Planting Date and Seeding Rate Effect on Corn Yield for Replant Decisions in Alabama

by

Murilo Trimer Morata

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 4, 2024

Keywords: crop management, maize, agronomic practices, seeding rate

Approved by

Dr. Eros A. B. Francisco, Chair, Assistant Professor, Department of Crop, Soil, and Environmental Sciences
Dr. Brenda V. Ortiz, Professor, Department of Crop, Soil, and Environmental Sciences
Dr. Steven M. Brown, Assistant Professor, Department of Crop, Soil, and Environmental Sciences

Abstract

Corn (*Zea mays* L.) stands as one of the most vital crops globally, being a crucial crop for agricultural economies. Two factors profoundly influence corn yield: plant population and planting date. These factors influence agronomic performance (plant height, stalk diameter, and ear size, among other agronomic variables) and have a huge impact on grain yield. The significance of these factors is not only in their direct effects but also have indirect implications for plant development and response to environmental conditions throughout the growing season.

The choice of seeding rate is directly related to the targeted plant population, forming the way for growth and yield potential. Insufficient plant population can lead to poor stand, leaving gaps in the field and negatively affecting productivity. Conversely, excessive seeding rate may result in high plant population, promoting competition for resources and limiting individual plant growth. Striking the optimal balance is crucial to ensure adequate plant performance to maximize yield potential while minimizing resource waste.

Equally critical is the selection of an appropriate planting date. The timing of planting has a huge impact, influencing crop development, flowering, and ultimately, grain fill. Early planting date offers the advantage of an extended growing season, allowing plants to capitalize on favorable conditions and accumulate biomass. However, early planting date carries the risk of exposing young seedlings to adverse weather events, such as cold stress and frost damage. Conversely, delaying planting date may result in reduced yield potential due to shorter growing seasons and increased susceptibility to heat stress or drought during critical growth stages.

Understanding this relationship holds relevance in the context of replant decisions. In instances where initial plant stands fall short of expectation, growers face the question of

whether to replant the field. By gaining insights into how plant population and planting date influence yield, growers can better assess the viability and potential benefits of replanting, thereby maximizing profitability and ensuring optimal land utilization.

This study seeks to understand the impacts of varying seeding rates and planting dates on corn grain yield and agronomic performance. Through a comprehensive analysis across multiple locations and seasons, the objective was to provide valuable insights into the complex dynamics of corn production and provide better insights for farmers on replant decisions.

Acknowledgments

Firstly, I want to thank God and the sacred family for hearing my prayers and opening doors of opportunity, always being there for me, and being a source of love and understanding.

I would like to thank my advisor Dr. Eros Artur Bohac Francisco, for all the support, guidance, and friendship that he provided as a mentor. I appreciate the many opportunities you provided for me. Also, I want to thank my committee members, Dr. Brenda Ortiz and Dr. Steve Brown, for their guidance and support. Thanks to the Alabama Wheat and Feed Grain Committee for funding this project.

I want to give a special thanks to my family, my father Julio Morata, my mother Regina Trimer, my sister Juliana Morata, and finally my dear brother and best friend Guilherme Morata, for all the encouragement, respect, and support you all always gave me.

I'd like to thank my friends that Auburn gave me, Lucas Ramon Teixeira, Thiago Bento Capputi and Mailson Oliveira, for giving me strength in the hard moments, crying, and laughing with me. The three of you are also my family. (R.I.P. Felipe Silva 07-31-2023).

And I would like to express my deepest gratitude to Jessi Richardson, the love of my life, and Kenzie for all supporting me throughout this journey of pursuing my master's degree. Their unwavering support, understanding, and patience have been my greatest source of strength. I love you both so much.

Table of Contents

List of Tables

List of Figures

.

I. LITERATURE REVIEW

1. Introduction

Corn, also known as maize (*Zea mays* L.), belongs to the tribe *Maydeae* of the grass family *Poaceae.* The origin of corn cultivation was in Central America dating 7,000 years ago. Evidence of this was discovered by archaeologists in Teotihuacan, a valley close to Puebla state in Mexico. Following the discovery of the Americas, corn was spread to Europe and North America (FAO, 1992; Latha & Lone, 2020).

Corn is one of the most important crops in the United States of America (USA), and the world, serving as a vital source of human or animal food. Corn is a source of hundreds of industrial products, including fuel, corn starch and corn syrup. These latter products are used in the milling industry and in the fermentation and distilling industries (Latha & Lone, 2020).

According to the United States Department of Agriculture - USDA (USDA, 2019), about a third of corn production is used to feed poultry, cattle, and pork, providing carbohydrates, while soybeans provide the protein to support animal production. A little over a third of the total production is used for ethanol, serving as a renewable fuel added to gasoline, while the rest is used for human food, beverages, and industrial processes inside the USA. Corn is also and being exported to numerous other countries, including Japan, Colombia, and Mexico.

Corn is a versatile crop produced in a wide variety of environments, from temperate climates to tropical regions. It is the only cereal capable of being harvested in different stages of plant. Corn can be classified into several groups based on the grain characteristics, varying both genotypically and phenotypically; five common categories include dent, sweet corn, flint, floury and popcorn (Jungenheimer, 1976).

Dent corn, known for its high starch and low sugar content, is the most commonly grown type. It is harvested when the kernels are fully dry and mature, and a considerable portion is used for animal feed due to the soft starch. It also finds applications in the distillation and fermentation industries. Sweet corn is harvested at the milk stage when still immature to prevent the sugar from converting into starch. It is largely used as a human food. Floury corn stands out with its soft-shelled, starchy kernels, being mostly used to produce corn flour, catering to a significant amount of the food industry (Jungenheimer, 1976).

Corn is genetically diverse with hundreds of hybrids available worldwide. These hybrids vary in yield, plant height, growth habits, leaf shape, ear size, kernel color and stalk diameter. Breeding programs have increased genetic diversity, enabling corn to adapt to new and specific environments, thus meeting the local growing environments and consumer needs (Latha & Lone, 2020).

2. US and worldwide corn production

The largest producers worldwide in 2021/2022 were: the USA with 382.9 MMT (Million metric tons), China 272.6 MMT, and Brazil 116.0 MMT. Among the primary feed grains - corn, sorghum, barley, and oats - corn stands as the dominant USA feed grain, contributing over 95% of the total production and consumption of feed grains. The USA is the leading producer, consumer, and exporter of corn. Corn exportation provided a revenue of $19.1 billion for the USA in 2022 (USDA, 2023a). Corn acreage increased over the past decades from 23 million hectares in 1983 to over 36 million hectares in 2022, down 1.4 million hectares from 2021 according to USDA Economics Statistics and Market Information System.

In addition to increases in acreage, corn yields have also increased dramatically, reflecting advances in genetics, technology and management practices. The average corn yield in the USA has increased from 2600 kg ha^{-1} in 1993 to 4440 kg ha-1 in 2021 (USDA, 2023b).

The leading corn-producing states in the USA are Iowa, Illinois, Nebraska, Minnesota, and Indiana, all situated in the so-called Corn-Belt region. Among them, Iowa and Illinois, together account for approximately one-third of the entire USA corn production. Respectively, Iowa and Illinois held 16.2% and 15.0% of the total national corn production in 2020. In the Southeast, the main corn producing states are Kentucky, Tennessee and Mississippi. In 2020, these states accounted for 1.8%, 0.6%, and 0.4% , respectively, of USA corn production, totaling 6,400, 3,500, 2,200 billion kilograms, respectively. (USDA, 2023c).

In Alabama, corn has contributed to the state's economy by providing feed and food for humans and livestock, with 121,400 hectares planted in 2022 (USDA,2023a). According to the National Agriculture Statistics Service (NASS), the Tennessee Valley, which is in the northern part of the state, is where the largest producer counties are located, each yielding 76 million kilograms of corn or more yearly. Among them, Lawrence County stands out as the largest producer with an average yield of 11,300 kg ha^{-1} and over 150 million kilograms in total in 2021.

3. Corn grain yield and agronomic performance

3.1 Definitions and how to measure

Corn grain yield is defined by these main yield components: number of plants per area, number of ears per plant, number of rows per ear, number of seeds per row, and seed weight (Assefa et al., 2016).

In commercial fields, there are two primary methods for measuring corn yield, both of which employ specific equipment. The first method involves using a yield monitor, which utilizes advanced satellite technology to provide yield measurements from various locations across the field. It then calculates an average yield for the entire field based on these measurements. The second method involves the use of weighing wagons. Harvested grain is loaded into the weighing wagon and the total weight is divided by the harvested acreage to determine the yield.

In addition to the previous methods, there are alternative approaches that do not rely on specialized equipment. Such approaches entail a process that includes selecting sampling areas, picking up ears, threshing and weighing the seeds, measuring the seed moisture content, and subsequently performing calculations to estimate the corn grain yield.

Agronomic corn performance refers to the evaluation of corn crops in terms of their growth, development, and yield potential. It involves assessing various agronomic factors such as plant height, stalk diameter, number of ears per plant, ear development which includes ear length, diameter and weight, and overall yield.

3.2 Environmental factors affecting corn grain yield

Corn phenology encompasses the development stages influenced by a combination of genetic and environmental factors. For corn, growth stages include germination, emergence (Ve), vegetative growth (V1-V14), reproductive growth (VT, R1-R5), and maturity (R6), as outlined by Abendroth et al. (2011). Each growth stage has a duration determined by environmental variables such as temperature, moisture, photoperiod and the specific hybrid of corn being cultivated.

Identifying and understanding the four key growth stages that significantly influence the grain yield aid in the development of best management strategies to achieve the best yield. The first crucial stage occurs when the corn ear sets the maximum number of kernel rows around the ear; this occurs in the vegetative development stage, approximately the V5 to V8 stage, and depends upon the genetics of a hybrid. A meristematic dome exists at the tip of the ear and promotes the development of new kernel rows, producing new rows of ovules along its length. These ovules eventually undergo division, resulting in the formation of pairs of rows from every single row. It is important to emphasize that cell division inhibitor herbicides, when applied at this stage, may prevent the single row from doubling and forming the paired row structure (Strachan, 2016).

The second vital stage, which occurs between the stages of ear initiation and pollination, is when the ear establishes the potential number of kernels. This second stage encompasses two steps, first is the initiation of ovules, and the second involves cell differentiation and division, processes that prepare the ovules for eventual fertilization (Strachan, 2016). Fischer and Palmer (1984) and Kiniry and Ritchie (1985) observed that a decrease in the number of viable kernels per ear can persist for a span of 2 to 3 weeks after the emergence of silks. Once the the maximum number of ovules is determined, sufficient energy, water and nutrients must be supplied for all the developing ovules to produce silks and be receptive to pollen.

The third crucial stage, occurring at VT (tasseling), is when the maximum number of ovules are pollinated to form developing embryos. There are two parts to this process. The first is when viable pollen reaches the silk on the female part. Strachan (2016) observed that at this stage pollen can lose viability with high temperatures (above 40 °C), and when water deficit stress is present. The second process is when the silk receives the pollen and must support the pollen tube formation to allow the male and female gametes to fuse. At this point, water and nutrient availability is crucial to promote the process, and any stress related to these two factors will delay or even prevent that the pollen tube to form, impacting on the number of kernels on the ear (Strachan ,2016).

The fourth critical stage is when the ear sets the maximum kernel size and weight; this occurs during the later portion of grain fill and ends at kernel black-layer formation. In this phase the corn plant requires nutrients and water for the kernels to develop and grow at the maximum kernel size and weight. Lack of any of these resources will decrease yield (Strachan, 2016).

In general, corn prefers warm temperatures, requiring at least 100 days of frost-free conditions to mature. Corn yield can be affected by heat stress or drought during flowering and grain filling stages, which requires water, at least 96 mm on early tasseling and 276 mm inches on corn grain filling stages from R3 to R6 (Hatfield & Dold, 2019).

Despite the impressive gains in corn yield over the past few decades, other factors limit potential for further improvement. One of the most important factors is soil degradation, which results from erosion, compaction, nutrient depletion, and the reduction of beneficial microorganisms. Poor soil management can reduce the ability of the plant to uptake water and nutrients and increase pests and diseases, limiting crop productivity (Hatfield & Dold, 2019).

Soil fertility is also an important factor that affects corn grain yield, with deficiencies in nutrients such as nitrogen, phosphorus, or potassium limiting growth and yield. Soil pH, texture and structure can also affect nutrient availability and water retention, thereby affecting yield.

3.3 Optimizing yield through best management practices

Among the critical growth stages for corn, emergence plays a significant role. Unlike crops like cotton, soybeans and peanuts, corn lacks the ability to compensate for low stand counts. Therefore, establishing an optimal and uniform stand is critical in achieving full grain yield potential. The primary issues that affect the establishment of a healthy initial crop stand include suboptimal seed germination, inadequate soil moisture, extreme heat or cold, improper machinery speed during planting, incorrect seeding depth, inconsistencies in field and seedbed terrain, pests and diseases and, notably, planting date and seeding rate.

In contrast to previous hybrids, modern hybrids require higher plant populations to achieve optimal yields (Hammer et al., 2009a; Tokatlidis & Koutroubas, 2003). The need for periodic reassessment of corn grain yield response to seeding rate has been emphasized, especially given the potential variations in optimum crop management practices across different hybrids (Cox et al., 1998; Stanger & Lauer, 2007; Widdicombe & Thelen, 2002). Optimal seeding rate for corn has shown an upward trend over time (Hammer et al., 2009b). Since 1986, average corn seeding rates used by growers in North America have increased by about 680 seeds ha-1 per year (Ciampitti, 2018).

The introduction of Bt (*Bacillus thuringiensis*) technology in corn production to control the damage caused by the fall armyworm (*Spodoptera frugiperda*) and other insects has notably mitigated the risk of stalk lodging under these increased seeding rates (Stanger & Lauer, 2007), which encourages farmers to increase their seeding rates for higher stands.

A further element influencing the increased plant population of corn is the narrowing of the space between rows. Butzen and Paszkiewwicz (2008) conducted research focusing on row spacing in corn and showed that yield benefits associated with narrower rows become less significant as one moves away from the northern latitudes of the Corn Belt. This is because corn in the central and southern regions of the Corn Belt is more adept at achieving optimal light absorption before the flowering stage.

While it is theoretically possible that higher plant populations could lead to increased yields, it is important to recognize that there exists a threshold related to seeding rate. This limitation arises due to the competition among plants for essential resources such as water, nutrients and light, which can paradoxically reduce rather than increase yields (Bullock et al., 1988; Duncan, 1984).

Environments with elevated yield potential demand greater plant densities to achieve heightened yields (Paszkiewicz & Butzen, 2007). In regions constrained by water availability or drought periods, the optimal plant density required to achieve this yield plateau is comparatively lower, in contrast to areas not subjected to these limiting factors (Cox & Cherney, 2012; Shanahan et al., 2004).

Over a span of four years (1987-1990), a research study in Monmouth and DeKalb, Illinois, indicated that the optimal plant population for achieving the highest yield was 70,800 plants per hectare (Nafziger, 1994). In a study conducted in southern Minnesota, Porter et al. (1997) reported that the optimal plant density for maximizing corn grain yield was 86,500 plants per hectare. More recently, Paszkiewicz and Butzen (2007) researched seven hybrids specifically adapted to the same region with relative maturity ranging from 98 to 104 days. They reported that the economically ideal seeding rate varied between 78,600 to 95,400 plants per hectare for these hybrids.

The ideal plant population for corn is subject to variation based on factors such as geographical location, primarily latitude. In regions of northern latitudes where occurrences of heat and drought stress are less frequent, higher plant populations are often beneficial (Widdicombe & Thelen, 2002). Optimal plant population has been documented to surpass 80,000 plants per hectare in northern states. Specific reports include 83,300 plants per hectare in Wisconsin, (Stanger & Lauer, 2007), about 90,000 plants per hectare in Iowa (Coulter et al., 2010), and 82,000 to 84,500 plants per hectare in Minnesota (Van Roekel & Coulter, 2011). In the southern reaches of the Corn Belt, particularly in Indiana, the ideal plant population rarely exceeds 69,000 plants per hectare (Robles et al., 2012), and Shapiro & Wortmann (2006) reported that 61,800 plants per hectare in rainfed conditions in Nebraska is the correct plant density, due to stresses associated with heat and drought.

In Wisconsin, Stanger and Lauer (2007) observed that as plant population increased from 64,200 to 123,500 plants per hectare, stalk lodging in corn increased from 6 to 18%. This highlights the significance of evaluating the effects of plant population on lodging and related phenotypic traits, as potential yield gains associated with higher plant densities can be compromised by harvest losses due to lodging (Olson and Sander, 1988). Therefore, it remains crucial to periodically assess the relationship between plant population, stalk lodging, and other characteristics associated with new hybrids (Stanger & Lauer, 2007).

In the southern region of the USA, there exists a notable lack of comprehensive information essential for determining the optimal plant population under the prevailing environmental conditions. Hence, there is a pressing need for focused research aimed at enhancing the understanding of this crucial aspect specific to this geographic area. Corn also must have the necessary time to allow the crop to mature before the dry and hot summer months. The timing of corn planting holds paramount significance in achieving high yields. The optimal timing of planting directly influences critical developmental stages, including germination, emergence, vegetative growth and ultimately, grain formation. This interdependence between planting date and crop success reflects the interaction between corn growth development and the prevailing climatic conditions, including temperature and moisture availability.

Well-timed planting can promote robust root establishment and early growth, thereby maximizing crop yield potential. Deviating from the ideal planting window can lead to reduced yields due to compromised plant development and increased vulnerability to various stressors. Delays in planting dates in the southeast portion of the USA often result in insect and disease problems in corn (Wìatrak et al., 2004). Therefore, comprehending the relationship between corn planting date and yield outcomes is crucial for crop productivity.

In the Corn Belt, corn is usually planted in late April through early May. In western Nebraska and northwest Kansas, dryland corn is typically planted from late April through early to mid-May. However, in these regions, seeding rates are usually no greater than 44,500 plants/hectare. This approach aims to mitigate the impact of drought stress (Norwood & Currie, 1996). In the northern Corn Belt, the most substantial corn yields under conventional tillage (CT) are achieved through plantings in late April or early May. Yield reductions become progressively more pronounced with delays in planting from May to early June (Hicks et al., 2004).

A study conducted in Illinois, with four planting dates (April 9 and 24, May 9, and 24) showed that corn grain yield usually increases from the middle of April to late April, while yield starts to decrease once that planting is delayed to May. The optimum planting date was around April 27 (Nafziger, 1994). In a study focused on dryland corn in Kansas, researchers observed that corn grain yield exhibited a more favorable response to early and mid-May planting dates compared to those conducted in late May (Norwood & Currie, 1996).

In the Southeast, corn can be planted from late February to early July, with the period from mid-April to early May being particularly beneficial due to the typically favorable summer rainfall conditions (Wìatrak et al., 2004). The influence of planting dates on corn yield is a critical factor that warrants thorough investigation. The existing knowledge demonstrates the substantial impact of timing on yield outcomes, particularly in regions like the Southeast. However, the lack of comprehensive information regarding optimal planting dates in this specific region brings up the need for further research. The relationship of climate, soil and other environmental factors unique to the Southeastern USA necessitates a better understanding of how planting dates can be arranged to maximize corn yield. By synergizing planting date insights with corn potential yield, researchers and farmers can pave the way for increased productivity, ensuring the prosperity of corn cultivation in the Southern United States.

Forecasting yield responses based on planting dates and plant populations in corn is an essential endeavor. This predictive approach is crucial for matching the appropriate plant population with specific planting dates and facilitating informed decisions regarding potential replanting scenarios (Nafziger, 1994). By anticipating how varying planting dates interact with different plant populations, farmers and agronomists can optimize their strategies to achieve the highest possible yields.

3.4 Corn Hybrids, relative maturity, and hybrid characteristics

Improved hybrids and production practices are helping corn growers increase yields. Over the past 20 years, U.S. yields have increased by an average of 100 kg ha^{-1} $year^{-1}$ (Jeschke, 2024). The selection of a corn hybrid is vital to optimize crop performance and adapt to the specific growth conditions and climate of a particular region or planting season. One crucial factor to consider is the relative maturity of the corn hybrid. Relative maturity refers to the duration from planting to physiological maturity. This maturity is often quantified in accumulated heat units, known as growing degree units (GDU) or growing degree days (GDD).

In the United States, corn relative maturity zones help categorize hybrids based on their adaptation to different climatic regions (Bansal et.al, 2022). In the northern part of the country, spanning zones 1 to 5, corn hybrids typically range from 80 to 110 days in relative maturity. This ensures that the hybrids reach maturity within the shorter growing season of these regions. Moving to the central zones, encompassing regions 6, 7, and 8, corn hybrids with relative maturities ranging from 110 to 119 days are commonly planted. These hybrids are suited to the longer growing seasons and warmer temperatures found in these areas. In the southern part of the country, including states like Alabama, corn hybrids with longer relative maturity periods of at least 120 days are preferred. These hybrids require a more extended growing season to reach maturity, aligning with the warmer temperatures and longer frost-free periods characteristic of the southern climate.

By selecting corn hybrids to the specific relative maturity zones, farmers can maximize yield potential, decrease risks associated with climate variability, and optimize resource utilization for better corn production.

Another characteristic that hybrids bring to corn production is corn traits, which refer to specific genetic characteristics or features of corn plants that influence their growth, development, and agronomic performance. These traits can be naturally occurring or introduced through breeding techniques such as traditional breeding or genetic modification.

Among the most common traits are herbicide tolerance, especially to *glyphosate* known as RoundupReady and *glufosinate* marketed as LibertyLink. These traits enable effective weed control. Another widely adopted trait is insect tolerance, with the most prevalent being the expression of *Bacillus thuringiensis* (Bt) proteins. Bt corn protects a range of damaging insect pests to corn production, including corn borers, corn rootworms, and corn earworms. Also, corn hybrids are often bred for disease tolerance, particularly against common threats like corn leaf blight, gray leaf spot, and common rust.

In conclusion, the selection of corn hybrids associated with specific relative maturity zones is essential for optimizing crop performance and adapting to varying climatic conditions across different regions of the United States. By matching hybrid relative maturity with the length of the growing season, farmers can maximize yield potential while minimizing risks associated with climate variability. Additionally, corn traits play a crucial role in enhancing agronomic performance and reducing production risks. Traits such as herbicide tolerance, insect tolerance, and disease tolerance contribute to effective weed control, pest management, and disease prevention, leading to more sustainable and profitable corn production practices.

4. Making replanting decision for corn

Starting from the moment a corn seed is placed within the furrow and covered with soil, all the way through to the point where matured grain is prepared for harvest, a multitude of challenges threaten the survival of the corn plant. Initial phases of the growing season often bring about adversities, including cold and waterlogged soils, unexpected late spring frosts, detrimental impacts of hail, the erosive force of winds, insect infestations, diseases, sudden floods and unfavorable conditions of the seedbed.

Periodically, a combination of these stressors can lead to substantial damage in the field, prompting the need to decide whether to replant. Any such decision should be based on evidence that the potential financial benefits of replanting surpass the associated costs.

Each of the following factors plays a crucial role in assessing the viability of replanting (Nielsen, 2020). The concept of the target population or intended plant stand differs from the seeding rate. Obviously, a seeding rate higher than the target population is employed, as seed germination and subsequent plant survival rarely achieve 100%. To obtain the target plant population, the original seeding rate must be divided by the seed germination percentage, found in the seed bag tags, and the expected plant survival rate, which changes with environment.

Accurately assessing the surviving plant population is pivotal for gauging the potential yield of a field impacted by the lack of plants. This evaluation should ideally take place within a span of 4 to 7 days following the initial occurrence of damage. Should a damaged plant exhibit no emergence of new green leaf material after this 4-day period, it is likely to be deceased (Nielsen & Christmas, 2002). In instances where damage is uniformly spread across the field, estimates derived from four representative sites tend to be sufficient. If damage is “uniform,” a single estimate should be sufficient. Conversely, if the damage is confined to specific sections of the field, it is advisable to generate estimates from one or two locations within each of these affected areas, and maybe only some areas of the field will need to be replanted (Nielsen & Christmas, 2002).

Not only does the loss of plants in a poor stand lead to yield reduction, but also the uneven distribution of the survivors can cause a decrease in yield (Nielsen, 2020). The greater the number and length of gaps between plants within rows, the more significant the yield loss (Johnson & Mulvaney, 1980). Research conducted in Illinois and Wisconsin has highlighted the possibility of reduced crop yields due to uneven plant emergence. In a study by Carter et al. (1992), it was observed that if half or more of the plants in a field emerge three weeks later than expected, there is potential for yield losses. In such cases, replanting the affected areas could lead to yield increases of up to 10%.

Fertilizer burn, frost, hail and wind can cause significant damage to young corn plants. The impact of this damage on the eventual corn yield is influenced by two main factors: the extent of the loss in the number of plants in the field (referred to as stand loss) and the amount of leaf loss on the plants that do manage to survive (known as defoliation). The degree of yield loss is determined by more than just the extent of defoliation (the percentage of lost or damaged leaf area). The growth stage at which the defoliation takes place also plays a crucial role in determining the impact on yield.

4.1 Original planting date

This is the original planting date that the field was planted. As previously discussed, the planting date is a crucial factor that impacts directly the yield, allowing or not the corn plant to have time to grow and get access to the necessary environmental conditions to grow in its full capacity.

4.2 Expected replanting date

This is the earliest date at which it would be feasible to replant. Consider various factors that could influence this decision, including the availability of labor and machinery, the procurement of necessary production inputs, and the preparation of the field for planting, for example applying herbicides to plowing the field.

4.3 Expected replanting costs

Even if the projected yield from replanting overcomes the potential yield losses of a marginal or poor stand, the expenses associated with replanting might still outweigh the income generated from the extra harvested bushels due to replanting. The primary factor to consider is the cost of seeds, which can range from no cost to the full market price, depending on seed pricing. Fuel cost is another factor in the expense of fuel for any extra fieldwork before or after replanting, in addition to the fuel cost associated with the replanting operation itself. Take into consideration the expenses associated with herbicides. If deep tillage is performed before replanting, it might be necessary to re-apply a preplant or preemergence herbicide. Additionally, the choice of herbicide should also consider the upcoming crop rotation for the next year, ensuring that any herbicides used do not carry over and negatively impact the following crop. Insecticide costs and other applications must also be included in the total replanting costs (Nielsen & Christmas, 2002).

According to the Alabama Extension Service at Auburn University (ACES, 2023), with a plant population of 86,000 plants per hectare, the estimated expenses are: seed costs $303.00 per hectare, fuel, and tractor/machinery expenses are around $91.00 per hectare, herbicide costs are $113.00 per hectare, totalizing a cost of $507.00 per hectare. Additional expenses include labor, the interest on loans obtained for purchasing replanting inputs and the increase in kernel-drying costs due to the higher moisture levels of replanted corn during harvest.

4.4 Corn grain yield

This represents the yield that the records of that area suggest could be achieved under typical conditions if there had been no stand loss or other damage. In 2021, Alabama produced an average of 11,300 kg ha^{-1}(USDA,2023b).

4.5 Corn expected marketing price

This is the anticipated price when you sell this grain in the market. According to data from the USDA Economic Research Service (ERS, 2023), corn prices have exhibited a rising trend since 2014. In 2014, the price was $10.50 per bushel, while in June 2023, it escalated to $15.00 per bushel.

4.6 Yield potential if damaged field is not replanted

Predicting the potential yield after damage is challenging due to the influence of numerous factors. These include plant population, planting date and the distribution of the stand. Additional loss can come with the defoliation of the plants and uneven plant stands.

For this study, a comprehensive board outlining various planting dates and corresponding plant populations was created, enabling us to precisely assess potential yield effects and the subsequent reductions in yield resulting from factors like late planting dates or varying seeding rates. This has enhanced our ability to provide a better estimation of the potential yield based on the current stand of plants.

4.7 Yield potential if damaged field is replanted

This is the desired plant population that will be used in replanting and reflects the targeted seeding rate, rate of seed germination and anticipated rate of plant survival. Expected yield from replanting is determining by plant population and replanting date, taking into consideration time from first planting date and necessary management decisions.

4.8 Assessing the viability of replanting

The yield gain or loss resulting from replanting is the difference between the expected yield of the replanted stand and the yield of the damaged original stand. This calculation serves as the foundation for determining the potential profitability of replanting. By evaluating the increase or decrease in yield of the replanted field along with the corn price, it becomes feasible to know the expected revenue generated through replanting. If this increase in revenue surpasses the total costs associated with replanting, replanting becomes a viable choice. Conversely, if the revenue increment falls short of covering the complete replanting costs, maintaining the existing stand becomes the more prudent course of action.

In conclusion, the literature reviewed underscores the significant influence of planting dates and seeding rates on corn grain yield. With the information from this research, farmers can make informed replant decisions crucial for optimizing crop productivity. Through an analysis of various studies conducted across different locations and growing conditions, it becomes evident that both factors play pivotal roles in determining corn yield potential (Nafziger, 1994).

Planting date emerges as a critical determinant of corn yield, with earlier planting generally resulting in higher yields due to extended growing seasons and favorable weather conditions during critical growth stages. Conversely, delayed planting often leads to reduced yields, attributed to increased exposure to adverse weather conditions, shortened growing seasons, and heightened susceptibility to pest and disease pressures.

Similarly, seeding rates significantly affect corn yield, with the optimal rate varying depending on factors such as soil type, environmental conditions, hybrid characteristics, and management practices (Cox & Cherney, 2012; Shanahan et al., 2004, Paszkiewicz & Butzen, 2007). While higher seeding rates may initially appear beneficial for achieving higher plant populations and potentially higher yields, they may also lead to increased competition for resources, such as water and nutrients, resulting in diminished yields and economic returns.

Furthermore, the interaction between planting dates and seeding rates adds complexity to yield outcomes, highlighting the importance of some agronomic practices for specific growing conditions. By understanding and optimizing these interactions, farmers can make more informed replant decisions to mitigate risks associated with poor initial stand establishment or uneven crop emergence.

Overall, this literature review underscores the need for a better approach to replant decisions in corn production, considering the dynamic interplay between planting dates, seeding rates, and environmental factors.

II. PLANTING DATE AND PLANT POPULATION EFFECT ON CORN GRAIN YIELD AND REPLANT DECISIONS IN ALABAMA

ABSTRACT

Corn yield is heavily influenced by plant population and planting date, and understanding the relationship between these is essential for optimizing yield. Poor stands and non-uniform plant density present significant initial challenges for farmers, leading to potential yield losses. When initial plant stands fall short of expectations, evaluating the need for replanting becomes crucial for maintaining profitability. To understand this relationship, a comprehensive study was conducted across three locations in Alabama during the 2022 and 2023 seasons.

