IMPACT OF BED PLANTING WINTER WHEAT ON GRAIN YIELD AND QUALITY

By

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Bachelor of Science in Agriculture

West Texas A&M

Canyon, Texas

2020

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2022

IMPACT OF BED PLANTING WINTER WHEAT ON GRAIN YIELD AND QUALITY

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ACKNOWLEDGEMENTS

During my time spent pursuing my master's degree, I have received an enormous amount of help. It is to those people that held out a helping hand that I owe my success to. I would first like to express my gratitude to my family, without their unending support I would not be here today. I would like to thank my advisor Dr. Brian Arnall and my committee members Dr. Amanda De Oliveira Silva and Dr. Jason Warren. Next I would like to thank the Soil Fertility Group and the Precision Nutrient Management Group. I am truly grateful to each and every one of you.
Thank you.
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Date of Degree: DECEMBER, 2022

Title of Study: IMPACT OF BED PLANTING WINTER WHEAT ON GRAIN YIELD AND QUALITY

Major Field: PLANT AND SOIL SCIENCES

Abstract: The bedded planting systems has been used for centuries, in this time these systems have been used for water management, and field access. This study was designed to evaluate the impact of permanent bed, nitrogen rate, and timing of fertilizer application on winter wheat grain yield and grain nitrogen concentration. Experiments were conducted at the location of Hennessy and Perkins Oklahoma in the 2019-2020, 2020-2021, and 2021-2022 growing seasons. Experiments consisted of a factorial combination of two planting systems (permanent beds and conventional flat), four rates of nitrogen (0, 56, 112, 160 Kg ha^{-1}) and two application timings (pre-plant and in-season). The experimental design was a randomized block design, where bedded treatments and flat treatments were blocked off from each other with five replications. Grain yield and grain nitrogen concentration was found to be not statistically different between the two planting methods. Further testing between the permanent bed planting system and conventional flat planting system will need to incorporate treatments with the same row configuration.

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CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is grown across the world in a variety of environments, everywhere from Africa to the Americas. The state of Oklahoma itself has a diverse environment, with the eastern part of the state tending to be the side of the state that accumulates more rainfall (1325-990 mm) and as you look westward the environments becomes increasingly more arid (685-508 mm) see Figure1. According to Britannica, (2022) wheat requires 30 and 90 cm of rainfall through the growing season. Even with this diversity of environments present within the state of Oklahoma, Oklahoma planted 1.78 million hectares of wheat, producing an average yield of 2623 kg ha^{-1} in the year 2021(NASS, 2022). Bedded planting systems have been used all over the world for decades, over this period of time bedded planting systems have been traditionally used for moisture control. In areas of rain fed agriculture production, bedded planting systems have been used in two ways, water prevention and water retention. The first is to prevent over saturation of the ground by providing better drainage for the field and thus preventing a crop from becoming waterlogged. The second way that a bedded planting system may be used in a rain fed cropping system is by retaining water within the furrow of the beds. This is achieved by creating dykes within the furrow to prevent water from escaping.

On the opposite side of agriculture bedded planting systems may be used in irrigated agriculture by using the furrows of the beds to irrigate the crop (Sayre, 2006). Bedded planting systems can be useful to a farmer in other ways than moisture control; the beds can provide a farmer with field access with the opportunity for tillage within the furrow giving the farmer the option of a non-herbicide option of weed control (Smika and Unger, 1998).

The objective of this study was to evaluate the impact of permanent beds, N rate, and timing of N fertilizer application on winter wheat grain yield (GY) and grain nitrogen concentration (GNC). It was hypothesized that permanent bed treatments would produce more grain yield and grain nitrogen concentration than the traditional flat treatments.

CHAPTER II

REVIEW OF LITERATURE

The concept of bedded planting systems have been around for a long period of time all over the world by both indigenous and modern people. Through time the bedded planting system has been associated with water management by either providing a way for water to be shed off a field in areas where a field may become saturated by rainfall, by providing a farmer the ability to irrigate the crop using the furrows of the bed, or by being a means for water collection in dry areas by catching water within the furrows in tandem with dykes (Sayre, 2006). In the case of permanent raised bed-planting systems, Verachtert et al. (2009) states that as a form of conservation agriculture, has been developed to reduce production costs while conserving resources and sustaining the environment. In the modern era bedded planting systems have shown to have many benefits other than water management such as controlling mechanical traffic to the furrows giving farmers the opportunity for mechanical weeding or the banding of fertilizers in furrow (Sayre, 2006). Hobbs et al. (1998) reported that there seemed to be the distinct advantages of the improved ability to distribute water and the efficiency of water, the ability to make fertilizer more efficient by improving the ability of the farmer to place the fertilizer preseason and in season applications, weed control, reduction in lodging, and reduction in seeding rate. (Limon-Ortega et al., 2000) reported that bedded planting systems may be useful in rain fed wheat production in Mexico, where areas experience instances of scarcity of rain and then an onslaught of rain caused by El Niño periods. This influx of rain can cause major crop damage, soil erosion, or both. So bedded planting systems were investigated as a solution to these problems caused by El Niño in these experiments, it was observed that the bed planting method has the possibilities to alleviate the effects of both water stress from drought and from erosion caused by an influx of water.

