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Addressing Challenges of Dryland Production of Sunflowers and Corn in the Semi-Arid High Plains of Nebraska

Zhan Orazov
University of Nebraska-Lincoln

ADDRESSING CHALLENGES OF DRYLAND PRODUCTION OF SUNFLOWERS AND CORN IN THE SEMI-ARID HIGH PLAINS OF NEBRASKA

by

Zhan Orazov

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ADDRESSING CHALLENGES OF DRYLAND PRODUCTION OF SUNFLOWERS AND CORN IN THE SEMI-ARID HIGH PLAINS OF NEBRASKA

Zhan Orazov, M.S.

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Advisor: Cody F. Creech and Amanda C. Easterly

Corn and sunflower are value crops for America. Cultivation of corn and sunflower often vary depending on growing environment. Selecting appropriate planting dates, hybrids and plant density frequently concerns farmers. This concern is understandable because the decision made directly impacts final income. The objectives were to evaluate interaction of corn and sunflower planting dates and hybrid maturity and evaluate interaction of corn flex hybrids and plant density under conditions of western Nebraska. Nine corn hybrids with relative maturity ranging from 86 to 105 days were sown between early May and late June in first and between late April and early June in second year of study at the High Plains Agricultural Laboratory near Sidney NE in 2021 to 2022. The optimal planting date to achieve maximum grain yield was early May in the first year and over 50% decrease of grain yield was observed when planting date was delayed from early May to late June. In the second-year planting dates had no significant variation in terms of grain yield while corn planted later than May failed to yield. Variation among hybrids in terms of grain yield was not significant in 2021 while in 2022 hybrid NK 0440 had an 85% decrease in yield in contrast to DKC 36-86 RIB. Three sunflower hybrids with relative maturities of 89, 94 and 98 days were sown between 9 May and 24 June at the High Plains Agricultural Laboratory near Sidney NE in 2021 to 2022. Sunflower planted in early May achieved maximum grain yield and 64% decrease of grain yield

occurred when planting date was delayed from early May to late May. Early maturing hybrid averaged across all planting dates indicated 70 percent greater grain yield than the medium maturity hybrid. Four corn hybrids with different ear flex characteristics were planted at 19,768; 27,181; 34,595; 42,007; and 49,420 plants per hectare populations in Nebraska, one near Sidney and the other in Box Butte County from 2021-2022. A plant population of 34,595 achieved greatest grain yield in 2021. When population was increased from 34,595 to 42,007 grain yield decline on 12% was observed. In 2022, grain yield varied significantly by hybrids. Hybrids CP 3337 and DKC 42-04 RIB had greatest grain yield of 2,295 and 2,271 kilograms per hectare. CP 3337 produced in average 32 percent secondary ears greater than all hybrids.

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Zhan Orazov

TABLE OF CONTENTS

LIST OF MULTIMEDIA OBJECTS

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Historical crop production in the High Plains

Sunflower (*Helianthus annuus L.*) is an annual plant native to North America, cultivated worldwide for its high oil content and achenes used for human consumption. Besides the human diet, sunflower oil can also be utilized for biodiesel manufacture and bird feed (Steer, B.T *et al.*,1984). The USDA estimated global production of sunflower at 50.04 million metric tons for 2021 and 1.35 million metric tons in the United States. According to USDA statistics Ukraine, Russia, and the European Union are the leading countries in sunflower production in both 2020 and 2021 years (USDA-NASS, 2020/2021). Historically, sunflower marketing and hybrids were divided into two major categories: confectionery and oil types. A newer market category was developed based on the content of high oleic acid in sunflower oil (Schild, 1991). High oleic sunflower oil is marketed as a monounsaturated cooking oil. The USDA foreign agricultural services analyzed the progress of sunflower production from 2008 to 2021. The index increased significantly from 33.13 to 57.04 million metric tons which can indicate growth in global demand. In the United States and particularly in Nebraska high plains cultivation of sunflowers started centuries ago by Native Americans and nowadays in the state of Nebraska sunflowers are planted at about 12,140 hectares of territory (Schild, 1991).

Corn (*Zea mays* L.) is another crop that originated in the western Hemisphere and is cultivated throughout the world (W.L. Brown, M.S. Zuber, M.L. Darrah, and D.V. Glover, 1990). It is widely used in human food, livestock feed and ethanol production (A. Liska, H. Yang, D. T. Walters, K. Cassman, T. Klopfenstein, G. Erickson, V. R. Bremer, R. K. Koelsch, D. Kenney and Patrick Tracy, 2009). The USDA report for 2021 accounted for 198.81 million hectares of corn production worldwide from which 33.31 million hectares belong to the United States (USDA, 2021). Corn was the first crop cultivated by settlers in Nebraska, however the fact that during his 1541 travels through what is now the American Southwest and into Kansas, Coronado discovered Indians growing corn for food indicates a longer historical presence of the crop in this region before the U.S. settlers came after the Louisiana Purchase (Sweedlun, 1942). Maize residues found in the caves of Mexico and New Mexico and fossil pollen discovered at 6 and 3.6-meters depths of Mexican valleys serve as archeologic evidence proving the origin of early corn (Mangelsdorf and Reeves, 1959). Meanwhile, the oldest ancestral corn was found in Central America, which was older than maize found in bat caves, and the prevalence of genetically close plants to ancestral maize such as Teosinte and Tripsacum pointed out that the single origin of corn is Middle America. Therefore, scientists assumed that early developments started in the central part of America and moved south. However, there are multiple hypotheses that are contrary and refute corn origin either in the Middle or in South America (Mangelsdorf and Reeves, 1959). Climatic instability in the Great Plains is a major hardship for dryland crop production, particularly in the High Plains of Western Nebraska. The climate in the Great Plains is highly variable and severe droughts often occur. As an example, In the 1930s there was a period of economic and environmental hardship known as the Dust Bowl. A long drought occurred in this area which lasted almost a decade, combined with unsustainable farming practices, and resulted in severe wind erosion (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). Less severe but still significant drought periods reoccurred in the early 1950s, 1970s, the middle of 1970s, early 2000s, and in the recent decade. When settlers started moving westward, they initially planted sod corn. They would break the sod and cut holes using an ax, then put kernels underneath the sod. This method of corn production required minimal cultivation. The major factor which inhibited settlers to develop corn production in this region was recurring droughts. During the Great Depression and Dust Bowl, severe winds during the summer season dried crops to a crunchy condition. For the settlers just beginning their first farm, it was an end of the business, so most people were forced to leave (Sweedlun, 1942). During this hardship period, corn production in the States of Kansas and Nebraska was reduced to almost zero (Richard Sutch *et al.*, 2011). Additionally, heavy attacks of grasshoppers and crop diseases made crop production suffering for the settlers (Sweedlun, 1942).

Farmers in the high plains of Western Nebraska had minimum knowledge and experience in growing dryland corn (Lyon, D., Hammer, G. L., McLean, G. B., and Blumenthal, J. M., 2003)**.** The settlers moving westward tried to use the continuous cropping systems that were traditional for Eastern Nebraska. However, this cropping system failed in the western regions and farmers needed to find new approaches which resulted in the adaptation of more enhanced crop rotation systems. This newer cropping system rotated between crop and fallow seasons, with the goal that the fallow period allowed the ground to store precipitation (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon, 2012).

The amount of dryland corn planted in Western Nebraska was approximately 3,800 hectares in 1997, however, by 1999, increased diversification of farmers and enhancement of dryland crop production led to a planted area of corn expanding to 28,000 hectares (NASS 2000). The long-term average yield of corn in the Central Great Plains varies from 4.8 metric tons per hectare and 5.2 metric tons per hectare in average (Nielsen and Hinkle, 1996). However, when rainfall was about 125% of normal, the yield can exceed 7 metric tons per hectare, whereas during the dry years with precipitation less than 40% of normal yield decrease can be below than 1 metric ton per hectare in average. (Anderson *et al.*,2013).

After long drought periods, heat tolerant corn hybrids gained increased popularity because the yield potential of these adapted hybrids was significantly improved over previous hybrids, particularly in the drought years (Richard Sutch 2011). The new corn hybrids increased crop production in the dryland territories of northern Great Plains, especially early maturing cultivars that suited the short growing season of the area (Lenssen *et al.*, 2018).

The main challenge for dryland crop production is in managing effective and economic practices to efficiently utilize precipitation and thereby reduce crop failure under erratic weather conditions in this region (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon, 2012).

Sunflowers

Sunflowers are also native to the Americas. Most of the modern lines of sunflowers are mainly obtained from the breading materials found in this period and since 1986 oilseed types of sunflowers became traditional crops for the United States

(Korell *et al.*, 1996; Lyon, D. J, and Hein, G., L, 2014). The Western and Northern Corn Belt fringes of the US have been traditional places to grow sunflower because the low level of precipitation and short growing season was unfavorable for alternative crops like soybean and corn (Swearingin M.L, 1984).

Challenges to the production of sunflowers include diseases, insect harm, weed, and severe bird damage (Putt 1997). Limited knowledge of management practices limited the production of the crop (Putt 1997). Management practices transited from deep tillage to reduced and no-tillage approaches and allowed the intensification of cropping systems by reducing frequency of fallow periods (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). Sunflower production in Western Nebraska gained additional popularity with an adaptation of no-till practices such as this method allowed farmers to include a wider range of crops thus improving economic return (Johnston *et al.*, 2002). The breeding process developed drought tolerant and early maturing hybrids suitable for semiarid regions with short growing seasons (Putt 1997).

Sunflower production started gaining popularity in Western Nebraska with the diversification of industry in this region such as poultry and bird feed production and sunflower oil manufacture. This influenced the expansion of sunflower acreage beginning from 4,047 hectares in 1988 and reaching 32,375 hectares in 7 years (Bhatti *et al.*, 1999). In 2012 the total production of oil sunflower in Nebraska was calculated at 9,525.5 metric tons on a planted are of 12,170 hectares whereas in 2017 territory planted accounted for 10,985 hectares indicating 14243 metric tons (NASS).

Adoption of No-Till Practices

No-till management practices generally mean full exclusion of all the traditional methods of cultivation, in other words, the complete absence of tillage with a goal of no soil disturbance (Powlson *et al.*, 2014). Dryland crop producers in the central Great Plains have been increasing the adoption of no-till practices during the last 20 years (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). The USDA report indicates 5% of increase of no-till management in the early 1900s and a 20% growth in 2011 (CTIC 2011). In the Great Plains, relative humidity in the summer season is often below 50%, so disturbance of moist soil increases evaporation rate and tillage on repeated occasion multiplies losses of moisture significantly (Fenster and Peterson, 1979). Dryland crop production relies on rainwater and crops can fail because of the unstable precipitation nature in this climatic zone (Nielsen *et al.*, 2009). The no-till system has been adopted to elevate the ability of soil to capture and hold rainfall water (Peterson *et al.,* 1996). In the Great Plains, precipitation is commonly accompanied by intensive thunderstorms which often cause runoff but wind erosion in this area affects more severely than water erosion and no-till is an effective method to decrease wind erosion (Norvell *et al.*, 2008), (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). Because any minimization of tillage leaves more residue on the soil, it serves as protection against wind erosion and runoff during severe weather events. Additionally, residue counteracts moisture evaporation by decreasing temperature of the soil surface (Fenster and Peterson, 1979). Research in the Western Kansas comparing no-till versus conventional tillage resulted in higher dryland corn yields in all the three years of study; in the driest year, when no-till corn yield was double that of conventional tilled areas

(Norwood and Currie, 1996). An adaptation of no-till started associated with increased production of effective herbicides and planting facilities, because no-till practices depend on herbicides to maintain weed control (Lyon *et al.*, 2004). However, an intensive transition to no-till started when new enhanced crop rotation systems were adapted which could decrease or exclude fallow season (Hansen *et al.*, 2012).

Common Crop Rotations in the High Plains

Failure in succeeding with continuous cropping led to adoption of a wheat-fallow cropping system, which was believed to be better for precipitation use efficiency in contrast to continuous cropping (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). Wheat-fallow crop rotation generally decreased risk of crop loss and provided for more consistent average yields, but only one crop was grown in a two-year cycle, thus limiting farmer income (Greb *et al.*, 1970, Baumhardt and Anderson, 2006). The period with no active crop production is known as summer fallow, and it was widely used as a traditional cropping system for the most of last century in the Great Plains (N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012). Despite the fact that the Great Plains belongs to a semiarid climatic zone, relatively humid years can also occur, so at the years when relative humidity is higher, summer fallow is inefficient. During dry years, summer fallow may be the only option to produce some crop versus no crop at all (Thornthwaite, 1941). Nevertheless, summer fallow was found ineffective in many aspects such as precipitation storage, erosion, maintenance of soil N and C organic matter as well as from a financial perspective (Black *et al.*, 1981; Campbell *et al.*, 1990). The precipitation capture during the fallow period is low, varying between 15 to 40 % (Black and Power, 1965; Peterson *et al.*, 1996). Therefore, to enhance the water use efficiency despite variable weather conditions as well as to mitigate economic risks, more research concentrated on ways to intensify crop rotations (Acosta Martinez *et al.*,2007; Anderson *et al.*,1999; Peterson *et al.*, 1993, Vigil and Nielsen, 1998). The farmers practicing no-till methods included corn or sorghum (*Sorghum bicolor* L.) in the 3 year rotation with wheat at the beginning, crop (corn/sorghum), and ending with fallow hence increasing moisture capture ahead of the wheat crop while decreasing the percentage of time of ground in fallow (Farahani *et al.*, 1998; N. C. Hansen, B. L. Allen, R. L. Baumhardt, D. J. Lyon 2012) and diversifying crop rotation subsequently diversifies risk (Anderson *et al.*, 1999). Oilseed crops also gained popularity within diversified crop rotations, and soybean or sunflower were primarily included. Inclusion of oilseed can elevate wheat production by increasing diversity through alternate crops with different physiologies, thus increasing overall net return and minimizing production risks (Johnston *et al.*, 2002).

Water is the Primary Yield Limiting Factor in the High Plains

Deficit of precipitation is the major factor inhibiting crop production in the Great Plains (Nielsen *et al.*, 2005) Rainfall in the Great Plains considerably increases as one moves from west to east (Rosenberg N.J., 1987). The level of precipitation in Western Nebraska significantly differs from the eastern part of the State as well as from the traditional Corn belt territories. For example, total precipitation averages from 1991 to 2020 in the Cheyenne area of Wyoming and neighboring part of Western Nebraska is 391.4 mm annually whereas eastern Nebraska (near the capitol of Lincoln) receives 745.2 mm and Des Moines area in Iowa receives an average of 928.3 mm (NWS).

Precipitation Timing and Types

Weather conditions in the Great Plains are represented by considerably high temperatures during the summer seasons and cool winter seasons (Farahani *et al.*, 1998). Climate can change sharply, both in short- term and long-term periods. Because the region is not surrounded by major water masses and air patterns can vary widely weather variability is not always predictable (Rosenberg N.J., 1987). In the Nebraska Panhandle, air temperature normally varies from -9.5 to 7.5 degrees by Celsius during the winter and goes up significantly beginning from March until late July reaching up to 38 degrees by Celsius (NWS 2021).

A major portion of rainfall in this area occurs beginning from April until early fall (Lyon, Drew J, Hammer, Graeme L, McLean, Greg B and Blumenthal, Jürg M, 2003). Severe windstorms, hailstorms and occasionally tornadoes are also possible in the region. The hailstorms tend to be concentrated predominantly in the southwest part of Nebraska Panhandle and neighboring regions of Colorado and Wyoming. In the average, approximately 9 days a year these territories receive a hailstorm (Rosenberg N. J., 1987)

Soil Water Storage and Management

In the regions where, annual precipitation level is below than 500 mm, 14 months of fallow season is the norm for crop-fallow rotations. The main goal of the fallow period was to sufficiently store moisture enough for next crop. However, precipitation capture during the fallow season is below than 25% and increased effectiveness is required to reach even the full 25% (Fenster and Peterson, 1979). Initial stages of fallow practices included active tillage measurements resulting in only 19% of moisture capture (Douglas *et al.*, 2006). Generally, three drying phases occur during the fallow period. At the first phase increased evaporation is experienced because soil surface is considerably humid and utilizes daily 70% of sun radiation. Transition to the next phase begins when upper level of soil water depletes and cannot respond to the evaporation demand. Soil surface at this phase loses its moist appearance and can become dry and cracked. At the final phase, the soil utilizes barely 5% of solar energy but if the high temperature is still present the vaporization process continues, heating up the wet layers of the lower soil (Idso *et al.*, 1974). Precipitation storage during the fallow increased to 35% when reduced tillage displaced discs and plows. Precipitation storage increased to 40% when a fully no-till system was used (Peterson *et al.*, 2013). Many practices have been done to improve water storage during fallow season from which conservation tillage, chemical fallow and no-till systems have been found to be highly efficient in accumulating precipitation, decreasing erosion, while intensifying soil organic matter and crop production (Chen *et al.*, 2009, Douglas *et al.*, 2006).

Precipitation Use Efficiency and Sustainable Intensification

Water is the most valuable resource in the Great Plains, so intensification of crop production in this area relies on effective utilization of precipitation (Peterson *et al.*, 2013). Precipitation use efficiency (PUE) implies as ratio between terrestrial prime production and amount of rainfall. It is a frequent term in the semi-arid and arid regions used to determine how vegetation productivity fluctuates at the limited moisture (Huxman *et al.*, 2004; Bai *et al.*, 2008). Intensive PUE practices, combined with principles to maximize soil water storage can allow for sustainable intensification (Peterson *et al.*, 2013). Generally sustainable intensification in agriculture means productive utilization of natural resources for long term social and ecological stability in the regional scale as well as worldwide (Rockström *et al.*, 2017). Several researchers in the Great Plains spent many decades improving PUE during summer fallow and it progressed notably when increased residual layer and decreased soil tillage used jointly (Creb,1979. Peterson *et al.*, 2013). Diversification of rotation system is another method which can increase efficiency of precipitation use and sustain crop production. Dryland crop production used fallow to decrease variability in yield caused by unstable precipitation. Therefore, intensification of crop rotation was thought can increase yield variability (Anderson *et al.*, 2013). However, recent studies show opposite results. Research conducted in Akron CO explains that diversification of crop rotation led to minimization of yield variability, such as yield variability during the wheat-fallow is often up to 32%, whereas 5% decrease observed when wheat-corn-millet rotation was practiced and highest corn grain yield observed under wheat-corn-millet-fallow rotation (Anderson *et al.*, 2013). Another study achieved 7% corn yield increase during a dry year when diversified crop rotations included five crops instead of just two (corn-soybean) (Gaudin *et al.*, 2015). Diversified crop rotations allow for growers to better use precipitation and soil nutrients, by manipulating soil water reserves through selecting crops that have different rooting systems, water use efficiency levels, and nutrient requirements. Diversification also mitigates risk of total crop failure (Klinkebiel, 1987). Reduced or no-till methods in combination with enhanced rotation systems and appropriate crop and hybrid selection are major factors contributing to sustainable intensification and precipitation use efficiency in this region (Nielsen, 2003, Peterson *et al.*, 2013).

Corn Population and Tillering Impacts on Production

Tillering of corn, defined as secondary stems from the main plant that produce an ear, largely depends on both genetic and environmental conditions. It is connected to the main stem by vascular tissues, and it roots independently from the main root branch (Keun *et al.*, 1989). Tillering can be motivated by increased amount of available soil water and nutrients and reduction of growth can be caused by increased plant density and unfavorable environmental conditions. There are some practices of removing corn tillers to increase grain yield, however it often leads to yield reduction instead (Keun *et al.*, 1989). Conversely, some research indicates that active tillers can be beneficial to minimize stress factors effecting crops during the critical stages of development (Keun *et al.*, 1989). The research of (Veenstra *et al.*, 2021) described helpfulness of tillers as alleviating flexible feature in highly variably climates.

The response of maize to the plant density (Liu *et al.*, 2004). Plant population density influences the formulation of structure of the plant and development. At increased plant densities, competition for minerals, moisture and light elevate significantly. This affects negatively potential yield such as exceedingly high internal competition can stimulate diseases, motivate excessive growth in height, decrease expression of kernels and ears (Sangoi, 2001, Abuzar *et al.*, 2011, Norwood and Randall. 1996).

However, in the territories where corn is traditionally grown, a high plant population increases the yield which is associated with elevated level of precipitation. Practices in Minnesota shows growing level of average plant density from 1979 when average density was 30,700 plants/ha and 73,900 plants/ha in 2010 (Roekel and Jeffrey, 2011). Moreover, experiment in South Dakota determined 11% yield growth per hectare and insignificant internal competition when plant population was raised from 74,500 to 149,000 plants/ha which can be explained by sufficiency of environmental resources even at this high plant density (Clay *et al.*, 2009). Meanwhile, dryland corn population in Western Nebraska are typically between 19,800 to 37,066 plants/ha that can be explained by limited resources due to which internal competition at high density can decrease yield colossally (Norwood and Randall. 1996). Despite that at low population rates majority of contemporary cultivars also express just one ear per plant but it reduces environmental stress especially under unpredictable climate allowing yield stabilization (Sangoi, 2001, Abuzar *et al.*, 2011, Norwood and Randall., 1996)

Determining Optimal Corn Populations

Optimal management of corn production needs periodic evaluation to provide growers with the advanced cultivation practices as hybrids and conditions change (Staggenborg *et al.*,1999). Previous research conducted from 1999 to 2000 in Banner, Kimball, Cheyenne, and Box Butte counties of Western Nebraska concluded that about 27,200 plants per hectare is the ideal plant population for this region (Blumenthal *et al.*, 2003).