Assess the effects of planting date and seeding rate on corn grain yield and agronomic performance; and develop a useful guide to guide replant decisions.

Corn hybrids included P1319R, P2042VYHR, DKB7045, P1170YHR, and P2042VYHR.

Seeding rates ranged from 29,600 to 88,800 seeds ha^{-1} and the five targeted planting dates ranged from March 30 to May 30 at 15-day intervals. Data collection included plant population, plant height, ear height, stalk diameter, ear length, weight, diameter, number of ears per plant, grain yield and test weight.

Seeding rate and planting date influenced most of the measured variables. Generally, lower seeding rates and late planting dates reduced yield. Higher plants and reduced stalk diameter were found in higher seeding rates while the variables number of ears ear per plant, ear length, ear diameter and ear weight were found to be greater in lower seeding rates.

INTRODUCTION

The United States holds a dominant position in the global corn market as the leading producer, consumer, and exporter of this vital commodity. Revenue generated from corn exports alone amounted to $19.1 billion in 2023, making a significant contribution to the nation's economic landscape (USDA, 2023a).

Over recent decades, acreage devoted to corn cultivation has experienced steady growth, increasing from 24.3 million hectares in 1983 to 36.3 million hectares in 2022, with some yearly fluctuations (USDA,2023a). Decisions such as planting date and seeding rate along with environmental conditions have a profound impact on yield. Farmers often encounter challenges such as poor stands and non-uniform plant density, leading to potential yield losses and added costs, yield losses of 10, 30 and 51% were observed when the stand was reduced by 25, 50 and 75 percent (Carter,1992). Corn yield is heavily influenced by planting date and seeding rate (Nafziger, 1994). While the seeding rate directly determines the number of plants, planting date indirectly impacts yield by influencing plant performance in response to environmental conditions throughout the growing season. Understanding the interaction between these factors is essential for optimizing yield and aiding farmers in making replant decisions (Nafziger, 1994). Long et al. (2017) discovered that optimal maize planting dates varied across latitude groups in the U.S., ranging from approximately days 42 to 135 of the year, depending on the latitude, with earlier planting dates for lower latitudes and later planting dates for higher latitudes. Westgate et al. (1997) observed that elevating plant density initially increases maize grain yield by promoting early canopy closure, which in turn enhances light interception. However, beyond an optimal threshold, further increases in density, as highlighted by Griesh and Yakout (2001), lead to a decline in maize grain yield. This decline is attributed to diminishing radiation use efficiency and heightened competition among plants for water and nutrients. Djaman et al. (2022), reported that each one-day delay in planting 88,000, 101,700, and 120,100 plant ha^{-1} decreased grain yield by 15.8, 12.8 and 23.8 kg ha^{-1}, respectively.

The present study assessed the effects of planting date and plant population on corn grain yield and agronomic performance in Alabama. The objectives of this study were to: (i) assess the effects of planting date and plant population on corn grain yield and agronomic performance; and (ii) develop a useful guide to assist farmers in replant decisions in Alabama.

By analyzing three distinct locations (Fairhope, Shorter, and Madison, AL) over two years (2022 and 2023), we sought to provide insight into the factors driving variability in corn yield and their related physiological responses on the plants. The results provided by these studies will help farmers gain understanding of the impact that planting date and seeding rate have on crop growth, yield and yield components and provide guidance for replant decisions.

MATERIAL AND METHODS

1. Site description

The research was conducted at three locations in Alabama (AL): In the at the Gulf Coast Research & Extension Center (GCREC) in Fairhope, ALin 2022 (30°32'10.5"N 87°52'42.0"W) under irrigation; in Central, AL at the the E.V. Smith Research Center (EVSRC) in Shorter, AL (32°25'35.1"N 85°53'26.4"W) in dryland conditions; and In Northt, AL the study was conducted at the Tennessee Valley Research & Extension Center (TVREC) near Madison, AL under irrigation (34°41'22.5"N 86°52'55.6"W).

At the GCREC, the predominant soil type was a Malbis fine sandy loam, characterized by 0 to 2 percent slope. The location has a mean annual precipitation ranging from 1,447 to 1,752 mm, along with a mean annual air temperature varying between 16.0 to 21.0 °C.

At EVSRC, the soil type was a Compass loamy sand, with slopes ranging from 1 to 3 percent. The location has mean annual precipitation ranging from 1,143.0 to 1,574.0 mm, along with an annual air temperature varying from 11.0 to 24.5 °C.

At TVREC the soil type was a Decatur silt loam with 0 to 2 percent slopes. The location has an annual precipitation ranging from 1,193.0 to 1,397.0 mm, along with the annual air temperature varying from 14.0 to 18.0 °C. (Weather data are reported in Figures 1.7-8.)

2. Experimental design

The experiment design was a split-plot, where planting dates were assigned as the main plot. Within each main plot (planting date), different seeding rates were applied as subplot treatments.

Each subplot comprised 4 rows (plot width) with a plot length of 7.6 m (EVSRC and TVREC) or 9.1 m (GCREC). Row spacing was 0.96 m, 0.91 m, and 0.7 m at the GCREC, EVSREC, and TVREC locations, respectively. All subplots were replicated 4 times. Table 1 shows the fertilization program for locations.

3. Research factors

3.1 Planting dates

To investigate the effects of planting dates on corn grain yield and corn plant performance, five different planting dates were employed. This approach aimed to assess how variations in planting timing, ranging from early to late, influenced plant characteristics.

Table 2 shows the targeted planting dates: March 30, April 15, April 30, May 15, and May 30. However, for GCREC in both 2022 and 2023, the actual planting dates were adjusted to March 17, March 31, April 20, May 1, and May 15. At EVSRC in 2022, planting occurred on March 30, April 11, April 29, May 12, and June 3. At the TVREC, planting dates were April 4, April 17, May 1, May 15, and May 30.

3.2 Plant population

In order to achieve different plant populations, five seeding rates were used 29,600, 44,400, 59,200, 74000, and 88,800 seeds ha^{-1} (Table 2). The study aimed to assess how differences in plant population influenced yield and the overall performance of corn plants.

4. Hybrids

Different hybrids were used at various locations. (Table 2). In this research, four corn hybrids were utilized: Pioneer 2042VYHR, Pioneer 1319R, Pioneer 1170YHR, and Dekalb 7045 across various locations and years (Table 2). These hybrids were selected because they represent a selection of relative maturity hybrids commonly planted in Alabama.

Pioneer 2042VYHR is specifically recommended for high-yielding corn silage environments and possesses a relative maturity (RM) from 117 to 120 days. This hybrid has a strong trait pyramid known as Optimum Leptra, which is produced to provide superior protection against common above-ground pests in corn crops. That consists of three distinct modes of action, that enhance control over pests such as corn borer, corn earworm, and fall armyworm, thereby contributing to improved crop health and yield potential. Additionally, this hybrid has Roundup Ready technology (RR2), which provides tolerance to the herbicide *glyphosate*, and Liberty Link technology (LL) which also provides tolerance to the herbicide *glufosinate*.

Pioneer 1319R, is a hybrid with an RM of 113 days and is a good hybrid for early to mid-late maturities, suitable for both dryland and full irrigation situations. This hybrid has the RR2 corn trait on it, which gives this hybrid tolerance to *glyphosate* herbicide.

Pioneer 1170YHR is a high-performing hybrid with RM of 111 days, making it well-suited for a range of growing conditions. One of its standout features is its incorporation of the Optimum® Intrasect® trait. This trait has two distinct modes of action and offers enhanced efficacy against a variety of common above-ground pests, including corn borers, corn earworms, and fall armyworms. Additionally, this hybrid has the technology RR2 and LL, which gives this hybrid tolerance to *glyphosate* and *glufosinate*.

Dekalb 7045 has an RM of 120 days, is equipped with VT Double PRO® corn trait, and is offers protection against a range of above-ground pests, including European and Southwestern corn borers, fall armyworms, and corn earworms. Also, this hybrid has RR2 technology, which provides tolerance to the herbicide glyphosate.

5. Corn emergence, growth, yield, and yield components

In this study, 10 variables were measured to assess the effects of planting date and seeding rate on corn growth and yield. Data collection included plant population (plants ha^{-1}), plant height (cm), ear height (cm), stalk diameter (mm), number of ears per plant (ears/plant), ear length (cm), diameter (cm), weight (g), corn grain yield (kg ha^{-1}), test weight (kg hL^{-1}).

The corn grain yield and test weight data were collected directly from the combine during harvest. Plant population data was collected from 1 m in the two center rows of each plot and then used to calculate plant ha^{-1}.

For plant height, ear height, stalk diameter, and the number of ears per plant, measurements were obtained from 10 randomly selected plants situated in the center rows of each plot. The final value for each variable represented the average of all 10 measurements taken. Plant height was recorded by measuring the height of the last leaf at the top of each plant. The height of the ear was measured at the base of the ear; in instances where a plant bore two ears, the height of the highest ear represented the ear height. Stalk diameter was measured directly in the internode below the highest ear of each plant. The number of ears per plant was determined by counts from ten different plants in each plot.

Two representative ears for each plot were hand harvested from the first and last rows of each plot. Measurements of length, diameter, and weight were recorded for each ear to generate an average.

The Growth Degree Units (GDU) or Growth Degree Days (GDD), were calculated using the equation below:

$$GDD_{daily} = \frac{(T_{max} + T_{min})}{2} - T_{base}$$

The max temperature (Tmax) is the maximum temperature recorded for the day (in Celsius or Fahrenheit), and the min temperature (Tmin), is the minimum temperature recorded for the day (in Celsius or Fahrenheit). The base temperature (Tbase) is typically around 10°C (50°F) for corn, representing the minimum temperature threshold for corn growth.

The GDU accumulation was calculated using the planting dates and the maturity group of the hybrid. Corn typically needs from 100 to 120 GDUs to emerge; depending on soil temperature can be as little as 3 to 5 days (R.L Nielsen, 2020), thus 3 to 5 days after the respective planting date, GDU accumulation begins.

6. Statistical analysis

In this study, an Analysis of Variance (ANOVA) was conducted to assess the effects of the factors of planting date and seeding rate on corn emergence, growth, yield, and yield components. ANOVA was used to determine whether there are significant differences among group means. By examining the variation between and within groups, ANOVA allows us to evaluate the influence of different factors and their interactions on the outcomes of interest. The statistical analyses were aimed to explore the main effect of planting date and seeding rate on the corn growth and yield parameters as well as their possible interactions.

After conducting the Analysis of Variance (ANOVA), a post-hoc comparisons using Tukey mean test at 10% probability for variables that showed significant differences among groups. Tukey mean test is a widely used method for pairwise comparisons of group means, particularly when conducting multiple comparisons. The Tukey mean test enabled the determination of which groups differed significantly from each other, providing further insights into the effects of the varying factors and a more detailed understanding of the relationships and differences observed in our study.

The analyses were extended to explore interactions between factors on the variables of interest. This involved applying a Tukey mean test to assess pairwise differences among levels of interaction terms identified in our Analysis of Variance (ANOVA).

Pearson correlation tests were conducted to explore the relationships between factors and corn growth and yield variables and the relationship between different variables. The Pearson correlation test is a statistical method used to assess the strength and direction association between pairs of variables. By examining the correlation coefficients to uncover any potential associations between the factors examined and the study variables. This analysis provided insights into the relationship between different factors and how they may influence the variable, and how the variables may be related to each other. Through the Pearson correlation tests, an attempt was made to identify any significant relationships that could provide valuable insights into the dynamics of our study.

7. Replant decision boards

The replant decision boards were made with the average corn yield for each seeding rate within each planting date. The highest seeding rate is assumed to represent 100% yield, meaning the highest yield achievable for each location across all planting dates and seeding rates. Additionally, the replant decision boards also included the value of corn yield (kg ha^{-1}) to present the yield produced in numbers. This offers a clear indication of how much each yield value represents in relation to the maximum achievable yield, aiding in the interpretation of the data and facilitating decision-making processes.

RESULTS AND DISCUSSION

1st case: GCREC for 2022, with the hybrid P2042VYHR

1. Growing degrees units

Growing Degree Units or Growing Degree Days (GDUs or GDDs) refers to heat accumulation, which is closely linked to crop development. By tracking GDU accumulation over time, this study was able to monitor the progress of crop growth and development stages such as emergence, flowering, and maturity. Figure 2.1 describes the GDU accumulation for the hybrid P2042VYHR in the GCREC in 2022 for all the planting dates.

The GDU accumulation was calculated using the planting dates and the maturity group of the hybrid, which in this case was 120 days. After emergence, the accumulation of GDUs was recorded to assess the duration from emergence to maturity for each planting date.

The cumulative GDU accumulation for each planting datewas as follows: 1,717 GDUs for the first planting date, 1,834 GDUs for the second planting date, 1,966 GDUs for the third planting date, 1,993 GDUs for the fourth planting date, and 1,989 GDUs for the fifth planting date.

2. Analyses of variance (ANOVA)

In 2022, at the GCREC ANOVA was conducted to assess the impact of planting date, seeding rate, and their interaction on various agronomic traits of the hybrid P2042VYHR. The results of this ANOVA (Table 3) reveal the significant effects and interactions of these factors on multiple variables, including test weight, yield, plant population, plant height, ear height, stalk diameter, number of ears, ear length, ear diameter, and ear weight.

While nearly all variables exhibited significant effects in response to planting date and seeding rate, test weight and ear diameter were not significantly influenced by from seeding rate; similarly, stalk diameter remained unaffected by variations in planting date. Moreover, the interaction between planting date and seeding rate significantly affected yield and plant population.

3. Tukey mean test

Table 4 and Table 5 present the results of the Tukey mean test, providing insights into the effects of planting date and seeding rate on various agronomic traits of hybrid P2042VYHR at GCREC in 2022. In this analysis, the planting date numbers represent the mean of all seeding rates on a specific planting date, while the seeding rate numbers represent the mean of all seeding rates across all planting dates for the studied variables.

Data reveals the interaction between seeding rate and agronomic traits such as plant height and stalk diameter. Increasing seeding rate leads to higher plant populations, resulting in greater competition among plants for essential resources such as nutrients, water, and light. Greater plant densities result in increased plant height (Ling et al., 2023). Plant height ranged from 242 to 250 cm from the lowest to highest seeding rates, respectively (Table 4). Conversely, stalk diameter reduced as the seeding rate were increased (Table 5), from 16.9 mm to 15.6 mm from the lowest to the highest seeding rate. This can be attributed to the reduced competition among plants in a less densely populated area, allowing individual plants to allocate resources towards lateral growth rather than vertical elongation, decrease.

The number of ears per plant decreased with later planting dates, from 1.25 ears per plant on the first planting date to 1.0 ears per plant on the last planting date (Table 5). This trend can be attributed to the limited time and less favorable conditions for ear development associated with later planting dates. Also, when examining seeding rates and the number of ears, lower plant densities allowed individual plants to access the necessary resources for ear development and grow more than one ear. In contrast, higher plant densities lead to increased competition, resulting in fewer ears per plant.

When analyzing the size and weight of ears across different planting dates and seeding rates, it becomes apparent that late planting dates result in decreased ear size and weight (Table 5), with reductions of 19.7 to 19.3 cm in length, 48.6 to 42.6 mm in diameter, and 287.7 to 186.0 g in weight from the first to the last planting date. This can be attributed to the limited time available for ear development and the less favorable growing conditions associated with later planting dates. Additionally, as seeding rates increase, there is a corresponding decrease in ear size and weight, as evidenced by reductions in ear length and weight; ear diameter was not significantly affected by seeding rates. This trend indicates that higher seeding rates lead to the production of smaller ears, with a reducing mean from 19.6 to 19.0 cm in length, 47.3 to 46.5 mm in diameter, and 256.1 to 241.0 g in weight from the first to the last seeding rate.

In Table 6, the interaction between each seeding rate and planting date is examined alongside the variables where the ANOVA indicated significant interactions. Data indicate that within each planting date, increasing seeding rates lead to a corresponding increase in yield from

10,300 to 14,500 kg ha^{-1} on the first, from 12.270 to 15,300 in the second, from 9,300 to 11,800 in the third, from 8,800 to 11,800 in the fourth and from 5,100 to 9,100 in the last planting date. However, as planting dates progressed, yields declined from 14,500 kg ha^{-1} at the first planting date to 9,100 kg ha^{-1} on the last planting date. Furthermore, at the last planting date, yields also declined as seeding rates declined.

4. Pearson correlation analyses

Table 37 provides an analysis of the Pearson correlation coefficients among the variables investigated in this study for this case. Specifically, the variable 'yield' demonstrates a statistically significant positive relationship with plant population (Figure 3.1 A), ear diameter (Figure 3.1 B), and ear weight (Figure 3.1 C). The correlation coefficients of 0.28, 0.61, and 0.65, respectively, indicate a direct relationship between yield and these factors.

In Figure 3.1 A, the interaction between planting date and plant population, and the variable yield is depicted, showing the differences in crop performance under varying conditions. Specifically, the hybrid P2042VYHR showed a consistent trend across all planting dates, it means that increasing the plant population also increases yield. However, the trend is similar for different planting dates.

With different planting dates the plant grows in distinct environmental conditions and, consequently, the response of the hybrid P2042VYHR to differing plant populations and planting dates shows fluctuations in yield. Environmental conditions play a significant role associated with plant physiology promoted by heat accumulation (Degree Units or "GDUs"). For this hybrid, the GDU accumulation required for flowering is 1,440 and for grain harvest maturity is 2,860.

As temperature rises along the season, delay in planting dates causes the plant to achieve flowering faster. In this case, the first planting date achieved flowering in 75 days, the second in 72 days, the third in 71 days, the fourth in 66 days, and the fifth in 65 days.

The second planting date, occurring on March 31, had a moderate average temperature of 22°C and a notably higher rainfall accumulation of 255 mm until flowering, this planting window provided optimal conditions for pollination, translating into higher yields. Following closely behind, the first planting date experienced relatively favorable conditions with an average temperature of 21°C and a rainfall accumulation of 204 mm. Subsequently, the third, fourth, and fifth planting dates encountered progressively higher temperatures and diminishing rainfall accumulation impacted negatively on pollination time (Figure 1.2). The third planting date, with temperatures averaging 24°C and rainfall accumulation of 178 mm, followed by the fourth and fifth dates with temperatures of 25°C and 26°C and 176 mm and 173 mm, respectively (Figure 1.2). These higher temperatures and decreasing rainfall accumulation maintained a consistent but lower yield compared to the first and second planting dates.

Comparatively, while the differences in days to grain harvest maturity among the planting dates are relatively minor, the second planting date is the best one with 148 days to maturity. This shorter duration to maturity allows harvesting the crop earlier, reducing the risk of exposure to potential quality threats, along with the other factors above promoting the highest yield. The first, third, fourth, and fifth planting dates all required 150, 146, 146, and 146 days, respectively, to reach grain harvest maturity.

For the variable ‘plant population’ (Figure 3.2), analysis revealed statistically significant relationships with five variables, all displaying negative relationships with the plant population. Stalk diameter (Figure 3.2 A) with a Pearson correlation coefficient of -0.43, indicates a moderate negative relationship; specifically, increasing plant populations decrease stalk diameter. Similarly, the number of ears per plant (Figure 3.2 B) showed a Pearson coefficient of -0.48, suggesting that as the population increased the number of ears per plant decreased. Furthermore, ear length (Figure 3.2 C) displayed a Pearson coefficient of -0.32, while ear diameter (Figure 3.2 D) and ear weight (Figure 3.2 E) exhibited coefficients of -0.21 and -0.26, respectively. This indicates that as population increases, lighter and smaller cobs are produced, as shown on Table 5.

5. Replant decisions boards

Table 7 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages depicted in the table are calculated relative to the maximum observed yield for each combination of the two factors.

This table offers critical insights for replant decisions. For instance, suppose a field was initially planted on March 17th with a target plant population of 79,900 plants ha^{-1} with a target for a yield of 13,755 kg ha^{-1} (89% of the maximum yield for this year and location). If the actual stand only reaches 50,000 plants ha^{-1}, that represents 78% of the maximum potential yield at 11,900 kg ha^{-1}. After 15 days, if the farmer opts to replant on March 31 and achieves the desired stand of 79,700 plants ha^{-1}, the new yield potential is 14,795 kg ha^{-1}, an increase of 2,895 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional gross return of $549.00 per hectare. The estimated cost for is approximately $506.00 ha^{-1} according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential gain from replanting outweighs the associated costs by $43.00 per hectare, it is economically advantageous for the farmer to proceed with replanting.

In another scenario, suppose a field was initially planted on March 31 with a target plant population of 64,400 plant $ha^{-1}$and a target for a yield of 13,471 kg ha^{-1}, which is 91% of the maximum yield for this year and location. If the actual stand only reaches 50,000 plants, representing 80% of the maximum potential yield at 12,275 kg ha^{-1}. After 15 days, on April 20, if the farmer opts to replant and achieves the desired stand of 64,400 plants per hectare, the new yield potential is 11,051 kg ha^{-1}, a decrease of 224 kg ha^{-1} from the initial stand. Given that the potential profit from replanting would be less than the initial stand, replanting is not recommended.

2^{nd} case: GCREC for 2022, with the hybrid P1319R.

1. Growing degrees units

In this scenario, the results are shown in Figure 2.2. The maturity group of the hybrid P1319 is 113 days. Across all planting dates, GDU accumulation was recorded as follows: 1,595 for the first planting date, 1,719 for the second planting date, 1,856 for the third planting date, 1,872 for the fourth planting date, and 1,902 for the fifth planting date.

2. Analyses of variance (ANOVA)

The ANOVA conducted for this case (Table 8) revealed significant effects of planting date on all variables studied. The seeding rate significantly influenced all variables except for the number of ears. Significant interactions occurred between seeding rate and planting date in the variables of yield (P>F < 0.0001) and plant population (P>F = 0.0489).

3. Tukey mean test

For the variable test weight, the results indicate that delaying the planting date leads to a decrease in test weight, highlighting a negative relationship between them (Table 9). Test weight decreased from 70.3 to 66.9 kg hL^{-1} from the first to the last planting date. Also, an inverse relationship is observed with the seeding rate, where increasing seeding rate corresponded to an increase in test weight ranging from 68.2 to 69.5 kg hL^{-1} from the first to the last seeding rate.

Also, plant height increased from 238.0 cm to 270.5 cm for the first to the third planting date (Table 9). However, it is worth noticing that due to excessive rainfall in that year, measurements of plant height were not possible for the last two planting dates. Similarly, as the seeding rate increased, plant height also increased, from 248.0 cm to 257.0 cm, for the lowest to the highest seeding rates.

As seeding rates increased, stalk diameter decreased (Table 10), which can be attributed to increasing competition among plants for water and nutrients. At the lowest seeding rate stalk diameter was 17.8 mm and 15.9 mm at the highest seeding rate.

In this case, planting date was the only variable that significantly affected the number of ears per plant, indicating a negative relationship between planting dates and ear numbers. Ears per plant declined from 1.02 to 0.95 ears per plant from the first to last planting date.

As planting dates are delayed, the size and weight of ears decline (Table 10). For instance, ear measurements transition from 19.7 cm in length, 48.0 mm in diameter, and 281.0 g in weight for the first planting date to 18.3 cm, 43.5 mm, and 199.0 g, respectively, for the last planting date.

Similar decreases occurred with increases in seeding rates. Across the range from the lowest to the highest seeding rates, there is a consistent decline in the mean values for ear length, diameter, and weight. Specifically, the measurements decrease from 19.9 cm in length, 47.0 mm in diameter, and 271.0 g in weight for the lowest seeding rate to 18.7 cm, 45.9 mm, and 231.0 g, respectively, for the highest seeding rate (Table 10).

Significant interactions between planting date and seeding rates are reported in Table 11. Data indicates that as seeding rates increase within each planting date, there is a corresponding increase in yield. For instance, the yield rises from 9,000 to 13,000 kg ha^{-1} in the first planting date and from 4,000 to 10,000 kg ha^{-1} in the last planting date. It is also noteworthy that while the yield increases similarly in all planting dates with increasing seeding rate, the mean of the lowest and highest seeding rates differs between the first and last planting dates. Specifically, the mean yield for the lowest seeding rate is higher in the first planting date compared to the last, ranging from 9,000 to 4,800 kg ha^{-1}, while for the highest seeding rates, it ranges from 13,000 to 10,000 kg ha^{-1} in the first and last planting dates, respectively.

A similar relationship between seeding rates within the planting dates and plant population is observed. Increasing the seeding rates correlates positively with plant population within each planting date. For instance, with the increase in the seeding rate from 29,600 to 88,800 seeds ha^{-1} on the first planting date, there is an increase in plant population from 33,600 to 84,100 plants ha^{-1}. Likewise, on the last planting date, increasing the seeding rate from 29,600 to 88,800 seeds ha^{-1} results in an increase in plant population from 45,300 to 82,800 plants ha^{-1}. This indicates that the planter dropped considerably more seed than intended at this location.

4. Pearson correlation analysis

Table 37 presents an analysis of the Pearson correlation coefficients among the variables investigated at this site. Figure 3.3 shows the relationship between yield and several variables. Yield and plant height and ear diameter demonstrate positive relationships with plant population (Figure 3.3A), as evidenced by coefficient of 0.52. 0.37, (Figure 3.3B) and 0.29, respectively (Figure 3.3D). Inversely, stalk diameter displays a negative relationship with yield (Figure 3.3C), characterized by a coefficient of -0.28.

Figure 3.3 A presents the dynamic interaction between planting date, plant population, and resulting yield, showcasing the differences in crop performance across varying conditions. Across all planting dates, the hybrid P1319R consistently demonstrates a positive relationship between plant population and yield, indicating that higher plant densities lead to increased yield. However, there are variations in how these factors interact and influence yield.

For this hybrid, the accumulation until flowering is recorded at 1,400 GDUs, with 2,700 GDUs accumulated until grain harvest maturity. As the planting dates progress forward into the season, there is a faster timing in achieving flowering. Specifically, the first planting date achieved flowering in 77 days, followed by the second in 74 days, the third in 70 days, the fourth in 65 days, and the fifth in 62 days.

The second planting date, occurring on March 31, stands out with a moderate average temperature of 23°C and significantly higher rainfall accumulation of 258 mm until flowering. These optimal conditions during the critical pollination period contribute to higher yields. In comparison, the first planting date (March 31) experienced favorable conditions with an average temperature of 21°C and rainfall accumulation of 210 mm (Figure 1.2). However, subsequent planting dates encountered progressively higher temperatures and less rainfall accumulation, negatively impacting the pollination process, with temperatures averaging 25°C and rainfall accumulation of 185 mm on the third planting date (April 20), followed by the fourth (May 1) and fifth dates (May 15) with temperatures of 26°C and 26°C and 180 mm and 170 mm, respectively (Figure 1.2).

Despite minor differences in the days to grain harvest maturity among planting dates, the second planting date was the best with 147 days to maturity. This period duration allows for earlier harvesting along with the other factors above promoting higher yields. Specifically, the first, third, fourth, and fifth planting dates required 150, 140, 140, and 135 days, respectively, to reach grain harvest maturity.

In Figure 3.4, the relationship between plant population and several variables is depicted. Notably, plant population demonstrates a positive relationship with plant height (Figure 3.4 A), as evidenced by a coefficient of 0.32, a relationship consistent with the findings from Table 10, where an increase in plant population increased plant height. Conversely, plant population exhibits negative relationships with other variables. Specifically, stalk diameter (Figure 3.4 B), ear length (Figure 3.4 C), ear diameter (Figure 3.4 D), and ear weight (Figure 3.4 E) all display negative relationships with plant population, with coefficients of -0.52, -0.38, -0.29, and -0.42, respectively. These relationships suggest that as plant population increases, stalk diameter decreases, along with reductions in ear length, ear diameter, and ear weight.

5. Replant decision boards

Table 12 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages in the table are calculated relative to the maximum observed yield for each combination of the two factors.

This table offers critical insights guiding replant decisions in agricultural management. For instance, suppose a field was initially planted on March 17 with a target plant population of 80,700 plants ha^{-1} with a target for a yield of 12,643 kg ha^{-1} (91% of the maximum yield for this year and location). If the actual stand only reaches 52,500 plants ha^{-1}, that represents 74% of the maximum potential yield, with 12,290 kg ha^{-1}. After 15 days, if the farmer opts to replant on March 31 and achieves the desired stand (80,700 plants ha^{-1}), potential yield in this new case is 13,917 kg ha^{-1}, an increase of 1,629 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional gain of $325.00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential costs outweigh the gain from replanting by $181.00 ha^{-1}, replanting is not recommended.

In another scenario, suppose a field was initially planted on March 17 with a target of 80,700 plants ha^{-1} with a target for a yield of 12,643 kg ha^{-1} (91% of the maximum yield for this year and location). If the actual stand only reaches 40,300 plants ha^{-1}, that represents 65% of the maximum potential yield, with 9,113 kg ha^{-1}. After 15 days, if the farmer opts to replant on March 31 and achieves the desired stand (80,700 plants ha^{-1}), potential yield in this new case 13,917 kg ha^{-1}, an increase of 4,804 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional gain of $960.00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for

2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential gain from replanting outweighs the associated costs by $454,00 per hectare, it is advantageous to replant.

3rd case: GCREC for 2023, with the hybrid DKB7045.

1. Growing degrees units

For the year 2023, at the GCREC, with the hybrid DKB7045, which achieves grain maturity at 120 days, the accumulation of GDUs is as follows in Figure 2.3. The recording of the GDU began at the emergence of the plants, which occurred two days after planting. The total accumulation of GDUs was recorded for all planting dates as follows: First planting date 1,720 GDUs, second planting date 1,850 GDUs, third planting date 2,080 GDUs, fourth planting date 2,150 GDUs, and last planting date 2,180 GDUs.

2. Analyses of variance (ANOVA)

The ANOVA for hybrid DKB7045 in 2023 at GCREC (Table 13) reveals that the main effects of planting date and seeding rate significantly influenced all variables except for ear length under the factor planting date. A significant interaction was observed between the planting date and seeding rate only for the number of ears per plant.

3. Tukey Mean Test

Yields decreased as the planting date was delayed, from 16,500 kg ha^{-1} in the first planting date to 10,500 kg ha^{-1} at the last planting date (Table 14). Unlike the previous year, there was no increase in yield from the first to the second planting date.

