20 | 66 | 65 | 1 |
| St20 | 78 | 66 | 12 |
| A21 | 70 | 68 | 2 |
| B21 | 58 | 61 | -3 |
| H21 | 76 | 78 | -2 |
| L21 | 60 | 59 | 1 |
| M21 | 76 | 84 | -8 |
| O21 | 68 | 69 | -1 |
| S21 | 68 | 67 | 1 |

**Figures**

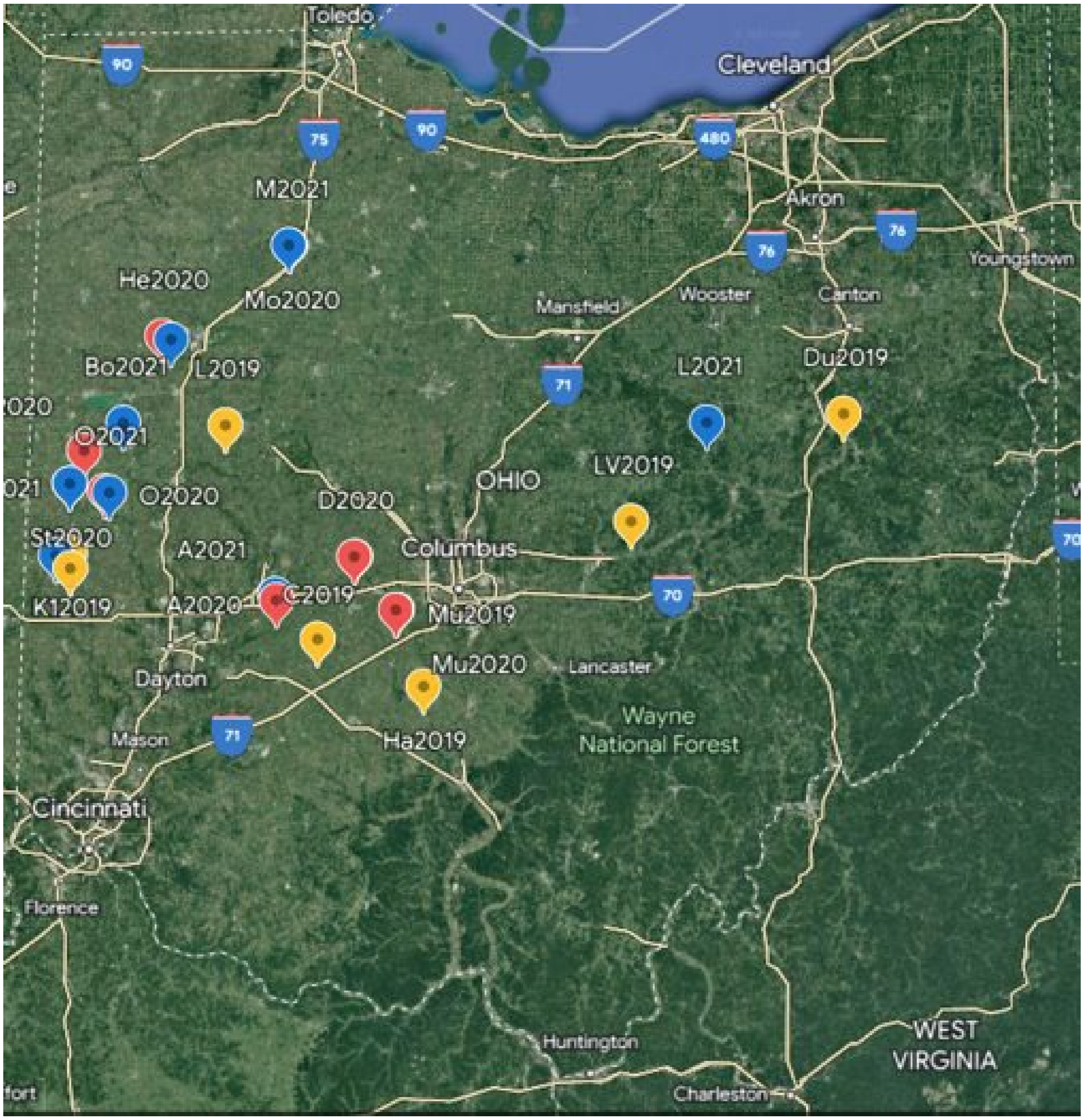



**Figure 1**. Map of Research Farm Locations Across Ohio

*Note.* Yellow pins indicate farms in 2019; red pins indicate farms in 2020; blue pins indicate farms in 2021.