During the same years, a simulation study was evaluated for conditions in Western Nebraska. This study evaluated optimal dryland corn populations based on three diverse levels of soil water at planting. The conclusions were that when population was three plants per square meter with an available soil water of 160 mm or 240 mm provided optimal yields (Lyon *et al.*, 2003). Other research conducted in Southwest Kansas determined optimal dryland corn population at no higher than 44,500 plants per hectare because at an increased population at 59,000 plants per hectare, results were poor in almost all years of the study. (Norwood and Randall. 1996).

Impacts of Planting Date

Crops in the High Plains may be subjected to heat stress at any planting date selected as optimal for each year because weather conditions can vary so dramatically in the region (Norwood and Randall. 1996). However, growers rely on appropriate management techniques to select suitable planting dates for their locality (Abendroth *et al.*, 2017). Variation in planting date largely depends on local climatic conditions and duration of growing season (Bruns, 2003). Dryland corn planting dates in the Western Nebraska and northwest Kansas are typically between late April and mid-May (Norwood and Randall. 1996). Planting crop very early can be risky because if soil temperature cannot provide enough heat, or the seed germinates late or fails to germinate (Schneider and Gupta, 1985). On the other side, planting very late shortens duration of growing season available to the crop, thus increasing risks of frost before the crop can reach physiological maturity (Nielsen *et al.*, 2002). Conversely, sometimes planting early can be beneficial for some regions if that allows to avoid or reduce crop loss (Gaile, 2012). For example, in the western Great Plains it can be reasonable to plant corn early if conditions allow in order to increase the likelihood the crop will complete pollination before increased temperatures in the middle of summer (Norwood, 2001). A four-year study examining optimal planting dates in southwest Kansas and Western Nebraska indicated decreased yield potential. Planting in mid-May was preferred in contrast to late May but one year it was subjected to heat stress during the pollination stage and crop yield decreased. The final recommendations suggested early May to mid-May which performed most reliably during the 4 years of study (Norwood and Randall. 1996). Research conducted by Baum *et al.*, (2019) explains that choosing appropriate planting date significantly impacts the yield. In this study, earlier planting dates in both April and May increased the yield compared to planted in June.

It is also important to manage deviations from optimal planting dates by using hybrids with appropriate and shorter relative maturities. For example, a study conducted in northeast Kansas evaluated three different planting dates associated with two different relative maturity hybrids. Results showed a 1544 kilograms per hectare advantage of the full-season hybrid when planted early, but a reduction of yield by 308 kilograms per hectare at the second planting date, making the short-season hybrid a better choice at the later planting date (Staggenborg *et al.*, 2013).

Impacts of Genetics and Hybrid Selection

Early production of corn was considered unpractical in semi-arid regions due to vulnerability nature of traditional corn hybrids to water stress. Starting in the early 1900s, corn production was reconsidered with the availability of new hybrids that were more suitable for dryland crop production (Tollenaar, 1989). Improvement of drought tolerance features in corn became highly important as corn production expanded beyond the Corn Belt territories, because soil water capture or precipitation level differentiated notably in the newer areas (Boyer *et al.*, 2013). Corn drought tolerance improved via traditional breeding as well as in combination of traditional and transgenic modification (Nemali *et al.*, 2015). Many native maize breeds have been selected based on water stress resistance, shorter blooming and silking phases and morphometric characteristics. Previous studies indicate that hybrids with moderated transpiration demonstrated increased heat stress resistance at the blooming and yielding phases thus reducing yield loss (Messina *et al.*, 2015). Other plant characteristics such as leaf size, root structure, and prevalence of stomatal pores play important role related to transpiration potential of a crop (Messina *et al.*, 2015). The research conducted in Kansas evaluated superiority of drought resistant hybrids in contrast to non-drought resistant primarily in conditions with high and medium evapotranspiration, demonstrating a 5-7% yield advantage (Adee *et al.*, 2016). Another study conducted in Nebraska, Wyoming, and Colorado evaluated grain yield potential of single cross cultivars comparing to double cross hybrids under dryland and irrigated conditions. Although, single cross cultivars indicated overall grain yield dominance, double cross hybrids demonstrated more stable yield in all environments (Guillen-Portal, *et al.*, 2013). Despite the many considerations corn producers in semi-arid regions must take into account, farmers mainly aim high for yield potential (Messina *et al.*, 2015).

The number of corn kernels and ear size are another major element contributing to overall yield. The corn hybrids cultivated in the high yield potential parts of the Corn Belt often have fixed ears which grow uniformly in size and in number despite the high density. However, corn production in the dry areas frequently prone to use flex or semi-flex maize hybrids. Corn hybrids with a “flex” characteristic can include plasticity in a number of ways. Flex cultivars may adjust the number of kernels based on environmental conditions (Abendroth *et al.*, 2011). A flex trait may also refer to the genetic capacity to produce more ears under optimal conditions. More information related to performance of flex hybrids under dry and irrigated environments of Western Nebraska will be evaluated in this study.

Recommendations for Semiarid Western Nebraska

The lack of a moisture is the main challenge for crop production in the Great Plains (Smika., 1970). Successful crop production in the Great Plains cannot be implemented without enhanced water use efficiency (WUE). Expedient crop and soil maintenance is important driver which intensifies WUE (Peterson *et al.*, 2013). Corn production requires proper management to succeed under dryland conditions. These practices include planting corn in appropriate dates, proper selection of corn cultivars and plant population (Norwood, 2001). Thorough crop and hybrid choice is essential such as yield potential largely depend on genetics and species (Guillen-Portal *et al.*, 2003, Peterson *et al.*, 2013). Climatic factors should also be carefully considered to forecast and prevent crop loss, such as weather in this region has unpredictable nature (Rosenberg, 1987). Such as precipitation is significantly low in this area, drought tolerance is one of the first aspects which should be considered by producers. Hybrid maturity between 95-105 days is the period that appropriately fits local growing season (Smolik and Evenson, 1987). Plant population can vary from 19,800 to 37,066 plants per hectare (Norwood and Randall. 1996). However, for dryland cropping system producers are recommended to plant at very low density between 17,300 to 24,700 plants per hectare. The reason is to avoid potential nutrition deficit and thus crop loss caused by high density such as moisture in the bad years can be a deficit even at low populations (Smolik and Evenson, 1987). Another reason is to save funds on seeds which takes colossal part of crop production expenses in Western Nebraska. Glyphosate ready trait is also appropriately fitting local growing conditions as such reduced or no-till methods are widely practiced in local crop production therefore relying on herbicides for weed control (Neild and Seeley, 1977).

Sunflower Population and Planting Date Impacts on Production

The study of Petcu *et al.*, (2006) concluded that plant population and planting date greatly affect both yield and seed quality of sunflower and planting date is the major driver of variability in oil proportion. Effects of plant population and planting date on production are highly associated with environmental conditions. Low populations tend to produce large heads and solid stems which significantly tolerates strong winds however bigger heads take longer to dry thus causing challenges at harvest. Additionally, lower populations can be subjected to lodging under heavy wind pressure (Bhatti *et al.*, 1999). A study conducted near Sidney, Nebraska suggested population higher than 15,000 plants/acre to avoid wind erosion and restrain invasive plants adding that higher population produce less massive heads which quickly dries. However, if weeds were suppressed then no oil or seed yield significantly increased under populations more than 35,000 plants per hectare, so producers can choose population based on availably budget and facilities (Bhatti *et al.*, 1999). Similarly, no significant difference in yield and quality observed in the central High Plains under irrigation between 45,000 plants per hectare and 40,000 plants per hectare. Higher population mostly was decompensated by decreased quantity of seeds and size. However, planting dates notably affected yield concentrating higher index at the late May and early June in contrast to early May and late June (Sunderman *et al.*,1997). Germination of sunflower seeds begins when soil temperature reaches 7-10 C° degrees, therefore adequate planting dates for sunflower in Western Nebraska generally occur between late May and mid-July. However, planting later than June 5 can be beneficial to minimize pest infestation but in this case oil and yield losses will be more likely (Crop Profile, 2003).

Determining Optimal Planting Date

Dryland sunflower in Western Nebraska can be planted from late May to mid-June (Crop profile 2003). Previous research conducted near Sidney Nebraska reported decreased potential of late planting date (PD) (Bhatti *et al.*, 1999). Planting later than 25 May resulted in reductions of net returns of $2 per hectare for every delayed day whereas sunflower planted on 25 May showed 224 kilograms per hectare seed yield and 2% oil yield superiority in contrast to 28 June (Bhatti *et al.*, 1999). As temperature increases significantly from March to late June with highest rates during the summer season (NWS 2021), late planted crop often subjected to heat stress during critical phases of development (Schneider and Gupta, 1985). Appropriate PD can considerably minimize attacks of some pests such as sunflower stem weevil (*Cylindrocopturus adspersus* Le Conte), red seed weevil (*Smicronyx fulvus* LeConte), sunflower bettle (*Zygogramma exclamationis*) and sunflower moth (*Cochylis hospes* Walsingham) (Oseto *et al.*,1982; 1987; 1989; Charlet and Knodel, 2003). A study conducted in the southwestern Great Plains tested five planting dates starting from early April with three weeks between each date, and it was discovered that every delay resulted in less damage by sunflower weevil (*Cylindrocopturus adspersus*) (Rogers and Jones, 1979). Similarly, research in North Dakota evaluated infestation variability by stem weevil (*Cylindrocopturus adspersus*) depending on PD. An early planting of May 4 corresponded with highest activity and numbers of adult weevils. A significant number of insects were also found on the PD in the middle of May, but rapid declines occurred with each subsequent two-week PD interval. Stem weevil larval rates followed a similar pattern as with adult insects (Oteso *et al.*,1982).

In addition to all above, PD can also affect sunflower head size which is one of the greatest contributors to overall yield. (Balalici *et al.*, 2016) studied influence of PD on sunflower head diameter. Each year differently influenced the study but considerable impact of PD on head size observed in all years. The impact of PD was clear at the phases of blooming and physiological maturity. Additionally, study observations indicated great effect of hybrids on growth of sunflower head size which is a greater factor than PD.

Impacts of Hybrid Selection

Selecting an appropriate hybrid is another key production decision in sunflower production in the semi-arid regions (Nasim *et al.*, 2017). Late maturing hybrids tend to fail or cause dry down issues in this region due to short growing season. The typical growing period in this area normally lasts 4–5-month, so short season hybrids most appropriately fit the needs of growers (Bhatti *et al.*, 1999). Drought tolerance and moderated evapotranspiration features are other elements that factor into hybrid selection because extreme high temperature during the summer can cause severe drought stress and reduce yield and volumetric weight (test weight) significantly (Shehzad *et al.*, 2021).

No till methods are predominant in this region, so herbicides are the main way to suppress weeds. The resistance to herbicides in sunflower occurs via two mechanisms. First, when mutation occurs in the target sector and second when in non-target sector of the herbicide. For oil sunflower it is important to select hybrids with good oil yield potential. Additionally, pest and disease resistance are necessary traits for hybrids, because in combination with enhanced crop rotation and planting date manipulations it becomes the most efficient way to control diseases and pest. Morphological characteristics can also be considered: strong stems and strong root systems considerably help against strong winds thus decreasing lodging (Markell, 2020).

Research Goals and Justification

Regardless of many challenges of dryland corn and sunflower production in the Western Nebraska, scientists maintain research and enhance its production practices to provide local producers with advanced management methods. Corn and sunflower are key players   crop rotations and have the potential to stabilize yield and increase net return. Highly variable weather, low precipitation, and short growing season immensely complicate determination of adequate management approaches and as a result, updates and reconsiderations to agronomic practices are warranted. While more humid regions can tolerate more established management practices, weather events or other biotic and abiotic factors often affect the ability of producers in semi-arid regions to be able to follow management practices the same way ever year, so it is extremely important to have reliable alternative options. Additional information necessary to evaluate interactions of maturity and planting date in sunflower, maturity and planting date in corn and productivity of corn hybrids and differences for dryland production can be more responsive due to the potential for volatile environmental conditions of this region.

The goals of this research project are to evaluate the interactions among hybrids with differing maturities and flex ear traits with cultural practices including planting date and population under semi-arid rainfed production. Responses studied include yield, components of yield, and differences in soil water contents over time. Because corn and sunflower have valuable places in dryland crop production in the High Plains, this work is necessary to provide guidance to growers on optimizing their productivity and net returns while maintaining high quality land stewardship.

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CHAPTER 2
EVALUATION OF INTERACTIONS OF CORN PLANTING DATES AND HYBRID MATURITY IN WESTERN NEBRASKA

ABSTRACT

Corn is the largest United States crop in terms of total production. However, cultivation of dryland corn requires additional attention to increase productivity. Selecting an appropriate planting date and respective hybrids is one of the key aspects that can increase corn productivity beyond the Corn Belt territories. The objectives were to evaluate interaction of corn planting dates and hybrid maturity for recommendation of optimal planting windows in western Nebraska. Nine corn hybrids with relative maturity ranging from 86 to 105 days were sown between early May and late June in first and between late April and early June in second year of study at the High Plains Agricultural Laboratory near Sidney NE in 2021 to 2022. The optimal planting date to achieve maximum grain yield was early May in the first year and over 50% decrease of grain yield was observed when planting date was delayed from early May to late June. In the second-year planting dates had no significant variation in terms of grain yield while corn planted later than May failed to yield. Variation among hybrids in terms of grain yield was not significant in 2021 while in 2022 hybrid NK 0440 had an 85% decrease in yield in contrast to DKC 36-86 RIB.

Introduction

Corn was the first crop cultivated by settlers in Nebraska (Sweedlun, 1942). It is widely used in human food, livestock feed, and ethanol production (Liska *et al.*,2009). Dryland corn production is mainly distributed across the southwestern Nebraska and neighboring regions of Colorado and Kansas (Tollenaar, 1989). The climate in these regions is highly variable with the large potential to experience heat stress during the cropping seasons. Corn is sensitive to high temperatures at the seedling, flowering, and grain filling stages (Edmeades *et al.*, 1993). Heat stress which occurs during these critical stages of development can result in severe yield loss (Kamara *et al.*, 2003). Improvement of drought tolerance features in corn became highly important as corn production expanded beyond the higher rainfall Corn Belt regions of Illinois, Indiana, and Iowa (Boyer *et al.*, 2013).

Dryland corn production gained popularity with the availability of new hybrids, which were developed to tolerate drought stress (Tollenaar, 1989). Proper management approaches can also be leveraged to avoid and manage drought stress and lack of moisture in this region. Suitable hybrids and corresponding appropriate planting times are effective way to improve yield (Kamara *et al.*, 2009).

Dryland corn planting dates in the Western Nebraska and northwest Kansas are typically between late April and mid-May (Norwood and Randall. 1996). However, Norwood and Randall, (1996) found that late May and mid-May are less optimal dates to plant corn in contrast to early May because of late season drought stress potential in this area. The research conducted by Baum *et al.*, (2019) found that reducing the growing period of corn by planting it late in June decreases the yield whereas planting earlier in April or May allows longer growing season consequently increasing the yield.

Staggenborg *et al.*, (2013) conducted a study in northeast Kansas evaluating three different planting dates associated with two different relative maturity hybrids. Results showed 45 kilograms per hectare improvement on yield of full-season hybrids when planted early and conversely, a reduction of yield by 15 kilograms per hectare followed with the second planting date and superiority of short-season hybrid was prevail at the late planting date. In the western Great Plains, dryland crops can be frequently subjected to late season drought stress during the grain filling period which results in lower yields and reduced volumetric weight (Nielsen and Halvorson, 1991).

Western Nebraska is characterized by unstable climatic conditions, limited precipitation with high level of evaporation and shorter growing season that needs frequent updates of management practices. Previous studies in this region indicated superiority of earlier planting dates and early maturing hybrids to receive best yield. However, a small range of planting dates were tested to determine interactions of planting dates and hybrid maturity. Objectives of this study were to test a wider range of planting dates against different maturing hybrids to evaluate the interactions of planting dates and hybrid maturity, creating multiple planting windows for producers who may be delayed in planting on-time and provide recommendations to selecting appropriate hybrid maturities for each sowing time.

Materials and Methods

Site Description and Experimental Design

The study was conducted at the High Plains Agricultural Laboratory (41°14'15.5"N 103°00'02.3"W) located near Sidney NE, in the years 2021 and 2022. The soil type at the study field in 2021 was Alliance loam (Fine-silty, mixed, mesic Aridic Argiustolls) with 1 to 3% slopes and Kuma loam with 0 to 1% slopes in 2022. Split Plot

Randomized Complete Block Design was used in this experiment. Planting dates (PD) were used as a whole plot factor and hybrids as a split-plot factor. The seeding rate was at 37,066 plants per hectare, the plot area was 1.5m × 9.1m, and 4 replications were used for each treatment. In total 5 planting dates and 9 hybrids from 3 companies were used in the study in both years. Information related to hybrids can be found in Table 1. Thirty-six neutron tubes were installed in selected plots by one tube in each plot to trace water movement within the whole growing season. Three different maturing (short, middle, and long) Dekalb hybrids were selected for monitoring of soil water content in both years. Readings were collected using an Am-Be Neutron Probe CPN 503 DR (InstroTek, inc, California).

Determining Soil optimal PD frequently correlates with soil temperature at planting which can vary significantly (Lafond and Fowler, 1989), thereby soil temperature at planting was also collected for each PD across the field area at 7.62 cm depth.

The very early (VE) planting dates began on May 6, followed by early (E) planting on 18 May. The 25 May was used as the optimal time (OT) while 2 June and 24 June were late (L) and very late (VL) planting dates in 2021. In the second year, the VE planting was on 27 April, followed by E on 9 May. The on-time planting date was 22 May while 27 May and 9 June were the L and VL planting dates.

Data Collection Processes

Data collection was based on two middle rows and carried out from early June to mid-October in both years. Soil temperature at planting was measured by hand thermometer at 10 cm depth from about 10-12 points of the field for accurate average data. Temperature varied depending on PD and ranged from 15 to 21 degrees C° across the two years from very early to late planting windows. First emergence of the crop and 50% emergence dates were collected. Final stand was collected after emergence had steadied in each year. Although stands were able to recover from one hailstorm in the mid-summer, several windstorms caused some crop lodging in 2021. A late spring freeze occurred in May 2022 after the planting of the VE and E PD, but all plants recovered.

Days to 50% flowering, measured as both pollen shed, and ear silk were collected. Flowering continued through August varying depending on PD and hybrid relative maturity in both years. Crop maturity was identified by identifying when ears reached black layer for individual plots, using one of the outer rows not used for harvest data. Most of PD reached black layer by the end of September in the first year however, many of VL PD plots never reached full maturity and were too wet/immature to be combine harvested. As a result, some plots were hand harvested and shelled by hand. In the second year of study black layer notes were fully collected in the beginning of October. A research plot combine harvest master (Zurn 150, Schöntal-Westernhausen, Germany). was used to harvest selectively only two middle rows. In the first study year, harvest was conducted in the mid-October except one replication of VL PD which completely failed and rest of the VL PD which were hand-harvested in late October. In the second study year, corn was ready for harvest earlier, because of severe drought which rapidly dried plants and planting time which was about 10 days earlier than in the first year of the experiment. The plot combine collected data for each plot on grain moisture (%), volumetric weight (test weight, measured in pounds per bushel), and grain weight (in pounds) at harvest. The yield data was all converted into metric mass units as grams, kilograms and kilograms per hectoliter. The same data was derived from the hand-harvested samples and converted into metric mass units, with grain moisture and volumetric weight measured using a stationary grain analysis computer (GAC 2700-AGRI Grain Analysis Computer, Dickey-John, USA).

Neutron tubes were installed in one of the middle two rows between two plants. Readings were provided at 15.24, 30.48, 45.72, 60.96 centimeters depth. In total 6 readings were taken during the whole season with an interval of two weeks beginning from July 3 until September 22 both years. All the raw reading data collected was processed using standard equation of 8000 in 2021 and using new standard equation taken at each reading time in 2022.

<u>Data Management and Analysis</u>

First emergence, 50% emergence, 50% silking, and 50% shedding date readings were manually converted from day of year into days from planting for each respective PD. Stand count per row within the plot was totaled and converted into a per hectare basis using the following formula:

$$\frac{plants}{hectare} = \frac{plants}{plot} * \frac{107639\ square\ feet}{hectare} * \frac{1\ plot}{150\ square\ feet}$$

Yield per plot was converted from pounds into kilograms using the formula below:

$$\frac{kilograms}{plot} = \frac{pounds}{plot} * \frac{1\ pound}{1\ kilogram}$$

Yield data per plot in kilograms was converted into per hectare basis as follows:

$$\frac{kilograms}{hectare} = \frac{kilogram}{plot} * \frac{number\ of\ \ suare\ meters\ per\ hectare}{plot\ size\ in\ sqaure\ meters}$$

Final yield data was adjusted to 15.5% moisture following this formula:

$$adjusted\ yield\,\frac{kg}{ha} = \frac{kilograms}{hectare} * \frac{100 - observed\ moisture}{100 - 15.5}$$

All the converted equations above were subjected to analysis of variances (ANOVA) using R 4.1.2 (R Core Team, 2022). The effect of hybrid and planting date on yield, test weight, stand count, and effect of hybrid and planting date on days to emergence, days to median emergence, median silk and median shedding time of dryland corn in both years were analyzed in R 4.1.2 (R Core Team, 2022) using following linear model:

$$Yijkl = \alpha i + \beta j + \lambda k + (\alpha\beta)ij + (\alpha\lambda)ik + (\beta\lambda)\,jk + (\alpha\beta\lambda)\,ijk + \varepsilon ijkl$$

Where αi is the main effect for year, βj is the main effect for planting date, and λk represents the main effect for hybrid. Error, including block error, is represented by ε., and tidyverse (Wickham, 2018), ggplot2 (Wickham, 2016) "gcookbook (Winston, 2018)", dplyr (Wickham *et al.*,2022) packages.