Regarding the effect of seeding rate, a similar trend to the previous year is observed, yield increased as seeding rate increased. Specifically, for the lowest seeding rate (29,600 seeds ha^{-1}), yield was 8,800 kg ha^{-1}, while for the highest seeding rate (88,000 seeds ha^{-1}), the yield reached 16,200 kg ha^{-1}.

Test weight exhibited a distinct pattern compared to yield (Table 14). Test weight decreased with delayed planting, declining from 69.5 kg hL^{-1} on the first date to 45.4 kg hL^{-1} on the last planting date. Conversely, as the seeding rate was increased, test weight also increased, ranging from 40.9 to 65.9 kg hL^{-1} from the lowest to the highest seeding rate.

While the planting date exhibited almost no significant effect on plant population, seeding rate had a significant positive relationship with plant population. As the seeding rate increased, so did the plant population, ranging from 35,700 plants ha^{-1} to 89,000 plants ha^{-1} from the lowest to the highest seeding rate (Table 14).

Plant height was affected by e planting date as follows: heights increased from the first to the second planting date, but subsequently, heights decreased with later planting dates. Heights were, ranging from 236, 253, 245, 227, and 226 cm, from the first to the last, respectively. Increased seeding rates positively influenced plant heights, ranging from 230.3 cm in the lowest seeding rate to 243.0 cm in the highest seeding rate (Table 14). Increasing seeding rates reduced stalk diameter, with 18.3 mm for the lowest seeding rate and 15.0 mm for the highest seeding rate (Table 15).

A negative relationship was observed between planting date and seeding rate with some variables. As planting dates were delayed, the size and weight of the ears decreased. Specifically, the measurements transition from 54 mm in diameter and 345.0 g in weight for the first planting date to 48.0 mm, and 270.0 g, respectively, to the last planting date (Table 15).

A similar effect is apparent with increases in seeding rate. From the lowest to the highest seeding rates, there is a consistent decline in ear length, diameter, and weight. Specific measurements were 21.0 cm in length, 53.0 mm in diameter, and 356.0 g in weight for the lowest seeding rate and 18.6 cm, 49.0 mm, and 278.0 g, respectively, for the highest seeding rate (Table 15).

Of the possible variables, the only significant interaction between planting date and seeding rate was the number of ears (Table 16). As the seeding rate increased within the first two planting dates, ear number decreased from 1.95 to 1.07 ears per plant in the first planting date and from 1.77 to 1.05 ears per plant in the second planting date. However, for all other planting dates, there was no significant statistical difference observed within the same planting dates for all seeding rates. Notably, the first two planting dates exhibited a higher mean for the first two seeding rates (29,600 and 44,400 seeds ha^{-1}) compared to the other planting dates.

4. Pearson correlation analysis

Table 37 provides a comprehensive analysis of the Pearson correlation coefficients among the variables investigated in this study. In Figure 4.1, the relationships for the variable yield and all statistically significant variables are presented. Figure 4.1 A illustrates the relationship between yield and plant population, revealing a positive relationship with a coefficient of 0.72. This indicates that as plant population increases, there is a corresponding increase in yield. In Figure 4.1, additional relationships between yield and various variables are highlighted. A positive relationship is observed between yield and plant height (Figure 4.1 B), with a coefficient of 0.44. This suggests that higher seeding rates lead to taller plants and result in increased yields, supporting the findings from Table 14. Conversely, a negative relationship is noted between yield and stalk diameter (Figure 4.1 C), with a coefficient of -0.57. This implies that an increase in stalk diameter negatively affects yield. Furthermore, a negative relationship is observed between yield and ear length, with a coefficient of -0.54. This indicates that even though larger cobs may be observed in lower populations, the reduced number of ears per plant is insufficient to promote better yields.

In Figure 4.2, the relationship between plant population and other variables is depicted. Plant population demonstrates a positive relationship with plant height (Figure 4.2 A), with a coefficient of 0.31, which aligns with findings in Table 14, that when the seeding rate increases, plant population increases and as a result promotes taller plants. Conversely, plant population exhibits negative relationships with several other variables. For stalk diameter (Figure 4.2 B), the number of ears per plant (Figure 4.2 C), ear length (Figure 4.2 D), ear diameter (Figure 4.2 E), and ear weight (Figure 4.2 F), the coefficients are -0.84, -0.52, -0.65, -0.27, and -0.50 respectively. These negative relationships suggest that as plant population increases, there is a decrease in stalk diameter, number of ears per plant, ear length, ear diameter, and ear weight.

5. <u>Replant decision boards</u>

Table 17 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages depicted in the table are calculated relative to the maximum observed yield for each combination of those two factors.

This table offers critical insights regarding replant decisions. For instance, suppose a field was initially planted on March 17 with a target plant population of 80,000 plants ha^{-1} with a target for a yield of 18,651 kg ha^{-1} (92% of the maximum yield for this year and location). If the actual stand only reaches 48,400 plants ha^{-1}, that represents 70% of the maximum potential yield, with 14,269 kg ha^{-1}, and the farmer starts considering replanting the field. After 15 days, on March 31st, if the farmer opts to replant and on March 15 achieves the desired stand (80,000 plants ha^{-1}), potential yield is 15,343 kg ha^{-1}, an increase of 1,074 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional profit of $214.80 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential costs outweigh the profit from replanting by $292.00 per hectare, replanting is not recommended.

In another scenario, suppose a field was initially planted on March 17 with a target plant population of 80,000 plants ha^{-1} with a target for a yield of 18,651 kg ha^{-1} (92% of the maximum yield for this year and location). If the actual stand only reaches 35,700 plants ha^{-1}, that represents 62% of the maximum potential yield, with 12,502 kg ha^{-1}. After 15 days, if the farmer opts to replant on March 31 and achieves the desired stand (80,000 plants ha^{-1}), potential yield is 15,343 kg ha^{-1}, an increase of 2,841 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional profit of $568.00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential profit from replanting outweighs the associated costs by $62,00 per hectare, replanting is a sound decision.

4th case: EVSRC in 2022, with the hybrid P2042VYHR.

1. Growing degrees units (GDU`s)

In the scenario results are shown in Figure 2.4. The maturity group of the hybrid P2042VYHR is 120 days. Across all planting dates, GDU accumulation was 1,680 for the first planting date, 1,760 for the second planting date, 1,815 for the third planting date, 1,846 for the fourth planting date and 1,770 for the fifth planting date.

2. Analyses of variance (ANOVA)

The ANOVA, conducted for this case (Table 18) indicated that the planting date factor showed a significant influence on all variables under consideration, besides plant population, that had a P>F (0.6425) bigger than the threshold of 0.05. The seeding rate factor did not demonstrate a significant effect on certain variables, such as test weight, plant height, and ear height, that had a P>F of 0.995, 0.366, and 0.109, respectively. The interaction between seeding rate and planting date demonstrated a significant effect on only yield (P>F 0.026) and number of ears (P>F 0.0001).

3. Tukey Mean Test

The analysis revealed that for the variable test weight was primarily influenced by the planting date (Table 19). Specifically, there was a noticeable decrease in the test weight from the first to the third planting date, decreasing from 74.5 to 73.1 kg hL^{-1} respectively. However, a slight increase was observed for the fourth planting date, rising to 74.4 kg hL^{-1}, before declining again to 66.4 kg hL^{-1} in the last planting date.

While variations in test weight were observed among different planting dates, statistical analysis revealed that the first to the third planting dates did not differ significantly. Similarly, there were no statistically significant differences between the second and third planting dates, nor between the third and fourth planting dates.

The analysis revealed that plant population was significantly influenced by seeding rate alone (Table 19). With the increase in seeding rate, there was a corresponding rise in plant population across the range of seeding rates. Notably, the initial seeding rate of 29,600 seeds ha^{-1} resulted in a plant population of 35,500 plants ha^{-1}, while the highest seeding rate of 88,800 seeds ha^{-1} led to a plant population of 86,000 plants ha^{-1}.

Plant height for this location was only affected by planting date, which showed an increase from the first to the second from 213.0 cm to 232.0 cm, and then a slight decrease on the third for 197,0cm, starting to increase again on the fourth 237,0 cm and the fifth planting dates to 250,8 cm (Table 19).

Stalk diameter exhibited a significant influence from both the planting date and seeding rate factors (Figure 3.3). Specifically, from the first to the second planting date, there was an increase from 16.0 mm to 17.0 mm, followed by a decrease in the third date to 13.2 mm. Subsequently, on the fourth planting date, plants showed an increase in stalk diameter to 17.7 mm before decreasing again on the last planting date to 16.7 mm. Despite the observed pattern of increase and decrease, statistical significance was only evident for the third date (April 29), indicating notable differences in stalk diameter at that specific planting date.

Regarding the seeding rate, while a decrease in stalk diameter was observed across the rates, statistical significance was only noted for the lowest rate (Table 20). Notably, this rate exhibited a significant difference compared to the others, decreasing from 17.1 mm to 15.9 mm from the lowest to the highest rate.

Earlier planting dates and lower seeding rates correlated with a higher number of ears per plant, suggesting that planting early in the season and using lower seeding rates could lead to increased ear production per plant (Figure 3.3).

When examining the size of the ears, both planting date and seeding rate demonstrated a negative relationship with ear length, diameter, and weight (Figure 3.3). Delaying the planting date resulted in smaller and lighter ears. Ear length decreased from 19.3 cm on the first planting date to 17.9 cm on the last planting date, while the diameter decreased from 46.3 mm to 44.4mm over the same period. Similarly, ear weight decreased from 246.0 g to 210.0 g from the first to the last planting date. While a decreasing pattern is evident across different seeding rates, it's notable that only the first planting date exhibited significantly better results compared to all other seeding rates. In a similar way, the impact of the seeding rate revealed a decrease in ear length from 19.2 cm to 17.1 cm, a reduction in ear diameter from 45.5 mm to 43.9 mm, and a decrease in ear weight from 239.0 g to 192.0 g, observed from the lowest to the highest seeding rate. For ear length, the seeding rate of 44,400 seeds ha^{-1} was the highest value and was statistically distinct from the other rates. In contrast, for ear diameter and ear weight, the seeding rates of 29,600 and 44,000 seeds ha^{-1} respectively exhibited the highest values, standing out significantly from all other rates.

Significant interactions between seeding rates and planting dates are reported in Table 21.

The data showed that as the seeding rate increases, there is a corresponding increase in yield. For instance, in planting date one, the yield rises from 4,900 kg ha^{-1} for the lowest seeding rate to 5,700 kg ha^{-1} for the highest seeding rate. On the last planting date, an increase ranging from 5,100 kg ha^{-1} to 6,700 kg ha^{-1} was observed from the lowest to the highest seeding rate. This pattern repeats in all the planting dates. The Tukey mean test revealed the interaction of planting date and seeding rate and the variable of the number of ears. As the seeding rate increases within each planting date, there is a decrease in the number of ears per plant. Notably, the first two planting dates exhibited statistically higher mean values for the two lowest seeding rates, with 1.62 ears per plant and 1.57 ears per plant for the seeding rate of 26,000 seeds ha^{-1}, and 1.45 and 1.42 ears per plant for the seeding rate of 44,400 seeds ha^{-1}. Indeed, this observation can be explained by when the planting date is early, that allows the crop more time to undergo development, potentially leading to the formation of more than one ear per plant. Moreover, the lower seeding rate facilitates better access to essential nutrients and water for individual plants, enabling them to redistribute these resources for the formation of additional ears.

4. <u>Pearson correlation analysis</u>

Table 37 offers an analysis of the Pearson correlation coefficients among the variables investigated. Figure 5.1 shows the relationship between yield and several variables. Yield showed a significant relationship with all the variables.

Figure 5.1 A shows the interaction between planting date, plant population, and resulting yield, depicting the differences in crop performance across varying conditions. Across all planting dates, the hybrid 2042VYHR consistently demonstrates a positive relationship between plant population and yield, indicating that higher plant densities lead to increased yield, but there are variations in how these factors interact and influence yield.

For this hybrid, the accumulation until flowering is recorded at 1,440 GDUs, with 2,860 GDUs accumulated until grain harvest maturity. As the planting dates progress forward into the season, there is a faster timing in achieving flowering. Specifically, the first planting date achieved flowering in 76 days, followed by the second in 70 days, the third in 70 days, the fourth in 64 days, and the fifth in 64 days.

In this location, all planting dates benefited from favorable conditions in terms of temperature and rainfall accumulation. The first planting date, on March 30, had an average temperature until flowering of 21°C and a substantial rainfall accumulation of 341 mm. Following closely, the second planting date, on April 11, experienced slightly warmer temperatures at 23°C and received 241 mm of rainfall. Similarly, the third planting date, occurring on April 29, encountered an average temperature of 25°C and received 296 mm of rainfall. On the fourth planting date, on May 12, the temperatures rose to 26°C with rainfall totaling 291 mm. Lastly, the fifth planting date, on June 3, registered an average temperature of 27°C and received 294 mm of rainfall, as depicted in Figure 1.6.

This location presented minimal differences in the days to grain harvest maturity among planting dates, the second planting date had 150 days to maturity, while the second, third, fourth, and fifth planting dates required 147, 146, 140, and 140 days, respectively.

In Figure 5.1 B, the relationship between yield and plant height, with a positive relationship with a Pearson coefficient of 0.40. This observation underscores the significant influence of plant height on yield outcomes within our study context. Increased seeding rates often result in taller plants. This positive relationship between yield and plant height aligns with the findings presented in Table 19, which demonstrate an increase in yield corresponding to increased seeding rates.

In Figure 5. C, yield and stalk diameter show a positive relationship, with a Pearson coefficient of 0.33. This suggests that an increase in stalk diameter is generally associated with higher yields. However, it's important to note that this positive relationship may only hold true up to a certain threshold. Beyond this threshold, further increases in stalk diameter may not result in significant yield improvements.

The variable yield exhibits negative relationships with other four variables, such as, number of ears per plant (Figure 5.1 D), ear length (Figure 5.1 E), ear diameter (Figure 5.1 F), and ear weight (Figure 5.1 E), with Pearson correlation coefficients of -0.21, -0.35, -0.55, and -0.49, respectively. These negative relationships suggest that as yield increases, there tends to be a decrease in the number of ears per plant, as well as in the length, diameter, and weight of individual ears. Such characteristics are typically associated with lower plant populations, higher numbers of ears, and larger and heavier ears. This relationship aligns with the findings presented in Tables 3.1 and 3.2, which indicate that higher yields are achieved with higher seeding rates. Consequently, the negative relationship observed between yield and these variables can be attributed to the impact of seeding rates on these factors.

In Figure 5.2, the relationship between plant population and other variables is depicted. Specifically, the number of ears per plant (Figure 5.2 A), ear length (Figure 5.2 B), ear diameter (Figure 5.2 C), and ear weight (Figure 5.2 D) exhibited negative Pearson correlation coefficients of -0.40, -0.50, -0.31, and -0.47, respectively. These negative relationships indicate that as plant population increases (directly related to the increase of the factor seeding rate), there tends to be a decrease in the number of ears per plant, as well as in the length, diameter, and weight of individual ears.

5. Replant decision boards

Table 22 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages in the table are calculated relative to the maximum observed yield for each combination of the two factors.

This table offers critical insights guiding replant decisions in agricultural management. For instance, suppose a field was initially planted on March 30 with a target plant population of 73,500 plants ha^{-1} with a target for a yield of 5,422 kg ha^{-1} (59% of the maximum yield for this year and location). If the actual stand only reaches 35,500 plants ha^{-1}, that represents 54% of the maximum potential yield, with 4,960 kg ha^{-1}, and the farmer starts considering replanting the field. After 15 days, on April 11, if the farmer opts to replant and achieves the desired stand (73,500 plants ha^{-1}), yielding in this new case 7,732 kg ha^{-1}, that is an increase of 2,772 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional gain of $554,00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential profit from replanting outweighs the associated costs by $554,00 ha^{-1}, it is economically advantageous for the farmer to proceed with replanting in this scenario.

In another scenario, suppose a field was initially planted on April 11^{t} with a target plant population of 73,500 plants ha^{-1} with a target for a yield of 7,732 kg ha^{-1} (85% of the maximum yield for this year and location). If the actual stand only reaches 35,500 plants ha^{-1}, that represents 71% of the maximum potential yield, with 6,458 kg ha^{-1}, and the farmer starts considering replanting the field. After 15 days, on April 29, if the farmer opts to replant and achieves the desired stand (73,500 plants ha^{-1}), yielding in this new case 5,298 kg ha^{-1}, that is a decrease of 1,934 kg ha^{-1}. In this case, the decrease of yield would not provide any additional profit for the farmer, so is recommended not to replant.

5th case: EVSRC in 2022, with the hybrid P1319R.

1. Growing degrees units (GDU`s)

In this scenario the results are shown in Figure 2.5. The maturity group of this particular hybrid is 113 days. Across the various planting dates, GDU accumulation was recorded as follows:1,560, 1,690, 1,700, 1,750, and 1,720 recorded from the earliest to the latest planting dates, respectively.

2. Analyses of variance (ANOVA)

The ANOVA conducted for this case is in Table 23. All the variables were significantly affected by the planting date factor, as evidenced by the P>F values of 0.0001. However, the seeding rate factor did not show significant effects on test weight (P>F, 0.8360), plant height (P>F, 0.97), ear height (P>F, 0.6377), and number of ears (P>F, 1.000). The interaction between planting date and seeding rate did not demonstrate any significant effect on any of the variables in this case.

3. Tukey mean test

The variable yield was influenced by both the planting date and seeding rate (Table 24). When considering the planting date, yield increased from the first to the second planting date, rising from 6,000 kg ha^{-1} to 8,700 kg ha^{-1}. However, there was a decrease in yield for the third planting date, dropping to 6,900 kg ha^{-1}, followed by another increase to 8,600 kg ha^{-1}. The last planting date had the lowest yield of 4,500 kg ha^{-1}. The seeding rate exhibited a pattern similar to the other cases, as the seeding rate increased was observed higher yields. Yields ranged from 6,300 kg ha^{-1} for the lowest seeding rate to 7,400 kg ha^{-1} for the highest seeding rate. While there was a slight increase in yield from the lowest to the highest seeding rates, statistical significance was observed only for the three highest seeding rates (59,200, 74,000, and 88,800 seeds ha^{-1}), which yielded better compared to the other two rates.

Test weight was only affected by planting date (Table 24). Test weight for the first two planting dates (March 30, and April 11) was significantly higher compared to the others, with values of 74.66 kg hL^{-1} and 74.26 kg hL^{-1}, respectively, indicating no statistical difference between them, but just from them to the other three dates (April 29, May 12, and June 3).

Plant population was affected by both planting date and seeding rate (Table 24). Across different planting dates, was observed minor fluctuations in plant population over time, with the overall mean remaining relatively consistent. However, as the seeding rate increased, so did the plant population. While the two lowest seeding rates did not exhibit any significant difference, all other seeding rates demonstrated a clear trend: higher seeding rates resulted in higher plant populations.

Only the planting date exhibited a significant effect on plant height (Table 24). Was observed a decrease in plant height from the first to the third planting dates, with measurements dropping from 229.0 cm to 212.0 cm and further to 200.0 cm, respectively. Although these differences were not statistically significant, they indicated a trend of decreasing height across these dates. Conversely, the fourth and fifth planting dates showed an increase in plant height, reaching 232.0 cm and 237.0 cm, respectively. While these heights did not differ significantly from each other, they were notably higher than those observed in the first three planting dates.

Both planting date and seeding rate exhibited significant effects on stalk diameter (Table 25). Was observed a decrease from the first to the third planting dates (16.4 mm, 15.5 mm, and 13.9 mm, respectively), followed by a slight increase on the fourth planting date to 16.1 mm, and then a decrease again on the fifth planting date to 14.8 mm. As for seeding rate, increasing the seeding rate led to a decrease in stalk diameter. Despite this trend, only the fifth seeding rate showed the lowest value, while the first two seeding rates (26,900 and 44,400 seeds ha^{-1}) exhibited the highest mean values for stalk diameter.

The number of ears per plant exhibited significant effects only for the planting date factor (Table 25). As the planting date was delayed to later dates, there was a decrease in the ears per plant, ranging from 1.0 on the first date to 0.97 ears per plant on the last date. While this trend was evident, only the third planting date (April 29) with 0.91 ears per plant, showed statistical significance compared to all the other four dates.

Planting date demonstrated a significant effect on ear sizes (Table 25). Ear length showed a slight decrease from the first date to the last (19.0 to 18.8 cm). However, the third planting date showed the lowest mean value and was statistically different from all the other ones, all the other dates showed no significant statistical difference. Similarly, ear diameter decreased as the planting date was delayed, ranging from 47.0 mm to 44.0 mm from the first to the last planting date respectively. The first planting date exhibited the highest value, which was statistically significantly different from the other planting dates. Ear weight decreased from the first to the third planting date (262.0 g, 239.0 g and 203.0 g), then showed an increase in the last two planting dates, reaching 222.0 g and 227.0g.

Seeding rates exhibited a similar effect on ear sizes as the seeding rate increased, there was a decrease in ear length, ear diameter, and ear weight. Across the planting dates, ear length decreased from 19.0 cm to 16.9 cm, ear diameter decreased from 46.0 mm to 44.5 mm, and ear weight decreased from 250.0 g to 197.0 g from the first to the last planting date respectively (Table 25).

The absence of a significant interaction between the planting date and seeding rate factors indicates that their combined effect on the variables under study did not deviate significantly from what would be expected based on their individual effects. In other words, the impact of one factor did not depend on the level of the other factor, and vice versa.

This lack of interaction suggests that the effects of planting date and seeding rate on the measured variables can be considered independently. Each factor may independently contribute to the observed outcomes without any synergistic or antagonistic effects resulting from their combination.

4. Pearson correlation analysis

Table 37 presents a comprehensive analysis of the Pearson correlation coefficients among the variables investigated in this study. In Figure 5.3, the relationships of the variable yield are depicted, revealing statistical significance in two variables. Firstly, yield demonstrates a positive relationship with plant population (Figure 5.3 A), with a coefficient of 0.305. This suggests that as plant population increases, there tends to be an increase in yield. Secondly, plant height exhibits a negative relationship with yield (Figure 5.3 B).

The relationships of the variable plant population with four other variables are depicted in Figure 5.4. The plant population exhibits negative relationships with stalk diameter (Figure 5.4 A), ear length (Figure 5.4 B), ear diameter (Figure 5.4 C), and ear weight (Figure 5.4 D), with coefficients of -0.34, -0.51, -0.36, and -0.61 respectively. The relationship between stalk diameter and plant population exhibits a pattern where there is a slight increase at the beginning, followed by a decrease, which explains the negative relationship observed. This suggests that initially, there may be some level of association between stalk diameter and plant population, possibly indicating that higher plant populations result in thinner stalks. However, as the plant population continues to increase, there is a subsequent decrease in stalk diameter. Also, the relationships A, B, and C indicate that as plant population increases, there is a tendency for plants for cobs to be smaller and lighter.

5. <u>Replant decision boards</u>

Table 26 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages in the table are calculated relative to the maximum observed yield for each combination of those two factors.

This table offers critical insights guiding replant decisions in agricultural management. For instance, suppose a field was initially planted on March 30 with a target plant population of 78,400 plants ha^{-1} with a target for a yield of 6,419 kg ha^{-1} (70% of the maximum yield for this year and location). If the actual stand only reaches 54,300 plants ha^{-1}, that represents 63% of the maximum potential yield, with 5,815 kg ha^{-1}. After 15 days, on April 11, if the farmer opts to replant and achieves the desired stand (78,400 plants ha^{-1}), yielding in this new case 9,035 kg ha^{-1}, that is an increase of 3,220 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase is an additional profit of $644,00 per hectare. Comparatively, the estimated cost for replanting is approximately $506.00 ha^{-1} according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential gain from replanting outweighs the associated costs by $138.00 ha^{-1}, it is economically advantageous for the farmer to proceed with replanting.

In another scenario, suppose a field was initially planted on April 11 with a target plant population of 78,400 plants ha^{-1}, with a target for a yield of 9,035 kg ha^{-1} (99% of the maximum yield for this year and location). If the actual stand only reaches 54,600 plants ha^{-1}, that represents 56% of the maximum potential yield, with 5,180 kg ha^{-1}. After 15 days, on April 29th, if the farmer opts to replant and achieves the desired stand (78,400 plants ha^{-1}), yielding in this new case 7,431 kg ha^{-1}, that is an increase of 2,250 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional gain of $450.00 per hectare. Comparatively, the estimated cost for replanting a hectare is approximately $506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential costs outweigh the profit from replanting by $56.00 ha^{-1}, it is not recommended for the farmer to proceed with replanting in this scenario.

6th case: TVREC in 2023, with the hybrid P1170YHR.

1. Growing degrees units (GDU`s)

For the year 2023, at TVREC, with the hybrid P1170YHR the accumulation of GDU is as follows in Figure 2.6. This particular hybrid has a maturity period of 111 days. The recording of GDU accumulation started post-emergence, with emergence occurring two days after planting.

Across the various planting dates, the GDU accumulation was as follows 1,365, 1,583, 1,656, 16,856, and 1,697 recorded from the earliest to the latest planting dates, respectively.

2. Analyses of variance (ANOVA)

The ANOVA table (Table 27) indicated that the factor of planting date had a statistically significant impact on all variables except for the number of ears (P>F = 0.8280). Also, the seeding rate factor showed a significant effect on almost all variables, except for test weight (P>F = 0.6914), plant height (P>F = 0.3544), ear height (P>F = 0.6152), and ear diameter (P>F = 0.9218). The interaction between these two factors was found to be statistically significant for Yield (P>F = 0.0001) and plant population (P>F = 0.0062), indicating that the variables studied had a direct impact on both corn grain yield and the number of plants in the area.

3. Tukey mean test

Test weight was only affected by planting date (Table 28), showing as the planting date is delayed, test weight decreases. The variable test weight for the first two planting dates (April 4, and April 17) was significantly higher compared to the others, with values of 73.3 kg hL^{-1} and 73.7 kg hL-1 respectively.

The seeding rate was shown to have an effect of increasing the plant population it was increasing (Table 28). However, it's important to note that the observed plant population was higher than the target seeding rate, which may explain the variation in results for variables related to the seeding rate in this study such as yield.

The planting date was the only factor that significantly affected plant height (Table 28). Unlike other locations, there was a positive relationship between planting date and plant height here, meaning that as the planting date was delayed, plant height increased. This phenomenon could be attributed to the higher temperatures experienced at this location, leading to increased accumulation of Growing Degree Units (GDUs), as depicted in Figure 2.6. These higher temperatures and GDUs likely facilitated greater elongation of the vegetative part of the corn plants, resulting in taller plants. The higher temperatures experienced at this location also had a notable impact on stalk diameter (Table 29), as the planting date was delayed there was an increase in stalk diameter. The stalk diameter increased from 14.0mm on the first planting date to 15.4mm on the last planting date, demonstrating a consistent upward trend.

The seeding rate also influenced stalk diameter (Table 29), displaying a pattern consistent with observations from other stations and years. As the seeding rate increased, there was a corresponding decrease in stalk diameter. Specifically, the stalk diameter decreased from 16.2 mm in the lowest seeding rate to 13.1 mm in the highest seeding rate. The decrease in stalk diameter with higher seeding rates can be attributed to increased competition among plants for resources such as water and nutrients. With more plants in the same area, each plant has access to fewer resources, leading to reduced lateral growth and resulting in a thinner stalk.

The seeding rate was the only factor that had a significant effect on the number of ears (Table 29), as the seeding rate is increased increased the seeding rate there is a decrease in number of ears per plant. Ranging from 1.88 ears per plant in the lowest seeding rate to 1.01 ears per plant in the last seeding rate.

Further investigation into ear size (Table 29) revealed a consistent trend across different years and cases. As planting dates were delayed, there was a noticeable reduction in ear size, evident in shorter ear lengths and smaller ear diameters and weights. Specifically, ear length decreased from 18.9 cm in the earliest planting date to 17.8 cm in the latest planting date.

Similarly, ear diameter decreased from 50.0 mm to 46.7 mm, and ear weight decreased from 283.0 g to 235.0 g over the same period. The seeding rate exhibited a similar pattern, an increase in seeding rate corresponded with a decrease in ear size parameters. Specifically, ear length decreased from 20.0 cm to 18.2 cm, ear diameter decreased from 48.0 mm to 46.7 mm, and ear weight decreased from 259 g to 236 g, moving from the lowest to the highest seeding rate. This trend suggests that higher planting densities result in smaller and lighter ears.

The results from the Tukey mean test for the interaction between planting date and seeding rates are presented in Table 30.

The variable yield across different seeding rates within each planting date consistently showed an increase followed by a decrease. This pattern can be attributed to variations in plant population resulting from the seeding rates. Specifically, the higher seeding rates led to a higher-than-intended plant population, causing increased competition among plants for resources such as water and nutrients. This heightened competition ultimately led to a decrease in yield, particularly evident in the higher seeding rates.

While the same overall trend is apparent across all planting dates, indicating an increase followed by a decrease in yield with higher seeding rates, there are differences in how the yield was impacted inside of each planting date. For the first planting date, all seeding rates yielded similarly, with only the fourth seeding rate showing statistical differences from the others. Moving to the second planting date, the highest yields were achieved at 44,400 and 59,200 plants ha^{-1}, reaching 14,720 and 14,900 kg ha^{-1}, respectively. The third planting date saw its highest yield (13,730 kg ha^{-1}) with a seeding rate of 44,400 seeds ha^{-1}. The fourth planting date did not exhibit statistically significant differences between seeding rates, except for the last one, which yielded less. Finally, on the fifth planting date, the first three seeding rates had similar effects on yield, with no statistically significant differences between them.

The variable population was also influenced by the interaction between the planting date and the seeding rate (Table 30). Across all seeding rates within each planting date, we observed a consistent increase in plant population as the seeding rate increased. However, there were no statistically significant differences between the same seeding rates across all planting dates, except for the 74,000 plants ha^{-1} in the second, third, and fourth planting dates. Each planting date, all seeding rates exhibited the same trend and were statistically different from each other, except on the third planting date between 44,400 and 59,200 plants ha^{-1}.

4. Pearson correlation analysis

Table 37 provides a comprehensive analysis of the Pearson correlation coefficients among the variables investigated in this study.