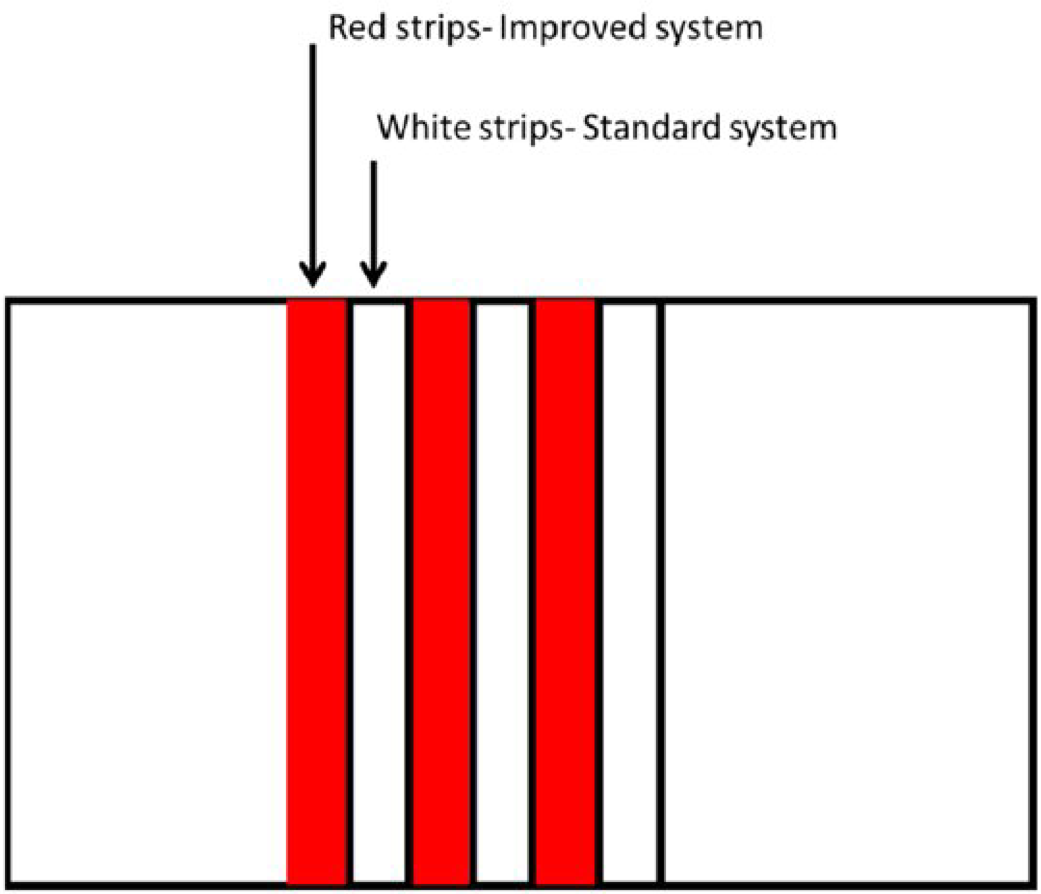



**Figure 2.** Research Field Layout for Combined Improved Management System (CIMP) and the Standard Management Practices (Control) Strips in Each On-Farm Trial Used in this Study

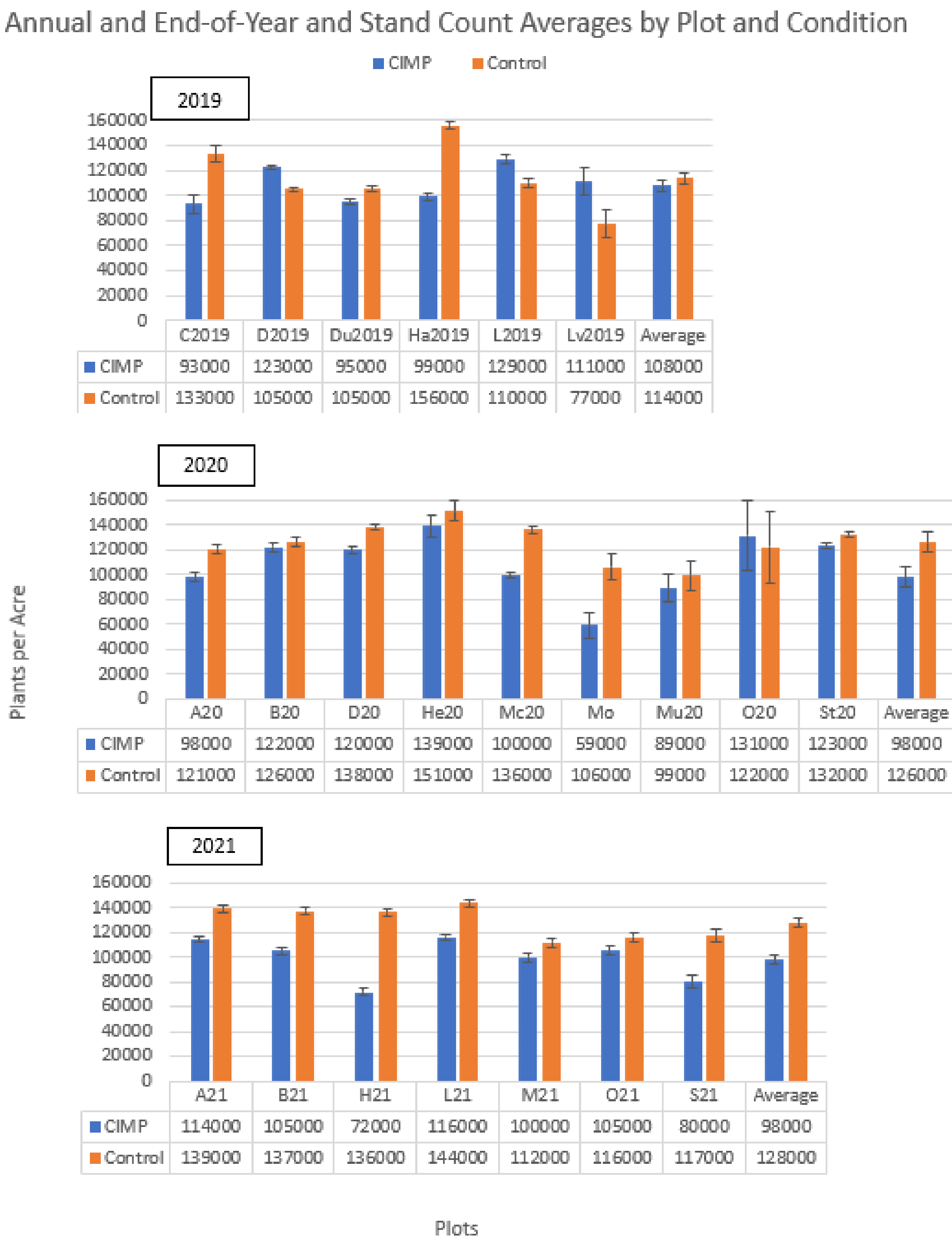



**Figure 3**. Annual End of Year and Overall Stand Count (plants/acre) Averages by Plot and Condition

*Note*. CIMP = combined improved management practices, error bars are standard error of the mean