To evaluate the differences in water usage in this experiment, which had both repeated measures and a split plot design and thus correlated errors in multiple dimensions, a mixed model multivariate analysis of variance (MANOVA) was used. Each depth was tested independently using PROC GLM in SAS Software 9.4 adjusted for the split plot design of hybrid within planting date, random effects for the replication within year, and a repeated effect for the water content across time. Because each depth was tested separately, comparisons can be made across years but not across depths.

Results and Discussion

Plant Emergence

Interaction of year × PD was significant both at first and median emergence (Table 2-3). Table 2-4 indicates details related corn first emergence.

In 2021, emergence for E, OT and L planting dates was 7 days and VL was 8 days. May of 2021 had nearly twice the amount of precipitation when compared to June and favorable air temperature created optimal conditions for emergence of E, OT and L PD as compared to the VL date. The VE PD was two days greater than E, OT and L PDs and is not surprising because planting was conducted into cooler soils and cooler ambient temperatures (Table 2-2). Gaile, (2012) similarly found emergence delays of earlier PD due to cooler weather conditions. The largest variation Gaile found in Southwest Latvia was 10 days between an early PD on 25 April and the latest PD on 25 May which took only 8 days to fully emerge. Alessi and Power, (1971) suggested that the amount of time to reach 80% corn emergence is reduced as temperature increases from 13.3 to 26.7 °C with appropriate soil water.

In 2022, spring precipitation was critically low comparing to 2021 (Table 2-2). This influenced plant emergence, which in 2022 generally took longer than in 2021 for all PDs except VL PD. Moreover, an early spring freeze at the end of April in 2022 additionally delayed emergence of VE PD which took 16 days to germinate. The E, L and OT PDs following similar trend among each other germinated for 10 days in 2022, while VL PD took 11 days. The results suggest that air temperature and decreased precipitation were the major factors that limited corn emergence. The observations indicated disadvantage of VE and VL PD, clarifying that corn emergence takes optimal duration of time at E, OT, and L PD under conditions of experimented location.

Stand Count

Corn stand count results are presented in Figures 2-1a and 2-1b. The three-way interaction of year x hybrid x PD was significant (Table 2-3).

The lack of precipitation during the 2022 growing season was the primary cause of stand reduction in 2022 compared to 2021 (Table 2-2). March-May 2021 precipitation exceeded March-May 2022 precipitation by 108.4 mm. Another contributing factor to the stand reduction was lower air temperature during the spring months in 2022 (Table 2-2). The spring was relatively cooler, and a hard frost occurred at the end of the April which likely reduced stands. Therefore, greater stands were observed in 2021 totaling over 42,000 plants ha per hectare compared to a little over 35,000 plants per hectare in 2022 In 2021, PDs had no significant variation except VL PD that indicated 30 percent decrease in contrast to E and OT PDs. Hybrids in 2021, had no significant variation. In 2022, variation among both PDs and hybrids were not significant, possibly due to reduced precipitation. VL PD was planted during cooler weather and that likely reduced number of stands.

Median Shedding and Median Silking.

Interactions of year × hybrid and year × PD were significant (Table 2-3). Figures 2-2 and 2-3 present details related corn median shedding.

Overall duration to reach median shedding was greater in 2022 which is associated with cooler air temperature during spring of 2022 comparing to 2021 (Table 2-3). Expectedly, duration to reach median shedding decreased as PD was delayed in both years. Largest variation of 12 and 22 days in average was between VE and VL PDs in 2021 and in 2022, respectively. Hybrids varied depending on maturity which was not surprising such as tassel formation is connected to hybrid genotype therefore short maturing cultivars require less time to reach shedding (Lejeune and Bernier, 1996). Gaile (2002) reported similar findings in Latvia. The results that Gaile found indicated greatest 79 days to reach median shedding for corn planted in late April while 19 days decrease was observed when PD was delayed from late April to late May.

Duration to reach median silking indicated similar trend to median shedding except year variation (Table 2-3). Silking followed shedding with a day or two difference. Figures 2-4 and 2-5 show summaries related corn median silking.

Median Black Layer

Interaction of Hybrid × PD was significant (Table 2-3) Figure 2-6 displays information related corn median black layer. Only one year data is presented.

Hybrids expectedly varied depending on maturity. Duration was decreased as PD was delayed which was also expected results, however all hybrids failed at VL PD. Moreover, three late maturing hybrids NK0440, P0339AM and DKC 55-54RIB also failed even at L PD. Failure of all hybrids at VL PD and three late maturing hybrids at L PD was associated with drought in the late summer (Table 2-2).

Grain Yield

Interactions of year × Hybrid and year × PD were significant (Table 2-3). Figures 2-7 and 2-8 indicate information related grain yield.

In 2021, grain yield was increased on 45, 55 and 25 percent at E PD in contrast to VE, VL and L PDs. In 2022, PDs had no significant variation, while VL PD completely failed to yield. Variation among hybrids in 2021 was not significant while in 2022, early hybrid NK 0440 indicated largest 85 percent of decrease of grain yield in contrast to DKC 36-86 RIB. Hybrid DKC 36-86 RIB is early maturing hybrid and that may fit the local growing season more appropriately than late maturing hybrid NK 0440. The farmers in the areas with unstable weather conditions and short growing season might consider using short maturing cultivars to decrease risks (Nielsen *et al.*, 2002). Rogers *et al.*, (2000) suggested that in New Zealand harvestable ears of sweet corn decreased on 1.6 tons at each delay of PD from on-time planting sowing period. Gaile, (2012) reported that in Latvia corn grain yield was increased when corn was planted in early May than in late May. However, Gaile suggested that increased rainfall (12.8 mm) in the day of plating of later PD created mud which limited growth of later PD.

Volumetric Weight

Interaction of year × hybrid and year × PD was significant (Table 2-3) Figures 2-9 and 2-10 indicate information related corn volumetric weight.

Hybrids, in 2021 were not significantly different while in 2022 hybrid NK0440 indicated 60 percent less test weight in contrast to NK 8618. PDs in both years were not significantly different. Late maturing hybrid NK 0440, likely could not complete filling stage due to heat stress, thus resulted in lighter seeds.

Soil Volumetric Water

Variation among years and PDs was significant (Table 2-3). Figure 11 displays data related soil volumetric water.

VL PD was the one that made significant variation between years. In second year, water use efficiency of VL PD increased at almost all the sampling times and depths comparing to first year.

In 2021, VL PD decreased water use efficiency from sampling date 2 to 5 at 3 depths from 30 to 60 centimeters comparing to E and OT PDs. In 2022, PDs had no significant variation while high slopes of VE PD at sampling time 1 and VL PD at sampling time 2 could be an experimental error or presence of high moisture during sampling times.

Conclusions

Corn is a crop with a long history that continues to be a food source, forage and in recent years a biodiesel for many nations in this world. Improving productivity of dryland corn can increase security of food supply chain worldwide. This study attempted to obtain information for recommendations of effective planting dates and respective hybrids as to increase yield or limit losses in western Nebraska. Results of the study suggested early or late May as optimal planting windows while late May could be less beneficial in dryer years. Planting corn earlier or later than May can be risky due to freeze damage or heat stress. Late maturing hybrids could be less effective in dry year than short season hybrids.

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Table 2-1. Corn hybrids selected for representation of relevant seed corn companies and relative maturity groups used in the years 2021-2022.

Company	Hybrids	Replaced hybrids in 2022	Relative Maturity
Syngenta	NK8618		86
	NK9610	NK9653	96
	NK0440		104
Dekalb	DKC 36-86RIB		86
	DKC 46-36RIB		96
	DKC 55-54 RIB		105
Pioneer	P8693		87
	P9608AM	8736AM	96
	P0339AM		105

Table 2-2. Weather during the growing seasons of 2021-2022 compared with long term averages for the High Plains Ag Lab near Sidney, NE. Both 2021 and 2022 had lower than average precipitation, with the precipitation totals more significantly impacted in 2022.

Month	Monthly average precipitation (mm)		Long-term average precipitation (mm, 30 years)	Monthly average air temperature (ºC)			
				2021		2022	
	2021	2022		Max	Min	Max	Min
January	0.5	16.2	7.3	6.1	-6.4	5.3	-7.7
February	17.2	9.9	9.1	-0.2	-11.3	6	-9.1
March	103.4	25.9	22.6	11.1	-2.7	13.2	-4.1
April	26.4	4.0	41.6	13.8	-0.6	18.1	-1.6
May	73.2	63.7	75.9	20.1	6.0	22.1	4.9
June	35.5	41.6	80.0	29.7	12.6	25.7	11.4
July	35.5	57.1	65.5	34.1	15	33.9	16.3
August	8.6	1.7	49.2	32.5	14.1	34.2	15.0
September	53.6	34.5	35.5	30.8	10.7	30.9	11.0

Table 2-3. Analysis of variances for the effect of planting dates (PD), hybrids and year on corn development at High Plains Ag Lab near Sidney, NE in 2021-2022.

Source of variation	DF	First emergence from PD (days)	Median emergence from PD (days)	Stand count (stands ha^{-1})	Median Shedding from PD (days)	Median silking date from PD (days)	Black layer (days)	Grain yield (kg ha^{1})	Test weight (kg hL^{-1})	Soil volumetric water (g cm^{-3})
Year	1	< 0.0001	< 0.0001	<0.0001	0.0032	0.83	-	< 0.0001	< 0.0001	0.0306
Hybrid	8	0.43	0.35	0.0133	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0059	0.68
PD	4	< 0.0001	< 0.0001	<0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0140	< 0.0001
Year × Hybrid	4	0.43	0.19	0.0097	0.0038	0.0011	-	0.0345	0.0250	0.62
Year × PD	4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-	0.18	0.0005	0.06
Hybrid × PD	32	0.47	0.48	0.0023	0.24	0.30	< 0.0001	0.93	0.34	0.65
Year ×Hybrid ×PD	32	0.47	0.49	0.0479	0.94	0.76	-	0.44	0.34	0.07

Significant at P≤0.05

Table 2-4. Days from planting until first emergence depending on planting dates only, due to no variation among hybrids and replications at High Plains Ag Lab near Sidney, NE in 2021-2022.

	Year	
Planting Date	2021	2022
Very Early (VE)	9[ce]	16[a]
Early (E)	7[d]	10[bc]
On-Time (OT)	7[d]	10[bc]
Late (L)	7[d]	10[bc]
Very Late (VL)	8[ed]	11[b]

The means followed the same letter are not significantly different at P≤0.05 level using least square means.

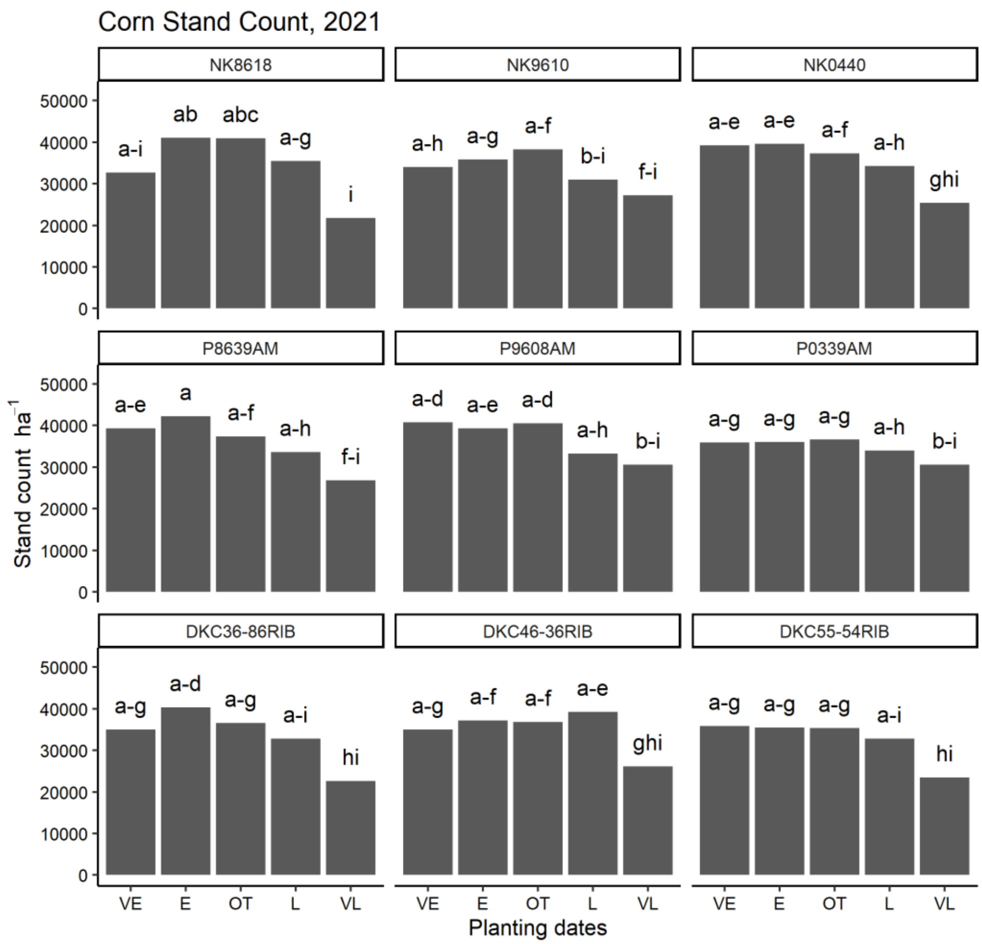

Figure 2-1a. Corn stand count in 2021. Y axis indicates number of stands per hectare. X axis indicates planting dates. Three companies are represented from top level to bottom (Syngenta, Pioneer, Dekalb). The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means noted with the same letters are not significantly different at P≤0.05 level using least square means. Means separation letters include comparisons for both Figures 2-1a and 2-1b.

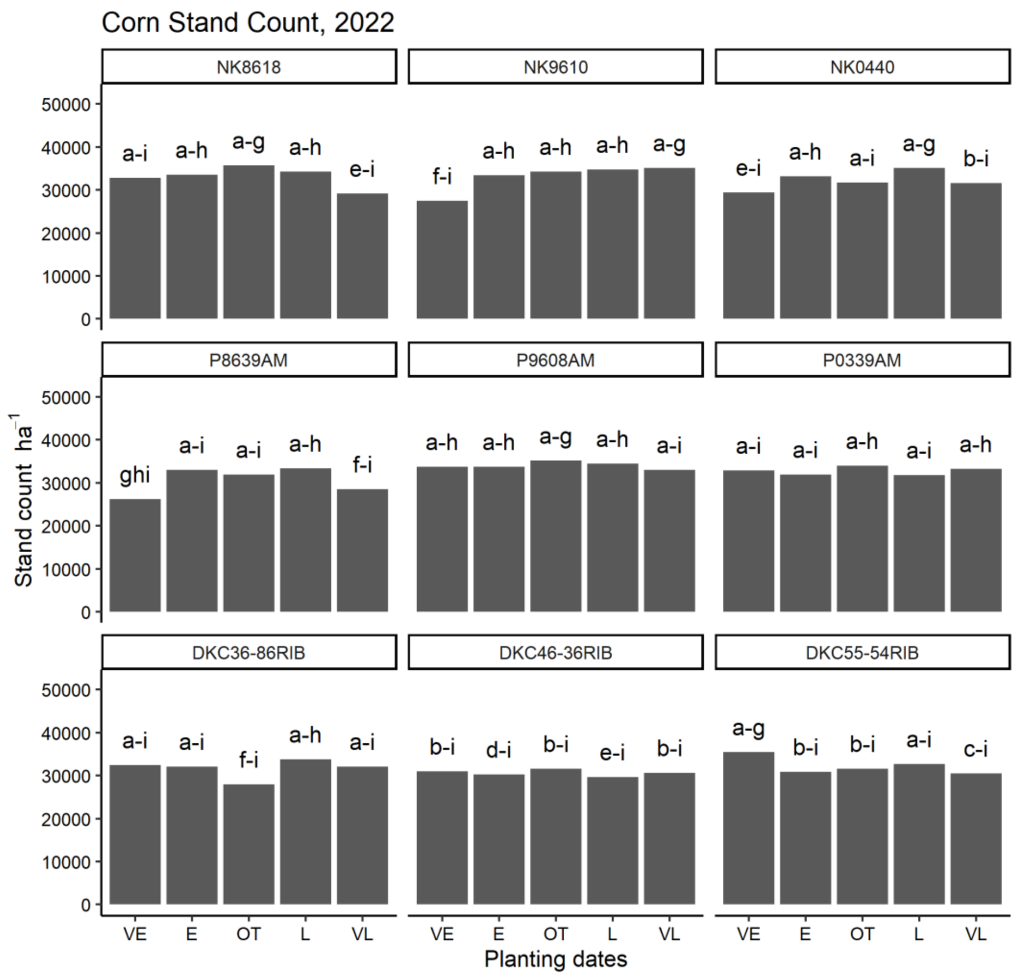

Figure 2-1b. Corn stand count in 2022. Y axis indicates number of stands per hectare. X axis indicates planting dates. Three companies are represented from top level to bottom (Syngenta, Pioneer, Dekalb). The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means noted with the same letters are not significantly different at P≤0.05 level using least square means. Means separation letters include comparisons for both Figures 2-1a and 2-1b.

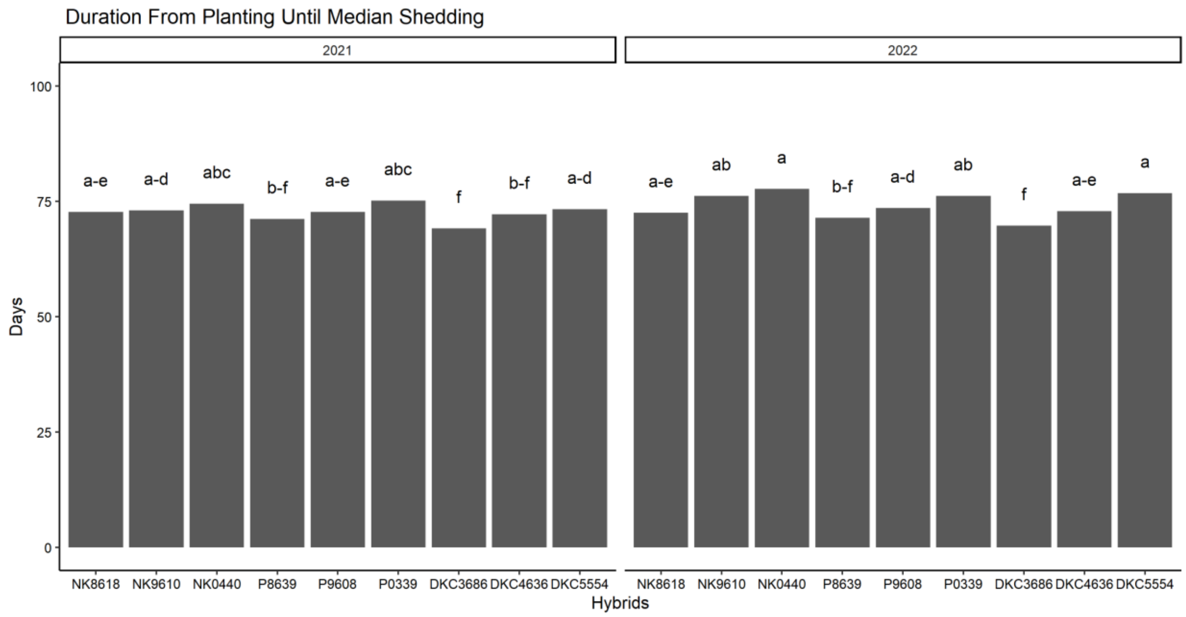

Figure 2-2. Days from planting until median shedding. Data is compared across the years. Y axis indicates days. X axis indicates hybrids. Three companies are represented from left to right (Syngenta, Pioneer, Dekalb). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letter are not significantly different at P≤0.05 level using least square means.

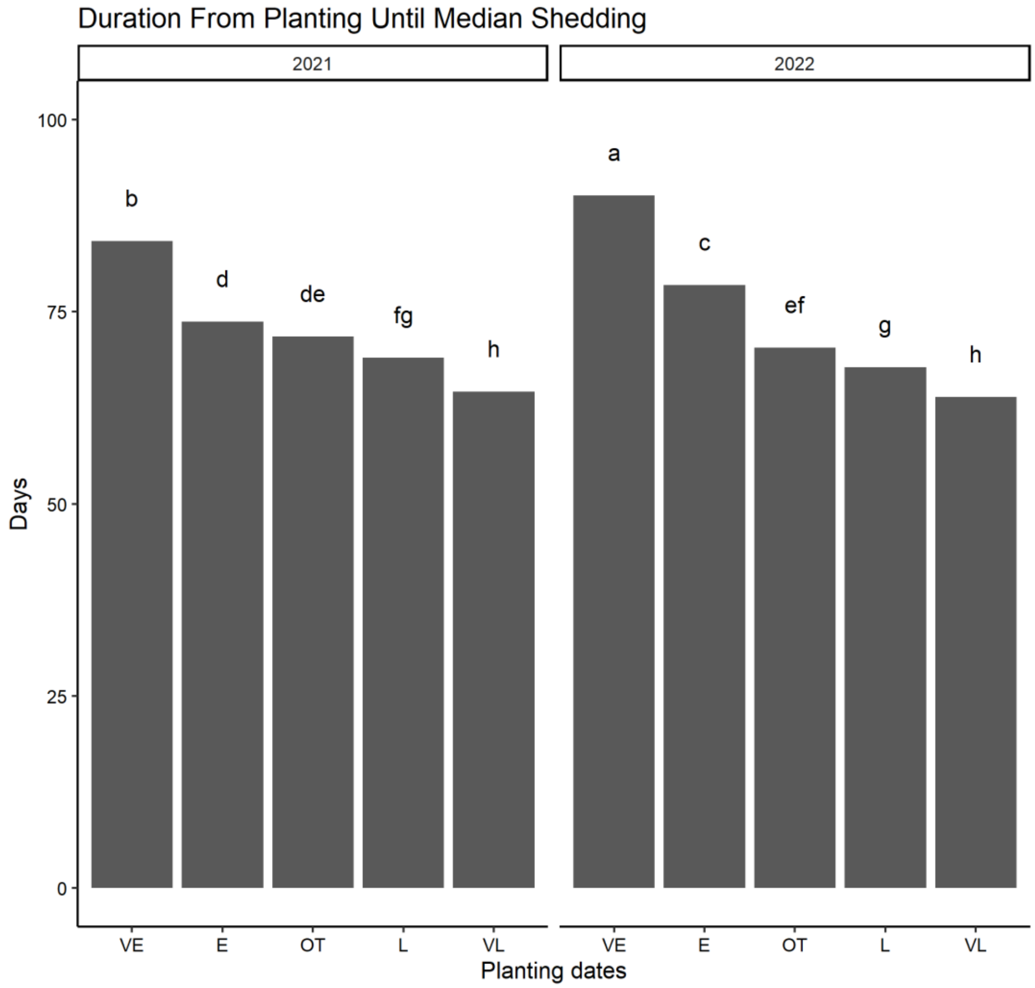

Figure 2-3. Duration from planting to median shedding date. Data is compared across the years. Y axis indicates days from planting. X axis indicates planting dates. The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). The means following the same letters are not significantly different at P≤0.05 using least square means.