The variable yield and its relationships are depicted in Figure 6.1. Yield exhibits negative relationships with two variables: plant population (Figure 6.1 A) and plant height (Figure 6.1 B), with Pearson coefficients of -0.33 and -0.68, respectively. These negative relationships suggest that as plant population and plant height increase, yield tends to decrease. Conversely, yield demonstrates positive relationships with five variables: number of ears per plant (Figure 6.1 C), ear length (Figure 6.1 D), ear diameter (Figure 6.1 E), and ear weight (Figure 6.1 F), with Pearson correlation coefficients of 0.27, 0.37, 0.24, and 0.51, respectively. These positive relationships indicate that as these variables increase, yield tends to increase as well.

Figure 6.1 A presents the interaction between planting date, plant population, and resulting yield, highlighting the differences in crop performance across varying conditions.

Throughout all planting dates, the hybrid P1170VYHR consistently illustrates a positive relationship between plant population and yield for the initial three plant populations, meaning that the increase in plant population increased yield. Conversely, a negative relationship emerges in the last two plant populations, where an increase in density leads to a decline in yield. The discrepancy in yield trends observed in the last two plant populations can be attributed to an excessive number of plants exceeding the targeted seeding rate. This excess of plants led to intensified competition for resources such as nutrients, water, and sunlight, impacting yield.

For this hybrid, the accumulation until flowering is recorded at 1,370 GDUs, and 2,760 GDUs until grain harvest maturity. As the planting dates progress forward into the season, there is a faster timing in achieving flowering. Specifically, the first planting date achieved flowering in 76 days, followed by the second in 73 days, the third in 72 days, the fourth in 70 days, and the fifth in 70 days.

The first planting date, occurring on April 4, stands out with an average temperature of 19°C and rainfall accumulation of 144 mm until flowering. These optimal conditions during the critical pollination period contribute to higher yields. In comparison, the second (April 17) and third planting dates (May 1) experienced favorable conditions with an average temperature of 21°C and 23°C and rainfall accumulation of 118 mm and 152 mm, respectively (Figure 1.2). The fourth planting date, occurring on May 15, was succeeded by the fifth planting date on May 30, both experiencing average temperatures of 24°C and 25°C, respectively (Figure 1.2). Notably, these dates coincided with significant rainfall events, with precipitation accumulating 234 mm and 267 mm, respectively. The high rainfall during the critical pollination period had adverse effects, negatively impacting the pollination process, and leading to a reduction in yield.

Minor differences in days to grain harvest maturity among planting dates were observed, the first planting date reached grain harvested maturity in 137 days, and the second, third, fourth, and fifth planting dates required 133, 130, 128, and 116 days, respectively.

In Figure 6.2, the results for the relationship between plant population and other variables are presented. Notably, plant population exhibited a negative relationship with all variables studied. Specifically, for plant height (Figure 6.2 A), stalk diameter (Figure 6.2 B), number of ears per plant (Figure 6.2 C), ear length (Figure 6.2 D), ear diameter (Figure 6.2 E), and ear weight (Figure 6.2 F), the respective correlation coefficients were -0.09, -0.77, -0.83, -0.38, -0.21, and -0.33. These negative relationships suggest that as plant population increases, there is a tendency for decreases in plant height, stalk diameter, number of ears per plant, ear length, ear diameter, and ear weight for this case.

5. Replant decision board

Table 31 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages in the table are calculated relative to the maximum observed yield for each combination of those two factors.

This table offers critical insights guiding replant decisions in agricultural management. For instance, suppose a field was initially planted on April 4, with a target plant population of 66,500 plants ha^{-1} with a target for a yield of 15,325 kg ha^{-1} (100% of the maximum yield for this year and location). If the actual stand only reaches 39,600 plants ha^{-1}, that represents 97% of the maximum potential yield, with 14,827 kg ha^{-1}. After 15 days, on April 17, if the farmer opts to replant and achieves the desired stand (65,500 plants ha^{-1}), yielding in this new case 14,929 kg ha^{-1}, that is an increase of 3,220 kg ha^{-1}. Considering a corn price of $12.00 per bushel, this increase translates to an additional profit of \$20,00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately \$506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential costs outweigh the profit from replanting by \$485 ha^{-1}, it is not recommended for the farmer to proceed with replanting in this scenario.

In another scenario, suppose a field was initially planted on April 17 with a target plant population of 52,700 plants ha^{-1}, with a target for a yield of 14,762 kg ha^{-1} (96% of the maximum yield for this year and location). If the actual stand only reaches 39,600 plants ha^{-1}, that represents 88% % of the maximum potential yield, with 13,561 kg ha^{-1}. After 15 days, on April 17, if the farmer opts to replant and achieves the desired stand (52,700 plants ha^{-1}), yielding in this new case 13,736 kg ha^{-1}, that is an increase of 175 kg ha^{-1}. Considering a corn price of \$12.00 per bushel, this increase translates to an additional profit of \$35.00 ha^{-1}. Comparatively, the estimated cost for replanting a hectare is approximately \$506.00 according to the Alabama enterprise budget for 2023 (Alabama Cooperative Extension System, 2023), including seed, herbicide, and machinery expenses. Given that the potential costs outweigh the profit from replanting by \$471 ha^{-1}, it is also not recommended for the farmer to proceed with replanting in this scenario.

7th case: TVREC in 2023, with the hybrid P2042VYHR.

1. Growing degrees units (GDU`s)

In this scenario results are shown in Figure 2.7. This hybrid has a maturity period of 120 days. The recording of GDU accumulation started post-emergence, with emergence occurring two days after planting. Across the various planting dates, the GDU as it follows:1,508, 1,623, 1,793, 1,818, and 1,833 recorded from the earliest to the latest planting dates, respectively.

2. Analyses of variance (ANOVA)

The ANOVA (Table 32), showed as a result for TVREC in 2023 with the hybrid P2042VYHR, a significant effect for all the variables regarding planting date. The seeding rate factor showed an effect in almost all the variables except for test weight (P>F 0.8360), and plant height (P>F 0.7412). The interaction between the factors was only significant for the factor yield with a P>F of 0.0001.

3. Tukey mean test

The variable test weight was only impacted by the factor planting date, showing a decrease in the mean value as the planting date is delayed delay the planting date, going from 74,7 kg hL-1 on the first planting date (April 4th), to 69,6 kg hL-1 on the last planting date (Table 33).

In contrast to other locations where a negative relationship was observed, the plant height had a relationship with the planting date, as the plating date was delayed, there was an increase in plant height, going from 220 cm to 255 cm from the first to the last planting date respectively. This anomaly may be attributed to the higher temperatures experienced in this location, as illustrated in Figure 2.7. Similarly, stalk diameter followed a similar trend with planting date, showing an increase as planting was delayed (Table 34). Stalk diameter ranged from 14.8mm to 16.3mm from the first to the last planting date, which may also be attributed to the warmer temperatures experienced during the growing season in this particular year and location.

At this location, the trend for stalk diameter in response to seeding rate aligned with observations from other locations. As the seeding rate increased, there was a corresponding decrease in stalk diameter. For instance, the mean stalk diameter was 17.4 mm for the lowest seeding rate and decreased to 13.4 mm for the highest seeding rate.

Both planting date and seeding rate influenced the number of ears per plant (Table 34). With delayed planting dates, there was a decrease in the mean number of ears per plant, indicating that plants had less time to develop multiple ears. The results showed that the mean number of ears per plant decreased from 1.30 for the first planting date to 1.11 for the last planting date.

Similarly, increasing the seeding rate led to a reduction in the number of ears per plant, going from 1.62 ears per plant in the lowest seeding rate to 1.05 in the highest seeding rate.

The effects of both planting date and seeding rate on ear size and weight were evident in this study (Table 34). With delayed planting dates, there was a consistent decrease in ear length, diameter, and weight. For example, the ear length decreased by almost 3 cm, the diameter decreased by almost 7 mm, and the weight decreased by almost 80 g from the first to the last planting date.

Similarly, increasing the seeding rate resulted in a reduction in ear size and weight. The length, diameter, and weight of the ears decreased by almost 3 cm, 3 mm, and 50 g, respectively, from the lowest to the highest seeding rate.

The Tukey's mean test further investigated the interaction between each planting date and seeding rate for the factor yield (Table 35).

The table illustrates that the yield responded consistently across the planting dates for each seeding rate. As the seeding rate increased within each planting date, there was a corresponding increase in yield. However, this trend was observed only up to the third seeding rate; beyond that, the yield began to decline. The analysis reveals that although the general pattern persisted across all planting dates, there were variations in the most effective seeding rate for each planting date. On the first planting date, the highest yield was observed with a seeding rate of 44,400 seeds ha^{-1}, although it was not statistically different from the first and third seeding rates. Similarly, the second planting date showed the highest yield with 70,800 seeds ha^{-1}, significantly different from all other rates. The third planting date yielded the highest with a seeding rate of 29,600 seeds ha^{-1}, although not statistically different from the second rate. For the fourth planting date, the highest yield was achieved with 44,400 seeds ha^{-1}, which did not significantly differ from the first and third seeding rates. Lastly, the last planting date saw the highest yield with a seeding rate of 44,400 seeds ha^{-1}, but statistically differentiated from all other rates except the last seeding rate.

4. Pearson Correlation Analysis

In Table 37, an analysis of the Pearson correlation coefficients among the variables investigated in this study is provided. The variable 'yield' exhibited a negative relationship with two variables: plant population (Figure 6.3 A) and plant height (Figure 6.3 B), with Pearson correlation coefficients of -0.23 and -0.72, respectively. Conversely, the variable yield showed positive relationships with four other variables. These relationships include the number of ears per plant (Figure 6.3 C), ear length (Figure 6.3 D), ear diameter (Figure 6.3 E), and ear weight (Figure 6.3 F), with Pearson correlation coefficients of 0.30, 0.54, 0.59, and 0.64, respectively.

In Figure 6.3 A, the interaction between planting date, plant population, and resulting yield are shown, highlighting the differences in crop performance under varying conditions.

Across all planting dates, the hybrid P2042VYHR consistently demonstrates a positive relationship between plant population and yield for the initial three plant populations, indicating that higher plant densities result in enhanced yields. However, a contrasting trend emerges in the last two plant populations, where an increase in density leads to a decline in yield. This reversal in yield trends can be attributed to a higher number of plants exceeding the targeted seeding rate, intensifying competition for essential resources like nutrients, water, and sunlight, consequently impacting yield.

For this hybrid, the heat accumulation until flowering is 1,440 GDUs, with 2,860 GDUs accumulated until grain harvest maturity. As planting dates progress further into the season, the time to achieve flowering reduces, because of higher temperatures. Specifically, the first planting date achieves flowering in 78 days, followed by the second in 76 days, the third in 74 days, the fourth in 74 days, and the fifth in 70 days.

The first planting date, set on April 4, experiences optimal conditions during the critical pollination period, with an average temperature of 19°C and rainfall accumulation of 146 mm until flowering, contributing to the highest yields among the planting dates. The second (April 17) and third (May 1) planting dates also encounter favorable conditions with average temperatures of 21°C and 23°C, and rainfall accumulation of 123 mm and 159 mm, respectively. Nonetheless, the conditions were favorable for the first three planting dates, having more time until flowering, due to the lower temperatures at the beginning of the season allowing the first planting date to promote better pollination and consequently higher yields. The fourth (May 15) and fifth (May 30) planting dates coincide with substantial rainfall events, accumulating 234 mm and 237 mm, respectively, during the critical pollination period. This excessive rainfall adversely impacts the pollination process, leading to a reduction in yield.

Minor differences in days to grain harvest maturity among planting dates were observed, the first planting date reaches grain harvest maturity in 140 days, while the second, third, fourth, and fifth planting dates require 136, 130, 125, and 111 days, respectively.

In Figure 6.4, the relationship between plant population and various variables is depicted. Notably, all the variables examined showed a negative relationship with plant population. Specifically, stalk diameter (Figure 6.4 A) exhibited a strong negative relationship with a coefficient of -0.80, indicating that as plant population increases, stalk diameter tends to decrease. Similarly, the number of ears per plant (Figure 6.4 B) displayed a negative relationship with plant population, with a coefficient of -0.61. This suggests that higher plant populations are associated with a lower number of ears per plant. Additionally, both ear length (Figure 6.4 C) and ear weight (Figure 6.4 E) showed negative relationships with plant population, with coefficients of -0.54 and -0.42, respectively. Similarly, ear diameter (Figure 6.4 D) exhibited a negative relationship with plant population, although the coefficient (-0.24) was relatively weaker compared to the other variables.

5. <u>Replant decision board</u>

Table 36 shows the effect of planting date and seeding rates combined on corn grain yield. The percentages in the table are calculated relative to the maximum observed yield for each combination of those two factors.

For instance, suppose a field was initially planted on April 4, with a target plant population of 70,800 plants ha^{-1} with a target for a yield of 15,068 kg ha^{-1} (99% of the maximum yield for this year and location). If the actual stand only reaches 39,700 plants ha^{-1}, that represents 98% of the maximum potential yield, with 14,936 kg ha^{-1}. After 15 days, on April 17, if the farmer opts to replant and achieves the desired stand (70,800 plants ha^{-1}), yielding in this new case 14,193 kg ha^{-1}, that is a decrease of 743 kg ha^{-1}. Given the potential decreasing in yield, that is not recommended for the replanting of the field.

In another scenario, suppose a field was initially planted on April 17 with a target plant population of 70,800 plants ha^{-1}, with a target for a yield of 14,193 kg ha^{-1} (94% of the maximum yield for this year and location). If the actual stand only reaches 39,700 plants ha^{-1}, that represents 84% % of the maximum potential yield, with 12,869 kg ha^{-1}. After 15 days, on May 1, if the farmer opts to replant and achieves the desired stand (70,800 plants ha^{-1}), yielding in this new case 11,206 kg ha^{-1}, that is an increase of 1,663 kg ha^{-1}. Given the potential decrease in yield, that is also not recommended the replanting of the field.

FINAL CONSIDERATIONS

Table 38 provides an overview of the impact of seeding rate and planting date on yield, illustrating the percentage of yield change from the minimum to the maximum seeding rate, as well as from the first to the last planting date.

Meanwhile, Figure 7.1 presents the percentage of maximum yield across different seeding rates for each planting date. The data reveal a consistent increase in yield from the first to the third seeding rate for all planting dates, followed by a plateau in yield for the following seeding rates.

In contrast, Figure 7.2 depicts the percentage of maximum yield across different planting dates. Here, the data set demonstrates a clear decrease in yield as planting dates are delayed, with the most significant decline observed at the last planting date. Notably, there is consistency in yield with the first and second planting dates, and the third and fourth planting dates, with the fifth planting date resulting in the lowest yield.

It is important to notice that Figures 7.1 and 7.2 were obtained with the average % of maximum yield, and the seeding rates and planting dates from the replant decision boards for all the cases.

SUMMARY AND CONCLUSIONS

The analysis reveals that across all cases, planting date exerts a stronger impact on corn grain yield compared to the seeding rate. The average loss with late planting dates was associated with a substantial 25% reduction in yield, while a 13% reduction was observed between the highest and the lowest seeding rate.

This implies that delaying the planting date poses a greater risk of reducing corn grain yield than adjusting the seeding rate. Also, it can be inferred that hybrids with longer maturity groups should be planted early to allow ample time for maturity before the conclusion of the growing season. Conversely, hybrids with greater yield potential may benefit from higher seeding rates to optimize plant density and overall productivity.

The factors of seeding rate and planting date demonstrated similar effects across all variables studied and locations. Increasing plant population with higher seeding rates corresponded to taller plants, smaller stalk diameters, and fewer ears per plant. Additionally, higher seeding rates exhibited a consistent trend towards smaller ear size and weight, including variables such as ear length, diameter, and weight.

Interestingly, lower seeding rates were associated with larger and heavier ears, as well as less ears per plant. However, this phenomenon did not significantly affect yield positively, since higher yields were consistently achieved with higher seeding rates across most cases.

Similar yields were achieved with plant populations ranging from 64,700 to 91,300 plants ha^{-1}, regardless of the environment (dryland or irrigated and north or south). Replanting may only be considered if the plant population is under 64,700 plants ha^{-1}.

On average, there is a 15% yield reduction from the 64,700 plants ha^{-1}, with the lowest observed plant population of 40,700 plants ha^{-1}. Additionally, it was observed that, on average, there is a 1.5% yield reduction for every 1,000 plants ha^{-1} decrease in plant population.

The best planting dates for corn in Alabama are considered as: March 20th to March 30th in the South location, April 1st to April 10th in the Central location and April 5th to April 15th in the North location. On average, there is a reduction of 72 kg ha^{-1} day^{-1} (equivalent to 1.2 bushels per acre per day) in yield after the best planting date is passed.

Replanting decisions should be carefully considered when the costs associated with replanting do not exceed the potential yield increase resulting from replanting. Growers should evaluate the expenses involved in replanting, such as additional seeds, labor and equipment costs ($500) against the anticipated increase in yield that can be found in the replant decision boards. If the potential yield increase is substantial enough to justify the replanting costs and ultimately lead to a net gain in profitability, then replanting is recommended.

However, if the costs of replanting outweigh the expected yield increase or if the yield increase is not significant enough to offset the expenses, then replanting may not be economically viable. In such cases, it may be more prudent for growers to keep the existing crop stand.

Table 1 Fertilization dates, rates and type of fertilizer, for all the stations and years.

Location / Year	***Dates***	**Rate**	**Fertilizer**
		Fertigation	
		(L ha^{-1})	*Type*
Fairhope, AL 2022	04/26/2022	560 [1]	24-0-0-3
	05/05/2022	490 [2]	28-0-0-5
	05/10/2022	560 [3]	24-0-0-3
	05/30/2022	500 [4]	24-0-0
	05/30/2022	500 [5]	24-0-0
Fairhope AL 2023	04/25/2023	560 [1]	24-0-0-3
	05/01/2023	560 [2]	24-0-0-5
	05/15/2023	490 [3]	24-0-0-3
	06/03/2023	490 [4]	24-0-0
	06/03/2023	490 [5]	24-0-0
		Side-dress	
		(kg ha^{-1})	*Type*
Shorter AL 2022	03/30/2022	67 [1]	34-0-0
	05/17/2022	101 [1]	28-0-0-5
	04/04/2022	67 [2]	34-0-0
	05/17/2022	101 [2]	28-0-0-5
	05/02/2022	67 [3]	34-0-0
	06/08/2022	101 [3]	28-0-0-5
	05/12/2022	67 [4]	34-0-0
	06/08/2022	101 [4]	28-0-0-5
	06/09/2022	67 [5]	34-0-0
	06/28/2022	101 [5]	28-0-0-5
		Side-dress	
		(*kg ha^{-1}*)	*Type*
Madison AL 2023	03/24/2023	110 [1]	28-0-0-5
	03/24/2023	225 [1]	9-23-30
	04/17/2023	110 [2]	28-0-0-5
	05/19/2023	170 [1,2]	28-0-0-5
	06/26/2023	170 [3,4,5]	28-0-0-5

[1] Applied at the first planting date; [2] applied on the second planting date; [3] applied on the third planting date; [4] applied on the fourth; [5] fifth planting date.

Table 2 Planting dates, hybrids, and maturity group, for all locations and years.

	Pioneer 2042VYHR (2022) Fairhope	**Pioneer 1319R (2022) Fairhope**	**Dekalb 7045 (2023) Fairhope**	**Pioneer 2042VYHR (2022) Shorter**	**Pioneer 1319R (2022) Shorter**	**Pioneer 1170VYHR (2023) Madison**	**Pioneer 2042VYHR (2023) Madison**
MG*	120	113	120	120	113	111	120
PD**	Mar-17	Mar-17	Mar-17	Mar-30	Mar-30	Apr-4	Apr-4
	Mar-31	Mar-31	Mar-31	Apr-11	Apr-11	Apr-17	Apr-17
	Apr-20	Apr-20	Apr-20	Apr-29	Apr-29	May-1	May-1
	May-1	May-1	May-1	May-12	May-12	May-15	May-15
	May-15	May-15	May-15	Jun-3	Jun-3	May-30	May-30
SR***	29,600	29,600	29,600	29,600	29,600	29,600	29,600
	44,400	44,400	44,400	44,400	44,400	44,400	44,400
	59,200	59,200	59,200	59,200	59,200	59,200	59,200
	74,000	74,000	74,000	74,000	74,000	74,000	74,000
	88,800	88,800	88,800	88,800	88,800	88,800	88,800

*Relative maturity of each hybrid in days; **Planting dates; *** Seeding rate in plants ha^{-1}.

Table 3 Analysis of variance for the variables evaluated in Fairhope, AL with the corn hybrid P2042VYHR in 2022.

Variables	Source of variation		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
		P > F	
Test Weight	0.0001	0.2992	0.9122
Yield	0.0001	0.0001	**0.0004**
Population	0.0001	0.0001	**0.0271**
Plant Height	0.0116	0.0116	0.9782
Ear Height	0.0001	0.0032	0.8770
Stalk Diameter	0.3298	0.0009	0.9994
Number of Ears	0.0001	0.0001	0.1499
Ear Length	0.0136	0.0014	0.1187
Ear Diameter	0.0001	0.0621	0.2622
Ear Weight	0.0001	0.0167	0.8336

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 4 Test weight (TW), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Fairhope, AL with the corn hybrid P2042VYHR in 2022.

Factor	TW		PH		EH	
	kg hL^{-1}		*cm*		*cm*	
Planting date						
March-17	70.6	A	226.2	C	113.0	C
March-31	70.6	AB	250.5	B	127.4	A
April-20	70.1	AB	264.8	A	129.2	A
May-1	69.7	B	-		126.3	A
May-15	65.8	C	-		118.7	B
Seeding Rate *(seeds.ha^{-1})*						
29,600	69.0		242.4	B	120.4	BC
44,400	69.3		241.7	B	119.4	C
59,200	69.4		249.9	AB	123.9	ABC
74,000	69.7		251.4	A	125.9	A
88,800	69.3		250.5	AB	125.1	AB

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 5 Corn stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in Fairhope, AL with the corn hybrid P2042VYHR in 2022.

Factor	SD		#E		EL		ED		EW	
	mm		*Ear plant^{-1}*		*cm*		*cm*		*mm*	
Planting date										
March-17	16.5		1.25	A	19.7	A	48.6	A	287.7	A
March-31	16.5		1.17	AB	19.9	A	49.2	A	290.2	A
April-20	16.6		1.11	BC	19.2	B	48.3	A	259.1	B
May-1	15.9		1.02	C	18.7	B	45.6	B	224.7	C
May-15	16.0		1.00	C	19.3	AB	42.6	C	186.0	D
Seeding rate (seeds.ha^{-1})										
29,600	16.9	A	1.24	A	19.6	A	47.3		256.1	AB
44,400	17.1	A	1.20	A	20.1	AB	47.5		260.5	A
59,200	16.3	AB	1.06	B	19.6	AB	46.7		256.9	A
74,000	15.7	B	1.01	B	18.7	C	46.3		232.3	B
88,800	15.6	B	1.02	B	19.0	BC	46.5		241.0	AB

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 6 Corn yield and plant population as affected by the interaction of planting date and seeding rate in Fairhope, AL with the corn hybrid P2042VYHR in 2022.

Planting date	Seeding rate	Yield		Plant population	
	seeds ha^{-1}	*kg ha^{-1}*		*plants ha^{-1}*	
March-17	29,600	10,360	Bc	33,600	BCc
	44,400	11,987	Ab	49,100	Ac
	59,200	13,470	Aab	63,400	Ab
	74,000	13,775	Aa	76,300	Aab
	88,800	14,584	Aa	85,400	Aa
March-31	29,600	12,272	Ab	31,000	Cd
	44,400	12,275	Ab	46,500	Ac
	59,200	13,971	Aa	60,800	Ab
	74,000	14,795	Aa	78,900	Aa
	88,800	15,318	Aa	86,700	Aa
April-20	29,600	9,344	Bc	47,800	Ac
	44,400	10,019	Bbc	50,400	Abc
	59,200	11,051	Bab	63,400	Ab
	74,000	11,724	Ba	78,900	Aa
	88,800	11,813	Ba	88,000	Aa
May-1	29,600	8,849	Ba	44,000	ABc
	44,400	9,017	Ba	49,800	Ac
	59,200	9,750	Ba	98,500	Ab
	74,000	10,780	Ba	81,500	Aab
	88,800	10,166	Ca	91,800	Aa
May-15	29,600	5,190	Cc	45,300	ABc
	44,400	6,998	Cb	54,300	Abc
	59,200	7,199	Cb	66,000	Ab
	74,000	7,531	Cb	84,100	Aa
	88,800	9,164	Ca	82,800	Aa

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 7 Effect of planting dates and seeding rates in corn grain yield in Fairhope, AL with the corn hybrid P2042VYHR in 2022.

Planting date	**Plant Population (plants ha^{-1})**				
	40,300	50,000	64,400	79,900	86,900
			kg ha^{-1}		
March-17	10,361	11,987	13,471	13,755	14,584
March-31	12,272	12,275	13,971	14,795	15,318
April-20	9,344	10,019	11,051	11,724	11,813
May-1	8,849	9,017	9,750	10,780	10,166
May-15	5,190	6,998	7,199	7,531	9,164
			% of maximum yield		
March-17	67	78	87	89	95
March-31	80	80	91	96	100
April-20	61	65	72	76	77
May-1	57	58	63	70	66
May-15	33	45	47	49	59

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 8 Analysis of variance test between the factors, and the variables evaluated in Fairhope, AL with the corn hybrid P1319R in 2022.

Variables	Source of variation		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
		P > F	
Test Weight	0.0001	0.0023	0.8080
Yield	0.0001	0.0001	**0.0001**
Population	0.0001	0.0001	**0.0489**
Plant Height	0.0001	0.0010	0.9223
Ear Height	0.0001	0.0135	0.7400
Stalk Diameter	0.0002	0.0001	0.7846
Number of Ears	0.0004	0.5408	0.9333
Ear Length	0.0001	0.0004	0.3076
Ear Diameter	0.0001	0.0049	0.3503
Ear Weight	0.0001	0.0001	0.6952

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 9 Test weight (TW), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Fairhope, AL with the corn hybrid P1319R in 2022.

Factor	TW		PH		EH	
	kg hL^{-1}		*cm*		*cm*	
Planting date						
March-17	70.3	A	238.2	C	120.5	C
March-31	70.9	A	257.9	B	136.7	A
April-20	69.7	B	270.5	A	134.0	A
May-1	68.8	B	-		125.1	B
May-15	66.9	B	-		125.1	B
Seeding rate (plants ha^{-1})						
29,600	68.2	B	248.3	C	124.6	B
44,400	68.9	AB	252.8	BC	127.4	AB
59,200	69.8	A	258.6	AB	129.6	A
74,000	70.2	A	260.7	A	129.8	A
88,800	69.5	AB	257.0	AB	130.0	A

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 10 Corn stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in Fairhope, AL with the corn hybrid P1319R in 2022.

Factor	SD		#E		EL		ED		EW	
	mm		*ear plant^{-1}*		*cm*		*cm*		*mm*	
Planting date										
March-17	17.3	A	1.02	AB	19.7	A	48.1	A	281.4	A
March-31	17.1	A	1.06	A	20.1	A	48.1	A	282.9	A
April-20	17.2	A	1.01	AB	19.9	A	48.9	A	275.9	A
May-1	15.5	B	0.97	BC	18.4	B	44.9	B	225.0	B
May-15	16.9	A	0.95	C	18.3	B	43.5	C	199.4	C
Seeding rate (plants ha^{-1})										
29,600	17.8	A	1.02		19.9	A	47.2	AB	271.6	A
44,400	17.8	A	1.01		19.8	A	45.5	A	276.6	A
59,200	16.8	AB	1.01		19.3	AB	46.7	AB	255.4	AB
74,000	15.7	C	0.98		18.6	B	45.9	B	230.2	C
88,800	15.9	BC	0.99		18.7	B	45.9	B	231.7	BC

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 11 Corn yield and plant population as affected by the interaction of planting date and seeding rate in Fairhope, AL with the corn hybrid P1319R in 2022.

Planting date	Seeding rate	Yield		Plant population	
	seeds ha^{-1}	*kg ha^{-1}*		*plants ha^{-1}*	
March-17	29,600	9,113	Ab	33,600	Ad
	44,400	10,290	Ab	49,100	Acd
	59,200	12,516	Aa	63,400	Abc
	74,000	12,643	Aa	76,300	Aab
	88,800	13,085	Aa	84,100	Aa
March-31	29,600	9,873	Ab	31,000	Ad
	44,400	10,308	Ab	46,500	Acd
	59,200	12,759	Aa	60,800	Abc
	74,000	13,917	Aa	77,600	Aab
	88,800	13,866	Aa	91,800	Aa
April-20	29,600	9,617	Ab	47,800	Ad
	44,400	10,473	Ab	50,400	Acd
	59,200	12,305	ABa	63,400	Abc
	74,000	13,739	Aa	82,800	Aab
	88,800	12,991	Aa	91,800	Aa
May-1	29,600	6,976	Bc	44,000	Ad
	44,400	8,539	Bb	62,100	Acd
	59,200	11,037	Ba	98,500	Abc
	74,000	11,056	Ba	82,800	Aab
	88,800	11,336	Ba	91,800	Aa
May-15	29,600	4,807	Cc	45,300	Ab
	44,400	8,480	Bb	54,360	Ab
	59,200	8,889	Cab	76,300	Aa
	74,000	8,963	Cab	84,000	Aa
	88,800	10,063	Ba	82,800	Aa

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 12 Effect of planting dates and seeding rates on corn grain yield in Fairhope, AL with the corn hybrid P1319R in 2022

Planting date	**Plant Population (plants ha^{-1})**				
	40,300	52,500	66,500	80,700	88,500
			kg ha^{-1}		
March-17	9,113	10,290	12,516	12,643	13,085
March-31	9,873	10,308	12,759	13,917	13,866
April-20	9,617	10,470	12,305	12,739	12,991
May-1	6,976	8,593	11,037	11,056	11,336
May-15	4,807	8,480	8,889	8,963	10,063
			% of maximum yield		
March-17	65	74	90	91	94
March-31	71	74	92	100	99
April-20	69	75	88	99	93
May-1	50	61	79	79	81
May-15	34	61	64	64	72

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 13 Analysis of variance test between the factors, and the variables evaluated in Fairhope, AL with the corn hybrid DKB7045 in 2023.