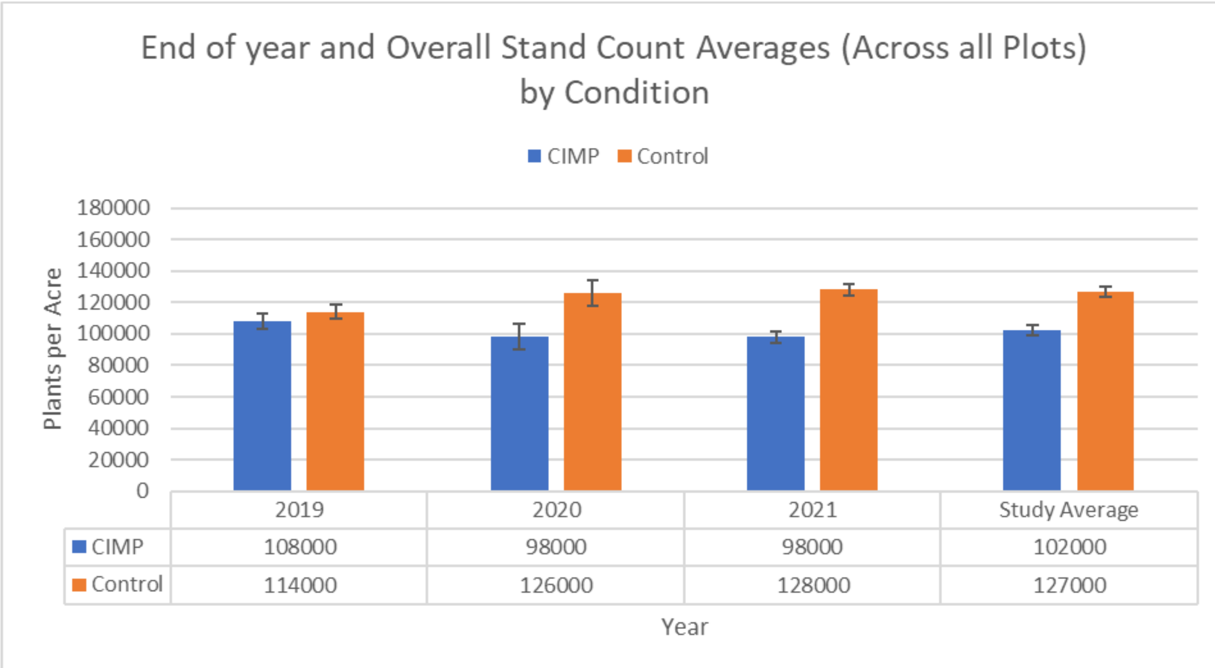



**Figure 4.** End-of-Year Stand Count (plants/acre) Averages and Overall Study Average by Condition

*Note.* CIMP = combined improved management practices, error bars are standard error of the mean

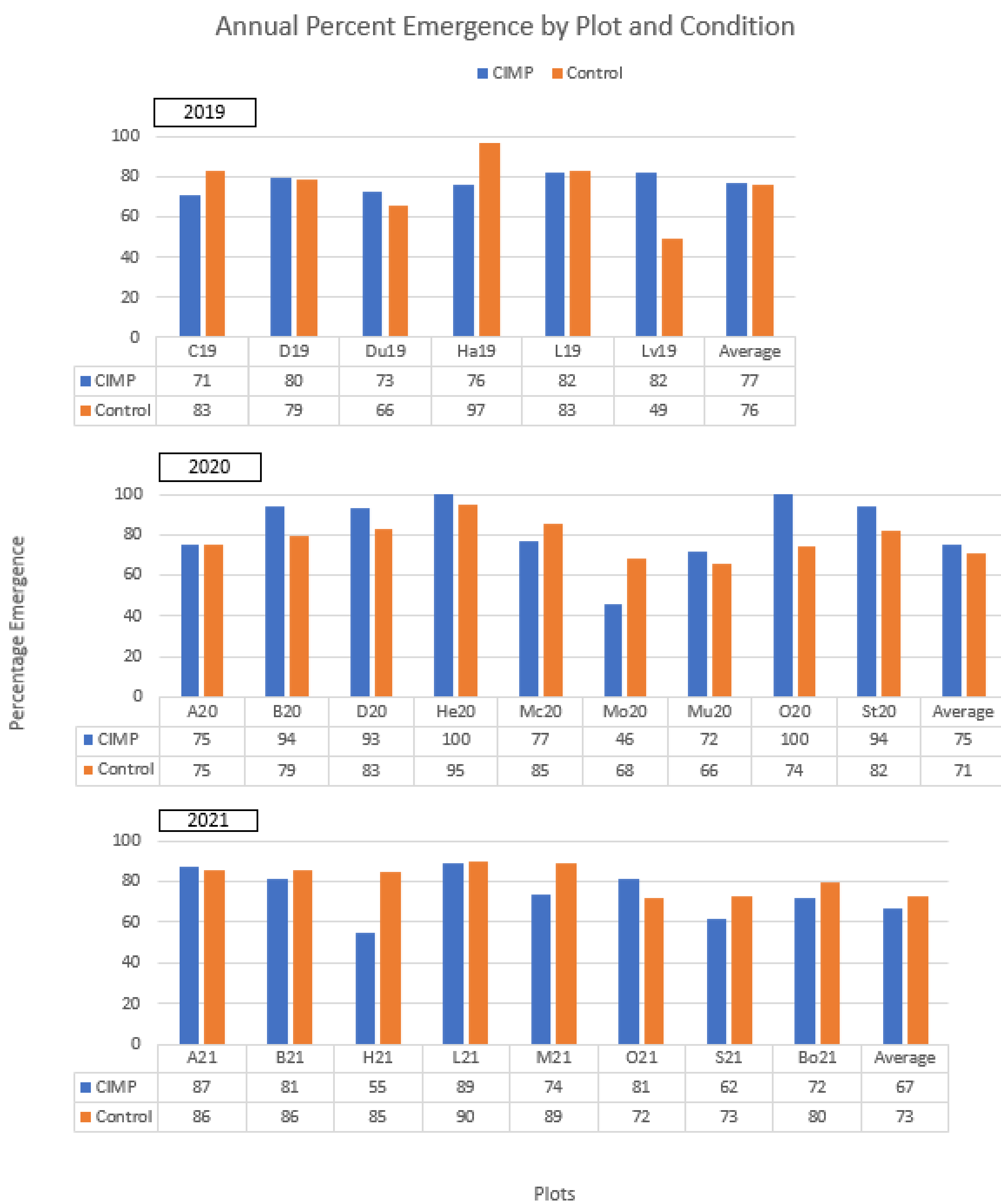



**Figure 5.** Annual Percent Emergence (%) by Plot and Condition

*Note.* CIMP – combined improved management practices, error bars are standard error of the mean