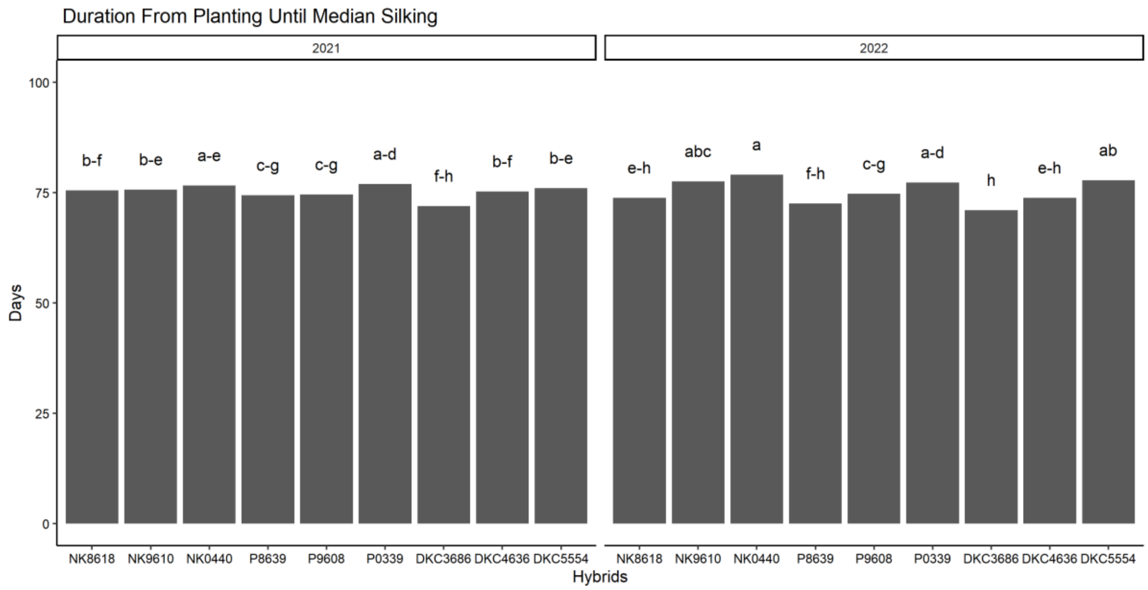

Figure 2-4. Duration from planting until median silking date by hybrid. Data is compared across the years. Y axis indicates days. X axis indicates hybrids. Three companies are represented from left to right (Syngenta, Pioneer, Dekalb). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letter are not significantly different at P≤0.05 level using least square means.

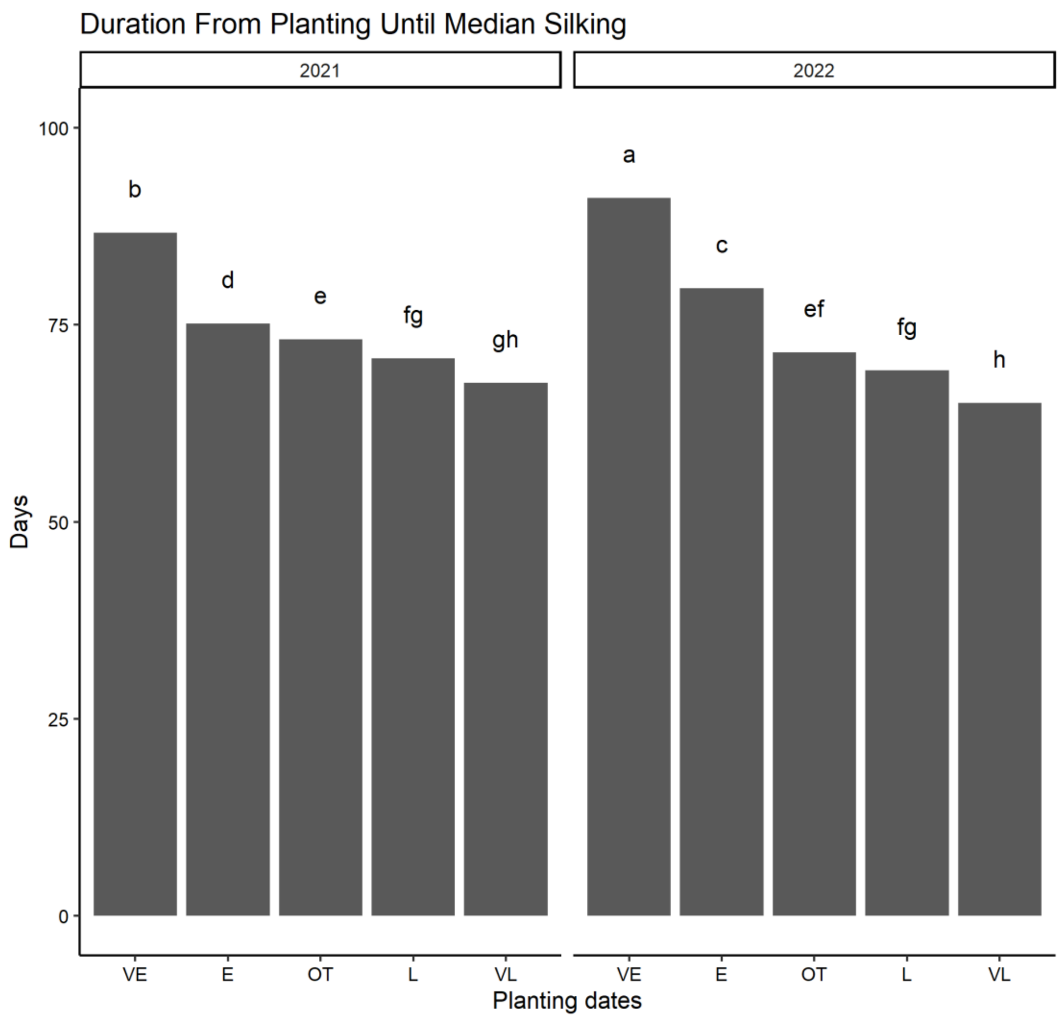

Figure 2-5. Duration from planting until median silking by planting date. Data is compared across the years. Y axis indicates days from planting until median silking. X axis indicates planting dates. The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). The means following the same letters are not significantly different at P≤0.05 using least square means.

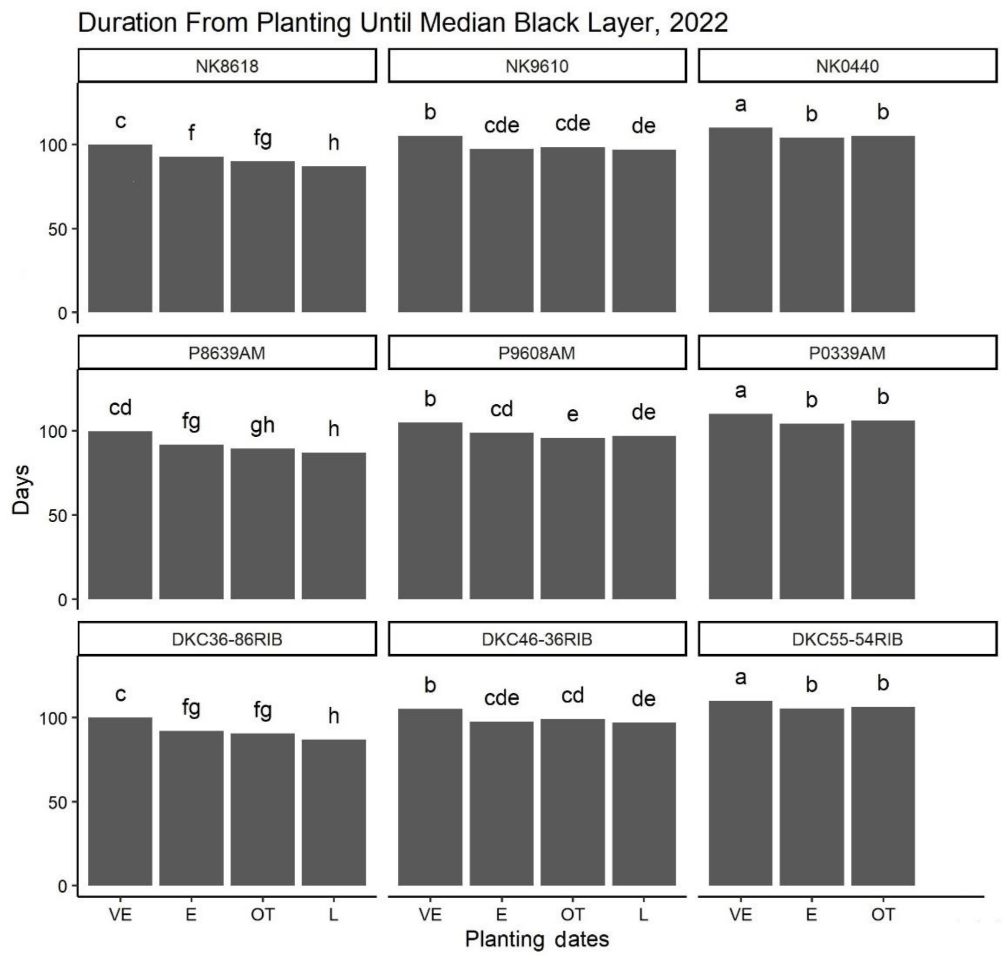

Figure 2-6. Time to reach median black layer by planting date and hybrid for 2022. Y axis indicates duration from planting until median black layer in days. X axis indicates planting dates. Three companies are represented from top level to bottom (Syngenta, Pioneer, Dekalb). The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means. The very late planting date across all hybrids and late planting date across late maturing hybrids (right hand column) failed to reach black layer, therefore data is not presented.

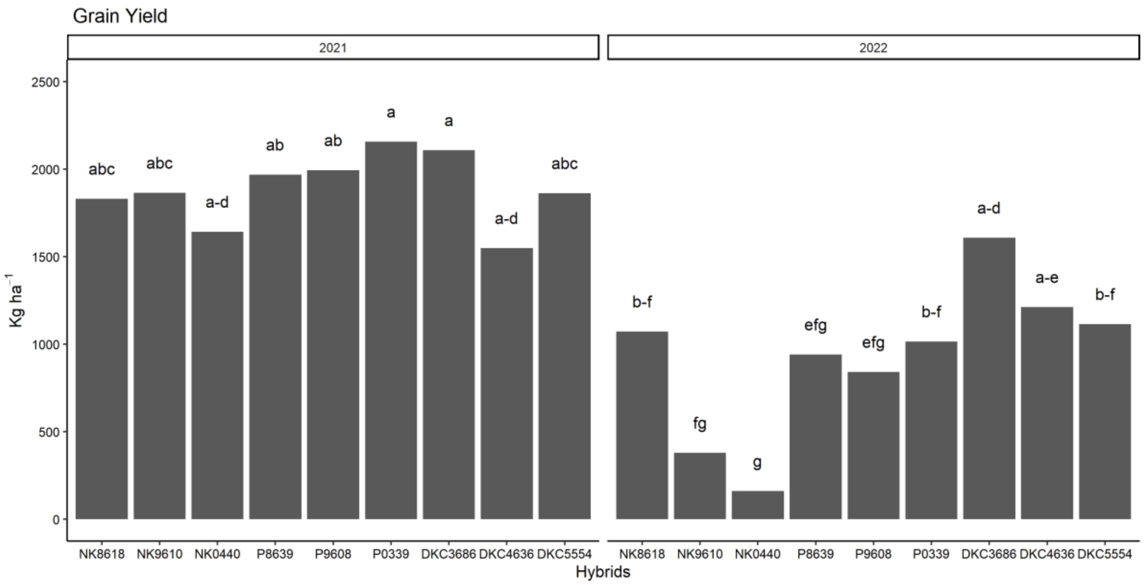

Figure 2-7. Grain yield by hybrid for both years. Data is compared across the years. Y axis indicates grain yield based on kilograms per hectare. X axis indicates hybrids. Three companies are represented from left to right (Syngenta, Pioneer, Dekalb). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letter are not significantly different at P≤0.05 level using least square means.

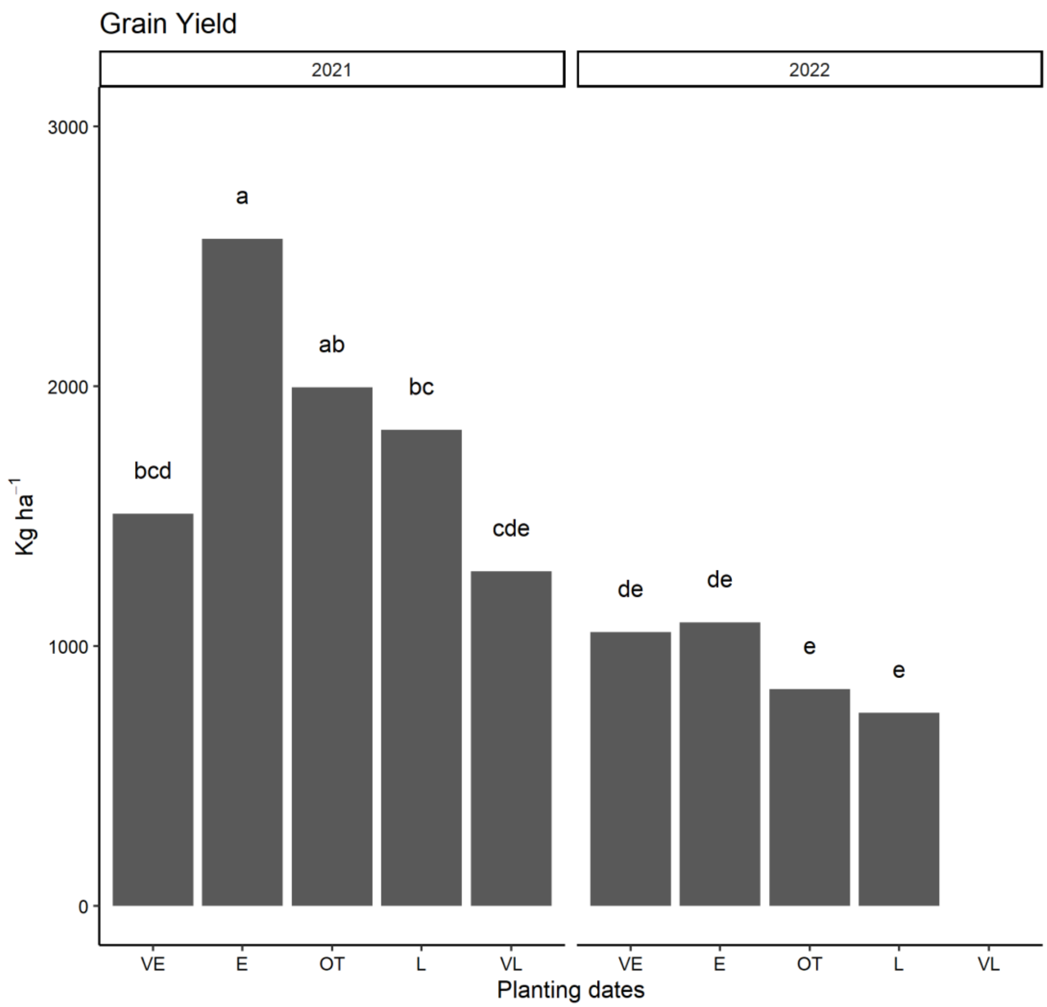

Figure 2-8. Grain yield by planting date for both years. Data is compared across the years. Y axis indicates grain yield based on kilograms per hectare. X axis indicates planting dates. The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). The means following the same letters are not significantly different at P≤0.05 using least square means. In 2022, there was no grain yield for the very late planting date.

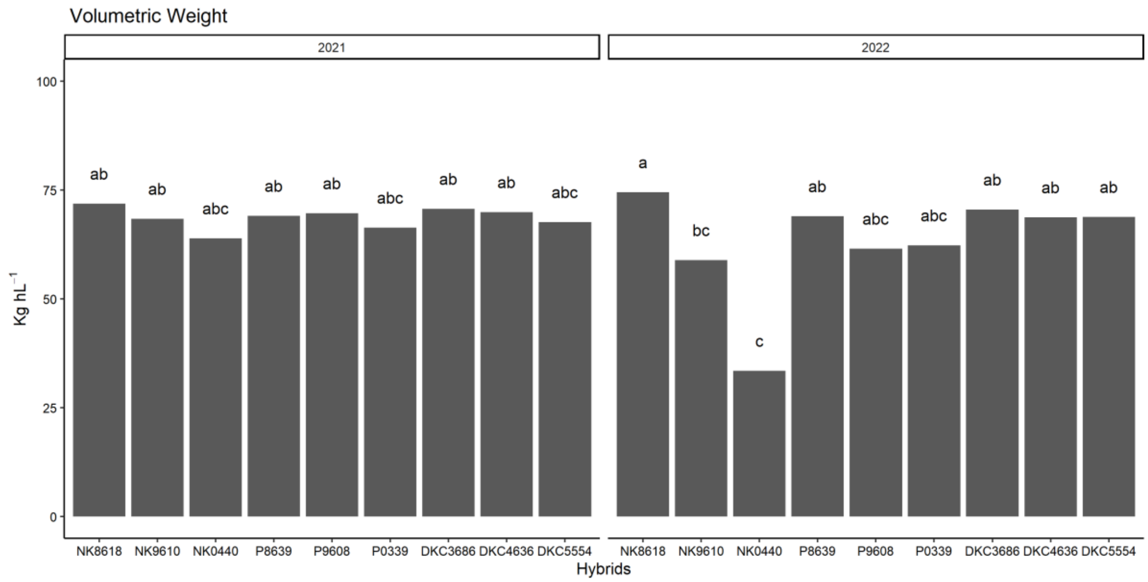

Figure 2-9. Grain volumetric weight by hybrid for both years. Data is compared across the years. Y axis indicates volumetric weight based on kilograms per hectoliter. X axis indicates hybrids. Three companies are represented from left to right (Syngenta, Pioneer, Dekalb). Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letter are not significantly different at P≤0.05 level using least square means.

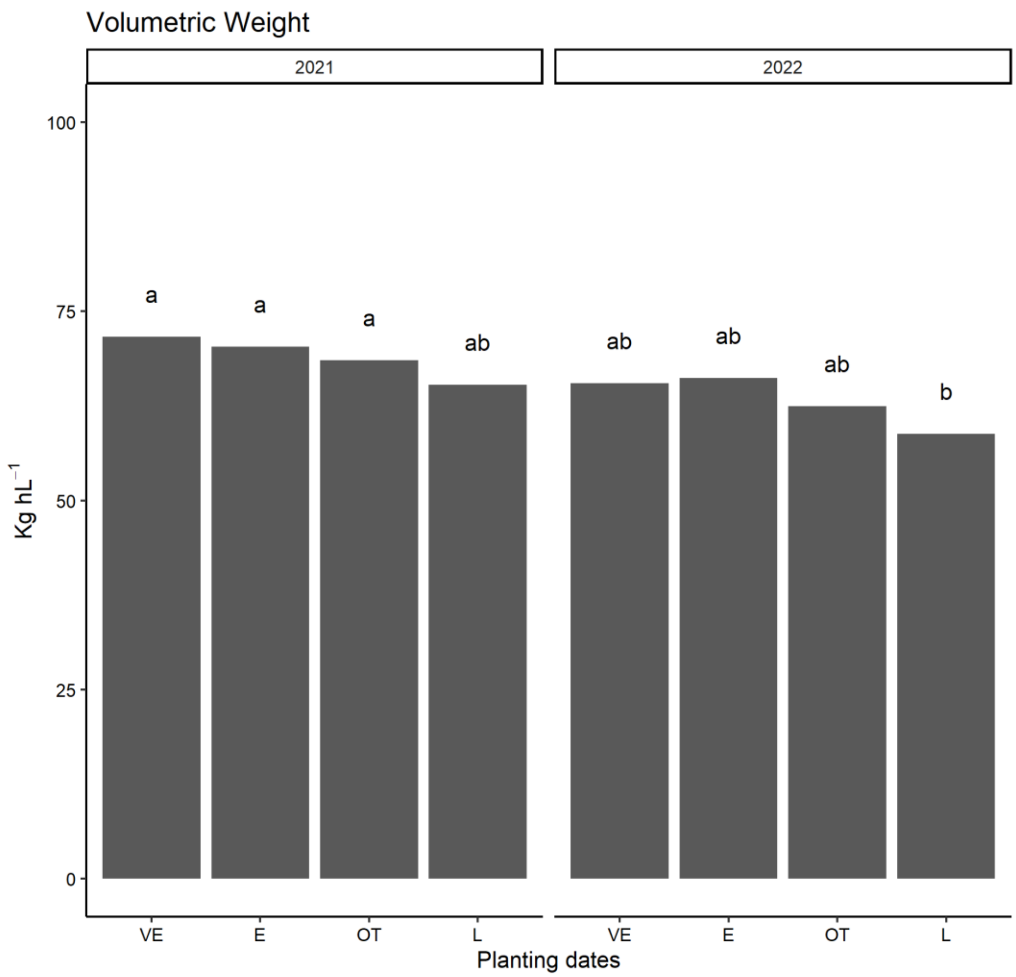

Figure 2-10. Grain volumetric weight by planting date for both years. Data is compared across the years. Y axis indicates volumetric weight based on kilograms per hectoliter. X axis indicates planting dates. Three companies are represented from left to right (Syngenta, Pioneer, Dekalb). The planting date abbreviations mean very early (VE), early (E), on-time (OT), late (L), very late (VL). The means following the same letters are not significantly different at P≤0.05 using least square means.