Variables	**Source of variation**		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
		P > F	
Test Weight	0.0001	0.0001	0.3790
Yield	0.0001	0.0001	0.0537
Population	0.0550	0.0001	0.9798
Plant Height	0.0001	0.0001	0.6497
Ear Height	0.0001	0.0001	0.9473
Stalk Diameter	0.0311	0.0001	0.7811
Number of Ears	0.0001	0.0001	**0.0001**
Ear Length	0.7460	0.0001	0.1092
Ear Diameter	0.0001	0.0008	0.2784
Ear Weight	0.0001	0.0001	0.9502

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 14 Corn yield (Y), test weight (TW), plant population (PP), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Fairhope, AL with the corn hybrid DKB7045 in 2023

Factor	**Y**		**TW**		**PP**		**PH**		**EH**	
	kg ha⁻¹		*kg hL⁻¹*		*plants ha⁻¹*		*cm*		*cm*	
Planting date										
March-17	16,509	A	69.5	A	62,600	AB	236.1	A	128.0	C
March-31	13,567	B	58.1	B	61,600	B	253.3	B	136.0	B
April-20	13,401	BC	55.2	BC	63,400	AB	245.2	C	142.0	A
May-1	12,285	C	50.8	C	65,400	A	227.5	D	129.0	B
May-15	10,599	D	45.4	D	64,100	AB	226.4	D	116.0	D
Seeding rate (plants ha⁻¹)										
29,600	8,811	E	40.9	D	35,700	E	230.3	C	124.0	C
44,400	11,498	D	48.5	C	48,400	D	234.4	C	128.0	C
59,200	14,405	C	59.7	B	64,100	C	238.2	B	130.0	B
74,000	15,281	B	64.7	AB	80,000	B	240.1	A	132.0	A
88,800	16,260	A	65.9	A	89,000	A	243.0	A	135.0	A

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 15 Corn stalk diameter (SD), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate Fairhope, AL with the corn hybrid DKB7045 in 2023.

Factor	SD		EL		ED		EW	
	mm		*cm*		*cm*		*mm*	
Planting date								
March-17	16.8	A	20.1		54.2	A	345.0	B
March-31	16.7	AB	20.1		55.7	A	375.0	A
April-20	16.1	B	20.2		50.7	B	320.0	C
May-1	16.2	B	20.5		50.0	BC	279.0	D
May-15	16.1	B	20.3		48.4	C	270.0	D
Seeding rate *(plants ha^{-1})*								
29,600	18.3	A	21.9	A	53.3	A	356.0	A
44,400	17.1	B	20.7	B	51.4	BC	333.0	AB
59,200	16.2	C	20.5	B	52.3	AB	319.0	BC
74,000	15.1	D	19.5	C	51.9	AB	303.0	C
88,800	15.0	D	18.6	D	49.9	C	278.0	D

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 16 Number of ears as affected by the interaction of planting date and seeding rate Fairhope, AL with the corn hybrid DKB7045 in 2023.

Planting date	Seeding rate	Number of ears	
	seeds ha^{-1}	*ear plant^{-1}*	
March-17	29,600	1.95	Aa
	44,400	1.47	Ab
	59,200	1.22	Abc
	74,000	1.02	Acd
	88,800	1.07	Ad
March-31	29,600	1.77	Aa
	44,400	1.27	ABb
	59,200	1.12	Ab
	74,000	1.06	Ab
	88,800	1.05	Ab
April-20	29,600	1.12	Ba
	44,400	1.02	BCa
	59,200	1.00	Aa
	74,000	1.00	Aa
	88,800	1.00	Aa
May-1	29,600	1.05	Ba
	44,400	1.00	Ca
	59,200	1.00	Aa
	74,000	1.00	Aa
	88,800	1.00	Aa
May-15	29,600	1.05	Ba
	44,400	1.00	Ca
	59,200	1.00	Aa
	74,000	1.00	Aa
	88,800	1.00	Aa

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 17 Effect of planting dates and seeding rates on corn grain yield in Fairhope, AL with the corn hybrid DKB7045 in 2023

Planting date	Plant Population (plants ha^{-1})				
	35,700	48,400	64,100	80,000	89,000
			kg ha^{-1}		
March-17	12,502	14,269	16,809	18,651	20,317
March-31	9,260	11,237	14,562	15,343	17,034
April-20	8,049	11,296	14,648	15,274	16,255
May-1	7,258	11,170	13,056	14,199	15,744
May-15	6,985	9,120	12,464	12,941	11,915
			% of maximum yield		
March-17	62	70	83	92	100
March-31	46	57	72	76	84
April-20	40	56	72	75	70
May-1	36	55	64	70	77
May-15	34	45	61	64	59

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 18 Analysis of variance test between the factors, and the variables evaluated in in Shorter, AL with the corn hybrid P2042VYHR in 2022

Variables	**Source of variation**		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
		P > F	
Test Weight	0.0001	0.9950	0.9614
Yield	0.0001	0.0001	**0.0266**
Population	0.6425	0.0001	0.9999
Plant Height	0.0001	0.3666	0.9580
Ear Height	0.0001	0.1090	0.8131
Stalk Diameter	0.0001	0.0155	0.1512
Number of Ears	0.0001	0.0001	**0.0001**
Ear Length	0.0018	0.0001	0.8725
Ear Diameter	0.0001	0.0001	0.0804
Ear Weight	0.0001	0.0001	0.7439

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 19. Test weight (TW), plant population (PP), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Shorter, AL with the corn hybrid P2042VYHR in 2022

Factor	**TW**		**PP**		**PH**		**EH**	
	kg hL-1		*plants ha^{-1}*		*cm*		*cm*	
Planting Date								
March-30	74.5	A	59,000		213.3	C	105.0	C
April-11	73.2	AB	59,500		232.6	B	123.8	B
April-29	73.1	AB	58,450		197.9	D	102.2	C
May-12	74.4	B	61,200		237.3	B	116.4	B
June-3	66.2	C	61,700		250.8	A	140.4	A
Seeding rate (plants ha^{-1})								
29,600	71.7		35,500	E	225.5		119.7	A
44,400	71.9		45,000	D	223.7		114.1	B
59,200	71.9		59,800	C	227.3		116.3	A
74,000	71.9		73,500	B	228.7		123.8	A
88,800	72.0		86,000	A	224.6		117.1	A

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 20 Corn stalk diameter (SD), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in Shorter, AL with the corn hybrid P2042VYHR in 2022

Factor	**SD**		**EL**		**ED**		**EW**	
	mm		*cm*		*cm*		*mm*	
Planting date								
March-30	16.6	A	19.3	A	46.3	A	246.1	A
April-11	17.2	A	18.5	AB	43.5	C	200.4	B
April-29	13.2	B	18.1	B	45.8	A	220.4	B
May-12	17.7	A	17.6	B	43.6	C	203.6	B
June-3	16.7	A	17.9	B	44.4	C	210.1	B
Seeding rate (plants ha^{-1})								
29,600	17.1	A	19.2	AB	45.5	A	239.9	A
44,400	16.5	AB	19.3	A	45.8	A	240.1	A
59,200	16.1	AB	18.2	BC	44.8	AB	211.1	B
74,000	15.8	B	17.7	CD	43.6	B	199.8	B
88,800	15.9	B	17.1	D	43.9	B	192.0	B

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 21 Corn yield and number of ears per plant as affected by the interaction of planting date and seeding rate in Shorter, AL with the corn hybrid P2042VYHR in 2022

Planting date	**Seeding rate**	**Yield**		**Number of ears**	
	seeds ha^{-1}	*kg ha^{-1}*		*ear plant^{-1}*	
March-30	29,600	4,960	Aa	1.62	Aa
	44,400	5,127	Ba	1.45	Aab
	59,200	5,215	Ba	1.15	Ab
	74,000	5,422	Ba	1.12	Ab
	88,800	5,743	Ba	1.05	Ab
April-11	29,600	6,458	Aa	1.57	Aa
	44,400	6,560	ABa	1.42	Aab
	59,200	7,713	Aa	1.12	Abc
	74,000	7,732	Aa	1.02	Ac
	88,800	7,299	ABa	1.00	Ac
April-29	29,600	3,861	Ab	1.02	Ba
	44,400	4,015	Cb	1.07	Ba
	59,200	5,228	Bab	1.05	Aa
	74,000	5,286	Ba	1.10	Aa
	88,800	5,798	Ba	1.05	Aa
May-12	29,600	6,293	Ab	1.00	Ba
	44,400	7,760	Aab	0.95	Ba
	59,200	8,396	Aa	1.00	Aa
	74,000	8,893	Aa	1.00	Aa
	88,800	9,058	Aa	0.95	Aa
June-3	29,600	5,189	Aa	1.00	Ba
	44,400	5,361	Ba	1.00	Ba
	59,200	5,606	Ba	1.00	Aa
	74,000	6,136	Ba	0.95	Aa
	88,800	6,715	Ba	0.95	Aa

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 22 Effect of planting dates and seeding rates on corn grain yield in Shorter, AL with the corn hybrid P2042VYHR in 2022.

Planting date	**Plant Population (plants ha^{-1})**				
	35,500	45,000	59,800	73,500	86,000
			kg ha^{-1}		
March-30	4,960	5,127	5,215	5,422	5,743
April-11	6,458	6,560	7,713	7,732	7,299
April-29	3,861	4,015	5,228	5,286	5,798
May-12	6,293	7,760	8,396	8,893	9,058
June-3	5,189	5,361	5,606	6,136	6,715
			% of maximum yield		
March-30	54	56	57	59	63
April-11	71	72	85	85	80
April-29	42	44	57	58	64
May-12	69	85	92	98	100
June-3	57	59	61	67	74

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 23 Analysis of variance (ANOVA) test between the factors, and the variables evaluated, in Shorter, AL with the corn hybrid P1319R in 2022

Variables	**Source of variation**		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
		P > F	
Test Weight	0.0001	0.8360	0.6772
Yield	0.0001	0.0001	0.1750
Population	0.0001	0.0001	0.0963
Plant Height	0.0001	0.9797	0.9279
Ear Height	0.0001	0.6377	0.8679
Stalk Diameter	0.0001	0.0033	0.6329
Number of Ears	0.0001	1.0000	0.9994
Ear Length	0.0001	0.0001	0.7143
Ear Diameter	0.0001	0.0259	0.9723
Ear Weight	0.0001	0.0001	0.9168

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 24 Corn yield (Y), test weight (TW), plant population (PP), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Shorter, AL with the corn hybrid P1319R in 2022

Factor	Y		TW		PP		PH		EH	
	kg ha^{-1}		*kg hL^{-1}*		*plants ha^{-1}*		*cm*		*cm*	
Planting date										
March-30	6,069	C	74.6	A	58,200	C	229.2	B	112.5	B
April-11	8,788	A	74.2	A	72,140	A	212.1	B	108.3	B
April-29	6,908	B	72.2	B	68,300	B	200.0	B	97.7	C
May-12	8,617	A	72.6	B	70,200	AB	232.3	A	113.5	B
June-3	4,520	D	69.5	C	70,200	AB	237.6	A	132.2	A
Seeding rate (plants ha^{-1})										
29,600	6,398	B	72.9		54,600	D	221.2		112.0	
44,400	6,638	B	72.5		54,300	D	224.1		113.8	
59,200	7,141	A	72.8		60,900	C	222.1		110.9	
74,000	7,289	A	72.5		78,400	B	221.8		112.2	
88,800	7,436	A	72.6		90,700	A	221.5		114.5	

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 25 Corn stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in in Shorter, AL with the corn hybrid P1319R in 2022

Factor	**SD**		**#E**		**EL**		**ED**		**EW**	
	mm		*ear plant^{-1}*		*cm*		*cm*		*mm*	
Planting date										
March-30	16.4	A	1.0	A	19.1	A	47.7	A	262.6	A
April-11	15.5	AB	1.0	A	19.1	A	46.4	AB	239.4	AB
April-29	13.9	C	0.91	B	16.5	B	44.9	BC	203.2	C
May-12	16.1	A	0.98	A	18.6	A	44.1	C	222.2	BC
June-3	14.8	BC	0.98	A	18.8	A	44.3	C	227.1	BC
Seeding rate (plants ha^{-1})										
29,600	15.9	A	0.97		19.5	AB	46.0	AB	251.0	AB
44,400	16.1	A	0.97		19.7	A	46.6	A	265.8	A
59,200	15.2	AB	0.97		18.5	BC	45.6	AB	230.0	BC
74,000	15.2	AB	0.97		17.4	CD	44.8	B	206.7	CD
88,800	14.5	B	0.97		16.9	D	44.5	B	197.7	D

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 26 Effect of planting dates and seeding rates on corn gain yield in Shorter, AL with the corn hybrid P1319R in 2022

Planting date	**Plant population (plants ha^{-1})**				
	54,300	54,600	60,900	78,400	90,700
			kg ha^{-1}		
March-30	5,815	5,180	6,160	6,419	6,770
April-11	8,492	8,316	8,997	9,035	9,104
April-29	6,177	6,023	7,277	7,431	7,632
May-12	8,604	8,301	8,832	8,995	8,352
June-3	4,103	4,169	4,439	4,566	5,322
			% of maximum yield		
March-30	63	56	67	70	74
April-11	93	91	98	99	100
April-29	67	66	79	81	83
May-12	94	91	97	98	91
June-3	45	45	48	50	58

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 27 Analysis of variance test between the factors, and the variables evaluated in Madison, AL with the corn hybrid P1170YHR in 2023

Variables	**Source of variation**		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
	P > F		
Test Weight	0.0001	0.6914	0.8145
Yield	0.0001	0.0001	**0.0001**
Population	0.0001	0.0001	**0.0062**
Plant Height	0.0001	0.3544	0.5410
Ear Height	0.0001	0.6152	0.0918
Stalk Diameter	0.0001	0.0001	0.9753
Number of Ears	0.8280	0.0001	0.7919
Ear Length	0.0001	0.0001	0.5728
Ear Diameter	0.0001	0.9218	0.9218
Ear Weight	0.0001	0.0001	0.1998

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 28 Test weight (TW), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Madison, AL with the corn hybrid P1170YHRP1170YHR in 2023

Factor	TW		PH		EH	
	kg hL⁻¹		*cm*		*cm*	
Planting Date						
Apr-4	73.3	AB	207.9	D	14.2	D
April-17	73.7	A	212.1	D	13.5	D
May-1	72.3	CD	217.3	C	14.2	C
May-15	72.6	BC	231.6	B	14.8	B
Jun-30	71.6	D	244.4	A	15.4	A
Seeding rate (plants ha^{-1})						
29,600	72.6		223.7		16.2	
44,400	72.5		223.1		15.3	
59,200	72.7		224.0		14.2	
74,000	72.8		222.5		13.4	
88,800	72.9		220.3		13.1	

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 29 Corn stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in Madison, AL with the corn hybrid P1170YHR in 2023

Factor	SD		#E		EL		ED		EW	
	mm		*ear plant^{-1}*		*cm*		*cm*		*mm*	
Planting date										
Apr-4	14.2	B	1.35		18.9	B	50.4	A	283.4	A
April-17	13.5	C	1.32		20.6	A	46.8	B	254.2	B
May-1	14.2	B	1.29		20.4	A	47.0	B	257.8	B
May-15	14.8	B	1.33		20.3	A	46.8	B	247.2	BC
Jun-30	15.4	A	1.31		17.8	C	46.7	B	235.1	C
Seeding rate (plants ha^{-1})										
29,600	16.2	A	1.88	A	20.0	AB	48.0		259.0	A
44,400	15.3	B	1.52	B	20.1	AB	48.3		272.1	AB
59,200	14.2	C	1.15	C	20.3	A	47.9		264.1	A
74,000	13.4	D	1.03	D	19.4	B	46.8		244.6	BC
88,800	13.1	D	1.01	D	18.2	C	46.7		236.2	C

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 30 Corn yield and plant population as affected by the interaction of planting date and seeding rate in Madison, AL with the corn hybrid P1170YHR in 2023

Planting date	Seeding rate	Yield		Plant population	
		kg ha^{-1}		*plants ha^{-1}*	
	29,600	14,827	Aa	40,800	Ae
	44,400	14,706	Aab	52,400	Ad
Apr-4	59,200	15,325	Aa	65,500	Ac
	74,000	13,260	Ab	91,800	Ab
	88,800	13,345	Ab	103,200	Aa
	29,600	13,561	ABbc	39,300	Ae
	44,400	14,762	Aab	52,400	Ad
April-17	59,200	14,929	Aa	72,100	Ac
	74,000	12,305	ABc	83,600	ABb
	88,800	13,094	Ac	98,300	Aa
	29,600	12,842	Bab	39,000	Ad
	44,400	13,736	ABa	52,400	Ac
May-1	59,200	12,689	Bab	62,300	Ac
	74,000	11,800	Bb	81,900	ABb
	88,800	12,493	Ab	100,000	Aa
	29,600	12,338	Ba	39,300	Ae
	44,400	12,466	BCa	50,800	Ad
May-15	59,200	12,371	Ba	65,500	Ac
	74,000	11,209	Ba	77,000	Bb
	88,800	9,347	Bb	93,400	Aa
	29,600	11,105	Ca	39,300	Ae
	44,400	11,580	Ca	55,700	Ad
Jun-30	59,200	11,440	Ba	67,200	Ac
	74,000	9,450	Cb	88,500	Ab
	88,800	8,374	Bb	100,000	Aa

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 31 Effect of planting dates and seeding rates on corn grain yield in Madison, AL with the corn hybrid P1170YHR in 2023

Planting date	**Plant population (plants ha^{-1})**				
	39,600	52,700	66,500	84,600	99,000
			kg ha^{-1}		
Apr-4	14,827	14,706	15,325	13,260	13,345
April-17	13,561	14,762	14,929	12,305	13,094
May-1	12,842	13,736	12,689	11,800	12,493
May-15	12,338	12,466	12,371	11,209	9,347
May-30	11,105	11,580	11,440	9,450	8,374
			% of maximum yield		
Apr-4	97	96	100	87	87
April-17	88	96	98	80	85
May-1	84	90	83	77	82
May-15	81	81	81	73	61
Jun-30	72	76	75	62	55

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 32 Analysis of variance test between the factors, and the variables evaluated in Madison, AL with the corn hybrid P2042VYHR in 2023

Variables	**Source of variation**		
	Planting Date	**Seeding Rate**	**Planting Date x Seeding Rate**
	P > F		
Test Weight	0.0001	0.8360	0.6772
Yield	0.0001	0.0001	**0.0001**
Population	0.0002	0.0001	0.0826
Plant Height	0.0001	0.7412	0.9821
Ear Height	0.0001	0.0041	0.3013
Stalk Diameter	0.0001	0.0001	0.7413
Number of Ears	0.0191	0.0001	0.1866
Ear Length	0.0001	0.0001	0.3260
Ear Diameter	0.0001	0.0124	0.5417
Ear Weight	0.0001	0.0001	0.6621

[1] P > F values less than 0.05 are considered statistically significant.
[2] Significant values (P>F < 0.05) suggest a notable impact of the factor or interaction on the variable.
[3] Insignificant values (P>F ≥ 0.05) imply that the factor or interaction does not significantly influence the variable.

Table 33 Test weight (TW), plant population (PP), plant height (PH), and ear height (EH) as affected by planting date and seeding rate in Madison, AL with the corn hybrid P2042VYHR in 2023

Factor	TW		PP		PH		EH	
	kg hL^{-1}		*plants ha^{-1}*		*cm*		*cm*	
Planting Date								
Apr-4	74.7	A	73,400	A	220.9	D	109.8	D
April-17	74.3	A	66,800	C	221.7	D	111.6	D
May-1	72.7	B	71,100	AB	229.2	C	116.5	C
May-15	72.3	B	98,800	BC	245.6	B	123.6	B
May-30	69.6	C	70,100	ABC	255.8	A	130.9	A
Seeding rate (seeds.ha^{-1})								
29,600	72.8		39,700	E	233.3		113.4	B
44,400	72.5		54,400	D	236.4		118.5	A
59,200	72.8		70,800	C	235.4		120.1	A
74,000	72.5		85,900	B	234.0		119.32	A
88,800	72.6		99,600	A	237.9		120.2	A

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 34 Corn stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) as affected by planting date and seeding rate in Madison, AL with the corn hybrid P2042VYHR in 2023

Factor	**SD**		**#E**		**EL**		**ED**		**EW**	
	mm		*ear plant^{-1}*		*cm*		*cm*		*mm*	
Planting date										
Apr-4	14.8	C	1.30	A	22.1	A	52.5	A	312.3	A
April-17	14.6	C	1.16	B	19.9	BC	50.3	AB	301.8	A
May-1	15.2	BC	1.18	AB	20.5	B	46.7	C	261.9	B
May-15	15.4	B	1.23	AB	20.4	B	47.9	BC	255.0	B
May-30	16.3	A	1.11	B	19.0	C	45.7	C	236.1	B
Seeding rate (plants ha^{-1})										
29,600	17.4	A	1.62	A	21.7	A	49.8	A	289.1	AB
44,400	16.1	B	1.21	B	21.6	A	49.8	A	303.7	A
59,200	15.2	C	1.14	BC	20.7	AB	48.7	AB	277.9	B
74,000	14.1	DE	1.15	BC	19.6	B	48.1	AB	267.7	B
88,800	13.4	E	1.05	C	18.4	C	46.8	B	232.1	C

Means followed by the same letter do not differ from each other by Tukey at 10% probability.

Table 35 Corn yield as affected by the interaction of planting date and seeding rate in Madison, AL with the corn hybrid P2042VYHR in 2023

Planting date	Seeding rate	Yield	
		*kg ha^-1^*	
	29,600	14,936	Aa
	44,400	15,148	Aa
Apr-4	59,200	15,068	Aa
	74,000	12,799	Ab
	88,800	13,456	Ab
	29,600	12,689	Bb
	44,400	13,009	Bab
April-17	59,200	14,183	Aa
	74,000	10,514	Bc
	88,800	12,775	Aab
	29,600	11,811	Ba
	44,400	11,479	Ca
May-1	59,200	11,206	Bab
	74,000	10,795	Bb
	88,800	9,016	Bc
	29,600	10,233	Ca
	44,400	10,611	Ca
May-15	59,200	9,802	Bab
	74,000	8,699	Cbc
	88,800	7,898	Bc
	29,600	7,566	Da
	44,400	7,232	Da
May-30	59,200	7,544	Ca
	74,000	6,221	Da
	88,800	5,157	Cb

Means followed by the same uppercase letter do not differ from each other within the same seeding rate, while means with the same lowercase letter do not differ from each other within the same planting date by Tukey at 10% probability.

Table 36 Effect of planting dates and seeding rates on corn grain yield in Madison, AL with the corn hybrid P2042VYHR in 2023

Planting date	Plant population (plants ha^{-1})				
	39,700	54,400	70,800	85,900	99,600
			kg ha^{-1}		
Apr-4	14,936	15,148	15,068	12,799	13,456
April-17	12,869	13,009	14,193	10,514	12,775
May-1	11,811	11,479	11,206	10,795	9,016
May-15	10,233	10,611	9,802	8,699	7,898
May-30	7,566	7,323	7,544	6,221	5,157
			% of maximum yield		
Apr-4	98	100	99	84	89
April-17	84	86	94	69	84
May-1	78	76	74	71	60
May-15	68	70	65	57	52
Jun-30	50	48	50	41	34

Yield percentages are calculated relative to the maximum observed yield for each combination of planting date and seeding rate.

Table 37 Correlation coefficients for the relationships between corn yield (Y)) or plant population (PP) and plant height (PH), stalk diameter (SD), number of ears (#E), ear length (EL), ear diameter (ED), and ear weight (EW) for all hybrids, years, and locations.

	Y	PP	PH	SD	NE	LE	ED	WE
				P2042VYHR (2022) Fairhope, AL				
Y	-	0.28^{**}	-0.15^{ns}	-0.11^{ns}	0.11^{ns}	0.07^{ns}	0.62^{**}	0.60^{**}
PP	0.28**	-	0.25^{ns}	-0.44^{**}	-0.48^{**}	-0.32^{**}	-0.22^{*}	-0.27^{**}
				P1319R (2022) Fairhope, AL				
Y	-	0.52^{**}	0.37^{**}	-0.28^{**}	0.14^{ns}	0.02^{ns}	0.29^{**}	0.15^{ns}
PP	0.52^{**}	-	0.32^{*}	-0.52^{**}	-0.18^{ns}	-0.38^{**}	-0.29^{**}	-0.42^{**}
				P2042VYHR (2022) Shorter, AL				
Y	-	0.39^{**}	0.40^{**}	0.3^{**}	-0.21^{*}	-0.35^{**}	-0.55^{**}	-0.49^{**}
PP	0.39^{**}	-	0.07^{ns}	-0.16^{ns}	-0.40^{**}	-0.50^{**}	-0.31^{**}	-0.47^{**}
				P1319R (2022) Shorter, AL				
Y	-	0.30^{**}	-0.21^{*}	0.08^{ns}	0.02^{ns}	-0.11^{ns}	-0.05^{ns}	-0.16^{ns}
PP	0.30^{**}	-	-0.04^{ns}	-0.34^{**}	-0.02^{ns}	-0.51^{**}	-0.36^{**}	-0.61^{**}
				DKB7045 (2023), Fairhope, AL				
Y	-	0.72^{**}	0.44^{**}	-0.57^{**}	-0.15^{ns}	-0.54^{**}	0.13^{ns}	-0.07^{ns}
PP	0.72^{**}	-	0.31^{**}	-0.84^{**}	-0.51^{**}	-0.65^{**}	-0.27^{**}	-0.50^{**}
				P1170YHR (2023) Madison, AL				
Y	-	-0.36^{**}	-0.68^{**}	0.02^{ns}	0.27^{**}	0.37^{**}	0.34^{**}	0.51^{**}
PP	-0.36^{**}	-	-0.09^{ns}	-0.77^{**}	-0.83^{**}	-0.38^{**}	-0.21^{*}	-0.33^{**}
				P2042VYHR (2023) Madison, AL				
Y	-	-0.23^{*}	-0.72^{**}	-0.07^{ns}	0.30^{**}	0.54^{**}	0.59^{**}	0.64^{**}
PP	-0.23^{*}	-	-0.03^{ns}	-0.80^{**}	-0.61^{**}	-0.54^{**}	-0.24^{*}	-0.42^{**}

**, * or *ns* indicate P > F is significant at 1%, 5% or non-significant.

Table 38 Seeding rate and planting date % of maximum yield reduction from highest seeding rate to lowest seeding rate, and from the first planting date to last planting date

Station / Year	Hybrid	%Seeding Rate	% Planting date
GCREC- 2022	2042	20	37
GCREC -2022	1319	30	24
GCREC -2023	7045	34	29
EVSRC - 2022	2042	18	6
EVSRC -2022	1319	9	17
TVREC -2023	1170	10	25
TVREC - 2023	2042	12	49
	Average	13	25

The numbers displayed on this table refer to the difference between the highest seeding rate to lowest seeding rate yield, and to the first to the last planting date.

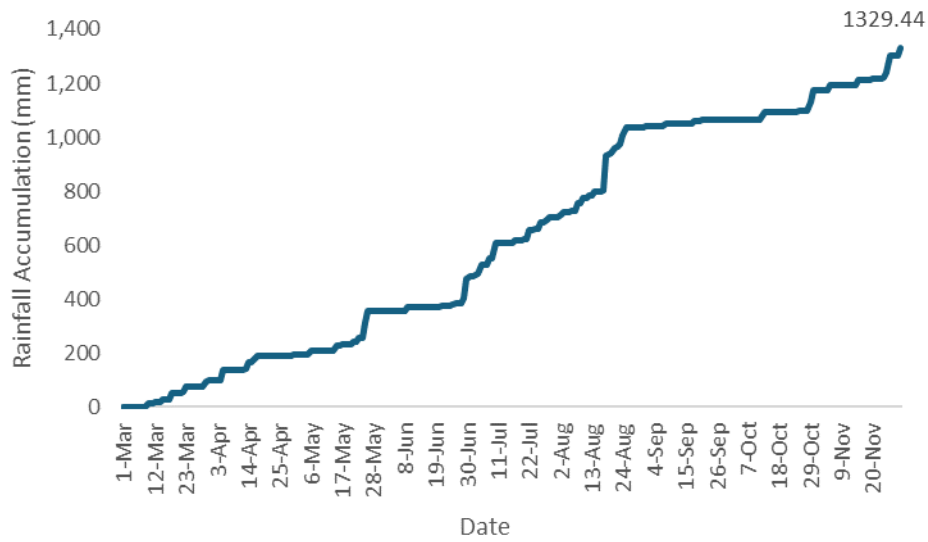

Figure 1.1 Precipitation accumulation (mm) Fairhope, AL 2022.

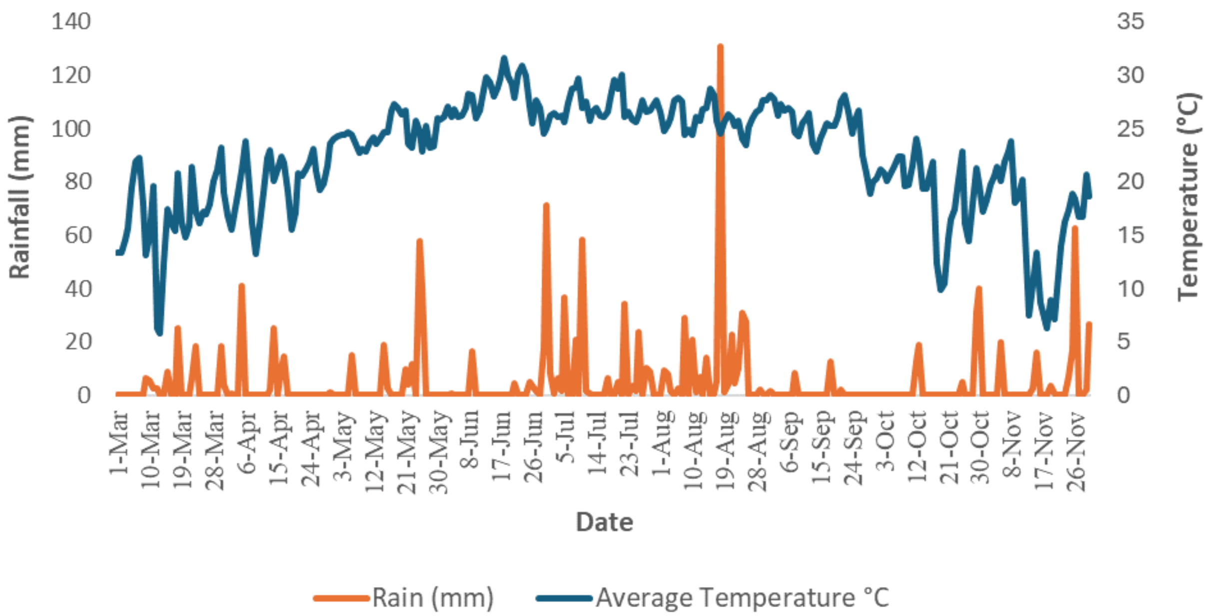

Figure 1.2 Average Temperature (°C), and Total Rainfall (mm) Fairhope, AL 2022.