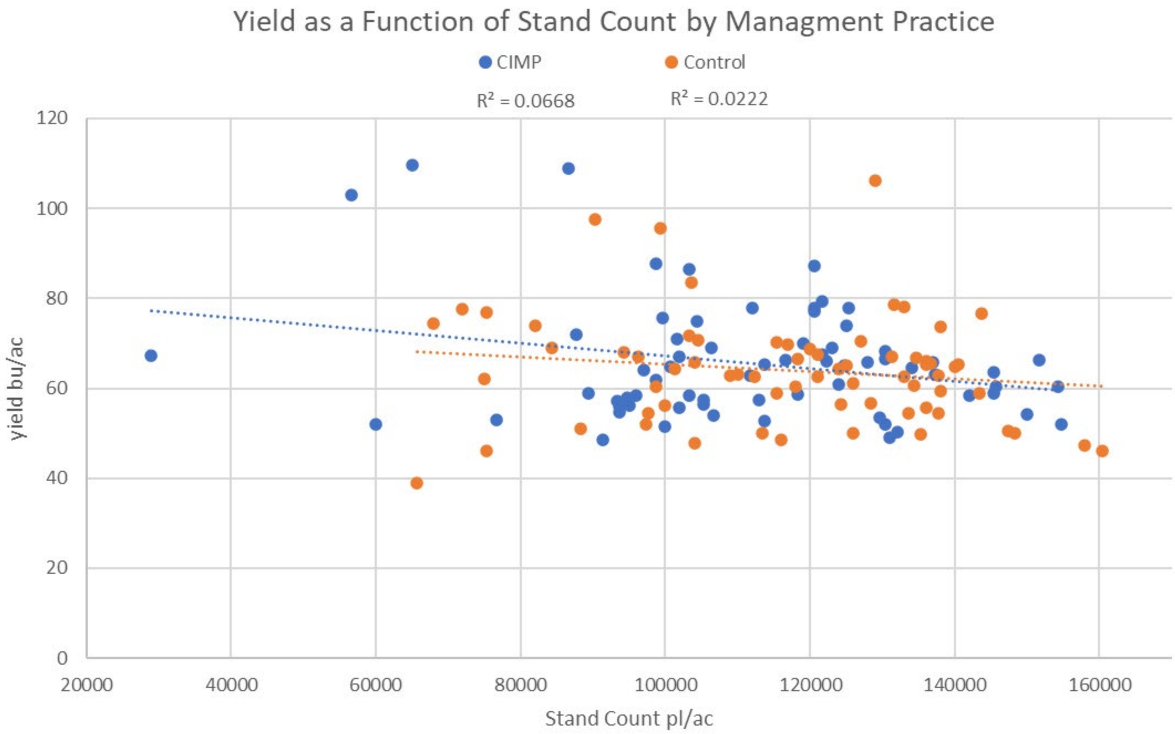



**Figure 6.** Scatter plot, correlation between Yield and Stand Count. Yield (bu/acre) clusters between 100,000 (plants/acre) and 140,000 (plants/acre)

*Note*. CIMP – combined improved management practices

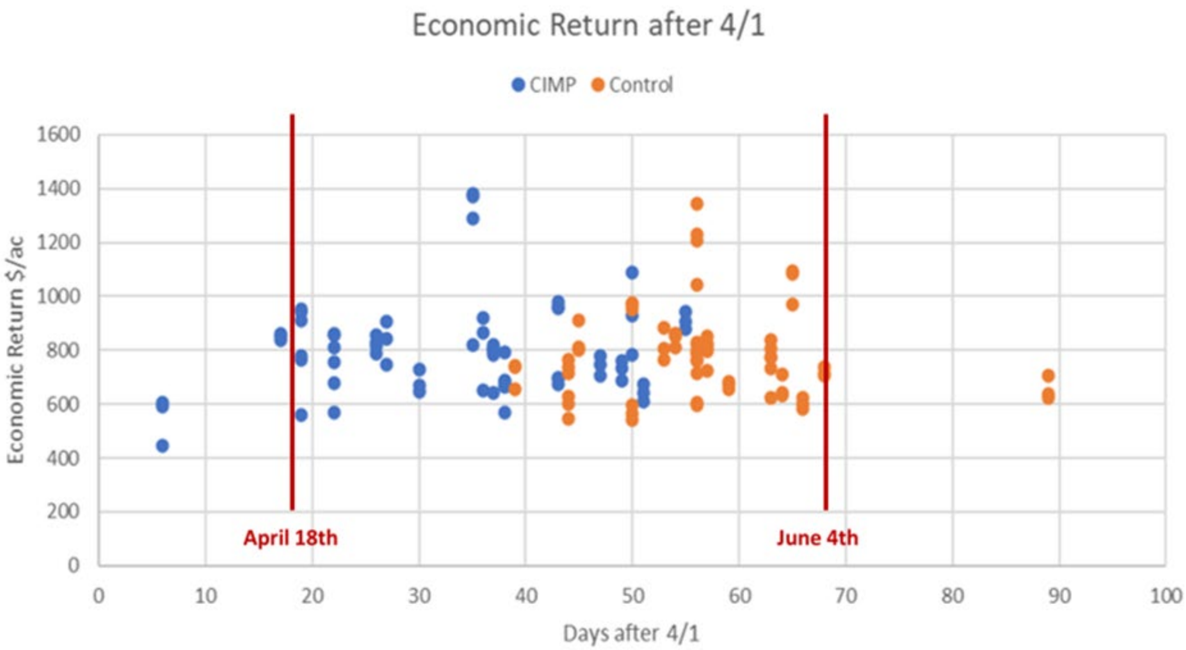



**Figure 7**. Economic return ($/acre) after 4/1. Showing the greatest probability of an economically viable yield between April 18th and June 4th