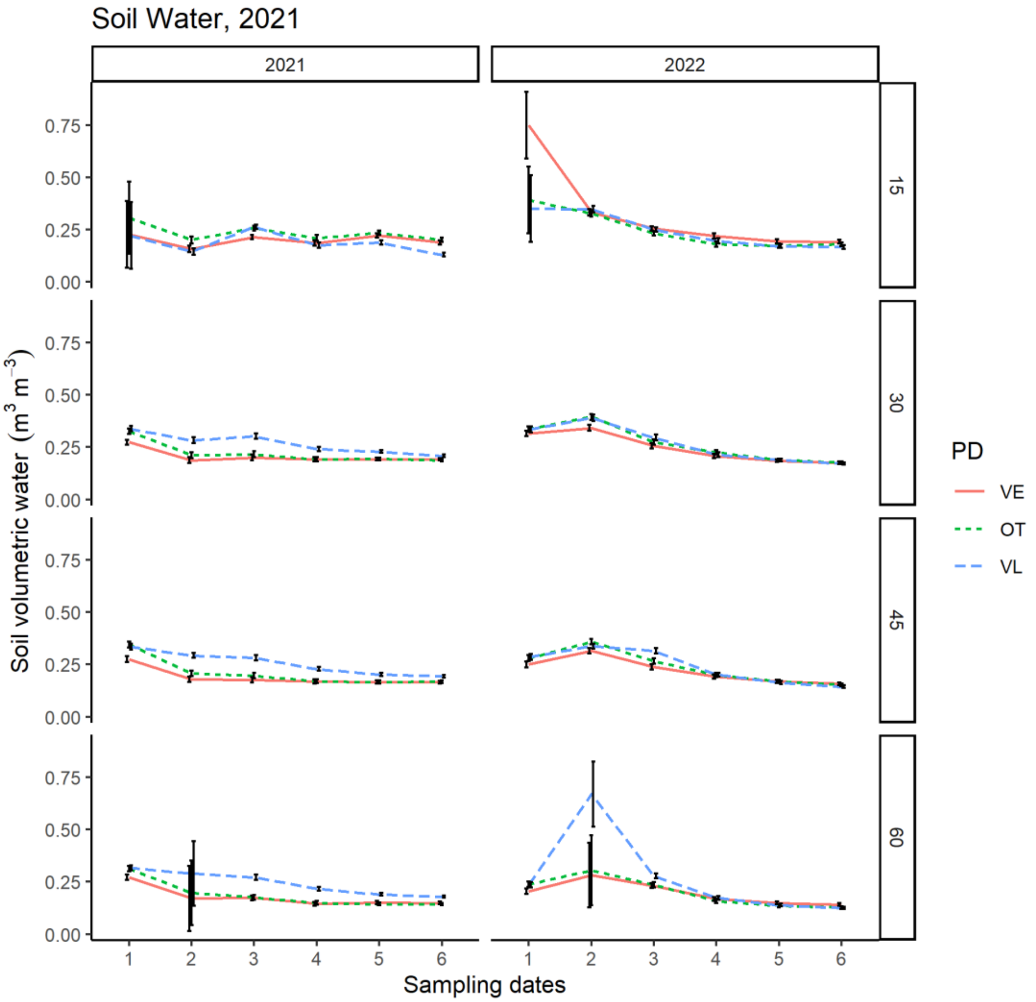

Figure 2-11. Soil volumetric water by depth and planting date for both years. Sampling date numbers in 2021 indicate 1- July 3, 2-July 29, 3-August 6, 4-August 24, 5-Septemper 9, 6-Septemper 22. Sampling date numbers in 2022 indicate 1-June 20, 2-July 12, 3-July 22, 4-August 9, 5-August 25, 6- September 27. PD indicates planting dates as very early (VE), on-time (OT), very late (VL). Numbers from 15 to 60 indicate soil depth in centimeters.

CHAPTER 3
EVALUATION OF INTERACTIONS OF SUNFLOWER PLANTING DATES AND HYBRID MATURITY IN WESTERN NEBRASKSA

ABSTRACT

Producers are often concerned about using appropriate hybrids and planting dates to maximize yields. Early maturing hybrids can avoid yield loss caused by late summer drought and more effectively use spring precipitation if planted early. The objectives of this research were to evaluate interaction of sunflower planting dates and hybrid maturity in Western Nebraska. Three hybrids with relative maturities of 89, 94 and 98 days were sown between 9 May and 24 June at the High Plains Agricultural Laboratory near Sidney NE in 2021 to 2022. The optimum sowing date to obtain maximum grain yield was when sunflowers were planted in early May. Grain yield declined to 64 percent when planting date was changed from early May to late May. Some hybrids planted later than May failed due to drought or insufficient length of growing season. Overall, the grain yield for the early maturing hybrid averaged across all planting dates was 70 percent greater than the medium maturity hybrid. The late maturing hybrid across all planting dates failed to produce grain yield. Planting sunflowers early should be dependent on environmental conditions and soil temperature. Early maturing hybrids have a potential to increase yield in semi-arid growing regions.

Introduction

Sunflower is native to the United States and is now cultivated across the world where it is valued for its high oil content and achenes that are used for human consumption, bird feed, and biodiesel production (Steer, 1984). Sunflower started gaining popularity in western Nebraska with the diversification of industry in this region such as poultry feed packaging and sunflower oil manufacture (Bhatti *et al.*, 1999). Intensification of local crop production by adopting no-till methods and enhanced crop rotations enabled producers to increase water use efficiency which made sunflowers attractive as alternative crops to wheat or corn (Johnston *et al.*, 2002; Acosta Martinez *et al.*, 2007; Anderson *et al.*, 1999). This led sunflower acres to expand in western Nebraska from 4,000 hectares in 1988 to 32,000 seven years later (Bhatti *et al.*, 1999).

Using an appropriate sunflower planting date could substantially influence grain yield (Anderson *et al.*, 1999). Sunflower seeds germinate at soil temperatures of 7-10 C° degrees, therefore, planting recommendations for western Nebraska are between late May and mid-July (Crop profile, 2003). A previous study conducted by Sunderman *et al.*, (1997) in Kansas determined late May or early June as optimum planting dates whereas, Bhatti *et al.*, (1999) found decreased yield potential of full season hybrids when planted late in the Nebraska Panhandle. The greatest net return for both oil and grain yield was associated with planting early on 25 May (Bhatti *et al.*, 1999). Since the time of Bhatti's work, located at the same site as these experiments, plant breeders have developed sunflower hybrids better suited to the growing region, and these genetic gains also influence yield potential and agronomic practices. This experiment evaluated the performance and influence of early, middle, and late maturing sunflower hybrids on yield and yield components as influenced by planting date under dryland conditions of semi-arid High Plains of western Nebraska.

Materials and Methods

Site Description and Experimental Design

The experiment was conducted on Keith loam soil with 1 to 3% slopes in both years, at the High Plains Agricultural Laboratory located adjacent to Sidney NE, (41°14'15.5"N 103°00'02.3"W). Experimental design was a split plot randomized complete block design with four replications, where planting date (PD) was the whole plot factor and cultivars were the subplot factor. Planting population was 43,243 seeds per hectare, which is the recommended seeding rate for the region. Each split plot (cultivar treatment) within a planting date was four 76 cm spaced rows wide and 9.1m long. Three PDs (early, on-time, and late) and three sunflower hybrids with different relative maturity ratings were tested. Information related to the sunflower hybrids is provided in Table 3-1.

Weather summaries for the growing seasons of 2021 and 2022 are provided in Table 3-2. In 2021, the early PD was on 20 May while on-time PD was on 2 June and Late on 24 June. In the 2022, early PD was on 9 May, while on-time PD and late PD were on 27 May and 14 June, respectively. These dates were used based on field accessibility and soil temperatures, though the on-time PD in 2022 was more representative of a typical year in the region.

To monitor available soil water and identify potential interactions between soil water and the experimental treatments, 27 aluminum access tubes were installed within the plots of three full replications. Soil moisture data was collected using a CPN 503 DR neutron probe (InstroTek, inc, California) and converted to gravimetric soil water content at 15 cm intervals to a final depth of 75 cm using an established equation for the experimental site and soil type. Soil water data was collected six times during growing period both years, following every two weeks from the first week of July until late September.

Data Collection

The middle two rows of the four-row plot was used for data collection to avoid border effects. First and median seedling emergence dates were collected for each plot with a visual rating. Due to technical issues with the planter in 2021, some plots had uneven stand and therefore the data was not used for final analysis. Stand count was collected once plants had fully emerged and flowering notes were taken visually as the date when 50% of plot had open blooms. In 2022, plot damage from badgers took place at the grain filling stage, and the yield data was lost for seven plots. Less affected plots were manually adjusted for reduced final stand and included in the final mixed model analysis.

Harvest Methods

Harvest was conducted by hand in both years to accommodate the variable times to maturity for the hybrids and planting dates. Head diameters were measured and then threshed using an ALMACO Low Profile Plot Thresher (Allan Machine Company, Nevada Iowa) in 2021. In 2022, heads were threshed by hand to avoid seed loss. A stationary grain analysis computer (GAC 2700-AGRI Grain Analysis Computer, Dickey-John, USA) was employed to obtain grain moisture (%) and volumetric weight (kg/hL).

Data Management and Analysis

All data was converted to appropriate metric scales as needed, and response variables related to date were calculated based on the appropriate planting date to which the plot corresponded.

Final yield results were adjusted to 9% grain moisture using the formula:

$$\frac{kilograms}{hectare} * \frac{(100 - observed\ moisture)}{(100 - 9)}$$

The PD and hybrids effect on yield, volumetric weight, stand count, and effect of PD and hybrid on duration from planting until first and median emergence, median flowering date of sunflowers were analyzed with an Analysis of Variance (ANOVA) in R 4.1.2 (R Core Team, 2022) using following linear prediction model:

$$Y_{jkl} = \alpha_i + \beta_j + \beta(\alpha)_{ij} + \varepsilon_{ijk}$$

Where Y_{jkl} represents the response variable of interest, α_i is the main effect for planting date, β_j is the main effect for hybrid within planting date, and residual error is denoted by ε, Tidyverse (Wickham, 2018), ggplot2 (Wickham, 2016) "gcookbook (Winston, 2018)", dplyr (Wickham *et al.*, 2022) packages were used within the R Studio (R Core Team, 2022) graphical user interface.

Results and Discussion

Plant Emergence

First plant emergence and median emergence was affected by PD only (Table 3-3). The date of first plant emergence for each PD were 23 May, 6 June, and 20 June for the early, on-time and late PD respectively. This was 14, 10 and 6 days after planting for each PD, respectively. The dates of median emergence were 2 May, 13 May, and 25 May for the early, on-time, and late PD, respectively. This was 22, 17, and 11 days after planting for each PD, respectively. Planting in early May could expose newly emerged sunflower seedlings to freezing temperatures that often occur in western NE in that month. Moreover, regardless of PD, a rainfall deficit can affect sunflower emergence at any sowing dates (Loose *et al.*, 2017). The on-time PD was planted in late May and average maximum temperature at this time was not considerably higher than the late PD that was planted in early June. However, the minimum average temperature in June increased to 11.9 C° from 4.9 C° in May. Higher temperatures increase metabolism and enzymatic expression in sunflower seeds (Orchard and Jessop, 1984). Therefore, increased temperatures could allow L PD to emerge more rapid than OT PD and E PD. Similar findings were reported by Unger, (1980). Their study conducted in the southern Great Plains indicated 14 days difference between earliest PD planted in late March and the latest PD in late July. Unger associated it with soil temperature that increased as PD was delayed. Similarly in western Nebraska, soil air temperature increases with delayed PD, however, planting very late can be risky due to potential heat stress. This can suggest that OT PD in late May is less subjected to weather effects that can limit plant emergence.

<u>Stand Count</u>

Planting date was the only factor that affected sunflower stands (Table 3-3). The effect of hybrids and interaction of hybrids × PD was not significant. Figure 3-1 summarizes the sunflower stand count data. The average number of plants per hectare at E PD was greater than at L PD for 7,669 stands per hectare while E and OT PD were not significantly different. These observations suggest that E and OT PD were optimal planting windows to reach highest number of stands. Late PD was least effective which can be associated with elevated temperatures and precipitation decrease common with mid-summer (Table 3-2).

Days to Median Flowering

Duration from PD until median flowering had significant differences by main factors of hybrids and PD while interaction of hybrids × PD was not significant (Table 3-3). The figure 3-2 displays information related to sunflower median flowering. The E PD took longest to reach median flowering, accounting for 78 days in average which was four days greater than average of OT PD while OT PD was five days greater than L PD. The duration to reach median flowering by hybrid means was 79 days for late 7919CL hybrid while mid 455E and early 432E hybrids were 3 and 9 days shorter than late hybrid 7919CL. This trend suggests that hybrids strictly followed their genetic characteristics while PDs responded decreasing duration to reach median flowering as temperature increased. Each PD associates with different air temperature which often cause variation between plants development (Loose *et al.*, 2017). The E PD planted in early May required more time to reach median flowering and significant variation of 10 days occurred between E and L PDs. Plants regulate phenotypic plasticity at the reproductive stage by complex genetic system which process diverse signals as temperature and photoperiod to begin flowering during the optimal time (Wilczek et al, 2010). Xiang-Min Piao *et al.*, (2014) reported performance of 16 sunflower genotypes in northwestern South Korea, to reach flowering stage depending on sowing dates. As temperature increased, duration decreased from 64 to 51 days in average indicating 13 days difference between first PD in early May and last PD in early June while all hybrids varied significantly depending on maturity. Alessi *et al.*, (1976) reported that in the Northern

Great Plains, both PD and plant density affected the duration of sunflower to reach blooming stage. Similar trend was found in this experiment.

The observations above indicate that L PD in average was 10 days faster over E and 6 days over OT PD to reach median flowering while hybrids in average had 3 days variation decreasing from late to early maturity. Although L PD was fastest to achieve median flowering, producers should consider duration of local growing season and climate variability to have appropriate period from blooming to full maturity.

Head Size

The interaction of Hybrid × PD was not significantly different while PD and Hybrids indicated significant difference in the mean values for sunflower head size. (Table 2-3). Sunflower average head size details are displayed in Figure 3-3.

The E PD averaged 1.8 centimeters greater than the OT PD and 2.8 centimeters greater than the L PD. Late PD had the smallest average head size at 4.1 centimeters which was 1 centimeter less than the OT PD. The largest difference between hybrids was among 432E and 7919CL. The early hybrid 432E head size was 1.7 centimeter greater than the average head size of 7919CL. Joskimovic *et al.*, (2003) reported that sunflower head size was affected by temperature and precipitation but was primarily driven by hybrid. Balalic *et al.*, (2016) studied the influence of PD on sunflower head diameter in Serbia. The 4 PDs studies were from late March to late May. The largest mean value (11.8 cm) of head size was associated with the last PD which had optimal weather conditions while the smallest (11.2 cm) was observed with the early PD. Dutta, (2011) conducted an experiment that evaluated sunflower head diameter across 5 PDs from

November to January in India. Analysis indicated declining tendency as PD was delayed due to cooler temperatures and late November exhibited largest head size (16.8 cm).

The observations of this experiment suggest that under dry conditions using early hybrids and planting early could be beneficial to alleviate late season drought effect on plants. However, except hybrids maturity, drought tolerance features should also be carefully considered.

Number of Heads

Interaction of Hybrid × PD was not significant while differences among hybrids and PD indicated significant difference (Table 3-3). Details related sunflower number of heads can be found in Figure 3-4. The E PD averaged 20,478 heads per hectare. This was 8,500 heads per hectare greater than the L PD. The E and OT PD were not different. Differences between hybrids declined from the early maturing 432E hybrid to the mid-maturing 455E 6,350 heads per hectare while 455E was 3,200 heads per hectare greater than the late hybrid 7919CL. Hybrid 432E was 9,550 heads per hectare greater than hybrid 7919CL. The L PD partially failed to form heads due to heat stress in late summer (Table 3-2). This also limited the performance of hybrids and the failure to form heads was also observed with the late hybrid 7919CL. The early maturing hybrid 432E was in a less susceptible stage of development in contrast to late hybrid 7919 CL during the heat effect in late summer.

Grain Yield

All hybrids failed to produce grain at the L PD and hybrid 7919CL failed across all PDs, thus only 2 hybrids and 2 PDs will be discussed. Hybrids and PD significantly affected grain yield (Table 3-3). The mean value of grain yield for hybrid 432E was 232 kilograms per hectare which was 155.25 kilograms per hectare greater than hybrid 455E (Figure 3-5). The E PD had 129.7 kilograms per hectare greater yield than the OT PD (Figure 3-5). The higher yield of E PD could be associated with greater abundance of rainfall in May (Table 3-2). Demir, (2019) reported similar findings in Turkey. Maximum grain yield was obtained from E PD in late April while minimum yield was obtained from last PD in late May due to decrease of precipitation. Although sunflower is considered moderately drought tolerant, it is highly vulnerable to heat stress from early blooming to grain filling stages due to ineffective regulation of transpiration during these period of development (Garcia-Lopez *et al.*, 2014). Buriro *et al.*, (2015) evaluated the response of sunflower grain yield on frequency of irrigation in Pakistan. Results indicated a decrease of grain yield from 2200 to 960 kilograms per hectare when irrigation regime decreased from 5 to 2 times within an interval of 15 days. Bhatti *et al.*, (1999) reported that in western Nebraska 50 kilograms per hectare grain yield increase was observed from sunflower planted in late May than in late June.

According to the findings of this experiment, planting later than May in a drought year can cause substantial grain yield losses. The overall mean value of E PD in early May in contrast to OT PD in late May indicated a 62 percent greater grain yield while hybrid 432 E had a 70 percent greater grain yield than cultivar 455E. These observations may suggest that producers could consider planting sunflower in early May and using early maturing hybrids to in some extend reduce production losses in drier years.

<u>Volumetric Weight</u>

The interaction of Hybrid × PD and between PDs were not significant. Significant differences were observed between hybrids (Table 3-3). Differences between hybrids indicated 4.1 kilograms per hectoliter advantage of hybrid 432E over 455E (Figure 3-6). Buriro *et al.*, (2015) reported that under water stress, sunflower produce lighter seeds. Demir, (2019) suggested that sunflower volumetric weight changed depending on hybrid genetic inclinations and environmental conditions. During the humid growing season, hybrid 'Tarsan' had the greatest volumetric yield (60.82 kilograms per hectoliter) among all hybrids tested while hybrid 'SanbroMr' had the greatest (47.60 kilograms per hectoliter) among the same cultivars during a drought period.

In this study, there is an assumption that mid maturing hybrid 455E could not reach physiologic maturity and finish grain filling. The mean value of hybrid 432E was 20 percent greater than hybrid 455E, however this may not be true with adequate precipitation. The observations above may suggest early 432E as slightly advantages over 455E in a dry season, however, evaluating a wider range of years could help to determine potentials of the hybrids under varies growing conditions.

Conclusions

Sunflower grain production improving worldwide. The cultivation methods vary dependent on growing environment. The careful approach to choose optimal planting dates and respective hybrid in semi-arid territories is major factor impacting final grain yield. This experiment studied the effect of sowing date and hybrid maturity on sunflower growth and yield under conditions of semi-arid High Plains of western Nebraska. Analysis of variances (ANOVA) indicated significant effect of PD on sunflower first and median emergence, median flowering, average head size, number of heads and grain yield (Table 4-3). Performance of hybrids significantly varied at median flowering, average head size, number of heads, grain yield and volumetric weight while interaction of hybrid × PD was not significant (Table 4-3). Greatest grain yield belonged to hybrid

432E (232 kg/ha) while lowest mean (76.75 kg/ha) belonged to hybrid 455E. Hybrid 432E had 20 percent greater volumetric weight than hybrid 455E. Late maturing hybrid 7919CL failed to yield across all PD. Early PD increased grain yield on 129.7 kilograms per hectare in contrast to OT PD. Overall sunflower development from emergence until median flowering was rapid for the L PD, however, the L PD failed at grain filling stage. The research results could be helpful in recommending optimal planting window and respective hybrid maturity.

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Table 3-1. Sunflower hybrids used in this experiment and relative maturity; all hybrids tested were sold by Croplan.

Hybrids	Maturity	Days to Maturity
432E	Early	89
455E	Middle	94
7919CL	Long	98

Table 3-2. Weather during the growing seasons of 2021-2022 compared with long term averages for the High Plains Ag Lab near Sidney, NE. Both 2021 and 2022 had lower than average precipitation, with the precipitation totals more significantly impacted in 2022.