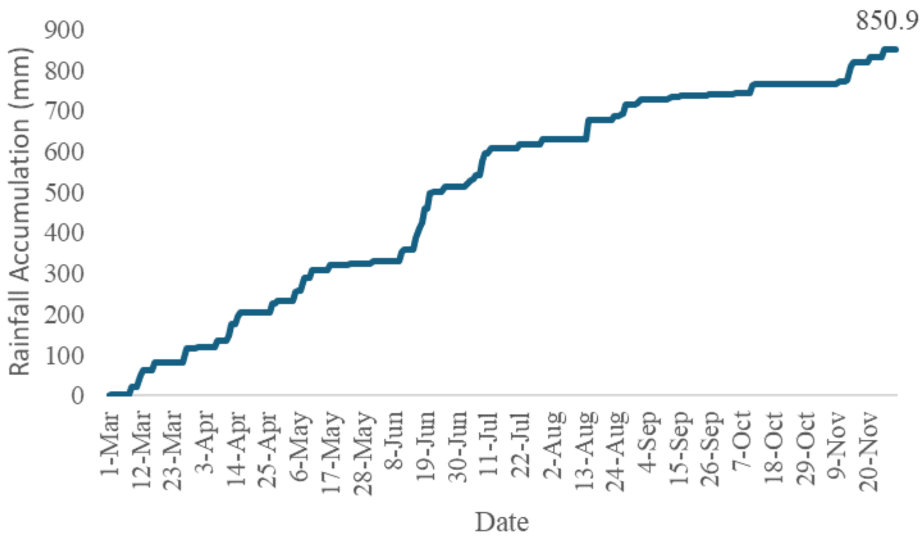

Figure 1.3 Precipitation accumulation (mm) Fairhope, AL 2023.

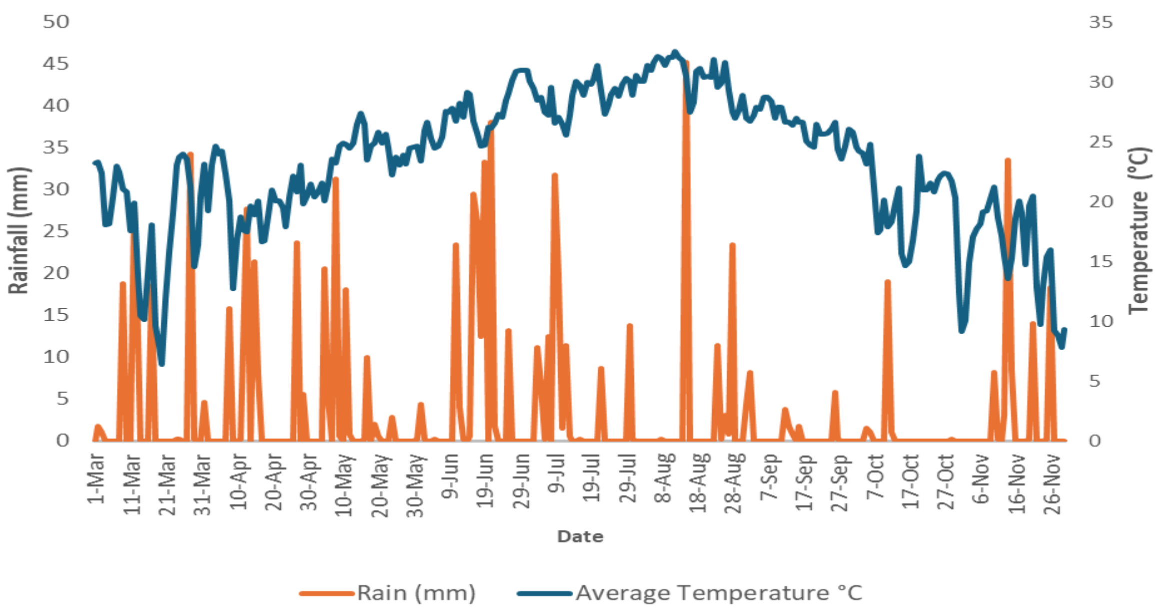

Figure 1.4 Average Temperature (°C), and Total Rainfall (mm) Fairhope, AL 2023.

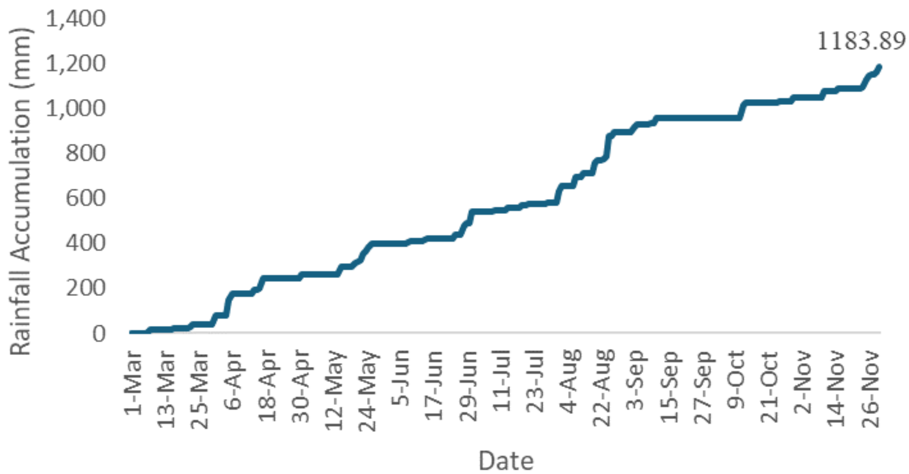

Figure 1.5 Precipitation accumulation (mm) Shorter, AL 2022.

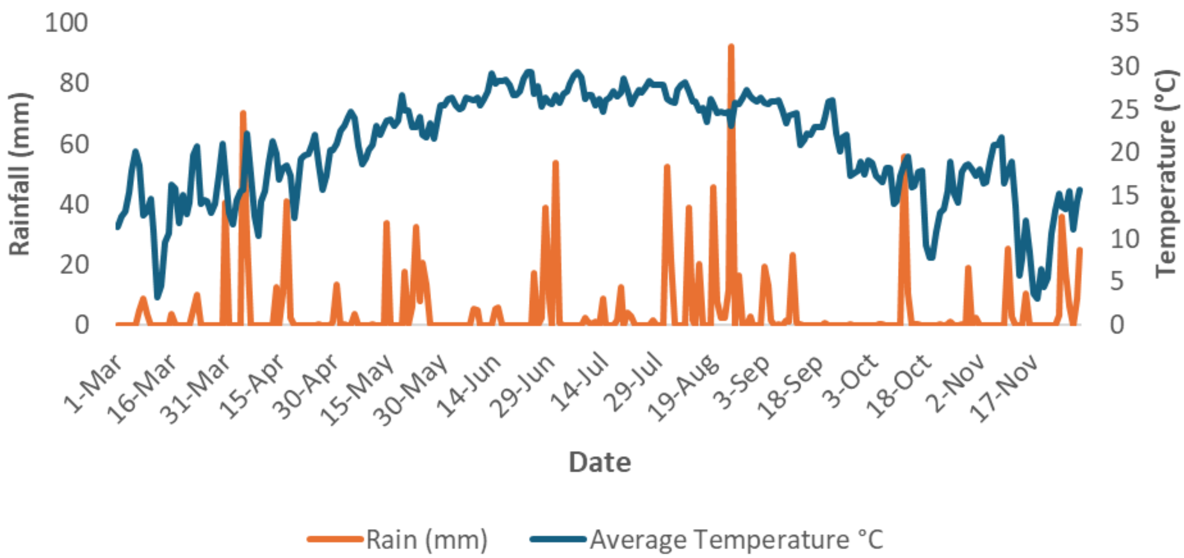

Figure 1.6 Average Temperature (°C), and Total Rainfall (mm) Shorter, AL 2022.

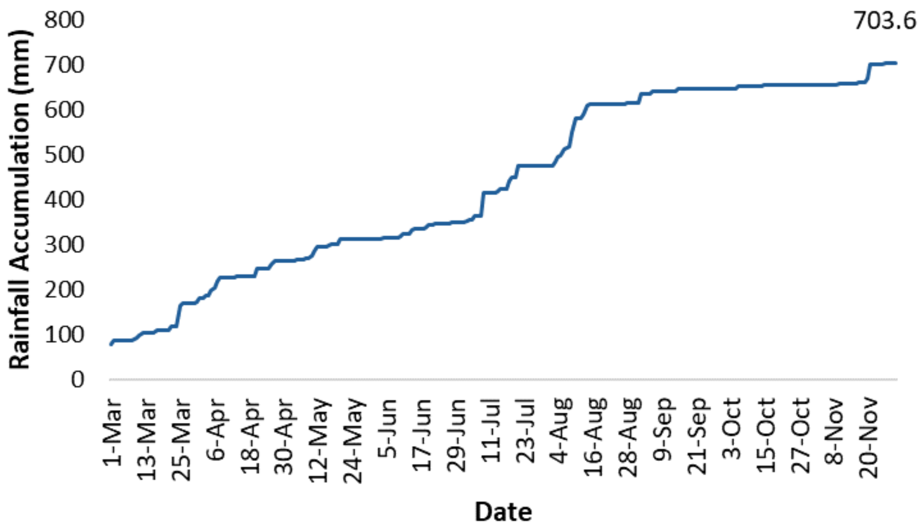

Figure 1.7 Precipitation accumulation (mm) Madison, AL2023.

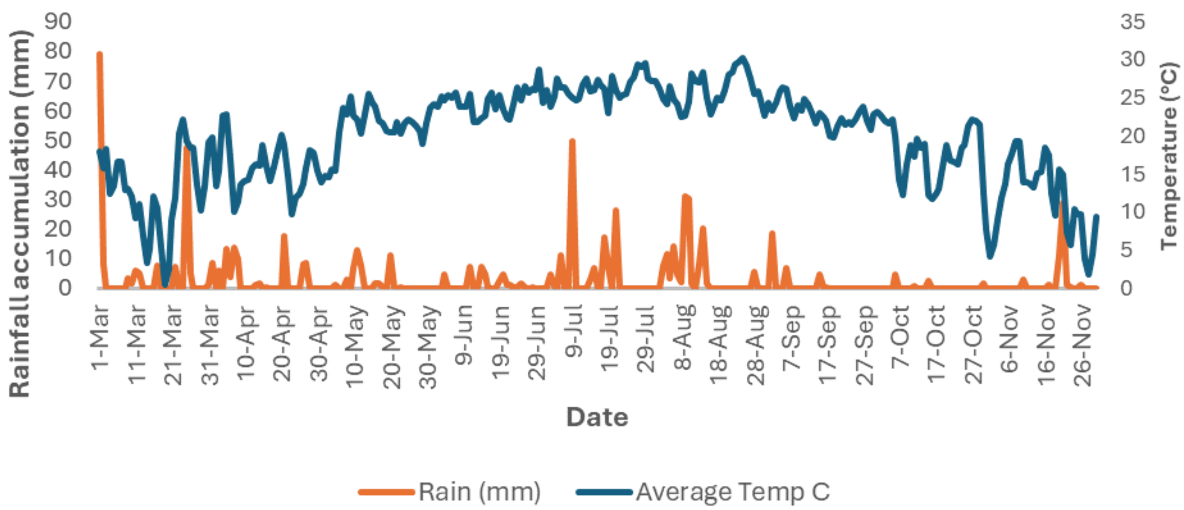

Figure 1.8 Average Temperature (°C), and Total Rainfall (mm) Madison, AL 2023.

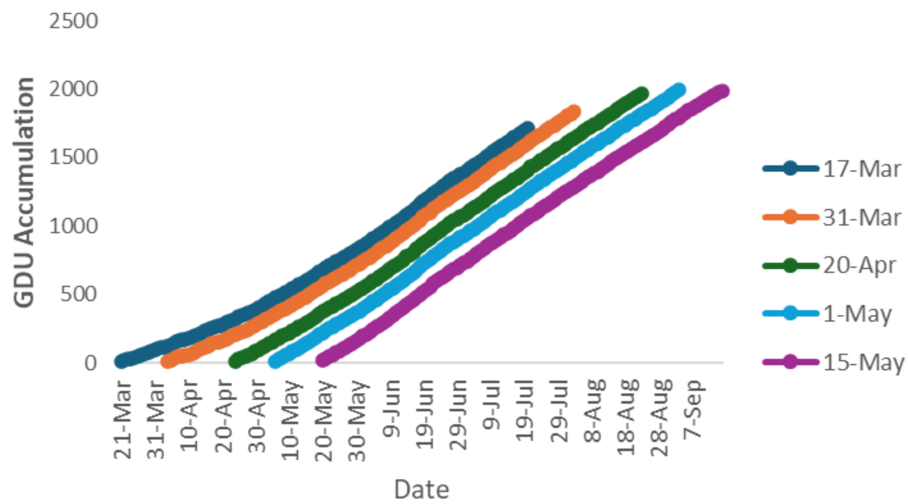

Figure 2.1 GDU Accumulation, Fairhope, AL 2022 Hybrid P2042VYHR.

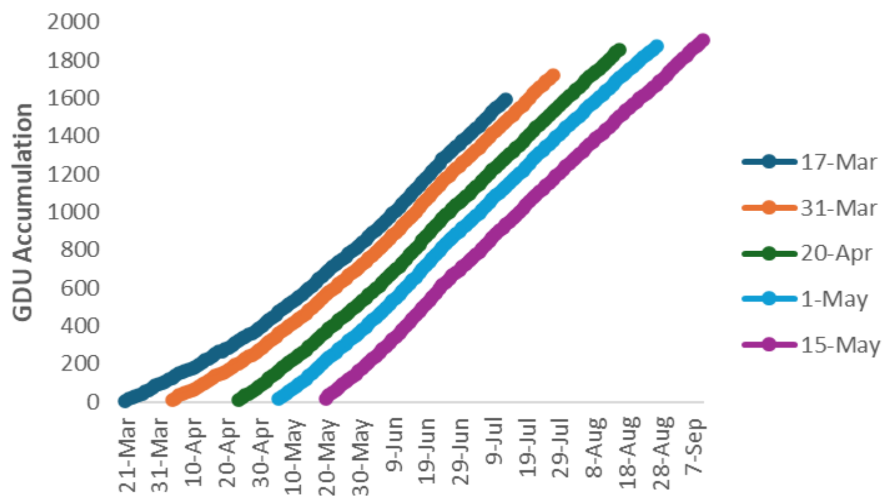

Figure 2.2 GDU Accumulation, Fairhope, AL 2022 Hybrid P1319R.

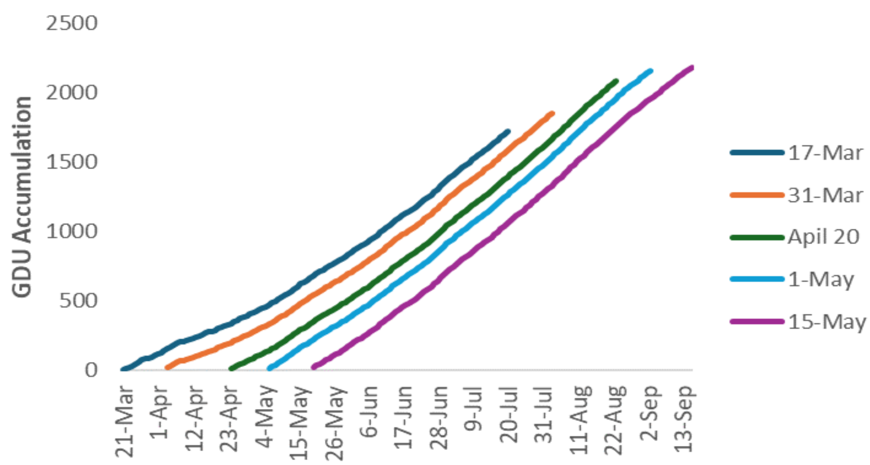

Figure 2.3 GDU Accumulation, Fairhope, AL 2023 Hybrid DK7045.

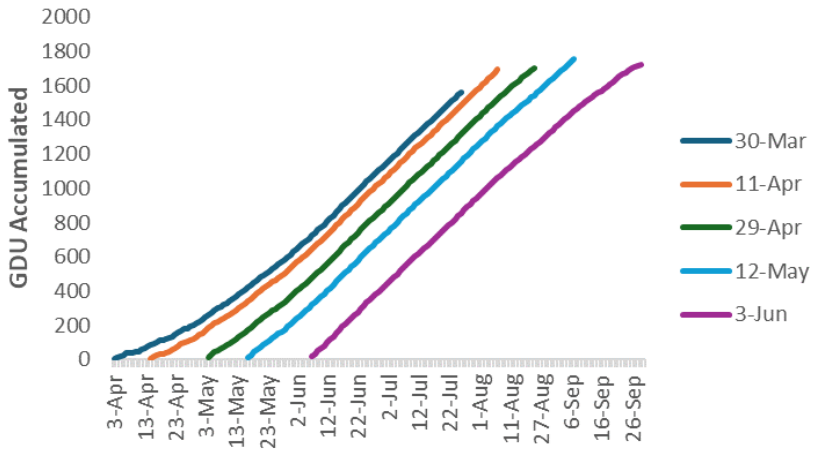

Figure 2.4 GDU Accumulation, Shorter, AL 2022 Hybrid P1319R.

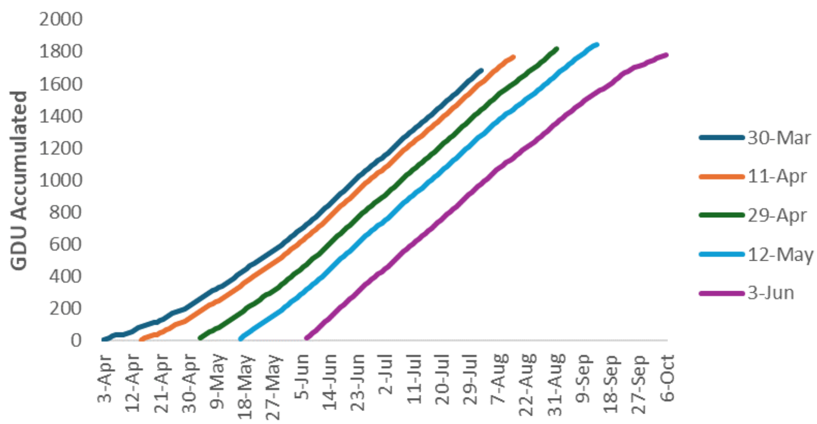

Figure 2.5 GDU Accumulation, Shorter, 2022 Hybrid P2042VYHR.

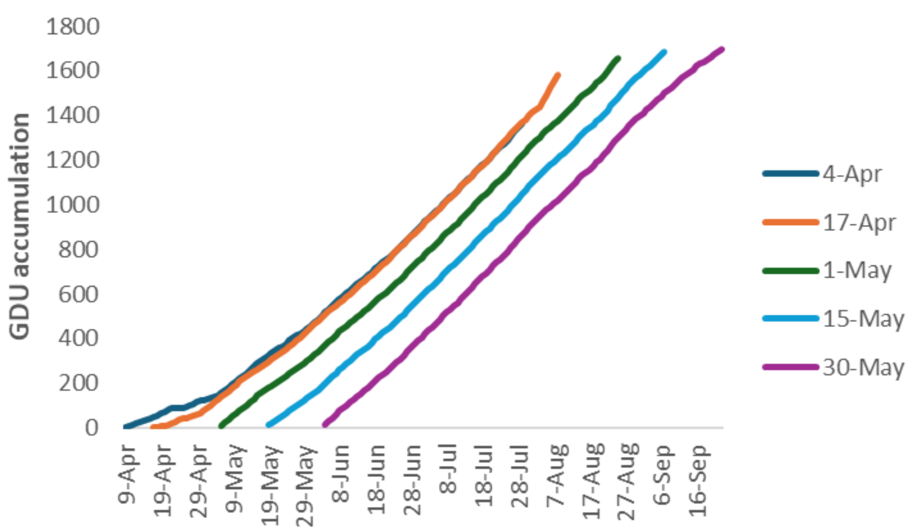

Figure 2.6 GDU Accumulation, Madison, AL 2022 Hybrid P1170YHR.

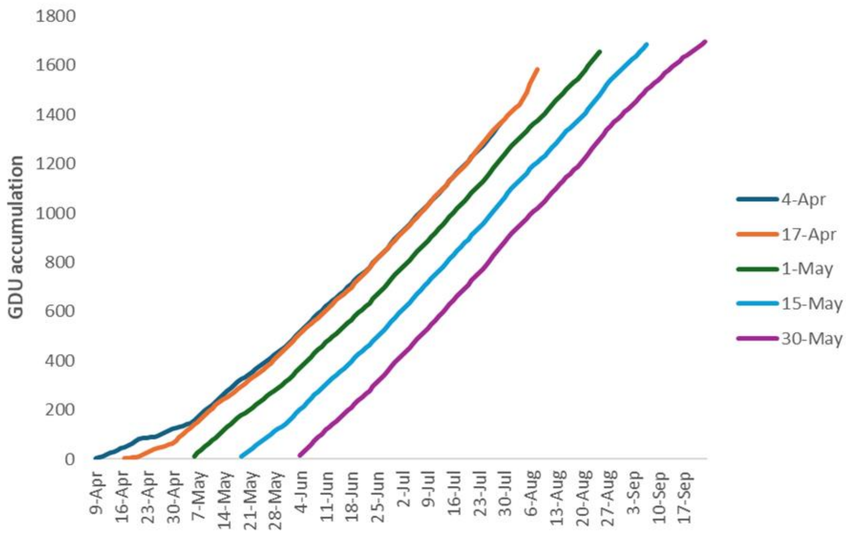

Figure 2.7 GDU Accumulation, Madison, AL 2022 Hybrid P2042VYHR.

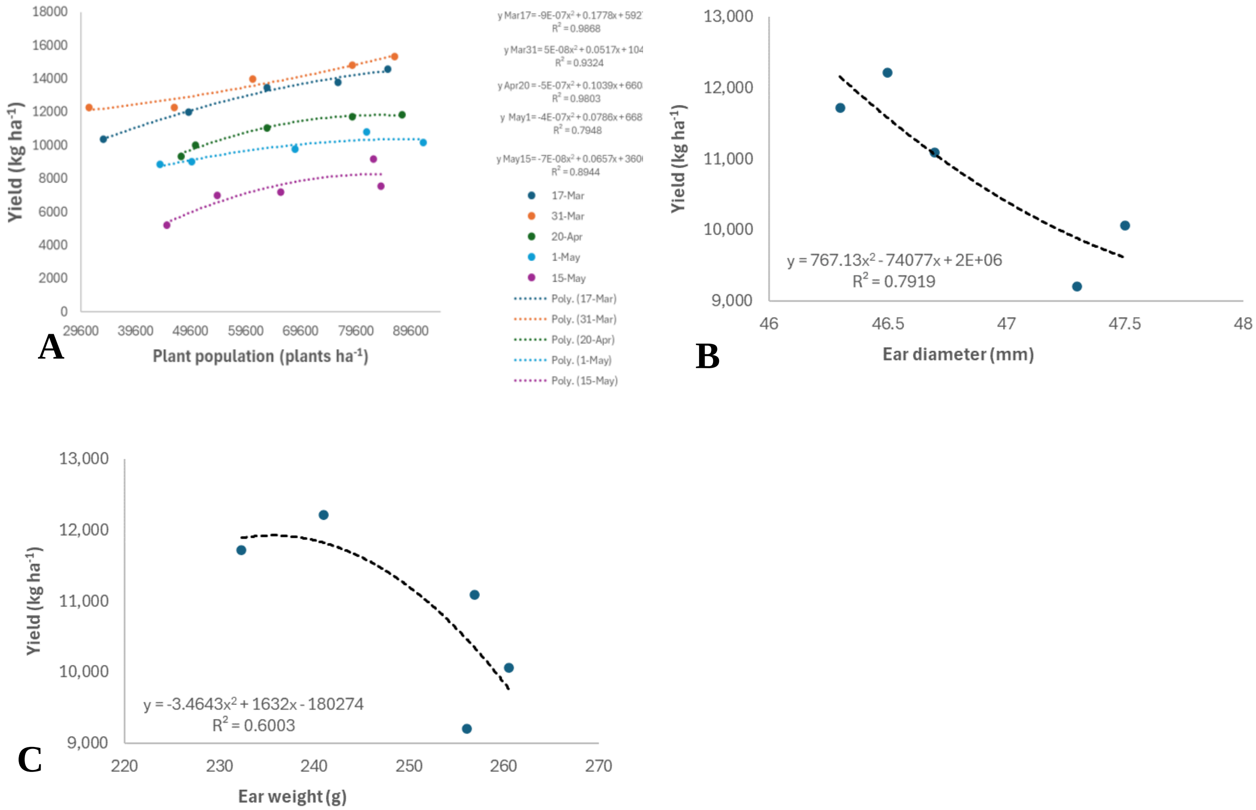

Figure 3.1 Relationship between corn yield and plant population (A), ear diameter (B) and ear weight, in Fairhope, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

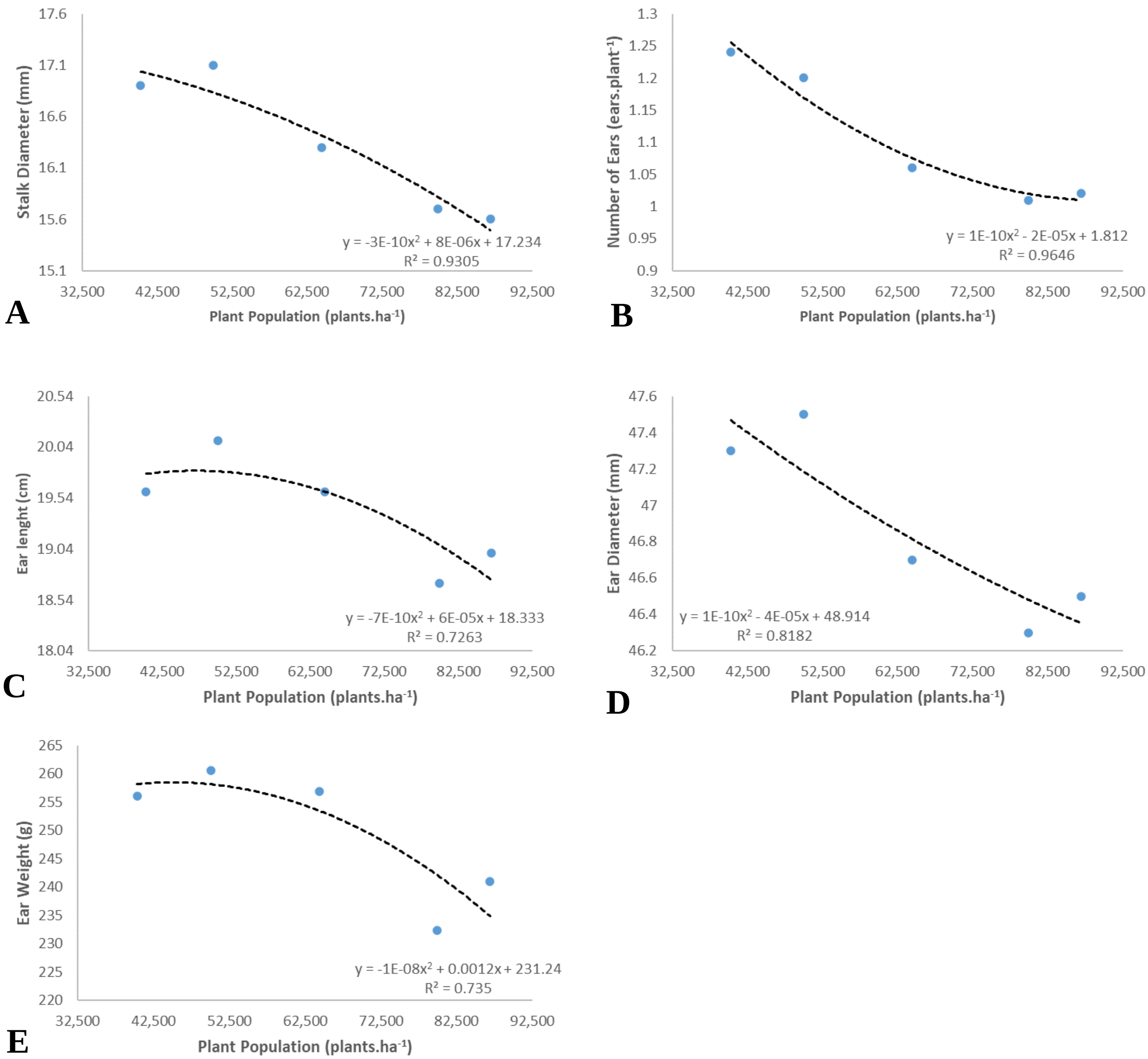

Figure 3.2 Relationship between plant population and stalk diameter (A), number of ears per plant (B), ear length (C), ear diameter (D), and ear weight (E) in 2022, in Fairhope, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

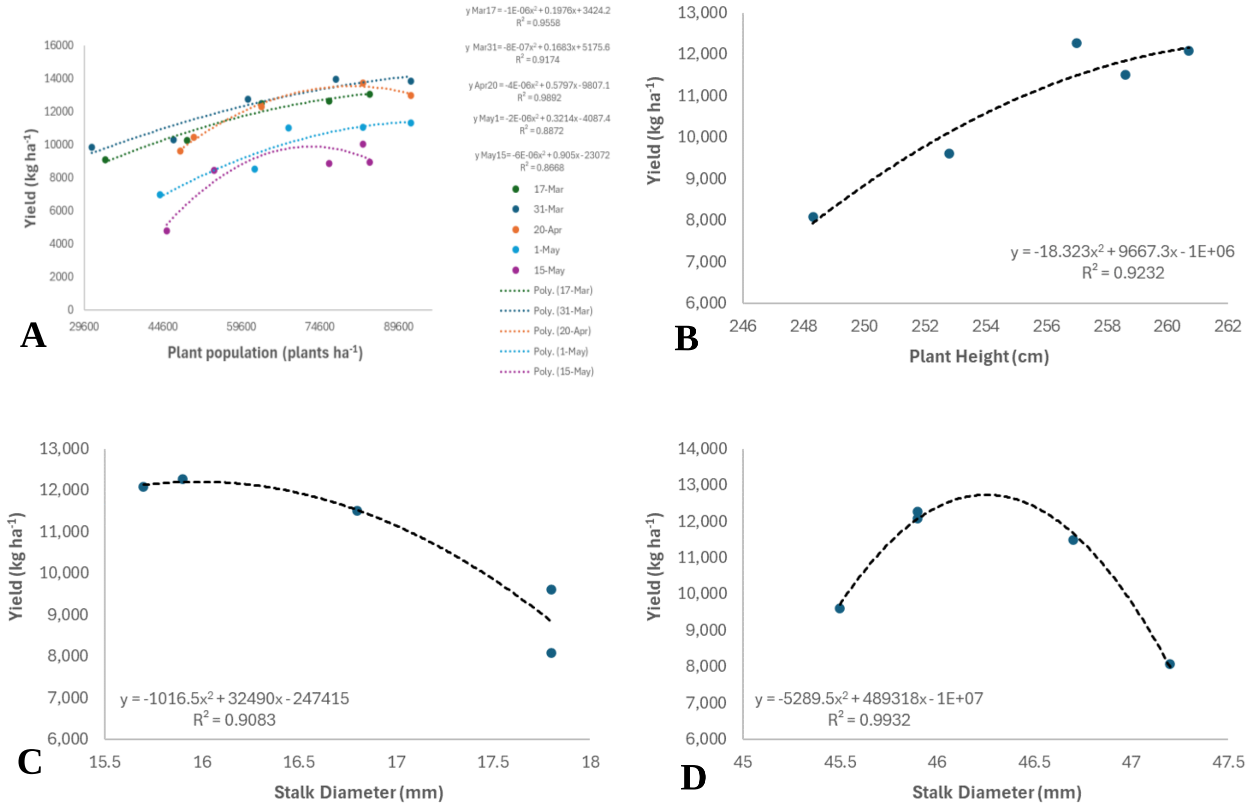

Figure 3.3 Relationship between corn yield and plant population (A), plant height (B), stalk diameter (C), and ear diameter (D), in 2022, in Fairhope, AL. Hybrid P1319R. Each data point represents the mean of the variables for each seeding rate.