Note. CIMP – combined improved management practices

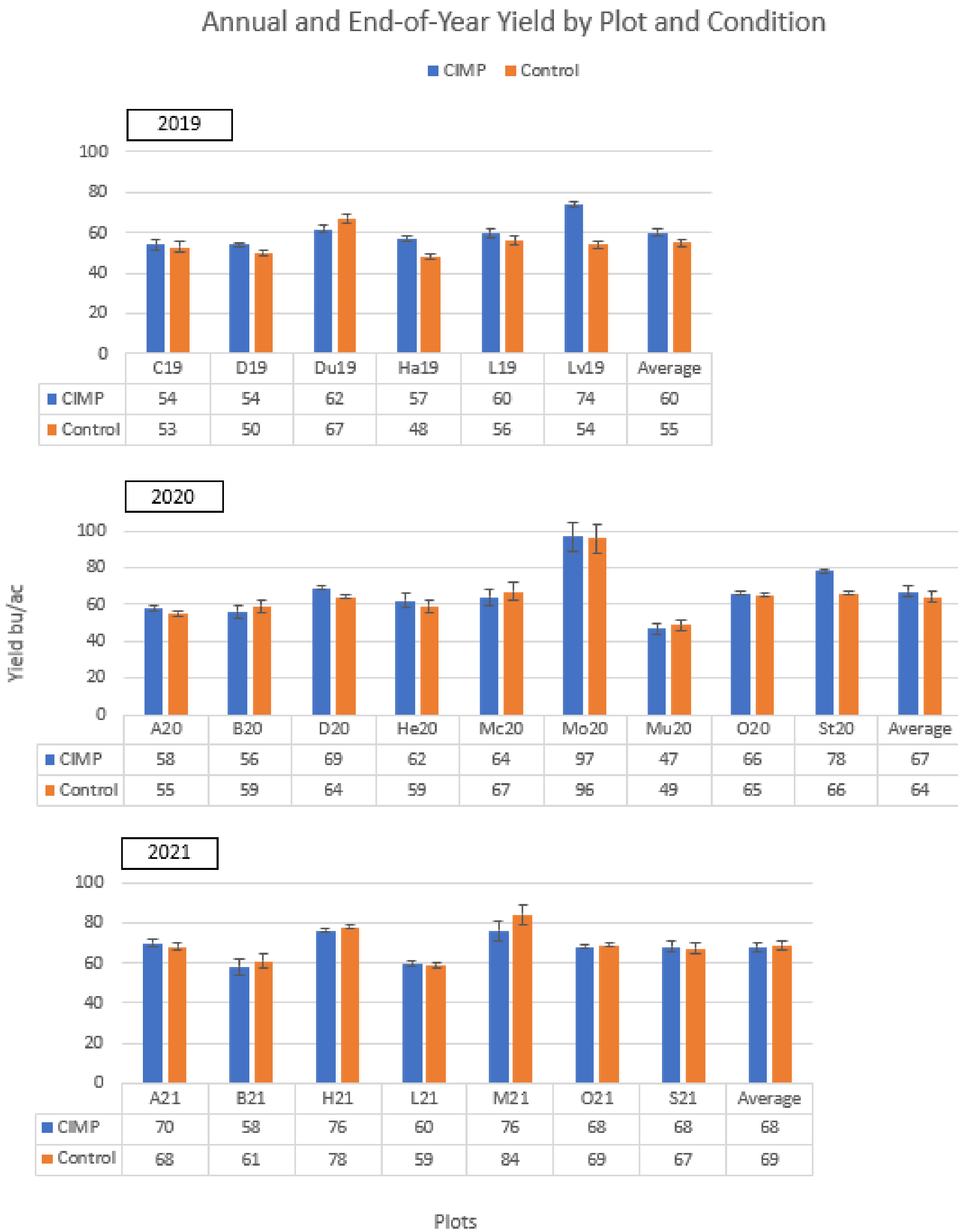



**Figure 8.** Annual End-of-Year Yield (bu/acre) by Plot and Condition

*Note*. CIMP – combined improved management practices, error bars are standard error of the mean