Month	Monthly average precipitation (mm)		Long-term average precipitation (mm, 30 years)	Monthly average air temperature (ºC)			
				2021		2022	
	2021	2022		Max	Min	Max	Min
January	0.5	16.2	7.3	6.1	-6.4	5.3	-7.7
February	17.2	9.9	9.1	-0.2	-11.3	6	-9.1
March	103.4	25.9	22.6	11.1	-2.7	13.2	-4.1
April	26.4	4.0	41.6	13.8	-0.6	18.1	-1.6
May	73.2	63.7	75.9	20.1	6.0	22.1	4.9
June	35.5	41.6	80.0	29.7	12.6	25.7	11.4
July	35.5	57.1	65.5	34.1	15	33.9	16.3
August	8.6	1.7	49.2	32.5	14.1	34.2	15.0
September	53.6	34.5	35.5	30.8	10.7	30.9	11.0

Table 3-3. Analysis of variances (ANOVA). Effect of planting dates and hybrids on sunflower development at the High Plains Agricultural Lab near Sidney, NE in 2022.

Source	DF	Emergence (Days from planting)	Median Emergence (Days from planting)	Stand (plants ha^{-1})	Median Flowering (Days from planting)	Average Head Size (cm)	Number of heads ha^{-1}	Grain Yield (kg ha^{-1})	Volumetric weight (kg hL^{-1})
Hybrid	2	0.78	0.46	0.18	0.0001*	0.0033*	0.0001*	0.0052*	0.0090*
Planting Date	2	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0476*	0.82
PD × Hybrid	4	0.43	0.40	0.33	0.36	0.26	0.17	0.58	0.73

*Significant at P≤ 0.05 level.

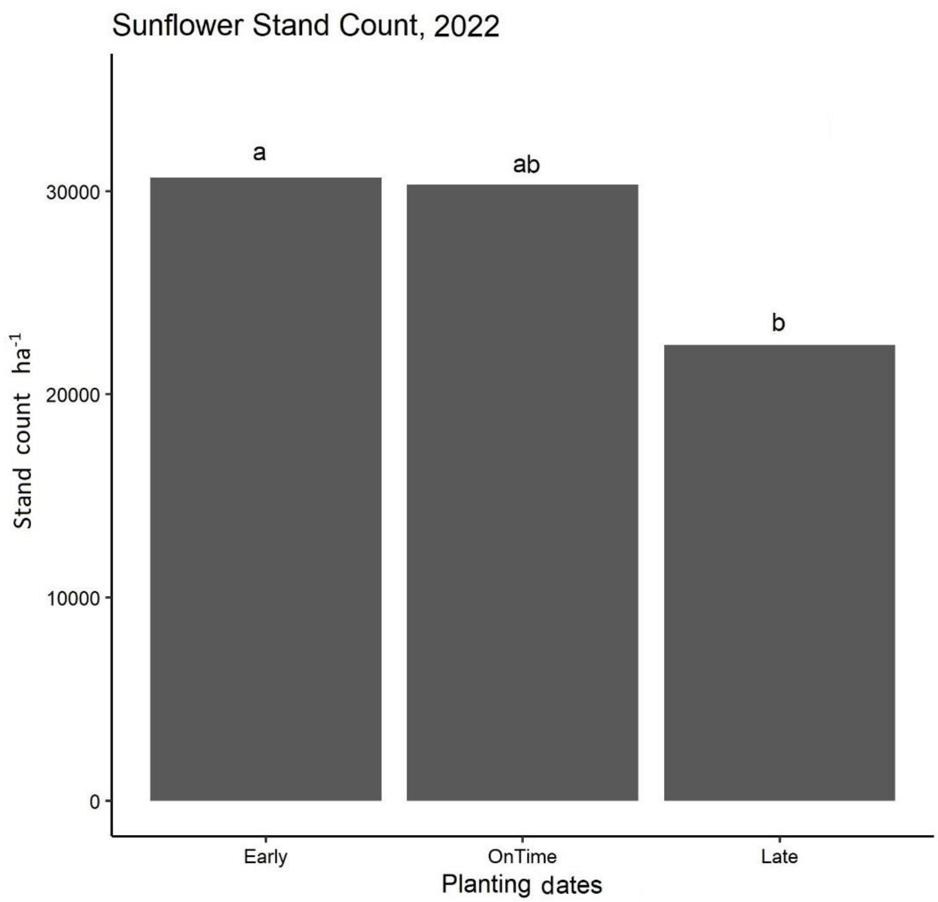

Figure 3-1. Stand count of sunflower in 2022 by planting date. Y axis indicates number of stands per hectare for sunflowers planted at the High Plains Ag Lab near Sidney, NE. X axis indicates planting dates. Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

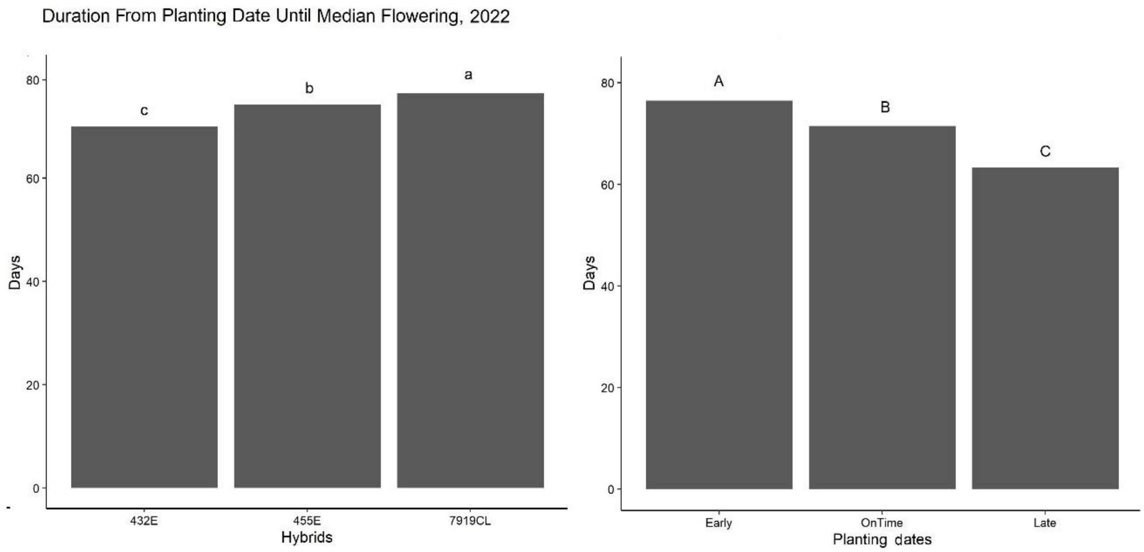

Figure 3-2. Duration to median flowering measured by days from planting for hybrids and planting dates. Data is compared within each panel. Y axes for both panels indicate duration from planting until median flowering in days for sunflowers planted at the High Plains Ag Lab near Sidney, NE. X axis for first panel indicates hybrids. X axis for second panel indicates planting dates. Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

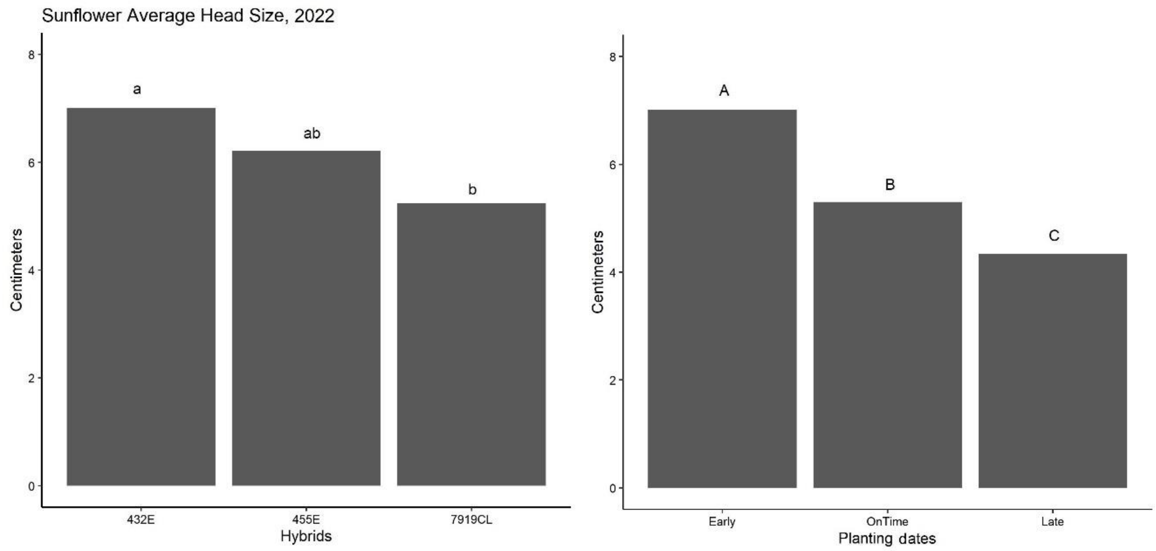

Figure 3-3. Average head size in 2022 by hybrids and planting dates. Data is compared withing each panel. Y axes for both panels indicate head size in centimeters for sunflowers planted at the High Plains Ag Lab near Sidney, NE. X axis for first panel indicates hybrids. X axis for second panel indicates planting dates. Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

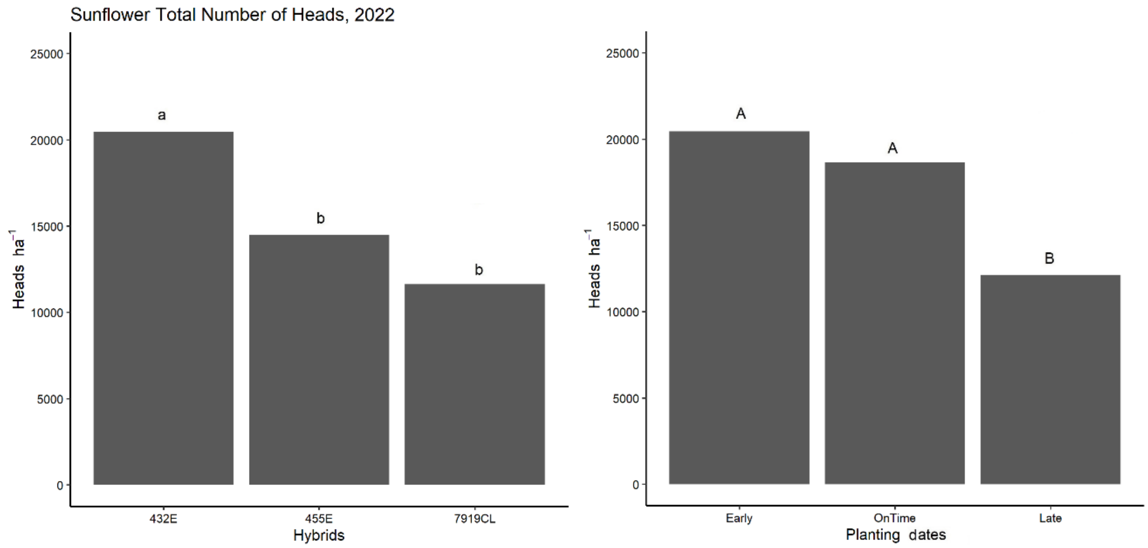

Figure 3-4. Total number of heads by hybrid and planting date. Data is compared withing each panel. Y axes for both panels indicate number of heads per hectare for sunflowers planted at the High Plains Ag Lab near Sidney, NE. X axis for first panel indicate hybrids. X axis for second panel indicates planting dates. Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

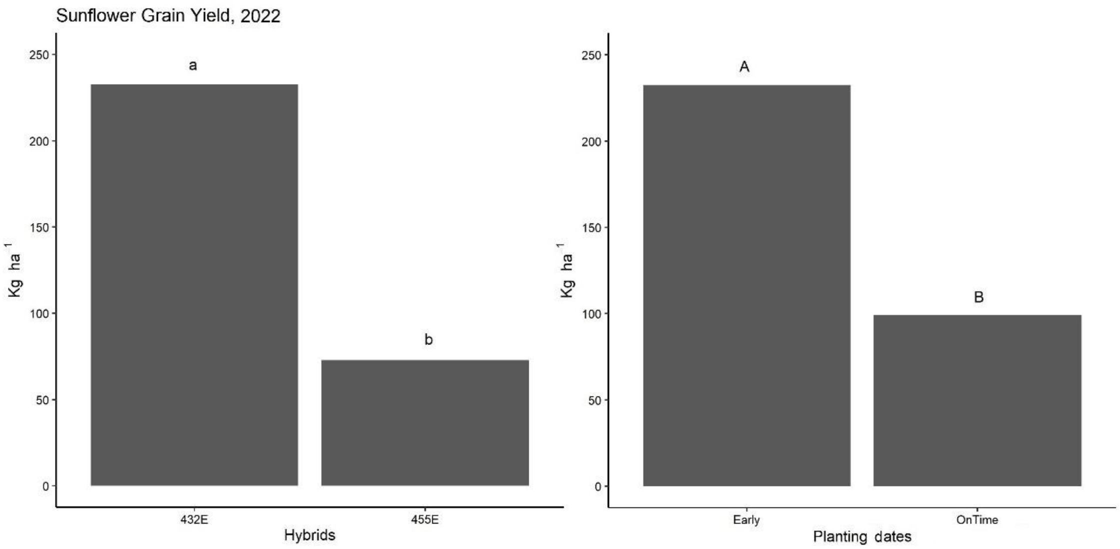

Figure 3-5. Grain yield by hybrids and planting dates. Data is compared within each panel. Y axes for both panels indicate grain yield based on kilograms per hectare for sunflowers planted at High Plains Ag Lab near Sidney, NE. X axis for first panel indicates hybrids. X axis for second panel indicates planting dates. Hybrids are presented by growing relative maturity (early, medium, late) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

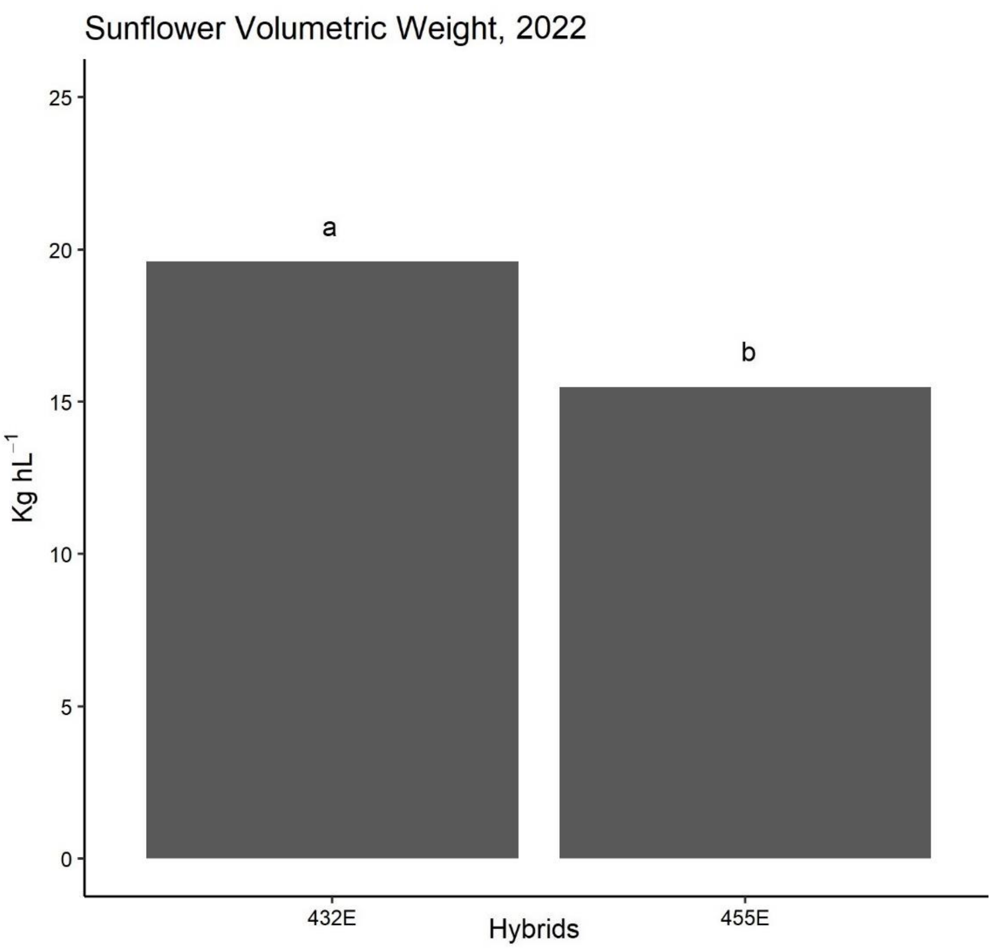

Figure 3-6. Volumetric weight by hybrid. Y axis indicates volumetric weight based on kilograms per hectoliter for sunflowers planted at High Plains Ag Lab near Sidney, NE. X axis indicates hybrids. Hybrids are presented by growing relative maturity (early and medium) from left to right. The means following the same letters are not significantly different at P≤0.05 level using least square means.

CHAPTER 4
EVALUATION OF INTERACTIONS OF CORN FLEX HYBRIDS AND PLANT DENSITY IN WESTERN NEBRASKA

ABSTRACT

Corn production is actively increasing beyond the Corn Belt territories. Optimizing corn yield requires to find an appropriate match of hybrids and plant density. The objectives of the study were to evaluate the interaction of corn flex ear hybrids and different population rates under conditions of western Nebraska. Four hybrids with different ear flex characteristics were planted at 19,768; 27,181; 34,595; 42,007; 49,420 plants per hectare populations in Nebraska, one at HPAL near Sidney and the other in Box Butte County from 2021-2022. The experiment consisted of two dryland and one irrigated trial. The optimal population for grain yield in 2021 was 34,595 plants per hectare. A significant decrease of grain yield for 699 kilograms per hectare was observed when population was increased from 34,595 to 42 007 plants per hectare. In 2022, grain yield varied significantly by hybrids. Hybrids CP 3337 and DKC 42-04 RIB indicated greatest grain yield of 2,295 and 2,271 kilograms per hectare. CP 3337 produced in average 32 percent secondary ears greater than all hybrids. Further research is needed to determine performance of corn flex hybrids at different populations however high plant densities could be less beneficial for semi-arid regions.

Introduction

Corn breeding led to significant yield increases while improvements in agronomic practices in the Corn Belt territories (Duvick *et al.*, 2004). Likewise, progress in more marginal corn producing regions has also occurred, increasing grain yield potential and stabilizing yields under dryland conditions (Duvick *et al.*, 2004). The corn hybrids grown in the Corn Belt under favorable conditions often have fixed ear traits which grow uniformly in size and in number in order to accommodate a high population density. Fixed ear hybrids do not exhibit much variability for ear number per plant and the trait is genetically controlled (Thomison and Jordan 1995). However, corn producers in dry or less favorable areas are more likely to want to use flex or semi-flex maize hybrids.

Flex hybrids tend to produce higher number ears under auspicious conditions and advantages of the flex hybrids can increase under low plant density (Abendroth *et al.*, 2011). Plant density is one of the most significant factors affecting yield (Fromme *et al.*, 2019).

Performance of contemporary maize hybrids are rarely commercially tested at low enough plant densities in semi-arid regions to adequately characterize flex characteristics. These areas often practice populations under 10,000 plants/ha to effectively utilize moisture, and at this plant density, corn tillering effects are frequently dynamic (Veenstra *et al.*, 2021). Flex corn hybrids also tend to intensively generate tillers which can be confounded with the flex characteristic's effect on overall yield (Thomison and Jordan 1995). (Downey, 1972) stated that active tillers can be beneficial to minimize stress during critical stages of development.

Research conducted in Kansas found no negative impact of tillers on corn productivity. In contrast, tillers had a positive effect on yield at low planting density but once plant population increases the contribution of tillers to yield decreases (Veenstra *et al.*, 2021). In areas with erratic weather conditions, reducing population in favor of encouraging tillering is a reasonable strategy to maintain crop productivity while alleviating risk of total failure and minimizing seed costs. Tillering effects may not be more beneficial than multiple ear production or higher plant density under ideal environmental conditions, however significant evidence is presented in another study describing how tillers act as an alleviating flexible feature in highly variably climates (Veenstra *et al.*, 2021).

The objectives of this study were to test the response of corn hybrids with different flex trait classifications with a range of plant populations in order to determine the performance of flex hybrids under dry and irrigated conditions of Western Nebraska.

Materials and Methods

Site Description and Experimental Design

The research was conducted in 2021 and 2022 at the University of Nebraska High Plains Agricultural Laboratory (HPAL) located close to Sidney NE (41°14'15.5"N 103°00'02.3"W). Three environments were tested: ‘HPAL Dryland’ classified as Alliance loam soil (Fine-silty, mixed, mesic Aridic Argiustolls) with 1 to 3% slopes, ‘HPAL Irrigated’ with Keith Loam soils with 0 to 1% slopes, and ‘Box Butte Dryland’ that is a combination of Rosebud loam with 1 to 3 % slopes and Alliance loam soils with 0 to 1% slopes. A randomized complete block design with a factorial treatment arrangement was used in this research. Four hybrids and five plant populations were used as treatment factors. Plant population rates were 19,768; 27,181; 34 594; 42,007; and 49,420 plants per hectare. Information related to hybrids can be found in Table 4-1. A summary of weather conditions during the experiment years of 2021 and 2022 can be found in Table

4-2. Treatments were planted as four row plots with a row spacing of 76 cm. Plot area was 1.5m × 9.1m, and 4 replications were used for each treatment. In the first year the experiment fields were planted in the middle of May and in the second year all three locations were planted at the end of May based on recommended soil temperatures and planting conditions in each year.