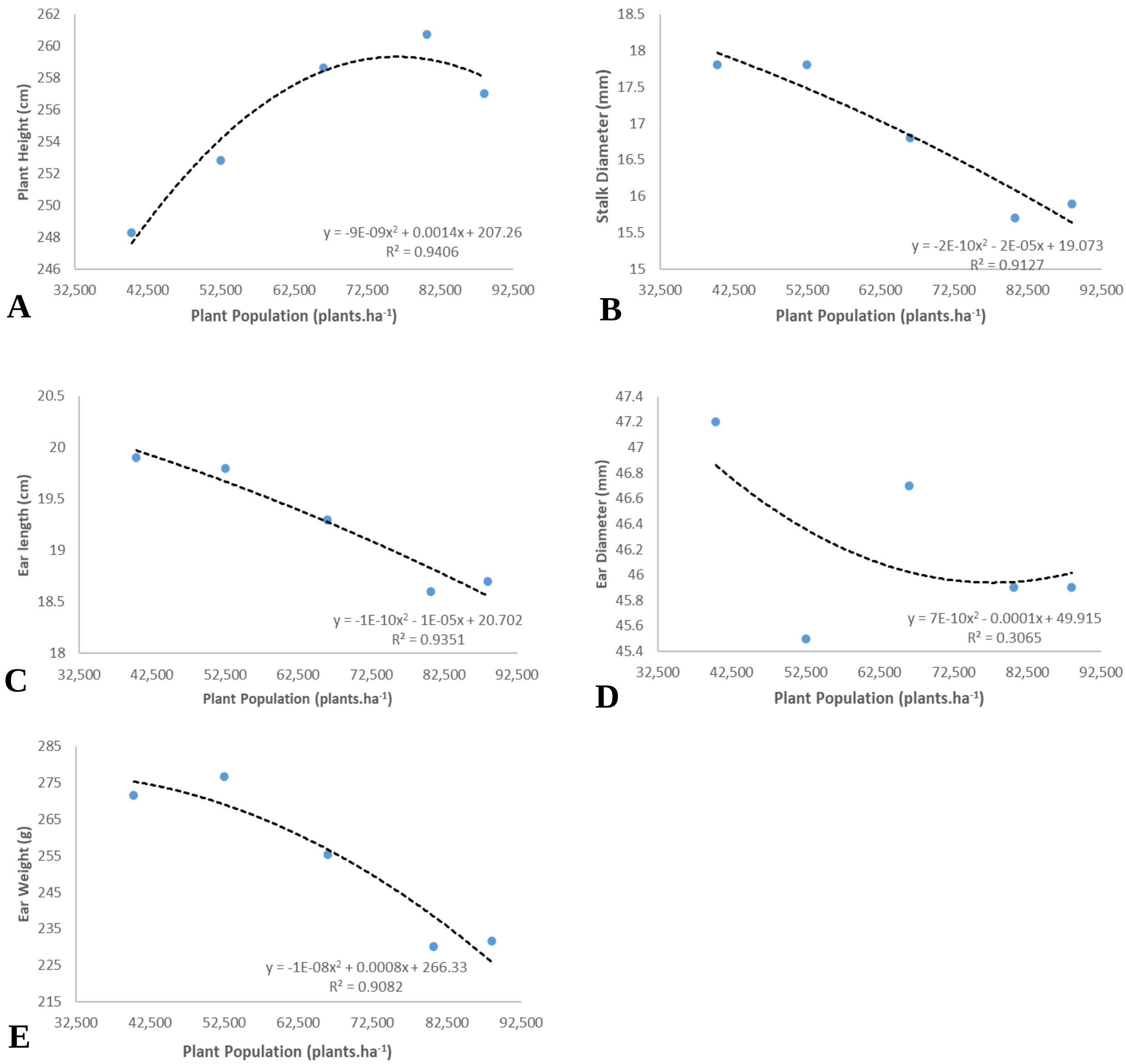

Figure 3.4 Relationship between plant population and plant height (A), stalk diameter (B), ear length (C), ear diameter (D), and ear weight (E) in 2022, in Fairhope, AL. Hybrid P1319R. Each data point represents the mean of the variables for each seeding rate.

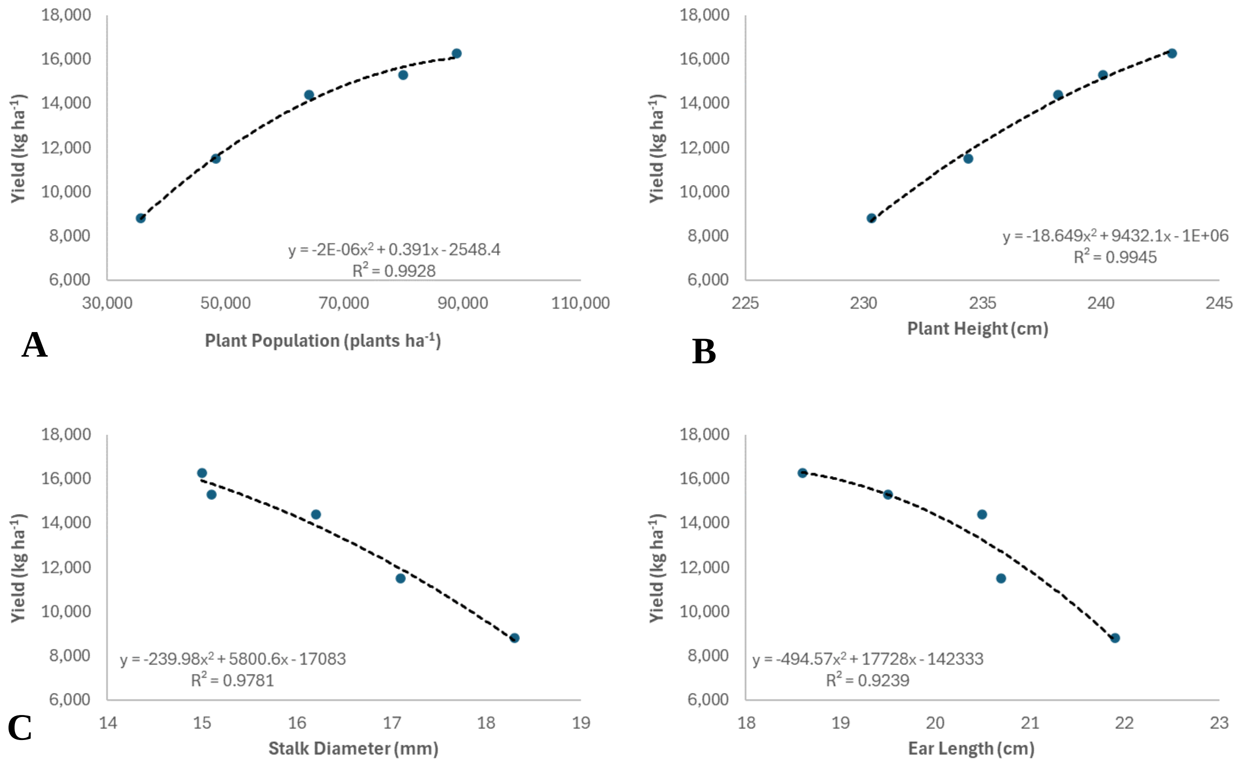

Figure 4.1 Relationship between corn yield and plant population (A) plant height (B), and stalk diameter (C), and ear length (D) in 2023, in Fairhope, AL. Hybrid DKB7045. Each data point represents the mean of the variables for each seeding rate.

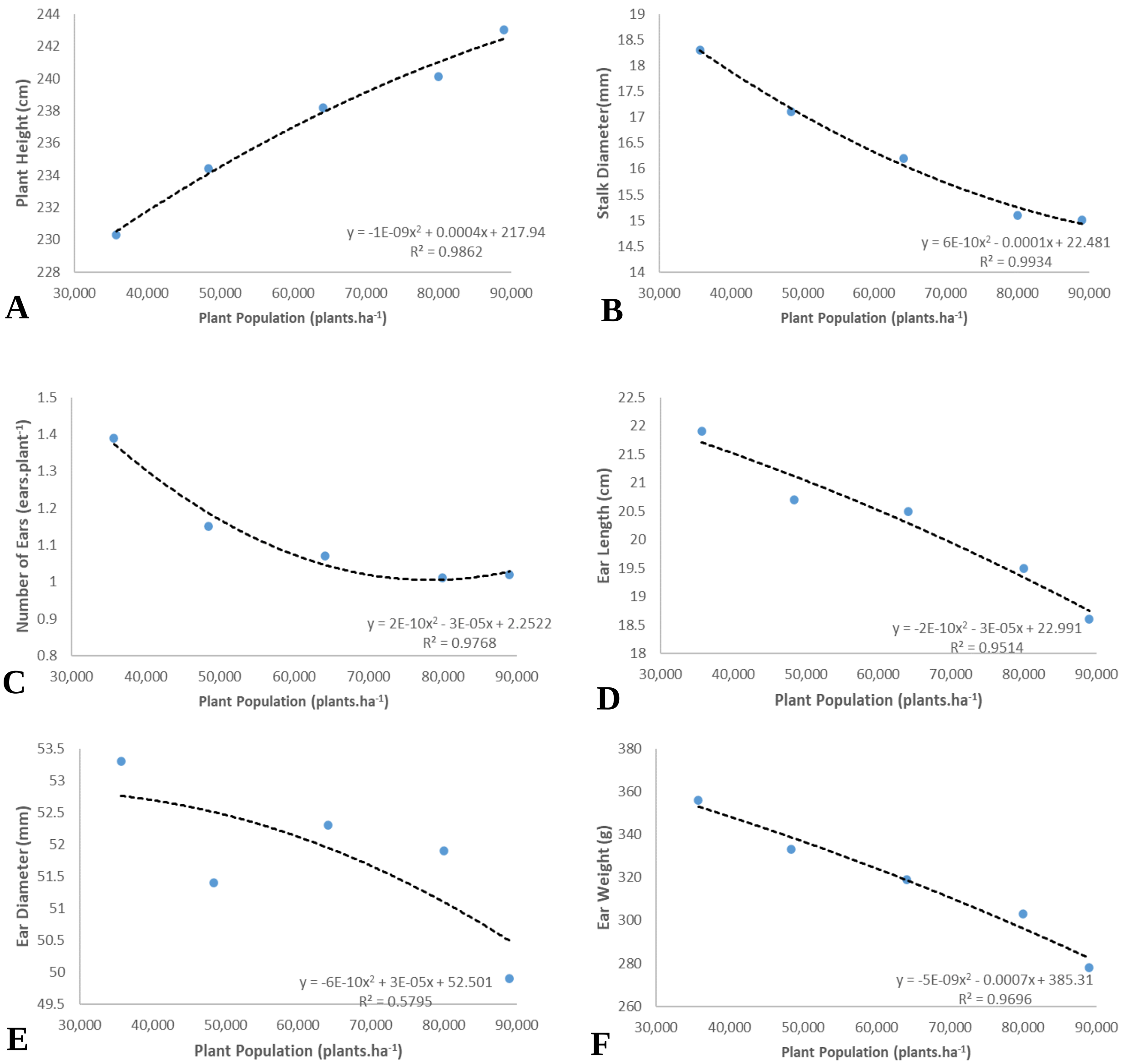

Figure 4.2 Relationship between plant population and plant height (A), stalk diameter (B), number of ears per plant (C), ear length (D), and ear diameter (E) and ear weight (F) in 2023, in Fairhope, AL. Hybrid DKB7045. Each data point represents the mean of the variables for each seeding rate.

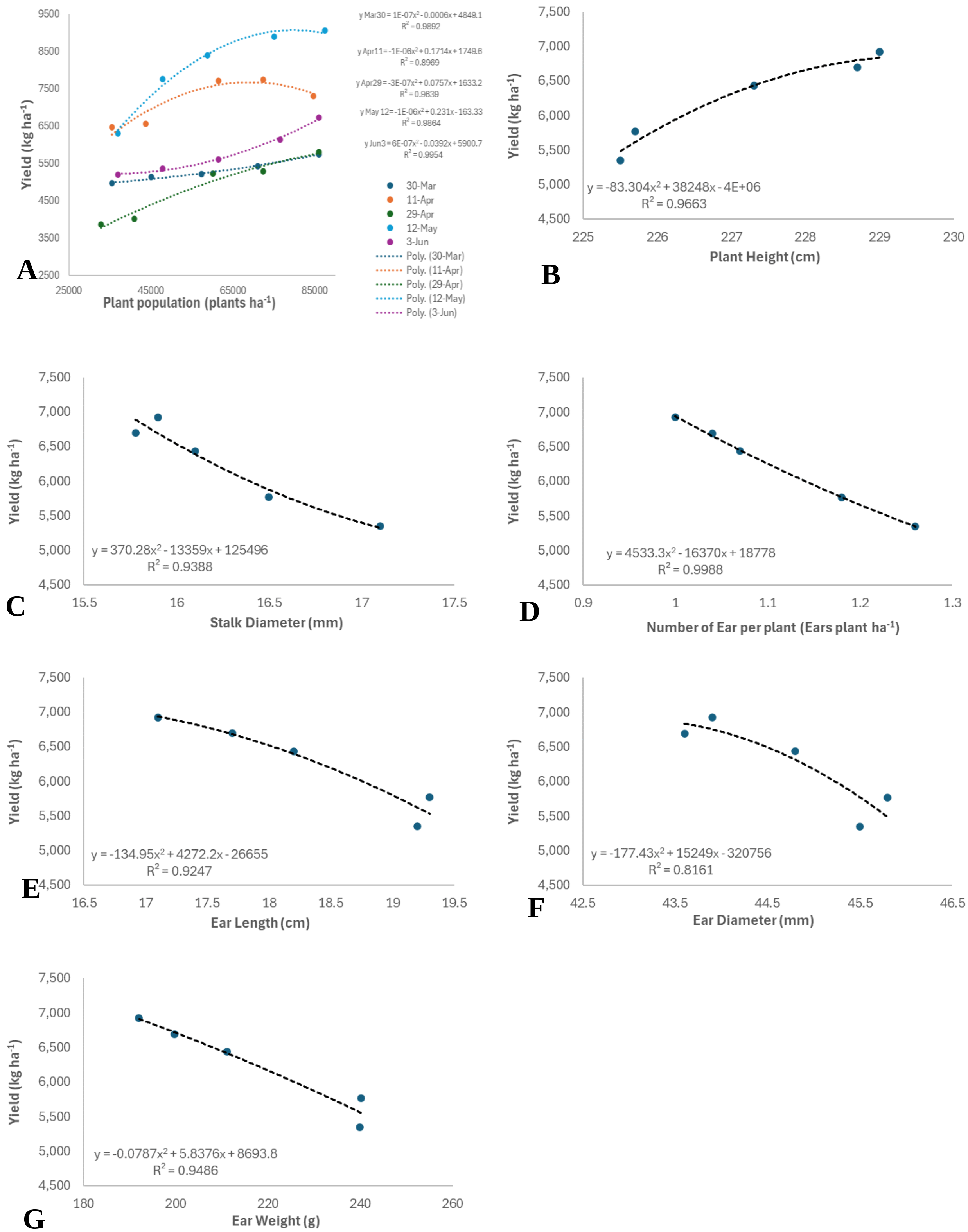

Figure 5.1 Relationship between corn yield and plant population (A), plant height (B), stalk diameter (C), number of ears (D), ear length (E), ear diameter (F), and ear weight (G) in 2022, in Shorter, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

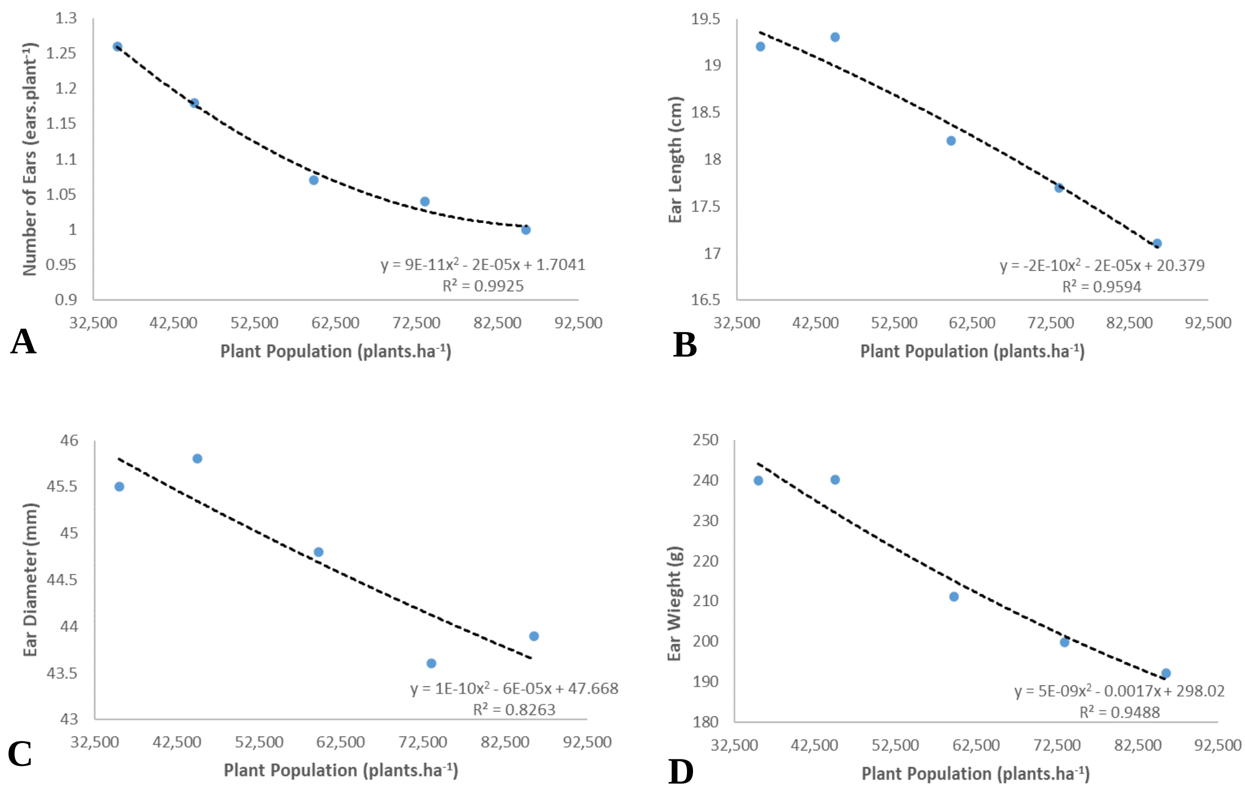

Figure 5.2 Relationship between plant population and number of ears per plant (A), ear length (B), ear diameter (C), and ear weight (D) in 2022, in Shorter, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

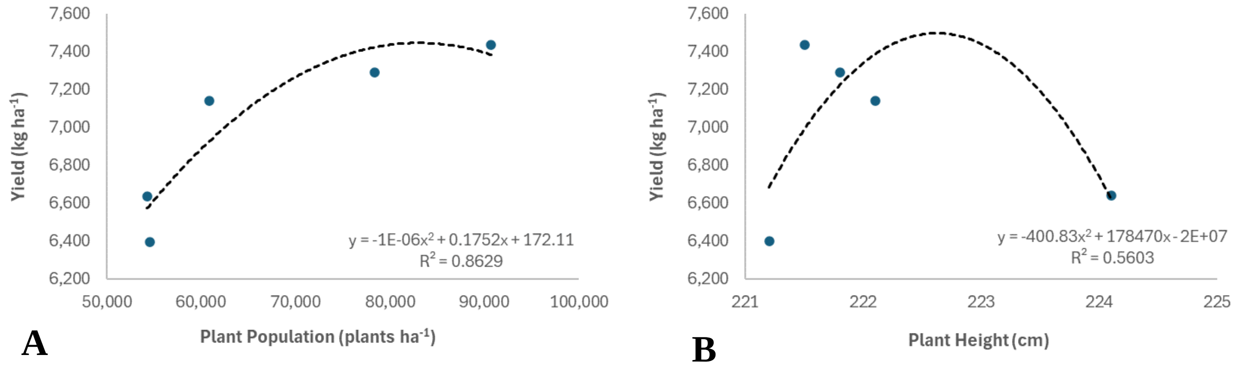

Figure 5.3 Relationship between corn yield and plant population (A), plant height (B) in 2022, in Shorter, AL. Hybrid P1319R. Each data point represents the mean of the variables for each seeding rate.

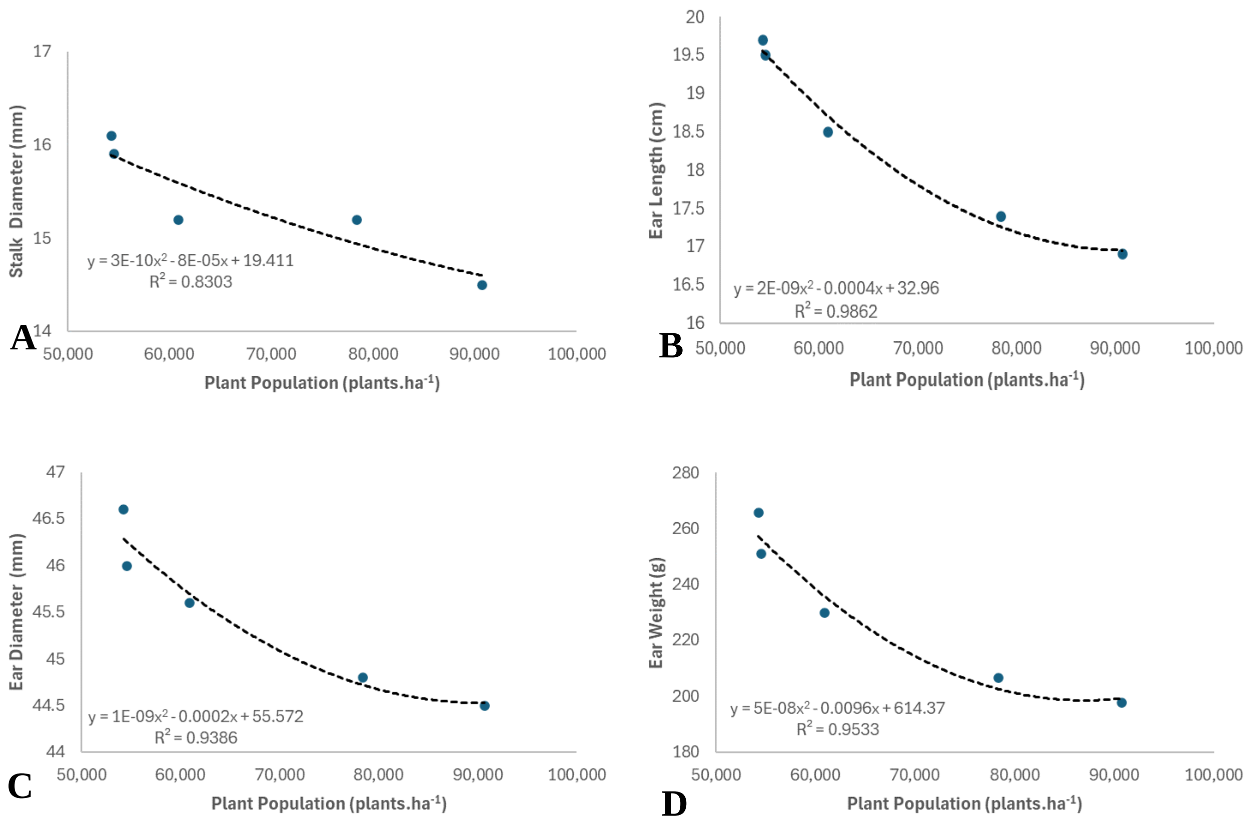

Figure 5.4 Relationship between plant population stalk diameter (A), ear length (B), ear diameter (C), and ear weight (D) in 2022, in Shorter, AL. Hybrid P1319VYHR. Each data point represents the mean of the variables for each seeding rate.

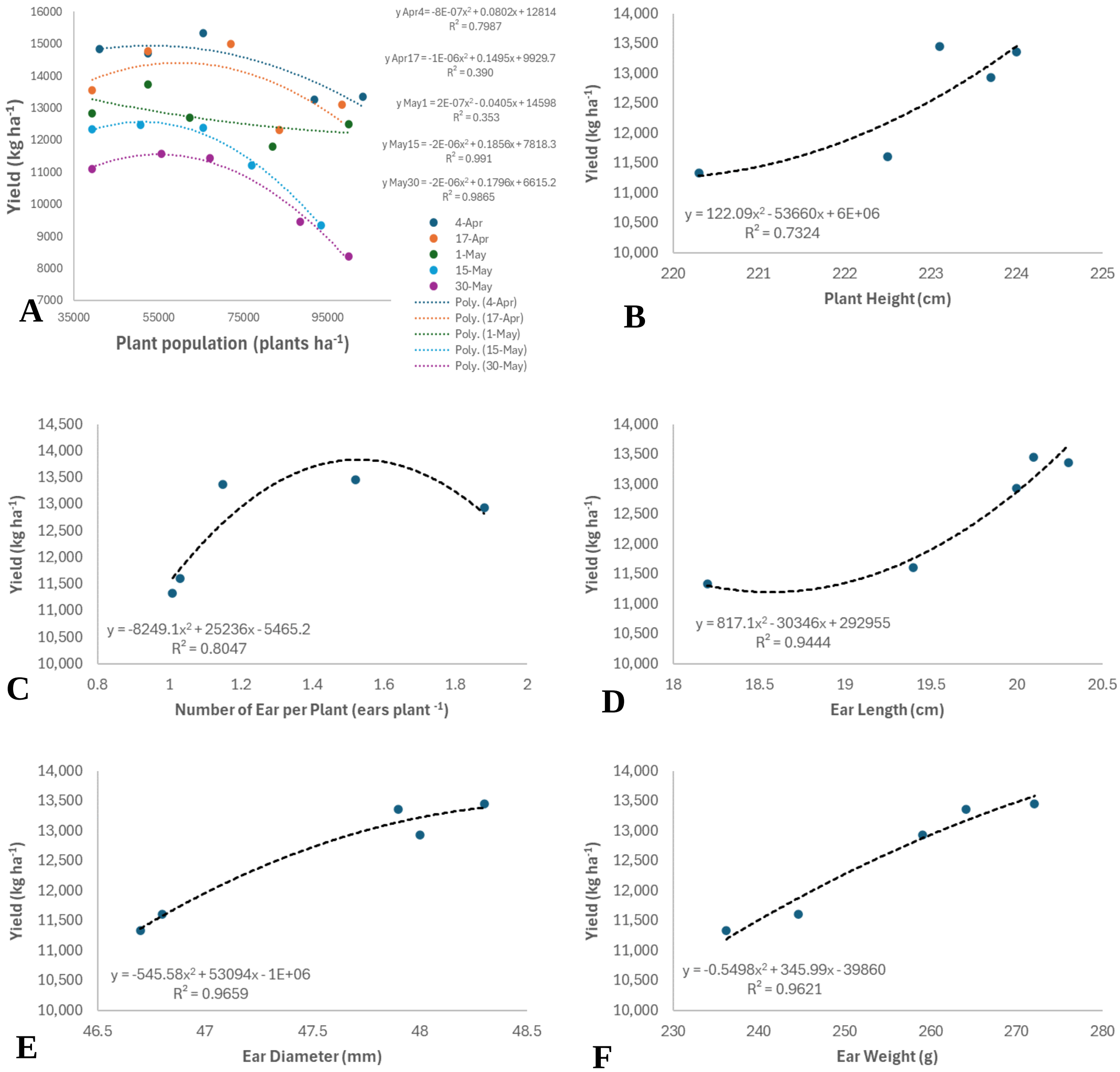

Figure 6.1 Relationship between corn yield and plant population (A), plant height (B), number of ears per plant (C), and ear length (D), ear diameter (E), and ear weight (F), in 2023, in Madison, AL. Hybrid P1170YHR. Each data point represents the mean of the variables for each seeding rate.