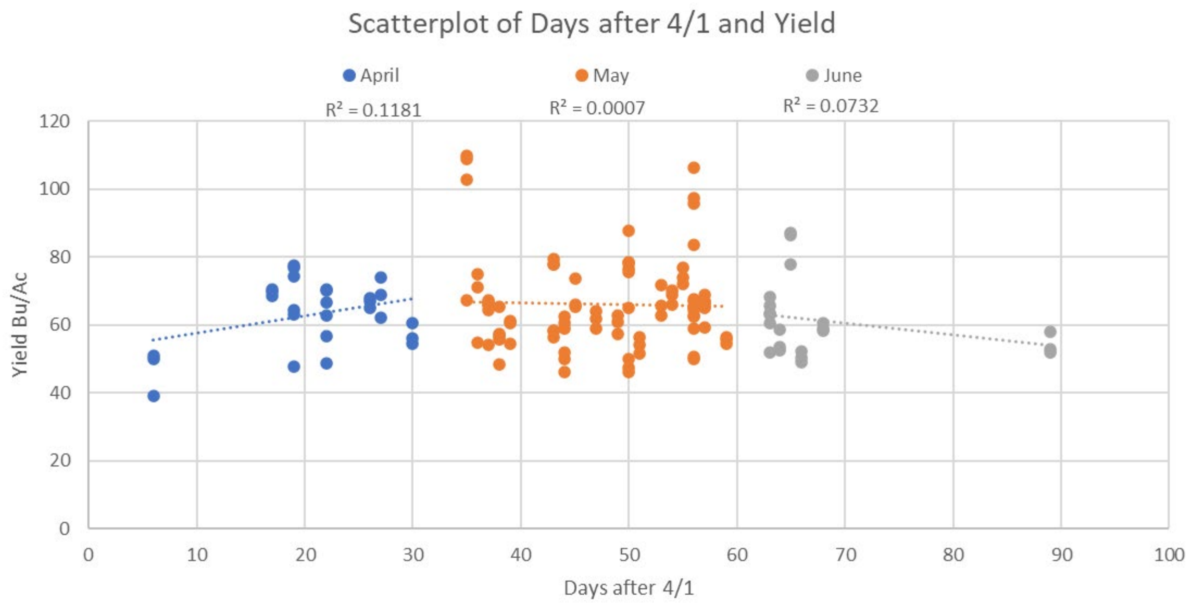
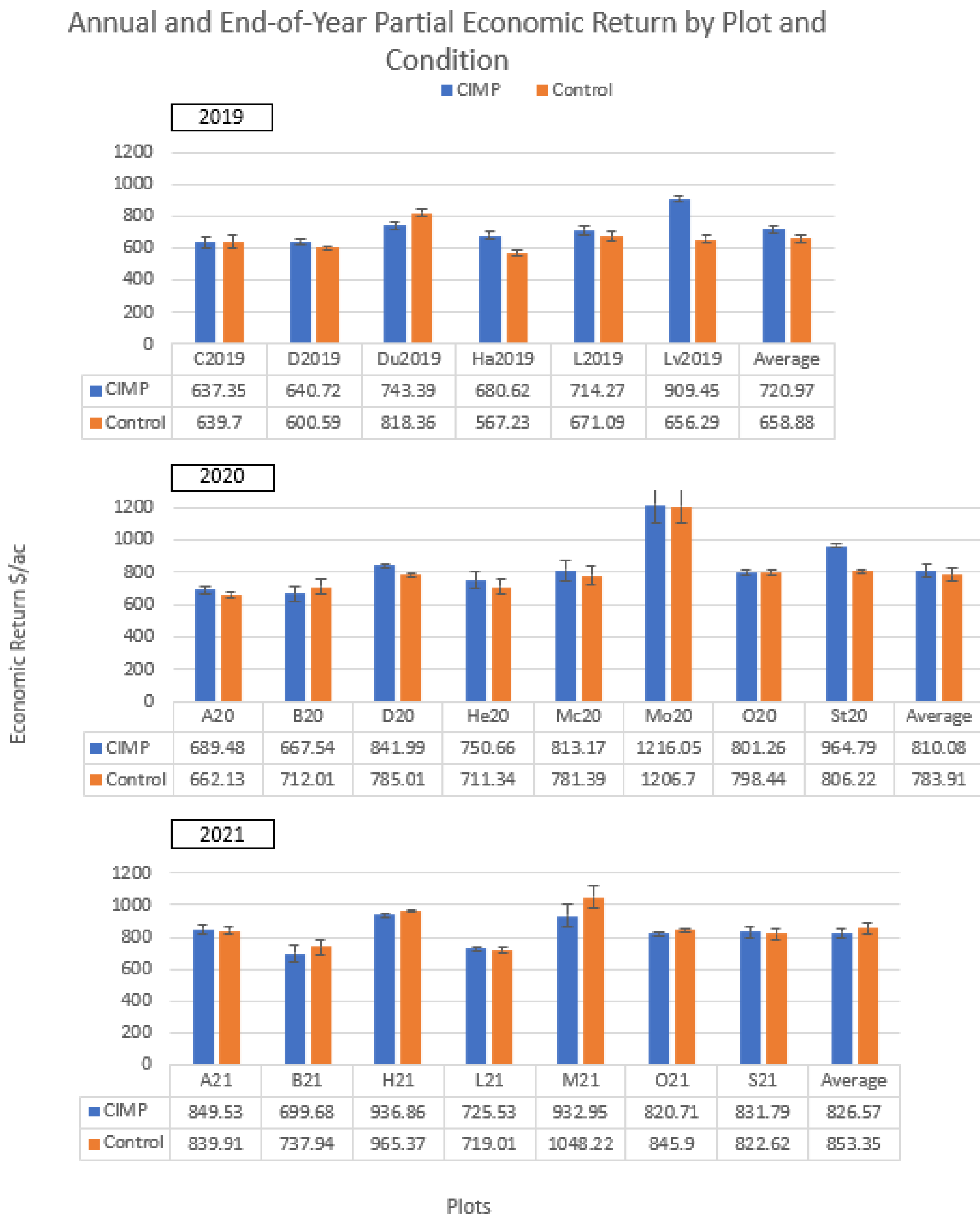



**Figure 9.** Scatterplot of Days after 4/1 and Yield (bu/acre) the time between April 18th and June 4th represents the time frame of greatest probability to obtain an economically viable return

*Note*. CIMP – combined improved management practices




| | C2019 | D2019 | Du2019 | Ha2019 | L2019 | Lv2019 | Average |
|---|---|---|---|---|---|---|---|
| CIMP | 637.35 | 640.72 | 743.39 | 680.62 | 714.27 | 909.45 | 720.97 |
| Control | 639.7 | 600.59 | 818.36 | 567.23 | 671.09 | 656.29 | 658.88 |

| | A20 | B20 | D20 | He20 | Mc20 | Mo20 | O20 | St20 | Average |
|---|---|---|---|---|---|---|---|---|---|
| CIMP | 689.48 | 667.54 | 841.99 | 750.66 | 813.17 | 1216.05 | 801.26 | 964.79 | 810.08 |
| Control | 662.13 | 712.01 | 785.01 | 711.34 | 781.39 | 1206.7 | 798.44 | 806.22 | 783.91 |

| | A21 | B21 | H21 | L21 | M21 | O21 | S21 | Average |
|---|---|---|---|---|---|---|---|---|
| CIMP | 849.53 | 699.68 | 936.86 | 725.53 | 932.95 | 820.71 | 831.79 | 826.57 |
| Control | 839.91 | 737.94 | 965.37 | 719.01 | 1048.22 | 845.9 | 822.62 | 853.35 |

**Figure 10.** Annual End-of-Year Partial Economic Return ($/acre) by Plot and Condition

*Note*. CIMP – combined improved management practices, error bars are standard error of the mean