Data Collection Process

Data collection was based on two middle rows to increase data accuracy by avoiding border effects. First emergence and median emergence dates were recorded as days after planting. At the end of June, all three fields had good and stable stands, so stand count was collected by counting second and third rows and converting to a plants per hectare basis. Pollen shedding and silk emergence notes were taken when 50 percent of the plot reached that stage of development, starting in late July through the first week of August. All the study fields uniformly started reaching physiological maturity as measured by black layer formation from mid-September until very early October. Tiller counts were taken from two middle rows and converted to a tillers ha^{-1} basis. From middle two rows of each plot before harvest, each the primary, secondary and tertiary ears were tallied by type of ear and converted to a per hectare basis. Harvest was completed using a research plot combine harvest master (Zurn 150, Schöntal-Westernhausen, Germany). The plot combine collected data for each plot on grain moisture (%), volumetric weight (test weight, measured in pounds per bushel), and grain weight (in pounds) at harvest. Yield data was all converted into metric mass units as grams, kilograms, and kilograms per hectoliter.

Data Analysis

Due to no variation among hybrids and population for first and median emergence, median shedding and silking and black layer dates, data were not subjected to analysis. Data for each trait were subjected to analysis of variances (ANOVA) using the GLIMMIX procedure within SAS 9.4 software. The effect of hybrids and plant population on stands, tillers, primary, secondary, and tertiary ears, grain yield and test weight of dryland corn in both years were analyzed using "GLIMMIX" procedure in SAS 9.4 software following linear mixed model below where years were considered separately, and location was a random effect:

$$Y_{ijk} = \alpha_i + \beta_j + \alpha\lambda\beta_{ij} + L_k + r(L)_{kl} + \varepsilon_{ijkl}$$

Where $\alpha_i$is the main effect for population, β_j is the main effect for hybrid, L_k is the random effect for location and $r(L)_{kl}$ is the random effect for replication nested within location. Residual error is indicated by ε.

Results and Discussion

Stand Count

Effect of population on stand count was significant ($P < 0.0001$) in both years, (Table 4-3). The stand count results are presented in Figure 4-1. In 2022, total precipitation from March to August was 88.64 mm less than in 2021. Both 2020 and 2021 had less than average precipitation across the growing season. This limited performance of hybrids in all the aspects, but more markedly in 2022.

In 2021, corn stands increased as population increased. The highest population of 49,420 plants per hectare indicated greatest mean of 40,172 stands per hectare that was 19,884 stands per hectare greater than the lowest mean at population of 19,768 plants per hectare. In 2022, Both populations of 42,007 and 49,420 plants per hectare indicated similarly greatest mean value of over 35,000 stands per hectare. This index decreased on over 5,000 stands per hectare as population decreased to 34,594 plants per hectare. Significant increase of 11,454 stands per hectare observed when plant density was increased from 19,768 to 34,594 plants per hectare. Fawcett *et al.*, (2015) reported similar growing trend of plant stands as population was increased in Iowa. At each increase of population on 2,000 plants per hectare, in average 1,200 stands per hectare increase was observed. Dungan *et al.*, (1959) suggested that soil productivity and weather can limit corn stands development, however it is frequent that higher populations produce higher number of stands. Pecinovsky *et al.*, (2011) reported that under four different tillage methods including no-till, corn and soybean final stands increased mainly depending on population in Iowa. The results of stand count in the current study in agreement with literature above, however at populations higher than utilized in this study decrease of plant stands or different variation trend could be observed.

Number of Tillers

The test for the main effect of population on number of tillers was significant ($P < 0.0001$) in both years (Table 4-3). In contrast the test for the main effect of hybrid on number of tillers was only significant ($P<0.05$) only in 2022. In neither 2021 nor 2022 was the interaction among the main effects significant.

The number of tillers increased as population was increased. In 2021, greatest number of tillers was observed at highest plant density of 49,420 plants per hectare with 44,230 tillers per hectare in average. This was 19,197 tillers per hectare greater than at lowest plant density of 19,768 plants per hectare. At population of 27,181 plants per hectare number of tillers increased on 6,965 tillers per hectare in contrast to lowest plant density. This growing tendency continued at populations of 34,594 and 42,007 plants per hectare reaching 3,384 and 5,211 tillers per hectare greater than at population of 27,181 plants per hectare.

In 2022, largest variation of 10,648 tillers per hectare was observed between highest 49,420 and lowest 19,768 plants per hectare populations with greatest number of 31,700 tillers per hectare at highest plant density. However, no significant difference was observed in number of tillers among populations of 49,420 and 42,007 plants per hectare. Population of 27,181 plants per hectare produced 4,081 tillers per hectare greater than lowest population of 19,768 plants per hectare, while 27,181 plants per hectare produced equal to population of 34,594 plants per hectare. The growth of number of tillers from population of 34,594 to 49,420 plants per hectare was 5,571 tillers per hectare. Downey, (1972); Yamaguchi, (1974) and Tetio-Kagho and Gardner, (1988) reported opposite results and indicated linear decrease of tillers as population was increased from 0.8 to 4 plants per meter square and no tillering at population over 4 plants per meter square. Muon, (1977) also reported substantial decline of number of tillers as population was increased. Rotini *et al.*, (2021) suggested that in Argentina hybrid genotype and environment affected modern corn hybrids tillering such as no tillering was also observed under low plant density depending on hybrids and environment. Results in current study is opposite to many previous studies and this could be because this experiment studied modern corn flex hybrids that promoted tillering, even at higher plant densities.

Number of Ears

Total amount of ears varied significantly by population in both years with (P<0.05), but no significant differences were detected among hybrids or the population x hybrid interaction in either year (Table 4-3).

In 2021, total number of ears increased linearly as population was increased (Figure 4-3).

In 2022, planting populations of 49,420 and 42,007 plants per hectare similarly produced greatest number of ears, both means were a little over 27,000 ears per hectare and was not statistically different. 20,742 ears per hectare was the lowest mean and corresponded to the lowest population of 19,768 plants per hectare.

When breaking down the types of ears on a plant, the number of primary ears again seemed to be significantly impacted by the population at (P < 0.0001) in both years (Table 4-3). The trends seen regarding the number of primary years was similar in both years; therefore, only data from 2021 is presented in Figure 4-4. The general trend is that primary ears per hectare seems to be correlated to planting population.

Secondary ears varied significantly both by population and hybrid though the interaction term was nonsignificant (Table 4-3). Both years again performed similarly, so only 2021 data is presented in Figures 4-5 and 4-6.

At a planting population of 19,000 seeds per hectare, we observed the highest number of secondary ears. At the remaining populations, there were secondary ears present, but at a much lower density. This supports the hypothesis that at lower plant densities, the plants may be able to compensate some for the reduced seeding rate by increasing secondary ears. However, this trend does not appear to be proportionally related to seeding rate and may level off at moderate to moderately high planting populations. With respect to the significant hybrid effect, when examining the actual means, CP 3337 had a significantly higher density of secondary ears and is classified as a hybrid not necessarily with a high flex trait, but as one responding better to population density. Surprisingly, there were no differences among the remaining DeKalb hybrids, despite having differing classifications when it comes to ear flex capabilities.

According to the results above, number of total and primary ears significantly increased at higher populations. Fawcett *et al.*, (2015) similarly found that increasing plant population increased number of ears in Iowa. The results indicated 5,059 ears per hectare variation between populations of 16,187 to 20,234 plants per hectare with increase from low to high. Abuzar *et al.*, (2011) reported that in Turkey overcrowding corn plants may result in reduction of number of ears. Results indicated that number of ears per plant was 1.33 ears at both 60,000 and 80,000 plants per hectare while highest population of 140,000 plants per hectare indicated largest 0.26 percent decrease in producing ears per plant.

Primary ears are, physiologically, the primary sink for nutrients whereas secondary ears generally only start assimilating mass after the primary ear has finished (Rodger *et al.*, 2000). The number of secondary ears also varied significantly by hybrids. Hybrid CP 3337 had an increase of 32 percent of secondary ears per hectare in contrast to other three hybrids. While we see some differences in both hybrids and populations with respect to the number of secondary ears, the real driver is how this difference may be related to final grain yield.

<u>Grain Yield</u>

Grain yield varied significantly among the tested planting populations in both years at (P<0.05). (Table 4-3). Figure 4-7 displays grain yield details for 2021 relating to the population effects. In 2022, hybrids also significantly affected grain yield (P<0.5), (Table 4-8). Figure 4-8 displays grain yield details in 2022.

In 2021, planting at the recommended seeding rate of 34,594 plants per hectare resulted in the highest grain yield of 4,251 kilograms per hectare in average. However, the remaining populations have means that are often overlapping in confidence intervals and it is difficult to parse out if the differences are driven mostly by population alone or impacted by the number of primary versus secondary ears. The lower relative grain yield when corn was planted at populations over 34,594 plants per hectare could be due to a deficit of moisture and mineral resources. Higher plant density increases abortion of kernels caused by higher stress level during the pollination and the phase of grain filling (Andrade *et al.*, 1999; Kiniry & Richie, 1985). Brad *et al.*, (2020) who reported that in state of Illinois increase of plant density from 94,000 to 109,000 and 124,000 plants per hectare maximized yield in average for about 0.5 metric ton at 51 cm row spacing. However, at population of 139,000 plants per hectare decrease of yield to a lowest level was observed despite row spacing. Norwood, (2001) reported that grain yield of dryland corn in Western Kansas increased on 13.5 percent when population increased from 30,000 to 45,000 plants per hectare however considerably smaller yield increase of 4.3 percent occurred when population increased from 45,000 to 60,000 plants per hectare.

In 2022, hybrids CP 3337 and DKC42-04 RIB had greatest grain yield. DKC 43-75 RIB decreased yield on 299 kilograms per hectare than CP 3337. Hybrid DKC 39-55

RIB increased grain yield on 133 kilograms per hectare in contrast to hybrid DKC 43-75 RIB but indicated lower yield comparing to CP 3337 and DKC42-04 RIB. Flex ear hybrids are described as having the ability to be more highly productive hybrids under unfavorable conditions than fixed ear hybrids because they can compensate for the available resources more efficiently. Observations in this study may suggest that different level of drought tolerance and response to plant density of flex hybrids used in this experiment could affect their grain yield performance. Abbas, (2012) reported that in Louisiana semi flex hybrid yield averaged across all populations indicated 2.75 percent greater grain yield than full flex hybrid due to higher drought tolerance. Fromme et al, (2019), reported that in south-central Louisiana fixed ear hybrid in average across all populations was 9,322 kilograms per hectare advantages over flex ear hybrids when precipitation was above normal but no significant difference among hybrids was observed in the dryer year. Smart *et al.*, (1993) reported that at low populations flex ear hybrids can maximize grain yield by maximizing size and number of kernels.

Volumetric Weight

Test weight in both years varied significantly by hybrids (P<0.0243), (P<0.0109) (Table 4-3). Figure 4-9 indicates details related test weight of flex corn in 2021-2022.

In both years hybrid DKC 39-55 RIB produced greater volumetric weight than hybrids DKC 42-04 RIB and DKC 43-75 RIB. Hybrid DKC 39-55 RIB in the first year produced over 0.5 and in second over 2.4 kilograms per hectoliter greater than hybrids DKC 42-04 RIB and DKC 43-74 RIB. Hybrids CP 3337 and DKC 39-55 RIB were not statistically different in both years.

Fromme *et al*., (2019) reported that in south-central Louisiana flex hybrid averaged across years produced 1.95 kilograms per hectoliter greater test weight than a fixed ear hybrid while semi-flex indicated 1.45 kilograms per hectoliter higher test weight than fixed ear. Grichar and Janak, (2018) reported that in central Texas semi-determinate ear hybrid was greater in test weight than semi-flex ear hybrid in both years. Results indicated 1.95 in first and 12.9 kilograms per meter cube higher test weight in second year.

Conclusions

Newer corn hybrids show superior performance over old hybrids in many aspects including tolerance to high plant density, water stress and N use efficiency (Haegele *et al.*, 2014). Corn flex hybrids have potential to increase yield beyond Corn Belt territories under less favorable conditions. This study attepmted to determine performance of four flex hybrids at different population rates under conditions of western Nebraska. Results of analysis of variances (ANOVA) indicated that effect of population on corn performance was highly significant at most of the aspects while hybrids effected significantly on number of secondary ears, grain yield and volumetric weight (Table 4-1). Higher populations over 34,594 plants per hectare maximized stand count, number of tillers, primary ears and total number of ears but decreased grain yield in first year of study (Figures 4-1 to 4-6). In 2022, hybrid CP 3337 produced about 1,900 secondary ears per hectare greater than all other hybrids and resulted in high total grain yiled. This could be considered as the advantage of the ability to produce multiple ears. However, further study is needed on how corn flex ear hybrids respond to different plant populations as weather and location variability tend to affect corn growth and yield in western Nebraska.

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Table 4-1. Corn flex hybrids selected for representation of relevant seed corn companies and ear flex groups used in the years 2021-2022.

Company	Hybrid	Relative maturity	Ear flex classification
Dekalb	DKC42-04RIB	92 days	Excellent ear flex
Dekalb	DKC43-75RIB	93 days	High yield potential, more fixed ear number under lower populations
Dekalb	DKC39-55RIB	89 days	Semi-flex
Croplan	CP3337	93 days	Moderate response to plant density

Table 4-2. Weather during the growing seasons of 2021-2022 compared with long term averages for the High Plains Ag Lab near Sidney, NE. Both 2021 and 2022 had lower than average precipitation, with the precipitation totals more significantly impacted in 2022. Weather for second site location at Box Butte County, NE during growing seasons of 2021-2022, was similar to Sidney, NE.

Month	Monthly average precipitation (mm)		Long-term average precipitation (mm, 30 years)	Monthly average air temperature (ºC)			
				2021		2022	
	2021	2022		Max	Min	Max	Min
January	0.5	16.2	7.3	6.1	-6.4	5.3	-7.7
February	17.2	9.9	9.1	-0.2	-11.3	6	-9.1
March	103.4	25.9	22.6	11.1	-2.7	13.2	-4.1
April	26.4	4.0	41.6	13.8	-0.6	18.1	-1.6
May	73.2	63.7	75.9	20.1	6.0	22.1	4.9
June	35.5	41.6	80.0	29.7	12.6	25.7	11.4
July	35.5	57.1	65.5	34.1	15	33.9	16.3
August	8.6	1.7	49.2	32.5	14.1	34.2	15.0
September	53.6	34.5	35.5	30.8	10.7	30.9	11.0

Table 4-3. Analysis of variances for the effect of corn flex hybrids and population on corn development at the High Plains Ag Lab near Sidney, NE 2021-2022.

Source of variation	DF	Stand count (plants ha^{-1})	Tiller count (tillers ha^{-1})	Total ears ha^{-1}	Primary ears ha^{-1}	Secondary ears ha^{-1}	Yield (kg ha^{-1})	Volumetric weight (kg hL^{-1})
2021								
Hybrid	3	0.49	0.19	0.28	0.48	0.0003**	0.35	0.0243*
Population	4	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	0.0338*	0.83
Hybrid×Population	12	0.80	0.43	0.28	0.28	0.68	0.40	0.25
2022								
Hybrid	3	0.19	0.0003	0.37	0.48	0.28	0.0368*	0.0109*
Population	4	<0.0001**	<0.0001**	0.0002**	<0.0001**	0.23	0.76	0.81
Hybrid×Population	12	0.78	0.19	0.79	0.28	0.11	0.61	0.36

*Significant at P ≤ 0.05 level, ** significant at P≤0.0001

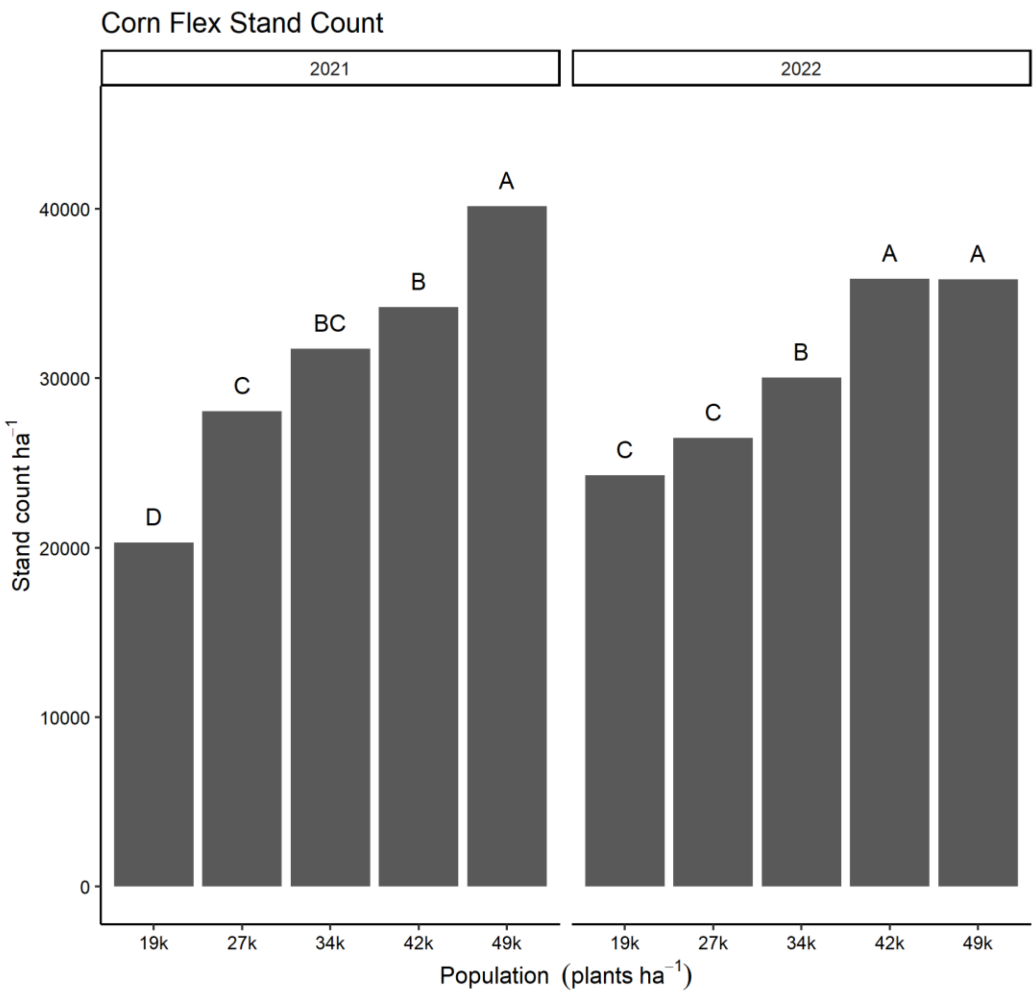

Figure 4-1. Stand count for 2021 and 2022 by planting population. Means separation letters are for within-year comparison only. Y axis indicates number of stands per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021 and 2022. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

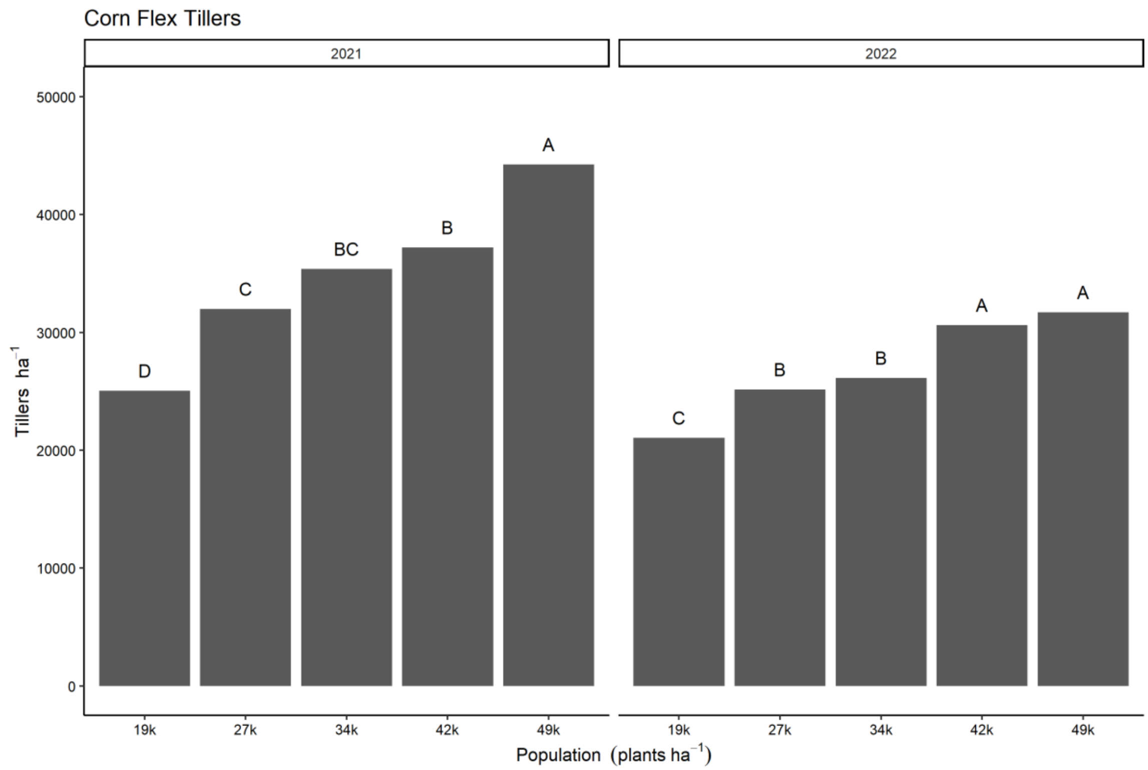

Figure 4-2. Number of tillers in 2021 and 2022 by planting population. Means separation letters are for within-year comparison only. Y axis indicates number of tillers per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021 and 2022. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