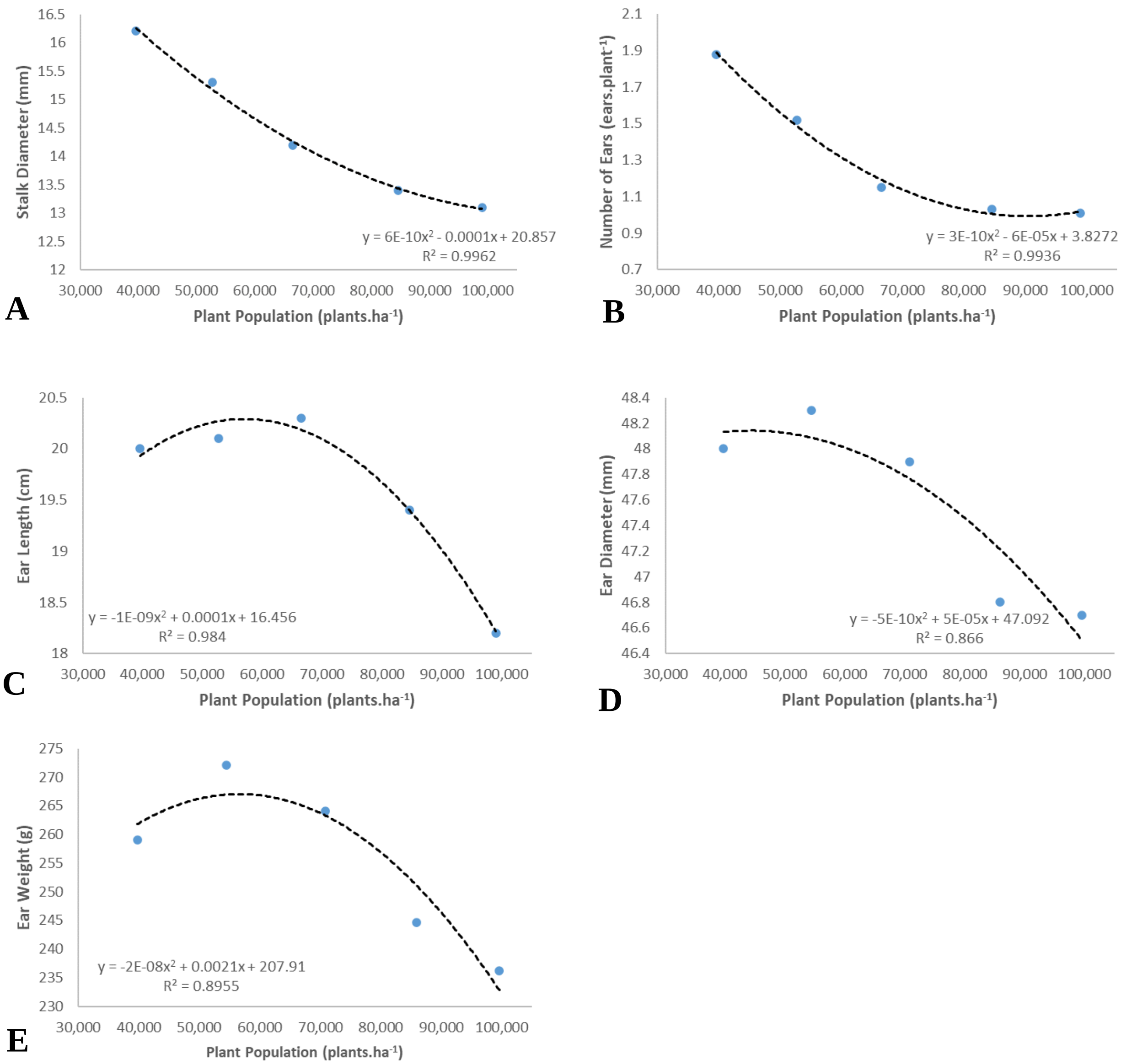

Figure 6.2 Relationship between plant population and stalk diameter (A), number of ears per plant (B), ear length(C), ear length (D), and ear diameter (E) and ear weight (F), in 2023, in Madison, AL. Hybrid P1170YHR. Each data point represents the mean of the variables for each seeding rate.

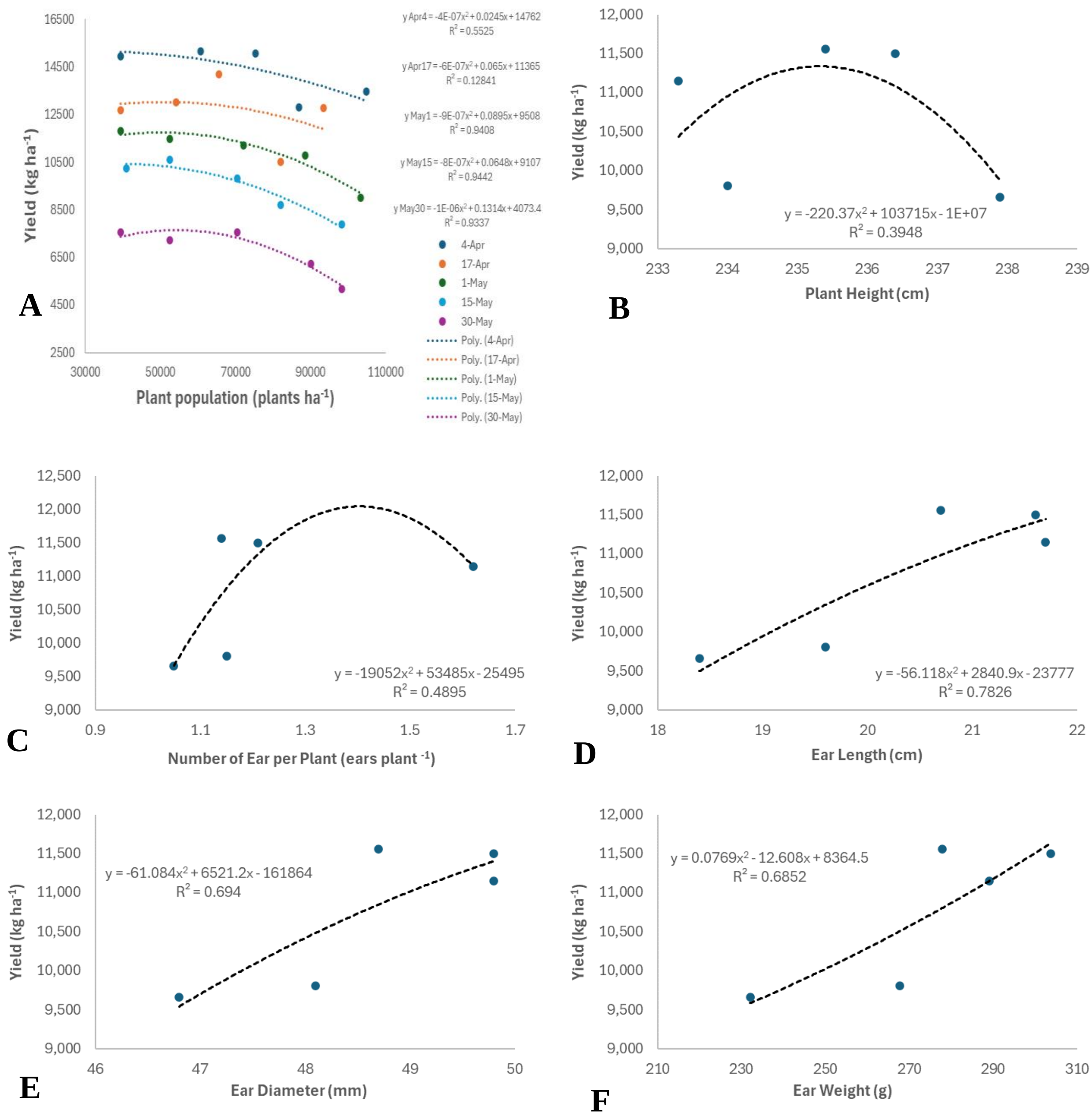

Figure 6.3 Relationship between corn yield and plant population (A), plant height (B), number of ears (C), ear length (D), ear diameter (E), and ear weight (F), in 2023, in Madison, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

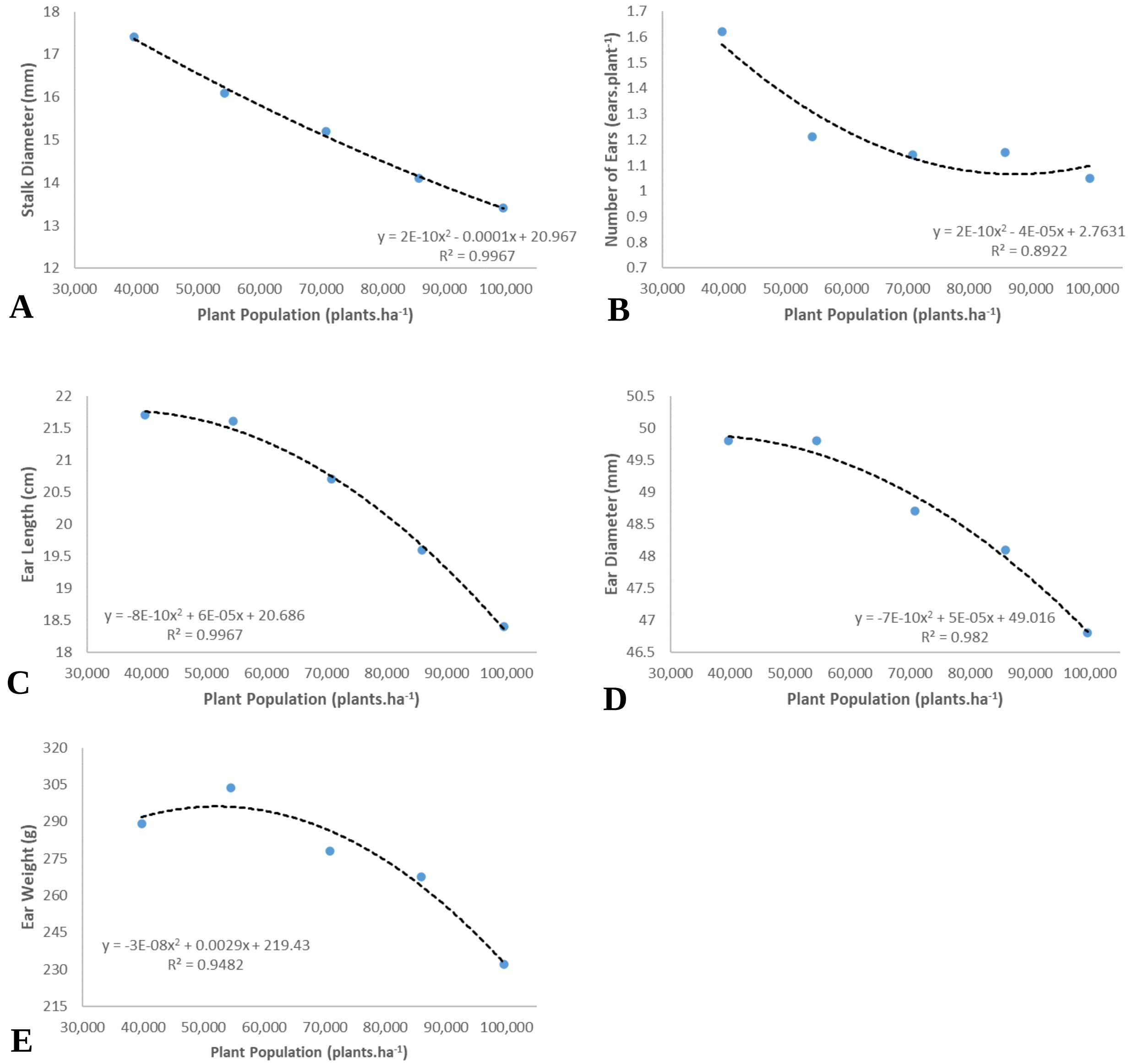

Figure 6.4 Relationship between plant population and stalk diameter (A), number of ears per plant (B), ear length (C), ear diameter (D), and ear weight (E) in 2023, in Madison, AL. Hybrid P2042VYHR. Each data point represents the mean of the variables for each seeding rate.

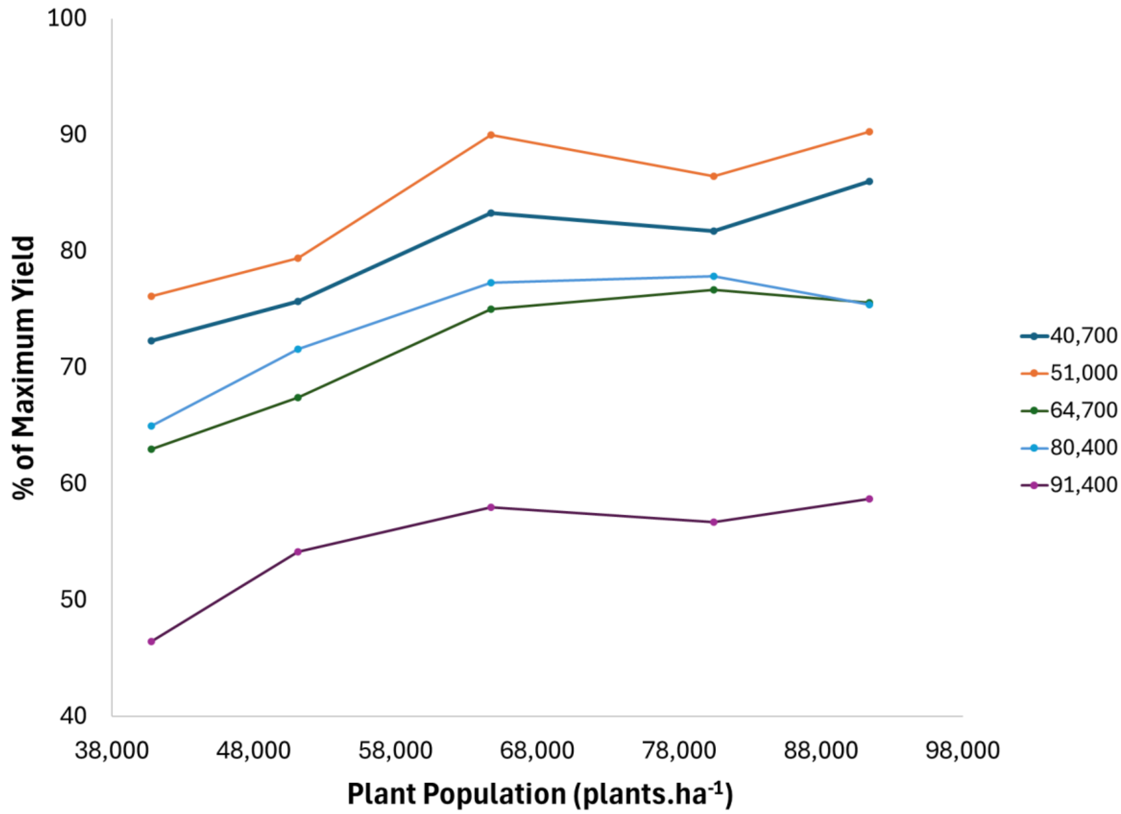

Figure 7.1 Variation in yield percentage across seeding rates for different planting dates. This figure represents the average maximum yield for all the replant boards for all the cases.

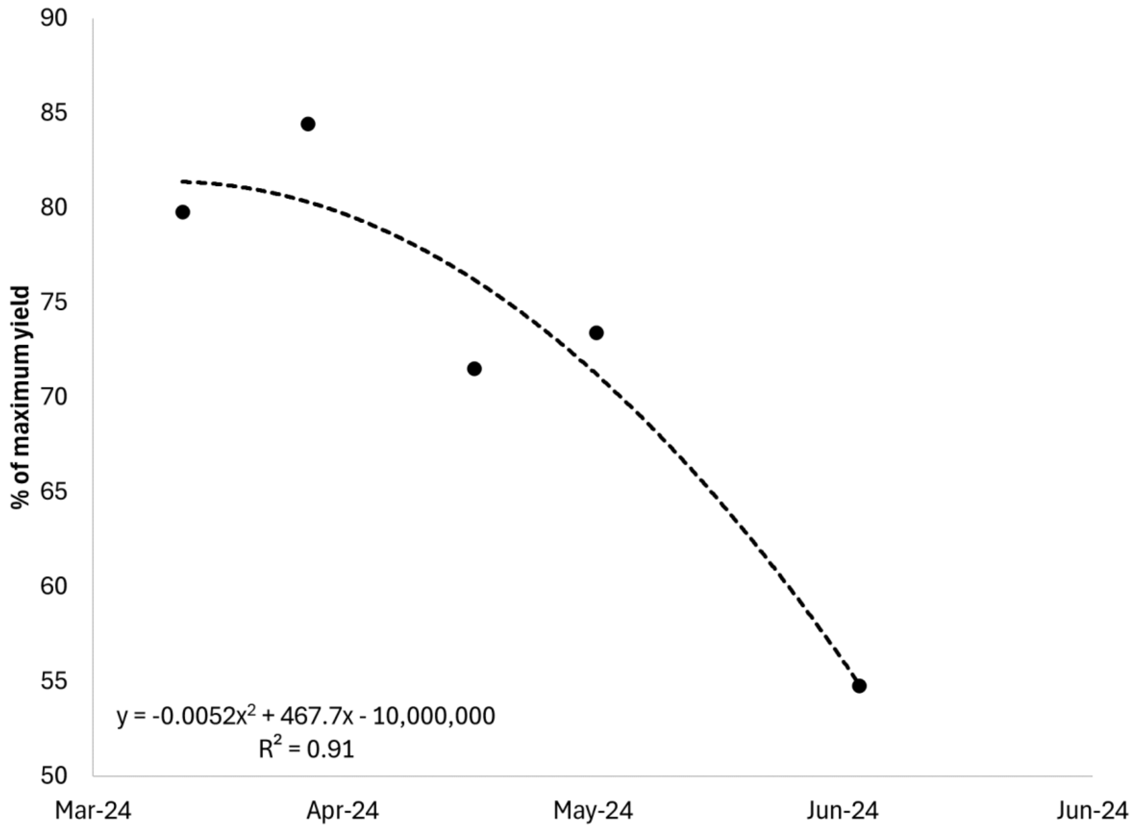

Figure 7.2 Percentage of maximum yield reduction across different planting dates. The dates in this figure are an average from all the replant boards for all the cases.

REFERENCES

Alabama Cooperative Extension System. (2023). ANR-2852: Corn Irrigation Recommendations for Alabama, 2023 [PDF]. Retrieved from https://www.aces.edu/wp-content/uploads/2023/04/ANR-2852_CornIRR23L.pdf

Abendroth, L. J., Elmore, R. W., Boyer, M. J., & Marlay, S. K. (n.d.). *Understanding corn development: A key for successful crop management*. Retrieved July 26, 2023, from https://www.store.extension.iaestate.edu/product/6065

Assefa, Y., Vara Prasad, P. V., Carter, P., Hinds, M., Bhalla, G., Schon, R., Jeschke, M., Paszkiewicz, S., & Ciampitti, I. A. (2016). Yield responses to planting density for US modern corn hybrids: A synthesis-analysis. *Crop Science*, *56*(5), 2802–2817. https://doi.org/10.2135/CROPSCI2016.04.0215

Bansal, Saurabh & Nagarajan, Mahesh. (2022). Portfolio Management Issues in the Commercial Seed Industry: A Modeling Framework and Industry Implementation. 10.1007/978-3-030-81423-6_4.

Butzen, S, and S. Paszkiewicz. 2008. *Narrow-Row Corn Production - When Does It Increase Yields?* Crop Insights, Vol. 18, No. 15. Pioneer Hi-Bred, Johnston, IA.

Bullock, D. G., Nielsen, R. L., & Nyquist, W. E. (1988). A Growth Analysis Comparison of Corn Grown in Conventional and Equidistant Plant Spacing. *Crop Science*, *28*(2), 254–258. https://doi.org/10.2135/CROPSCI1988.0011183X002800020015X

Carter, P.R., E.D. Nafziger, and D.R. Hicks. 1992. Effects of Uneven Seedling Emergence in Corn (NCH-36) [Online]. National Corn Handbook Series, Purdue Univ. Coop. Ext. Service, W. Lafayette, IN 47907. http://www.agcom.purdue.edu/AgCom/Pubs/ NCH/NCH-36.html (Verified 04/10/2023).

Coulter, J. A., Nafziger, E. D., Janssen, M. R., & Pedersen, P. (2010). Response of bt and near-isoline corn hybrids to plant density. *Agronomy Journal*, *102*(1), 103–111. https://doi.org/10.2134/AGRONJ2009.0217

Ciampitti, I. 2018. *Trends in Optimum Plant Density and Yields Gains for Corn in North America*. Pioneer Agronomy Research Update.

Cox, W. J., Cherney, D. R., & Hanchar, J. J. (1998). Row spacing, hybrid, and plant density effects on corn silage yield and quality. *Journal of Production Agriculture*, *11*(1), 128–134. https://doi.org/10.2134/JPA1998.0128

Cox, W. J., & Cherney, J. H. (2012). Lack of hybrid, seeding, and nitrogen rate interactions for corn growth and yield. *Agronomy Journal*, *104*(4), 945–952. https://doi.org/10.2134/AGRONJ2012.0027

Duncan, W. G. (1984). A Theory to Explain the Relationship Between Corn Population and Grain Yield1. *Crop Science*, *24*(6), 1141–1145. https://doi.org/10.2135/CROPSCI1984.0011183X002400060032X

Djaman, K., Allen, S., Djaman, D.S., Koudahe, K., Irmak, S., Puppala, N., Darapuneni, M. K., Angadi, S.V., 2022. Planting date and plant density effects on maize growth, yield and water use efficiency. Environ. Chall. 6, 100417 https://doi.org/10.1016/j. envc.2021.100417.

Fischer, K.S., Palmer, A.F.E., Gold-sworthy, P.R., Fischer, N.M.,1984. Tropical maize. In:The Physiology of Tropical Field Crops. Wiley, New York, pp. 213-248.

Food and Agriculture Organization of the United Nations., & FAO. (1992). Maize in Human Nutrition. *Food & Agriculture Organization of the United Nations*, 160. http://www.fao.org/3/T0395E/T0395E00.htm#Contents

Griesh, M.H., Yakout, G.M., Horst, W.J., et al., 2001. Effect of plant population density and nitrogen fertilization on yield and yield components of some white and yellow maize hybrids under drip irrigation system in sandy soil. Plant Nu trition. Developments in Plant and Soil Sciences, 92 (eds). Springer, Dordrecht doi:10.1007/0-306-47624-X_394

Jungenheimer, D. W. (1976). *Corn: Improvement, Seed Production and Uses.* Robert W. Jungenheimer.

Hammer, G. L., Dong, Z., McLean, G., Doherty, A., Messina, C., Schussler, J., Zinselmeier, C., Paszkiewicz, S., & Cooper, M. (2009a). Can changes in canopy and/or root system architecture explain historical maize yield trends in the U.S. corn belt? *Crop Science*, *49*(1), 299–312. https://doi.org/10.2135/CROPSCI2008.03.0152

Hammer, G. L., Dong, Z., McLean, G., Doherty, A., Messina, C., Schussler, J., Zinselmeier, C., Paszkiewicz, S., & Cooper, M. (2009b). Can changes in canopy and/or root system architecture explain historical maize yield trends in the U.S. corn belt? *Crop Science*, *49*(1), 299–312. https://doi.org/10.2135/CROPSCI2008.03.0152

Hatfield, J. L., & Dold, C. (2019). Water-use efficiency: Advances and challenges in a changing climate. *Frontiers in Plant Science*, *10*. https://doi.org/10.3389/FPLS.2019.00103/FULL
Hicks, D. R.; Thomison, P. R., 2004. Corn management. In: Smith, C. W.; Betrán, J.; Runge, E. C. A. (Eds), Corn: Origin, History, Technology, Production. p: 481-522. John Wiley & Sons, Inc.

Johnson, R. R., & Mulvaney, D. L. (1980). Development of a Model for Use in Maize Replant Decisions 1 . *Agronomy Journal*, *72*(3), 459–464. https://doi.org/10.2134/AGRONJ1980.00021962007200030013X

Kiniry, J. R., & Ritchie, J. T. (1985). Shade-sensitive interval of kernel number of maize. Agronomy Journal,77(5), 711–715.https://doi.org/10.2134/agronj1985.00021962007700050012x

Latha, V. S., & Lone, A. (2020). *Maize Breeding Manual Development of high yielding-Sweet corn Hybrids View project Optimization of organic seed production system in maize View project*. https://www.researchgate.net/publication/350312933

Ling, Y., Liu, M., Feng, Y., Xing, Z., Gao, H., Wei, H., Hu, Q., & Zhang, H. (2023). Effects of increased seeding density on seedling characteristics, mechanical transplantation quality, and yields of rice with crop straw boards for seedling cultivation. *Journal of Integrative Agriculture*. Advance online publication. https://doi.org/10.1016/j.jia.2023.12.018.

Long, N.V., Assefa, Y., Schwalbert, R., Ciampitti, I.A, 2017. Maize yield and planting date relationship: a synthesis analysis for US high-yielding contest-Winnerand field research data. Front. Plant Sci. 8, 2106 https://doi.org/10.3389/fpls.2017.02106

Nafziger, E. D. (1994). Corn planting date and plant population. *Journal of Production Agriculture*, *7*(1), 59–62. https://doi.org/10.2134/JPA1994.0059

Nielsen, R. L. (Bob). (2020). Estimating Yield and Dollar Returns From Corn Replanting. Retrieved March 12, 2023, from https://www.agry.purdue.edu/ext/corn/news/timeless/CornReplant.html

Nielsen, R.L. (Bob) and Ellsworth Christmas. 2002. Early Season Frost & Low Temperature Damage to Corn and Soybean [Online]. Purdue Univ. Coop. Ext. Service, W. Lafayette, IN 47907. http://www.kingcorn.org/news/articles.02/Fro st_Freeze-0520.html. (Verified 04/25/2023).

Nielsen, R.L. (Bob). (2020). *The Emergence Process in Corn*. Retrieved February 24, 2024, from http://www.kingcorn.org/news/timeless/Emergence.html.

Norwood, C. A., & Currie, R. S. (1996). Tillage, planting date, and plant population effects on dryland corn. *Journal of Production Agriculture*, *9*(1996), 119–122. https://doi.org/10.2134/JPA1996.0119.

Olson R. A., ,and Sander D. H.1988. Corn Production. In *Corn and Corn Improvement*, edited bySprague G. F., and Dudley J. W.pp. 639–686, 3rd edition. Agronomy Monograph 18. American Society of Agronomy, Madison, WI.

Paszkiewicz, S., and S. Butzen. 2007. Corn hybrid response to plant population. Crop Insights 17:1–4.

Porter, P.M., D.R. Hicks, W.E. Lueschen, J.H. Ford, D.D.Warnes, and T.R. Hoverstad. 1997. *Corn response to row width and plant population in the Northern Corn Belt*. J. Prod. Agric. 10:293–300.

Robles, M., Ciampitti, I. A., & Vyn, T. J. (2012). Responses of Maize Hybrids to Twin-Row Spatial Arrangement at Multiple Plant Densities. *Crop Ecology & Physiology Published in Agron. J*, *104*, 1747–1756. https://doi.org/10.2134/agronj2012.0231

Shanahan, J., Doerge, T. A., Johnson, J. J., & Vigil, M. F. (2004). *Feasibility of Site-Specific Management of Corn Hybrids and Plant Feasibility of Site-Specific Management of Corn Hybrids and Plant Densities in the Great Plains Densities in the Great Plains "Feasibility of Site-Specific Management of Corn Hybrids and Plant Densities in the Great*. https://digitalcommons.unl.edu/agronomyfacpub/4

Shapiro, C. A., & Wortmann, C. S. (2006). *Corn Response to Nitrogen Rate, Row Spacing, and Plant Density in Eastern Nebraska*. https://doi.org/10.2134/agronj2005.0137

Stanger, T. F., & Lauer, J. G. (2007). Corn stalk response to plant population and the Bt-European corn borer trait. *Agronomy Journal*, *99*(3), 657–664. https://doi.org/10.2134/AGRONJ2006.0079

Strachan, S. D. (2016). *Corn Grain Yield in Relation to Stress During Ear Development*.

Tokatlidis, I. S., & Koutroubas, S. D. (2003). *A review of maize hybrids' dependence on high plant populations and its implications for crop yield stability $*. https://doi.org/10.1016/j.fcr.2003.11.013

USDA. (2019). Corn Is America's Largest Crop in 2019. Retrieved March 25, 2023, from https://www.usda.gov/media/blog/2019/07/29/corn-americas-largest-crop-2019

USDA ,(2023a) | Acreage | ID: j098zb09z | USDA Economics, Statistics and Market Information System. (2023). Retrieved March 12, 2023, from https://usda.library.cornell.edu/concern/publications/j098zb09z

USDA (2023b) - National Agricultural Statistics Service - Charts and Maps - Corn: Yield by Year, US. (2023). Retrieved March 7, 2023, from https://www.nass.usda.gov/Charts_and_Maps/Field_Crops/cornyld.php

USDA. (2023c) "Corn Production by State 2023." Retrieved March 12, 2023, from World Population Review website: https://worldpopulationreview.com/state-rankings/corn-production-by-state

USDA Economic Research Service. (2023d). Feed Grains Sector at a Glance. Retrieved April 12, 2023 from https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/

Van Roekel, R. J., & Coulter, J. A. (2011). Agronomic responses of corn to planting date and plant density. *Agronomy Journal*, *103*(5), 1414–1422. https://doi.org/10.2134/AGRONJ2011.0071

Westgate, M.E., Forcella, F., Reicosky, D.C, Somsen, J. 1997. Rapid canopy closure for maize production in the norther US corn belt: radiation-use efficiency and grain yield. Field Croops Res. 49, 249-258. https://doi.org/10.1016/S0378-4290(96)01055-6

Wìatrak, P. J., Wright, D. L., Marois, J. J., & Sprenkel, R. (2004). Corn hybrids for late planting in the Southeast. *Agronomy Journal*, *96*(4), 1118–1124. https://doi.org/10.2134/AGRONJ2004.1118

Widdicombe, W. D., & Thelen, K. D. (2002). Row width and plant density effects on corn grain production in the northern Corn Belt. *Agronomy Journal*, *94*(5), 1020–1023. https://doi.org/10.2134/AGRONJ2002.1020