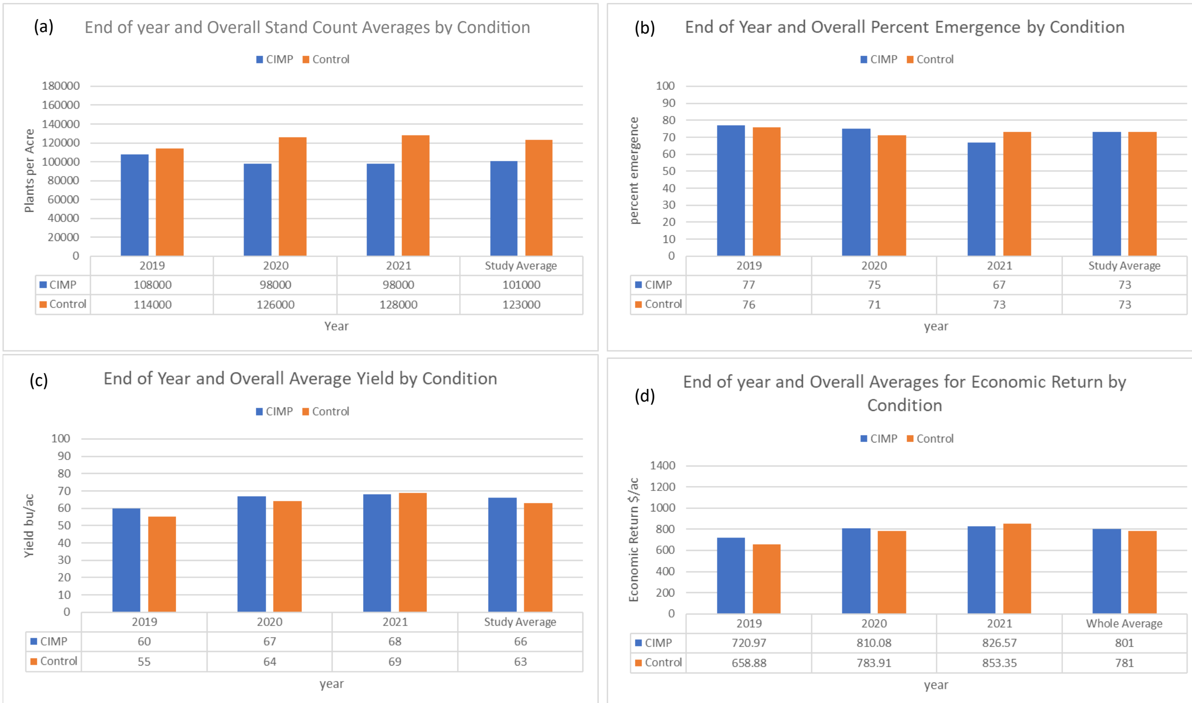



**Figure 11.** End of Year and Overall Averages of Stand Count (plants/acre), Percent Emergence (%), Yield (bu/acre), and Economic Return ($/acre) by Condition

*Note.* CIMP – combined improved management practices; (a) represents End of Year and Overall Stand Count Averages by Condition; (b) represents the End of Year Overall Percent Emergence by Condition; (c) represents End of Year and Overall Average Yield by Condition; (d) End of Year and Overall Averages for Economic Return by Condition

## Appendix

**Table A1.** 2019 Means, Standard Errors, and P-Values for Average Yield (bu/acre), Partial Economic Return ($/acre), and Average Stand (plant/acre) by Plot and Year Overall

| Farm Year 2019 | Average Yield | Partial Economic Return | Average Stand |
|---|---|---|---|
| | *bu/acre* | *$/acre* | *plant/acre* |
| C2019 Improved | 53.89 A | 637.35 | 92778 |
| C2019 Control | 53.07 A | 639.70 | 132666 |
| P | 0.7592 | 0.9467 | 0.0509 |
| St. Error | 2.8071 | 37.3346 | 6619.74 |
| D2019 Improved | 53.97 | 640.72 | 122778 |
| D2019 Control | 50.47 | 600.59 | 105111 |
| P | 0.0956 | 0.1228 | 0.0059 |
| St. Error | 1.1851 | 15.7617 | 1480.32 |
| Du2019 Improved | 61.69 | 743.39 | 95000 |
| Du2019 Control | 66.68 | 818.36 | 105444 |
| P | 0.0546 | 0.0437 | 0.0909 |
| St Error | 2.1317 | 28.3517 | 2393.41 |
| Ha2019 Improved | 56.97 | 680.62 | 98778 |
| Ha2019 Control | 47.80 | 567.26 | 155556 |
| P | 0.0138 | 0.0159 | 0.0039 |
| St Error | 1.5102 | 20.0850 | 2641.08 |
| L2019 Improved | 59.50 | 714.27 | 129111 |
| L2019 Control | 55.61 | 671.09 | 110444 |
| P | 0.2572 | 0.3207 | 0.0422 |
| St Error | 2.1468 | 28.5524 | 3849.00 |
| LV2019 Improved | 74.33 | 909.45 | 111111 |
| LV2019 Control | 54.33 | 656.29 | 77111 |
| P | 0.0008 | 0.0009 | 0.0418 |
| St Error | 1.6667 | 22.1667 | 10936 |
| **2019 Average Improved** | **60.06** | **720.97** | **108259** |
| **2019 Averages Control** | **54.66** | **658.88** | **114388** |

[a] result based on a two-tailed mixed method ANOVA (α = .05)
[b] results based on a two-tailed mixed method ANOVA (α = .05)
[c] results based on a two-tailed mixed method ANOVA (α = .05)

**Table A2**. 2020 Means, Standard Errors, and P-Values for Average Yield (bu/acre), Partial Economic Return ($/acre), and Average Stand (plant/acre) by Plot and Year Overall