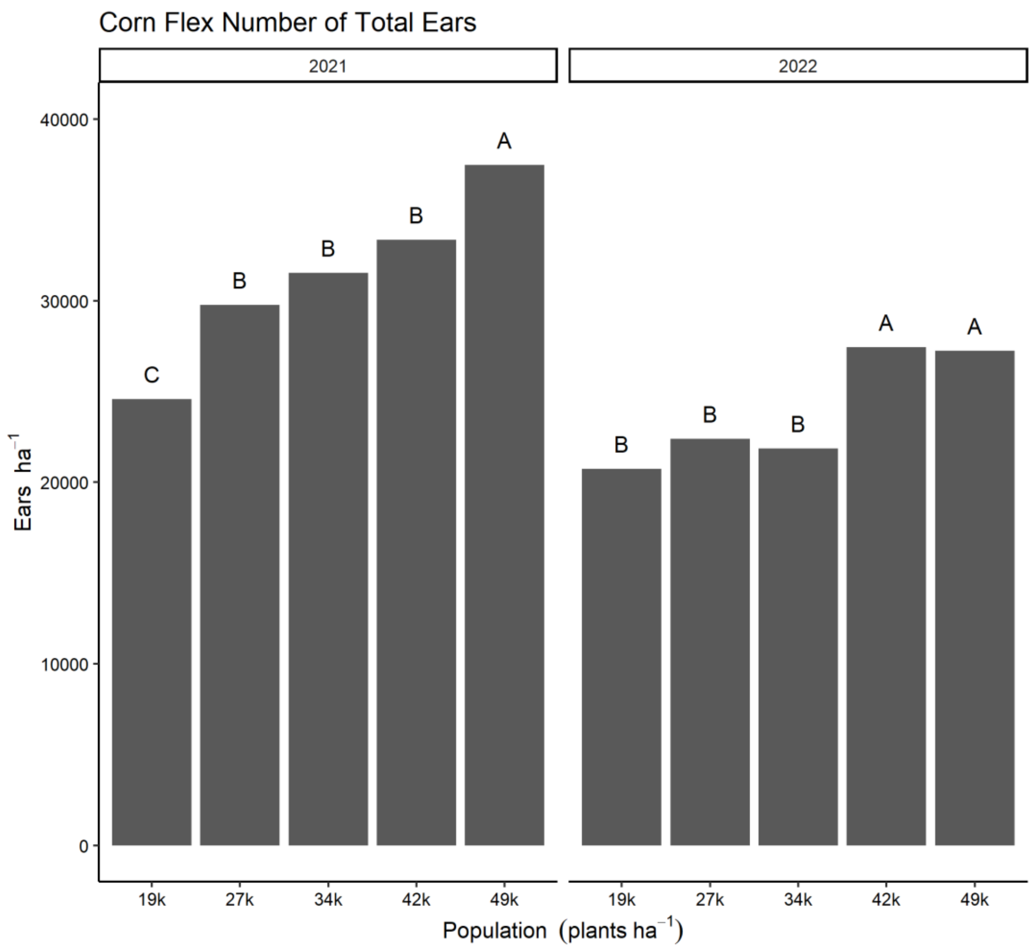

Figure 4-3. Total number of ears per hectare for 2021 and 2022 by planting population. Means separation letters are for within-year comparison only. Y axis indicates number of total ears per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021 and in 2022. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

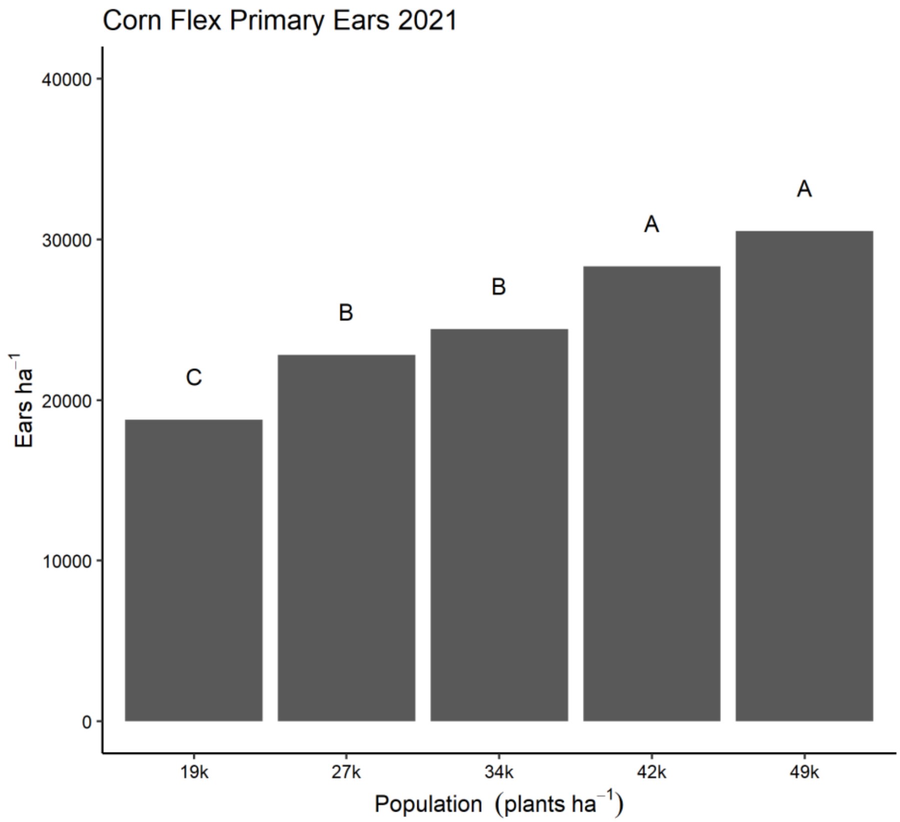

Figure 4-4. Number of primary ears per hectare planting population for 2021. Y axis indicates number of primary ears per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

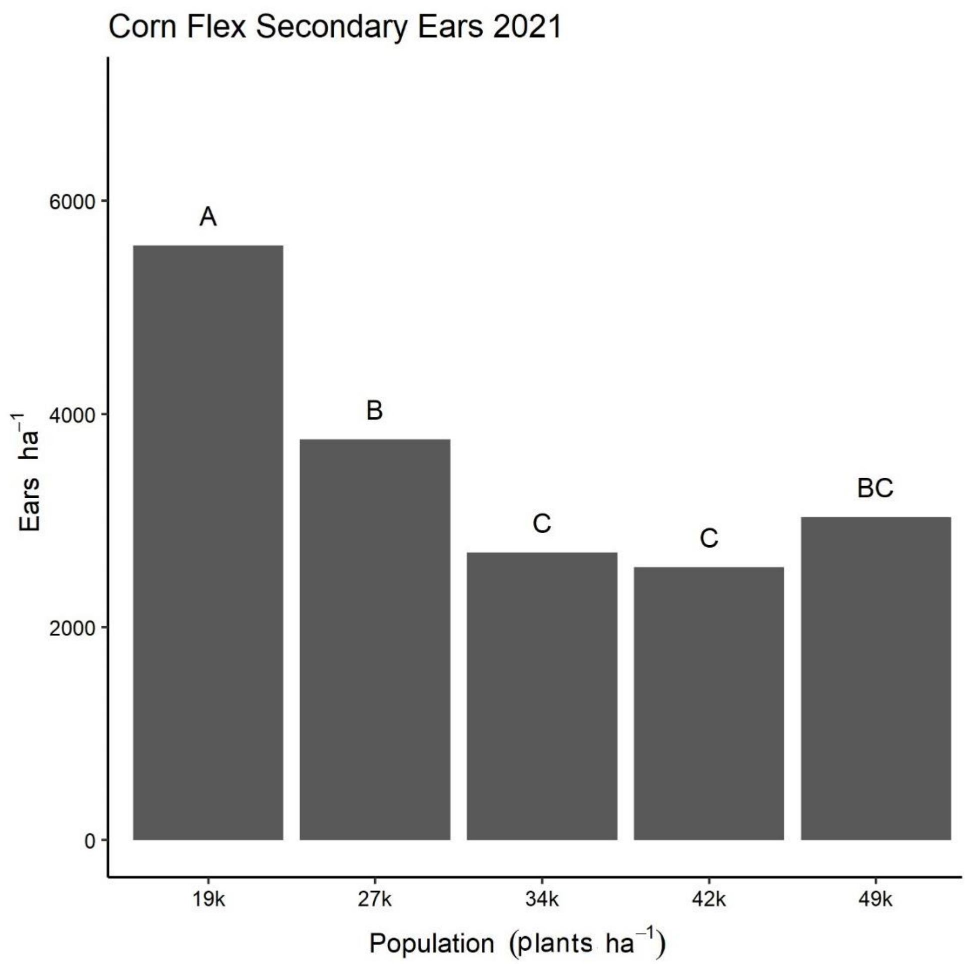

Figure 4-5. Number of secondary ears per hectare for 2021 by planting population. Y axis indicates number of secondary ears per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

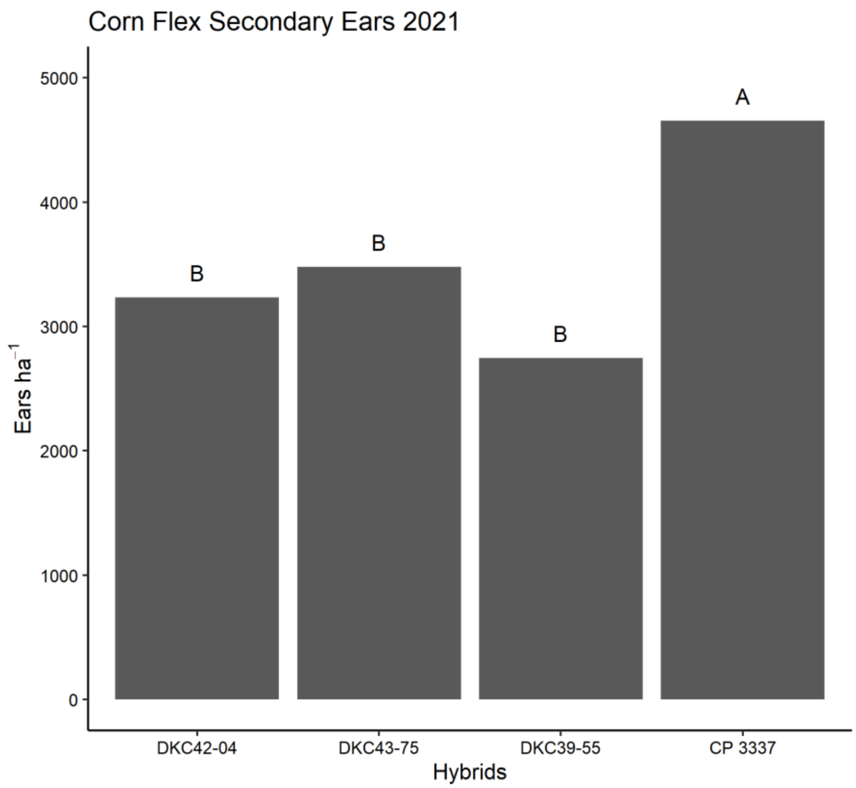

Figure 4-6. Number of secondary ears per hectare by hybrid for 2021. Y axis indicates number of secondary ears per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021. Hybrids are indicated on the x axis. Three Dekalb hybrids full spelling: DKC 42-04 RIB, DKC 43-75 RIB, DKC 39-55 RIB. The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

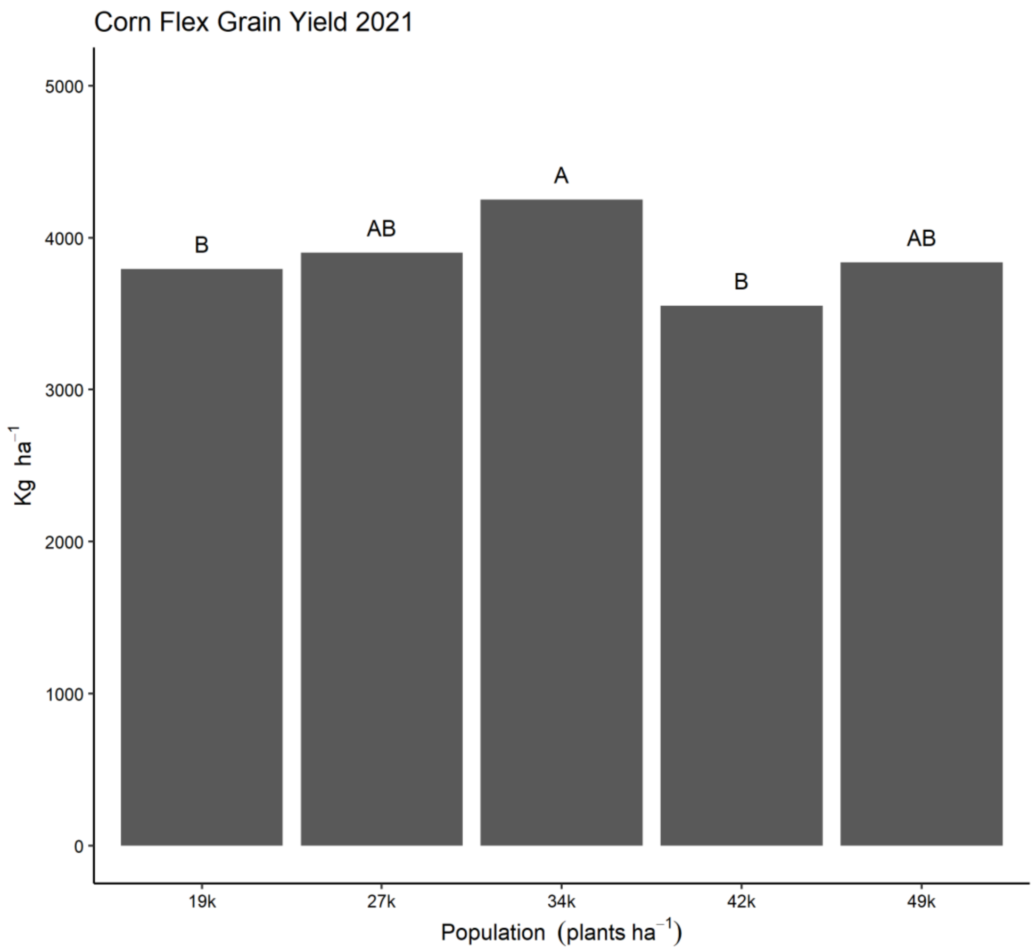

Figure 4-7. Grain yield for 2021 by planting population. Y axis indicates grain yield based on kilograms per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021. The populations on the x axis are based on plants per hectare system and rounded in following way 19,768 (19k), 27,181 (27k), 34,594 (34k), 42,007 (42k), 49,420 (49k). The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

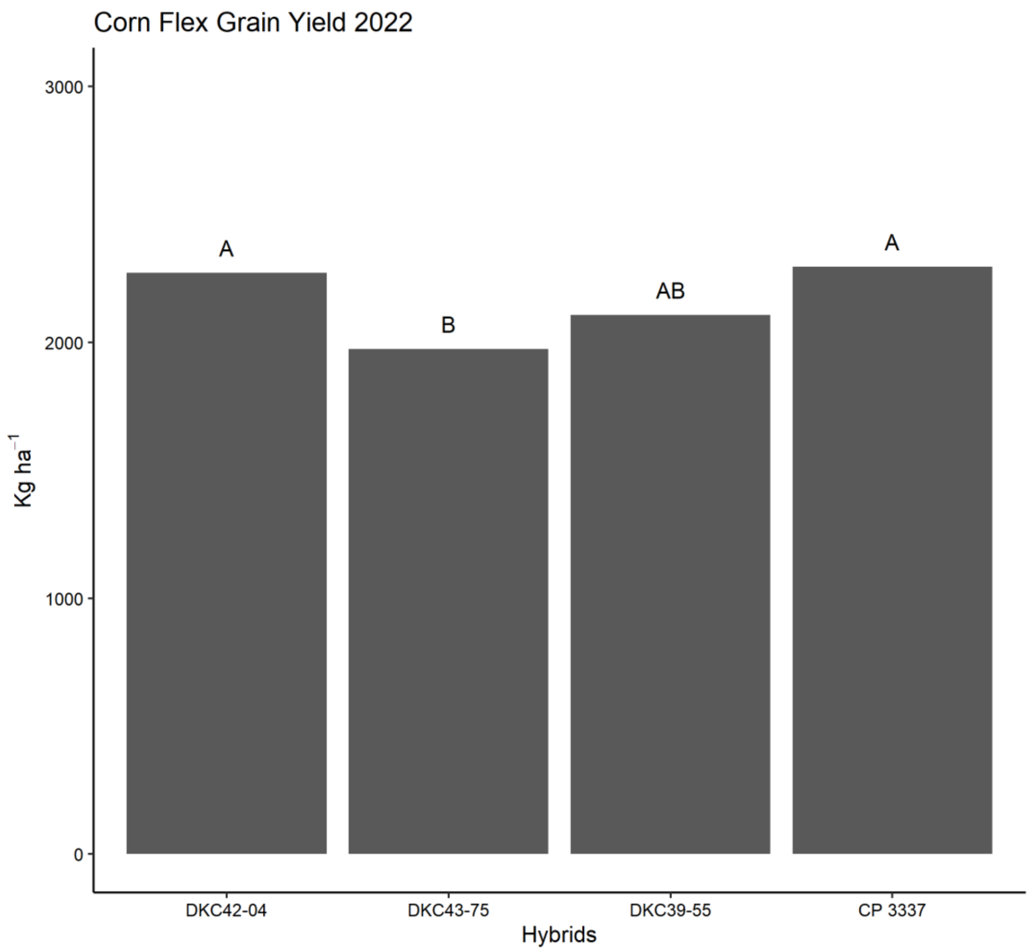

Figure 4-8. Grain yield for 2022 by hybrid. Y axis indicates grain yield based on kilograms per hectare combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2022. Hybrids are indicated on the x axis. Three DeKalb hybrids full spelling: DKC 42-04 RIB, DKC 43-75 RIB, DKC 39-55 RIB. The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.

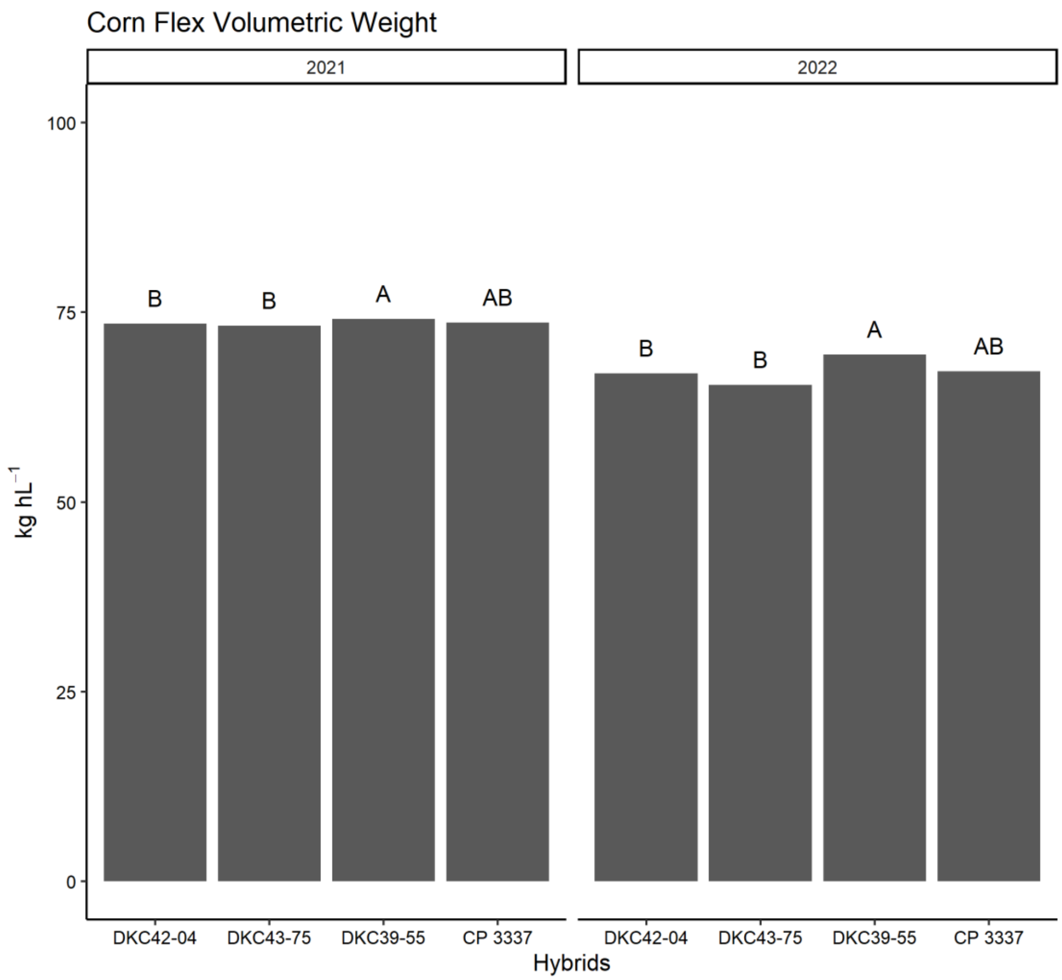

Figure 4-9. Grain volumetric weight by hybrid for 2021 and 2022. Means separation letters are for within-year comparison only. Y axis indicates volumetric weight based on kilograms per hectoliter combined for corn planted at High Plains Ag Lab near Sidney, NE and for corn planted at the Box Butte County, NE in 2021 and 2022. Hybrids are indicated on the x axis. Three Dekalb hybrids full spelling: DKC 42-04 RIB, DKC 43-75 RIB, DKC 39-55 RIB. The means followed the same letter are not significantly different at $P \leq 0.05$ using least square means.