| Farm Year 2020 | Average Yield | Partial Economic Return | Average Stand |
|---|---|---|---|
| | *bu/acre* | *$/acre* | *plant/acre* |
| A2020 Improved | 57.63 | 689.48 | 98,111 |
| A2020 Control | 54.93 | 662.13 | 120,556 |
| P value | 0.2324 | 0.3262 | 0.0538 |
| St Error | 1.4199 | 18.8846 | 3838.5 |
| B2020 Improved | 55.98 | 667.54 | 121,778 |
| B2020 Control | 58.68 | 712.01 | 125,889 |
| P value | 0.6158 | 0.5420 | 0.1508 |
| St Error | 3.2446 | 43.1529 | 3973.65 |
| D2020 Improved | 69.10 | 841.99 | 120,222 |
| D2020 Control | 64.33 | 785.01 | 137,889 |
| P value | 0.0834 | 0.1005 | 0.0409 |
| St Error | 1.0403 | 13.8360 | 2605.86 |
| He2020 Improved | 62.23 | 750.66 | 139,444 |
| He2020 Control | 58.63 | 711.34 | 151,444 |
| P value | 0.0972 | 0.1350 | 0.2874 |
| St Error | 3.7645 | 50.0672 | 8345.16 |
| Mc2020 Improved | 66.93 | 813.17 | 99,889 |
| Mc2020 Control | 63.9 | 781.39 | 136,444 |
| P value | 0.6900 | 0.7513 | 0.0083 |
| St Error | 4.6530 | 61.8851 | 2367.35 |
| Mo2020 Improved | 97.23 | 1216.05 | 59,333 |
| Mo2020 Control | 95.75 | 1206.71 | 105,583 |
| P value | 0.8298 | 0.9189 | 0.0470 |
| St Error | 7.8578 | 104.51 | 10267 |
| Mu2020 Improved | 46.67 | 545.77 | 89,111 |
| Mu2020 Control | 49.33 | 591.93 | 99,556 |
| P value | 0.3714 | 0.2752 | 0.5588 |
| St Error | 2.9907 | 394.88 | 11449 |
| O2020 Improved | 66.04 | 801.26 | 130,750 |
| O2020 Control | 65.34 | 798.44 | 122,167 |
| P value | 0.3686 | 0.7683 | 0.1939 |
| St Error | 0.9948 | 16.6473 | 28216 |
| St2020 Improved | 78.33 | 964.79 | 122,556 |

| | | | |
|---|---|---|---|
| St2020 Control | 65.77 | 806.22 | 131,889 |
| P value | 0.0148 | 0.0165 | 0.0297 |
| St Error | 1.0960 | 14.5762 | 2222.10 |
| | | | |
| **Average Improved** | **66.69** | **810.08** | **98,120** |
| **Averages Control** | **64.07** | **783.91** | **125,713** |

[a] result based on a two-tailed mixed method ANOVA (α = .05)
[b] results based on a two-tailed mixed method ANOVA (α = .05)
[c] results based on a two-tailed mixed method ANOVA (α = .05)

**Table A3**. 2021 Means, Standard Errors, and P-Values for Average Yield (bu/acre), Partial Economic Return ($/acre), and Average Stand (plant/acre) by Plot and Year Overall

| Farm Year 2021 | Average Yield[a] | Partial Economic Return[b] | Average Stand[c] |
|---|---|---|---|
| | *bu/acre* | *$/acre* | *plant/acre* |
| A2021 Improved (*M*) | 69.67 | 849.53 | 113,833 |
| A2021 Control (*M*) | 68.30 | 839.91 | 138,167 |
| p-value | 0.5954 | 0.7722 | 0.0340 |
| St Error | 1.9189 | 25.5215 | 2319.99 |
| B2021 Improved | 58.40 | 699.68 | 105,111 |
| B2021 Control | 60.63 | 737.94 | 136,889 |
| p-value | 0.7220 | 0.6508 | 0.0019 |
| St Error | 3.8606 | 51.3454 | 2923.93 |
| H2021 Improved | 76.23 | 936.86 | 71,778 |
| H2021 Control | 77.73 | 965.37 | 136,111 |
| p-value | 0.0532 | 0.0271 | 0.0045 |
| St Error | 0.7796 | 10.3687 | 3075.19 |
| L2021 Improved | 60.34 | 725.53 | 116,222 |
| L2021 Control | 59.21 | 719.01 | 144,333 |
| p-value | 0.5764 | 0.8020 | 0.0148 |
| St Error | 1.2121 | 16.1212 | 2884.57 |
| M2021 Improved | 76.10 | 932.95 | 99,667 |
| M2021 Control | 83.83 | 1048.22 | 112,000 |
| p-value | 0.3976 | 0.3542 | 0.1341 |
| St Error | 5.1235 | 68.1429 | 3561.76 |
| O2021 Improved | 67.50 | 809.63 | 105,222 |
| O2021 Control | 68.75 | 840.35 | 115,889 |
| p-value | 0.4308 | 0.2613 | 0.5112 |
| St Error | 0.9351 | 12.4372 | 3638.59 |
| St2021 Improved | 68.33 | 831.79 | 80,444 |
| St2021 Control | 67.00 | 822.62 | 116,556 |
| p-value | 0.6254 | 0.7954 | 0.0438 |
| St Error | 2.5927 | 34.4832 | 5525.50 |
| Bo2021 Improved | - | - | 92,792 |
| Bo2021 Control | - | - | 127,583 |
| p-value | - | - | - |
| St Error | - | - | - |
| **2021 Average Improved** | **68.08** | **826.57** | **98,133** |
| **2021 Averages Control** | **69.35** | **853.35** | **128,441** |

[a] result based on a two-tailed mixed method ANOVA ($\alpha = .05$)
[b] results based on a two-tailed mixed ANOVA ($\alpha = .05$)
[c] results based on a two-tailed mixed method ANOVA ($\alpha = .05$)

**Table A4**. Means, Standard Errors, and P-Values for Average Yield (bu/acre), Partial Economic Return ($/acre), and Average Stand (plant/acre) by Year and Overall

| Farm Year | Average Yield | Partial Economic Return | Average Stand |
|---|---|---|---|
| | *bu/acre* | *$/acre* | *plant/acre* |
| 2019 Improved | 60.06 | 720.97 | 108,259 |
| 2019 Control | 54.66 | 658.88 | 114,388 |
| 2020 Improved | 66.69 | 810.08 | 98,120 |
| 2020 Control | 64.07 | 783.91 | 125,713 |
| 2021 Improved | 68.08 | 826.57 | 98,133 |
| 2021 Control | 69.35 | 853.35 | 128,441 |
| **Average Improved** | **66.0301 (64.94)** | **801.07 (785.87)** | **102,238 (101504)** |
| **Average Control** | **63.8716 (62.69)** | **781.15 (765.38)** | **126,822 (122847)** |
| **P value** | **0.6114** | **0.4767** | **<.0001** |
| **Standard Error** | **1.4844** | **19.7356** | **3318.68** |

a result based on a two-tailed mixed method ANOVA ($\alpha = .05$)
b results based on a two-tailed mixed ANOVA ($\alpha = .05$)
c results based on a two-tailed mixed method ANOVA ($\alpha = .05$)