Water management

Even with the advancements of modern technology and the efficiency of irrigated crop production 60% of cereal grains are produced by rain fed agriculture (Rosegrant et al,. 2002). In a paper published in 2012, Limon-Ortega et al. (2012) stated that GY variance in a dryland permanent bedded planting system is determined by the variance in daily rainfall over the growing season. That being said, rain fed agriculture does not always mean that moisture is a scarce commodity. In water stressed environments conserving soil moisture can be a challenge to farmers, so solutions have been researched over time to give farmers tools to continue to produce in these conditions. The use of beds have been described to be traditionally used for the management of water issues (Sayre, 2006). One example of bedded planting systems helping to relieve this issue is in Northwest Mexico where Hobbs et al. (1998) reported that water in this area in Mexico was an exceptionally scarce resource and one way that farmers in the area were mitigating this issue was by shifting to the bedded planting system. In the Yaqui valley of Mexico Sayre (2006), stated farmers that had changed over to the bed planting system saved roughly 25% water, saving roughly 25% in operational costs while observing roughly an 8% increase in yields when irrigating in furrow compared to flooding on flats. Fahong et al. (2004) showed that the bedded planting system in China saved up to 30% of irrigation water with furrow irrigation as compared with flood irrigation in a traditional flat planting system. Ma Zhongming et al. (2006) reported that bedded planting could reduce the need of irrigation by 25-30% without yield loss in spring wheat when the correct bed width, planting density, fertilizer rate, and suitable wheat varieties are allocated. In 2013 an experiment testing the alternative soybean wheat rotation to evaluate the effects tillage, yield, profitability and water use efficiency, reported that soybeans and wheat grown on raised beds had roughly 17-23%greater water use efficiency than traditional flat tillage (Ram et al., 2013). Conversely, the bedded planting system is not strictly used for irrigation, the bedded system can also be used to alleviate excess water or collect water in a dryland cropping system as well. In parts of Australia the beds are used to alleviate saturated soils (Sayre, 2006). Saturated soil can effect a wheat plants ability to grow by hampering its roots growth thus impeding the plants ability to uptake nutrients (Trought, 1980). Sweeney and Sisson (1988) stated that GY can be increased with raised beds on soils that drain poorly.

Nitrogen use Efficiency

With the ever growing world population, the demand for food will be ever growing as well. This demand for food falls squarely on the shoulders of the farmers, who are having to produce at higher and higher levels with limited resources. One way these farmers can continue to produce and meet demands of the world is to increase their nitrogen use efficiency (NUE). In 1999 the worlds NUE was 33% with developed countries NUE being roughly 42% and undeveloped countries roughly being as low as

29% (Raun and Johnson, 1999), in recent years these estimations have been reexamined with Omara et al. (2019) showing that the worlds NUE had increased to 35% by 2015. Even with the improvements in NUE that the world has made since 1999 there still need for improvement.

The question of how to increase NUE then arises, in Thomason et al. (2002) it is stated that there are many different approaches that can be taken in the attempt to increase NUE in wheat production. Raun and Johnson (1999) stated that one method in which NUE could be increased is through the implementation of conservation tillage and the subsurface placement of N. Other suggested ways to improve NUE were crop rotations, forage systems, in season N applications, improvements in cultivar, using ammonium (NH_4) as an N source, and finally proper irrigation.

Research has supported the concept that the bedded planting system could provide opportunity to improve NUE. In Pakistan it was observed that at a rate of 120 kg N ha^{-1} the bedded planting system had a 15% higher NUE than traditional flat planting systems (Majeed et al., 2015). A similar observation was made in Northwest Mexico where it was observed that the permanent bed systems that had the stubble burned off and the systems that had the stubble left had the highest NUE compared to conventional tillage beds, permanent beds with the stubble partially removed, and permanent beds that have had all of their stubble removed (Limon-Ortega et al., 2000). In China it was found that NUE could be improved by 10% because of bed planting system to provide better placement of nitrogen fertilizer (Fahong et al., 2004).

Soil physical and biological characteristics

In a conventional tillage system, the tillage increases the availability of soil organic matter to the biomass of microbes by soil aggregate disruption, so when each tillage event occurs carbon mineralization will ramp up (Verachtert et al., 2009). Permanent raised beds have the potential to provide positive contributions to agriculture in face of agriculture’s problems with soil quality and productivity (Hui et al., 2014). One area that permanent raised beds can help with is soil aggregates, soil aggregate influences several aspects of a soils physical behavior such as infiltration, crusting and erosion (Le Bissonais, 2003). The manuscript goes on to say that soil aggregate breakdown is a good measure for a soils ability to erode because as the soil becomes finer and finer it becomes easier to transport and in turn more erodible.

Research conducted in El Batan Mexico evaluated the influence of permanent bed planting and residue management, and this work concluded that permanent beds increased soil quality (Govaerts, 2007). Also, from the same region in Mexico, Litcher et al. (2008) found that the percentage of both small and large macro-aggregates and the mean weight diameter was significantly larger in permanent raised beds as compared to conventionally tilled beds, while the presence of micro-aggregates was less. Limon-Ortega et al. (2006) reported that in the case of permanent bed planting system there can be seen an improvement in soil aggregation, soil stability, and increases C and N when crop residue is retained as stubble. This is supported by (Naresh, 2012) where It was observed that permanent beds that retained all residue had higher mean soil weight diameter as well as a higher aggregate stability. (Naresh, 2012) reported that soil organic matter in these treatments was 1.6 times greater within the first five centimeters of soil as compared to conventionally tilled beds. In rice production, Naresh et al. (2014) showed that soil aggregation and infiltration rate were higher in permanent bed and no-till systems as compared to conventional-tilled puddle transplanted rice (*Oryza sativa*).

CHAPTER III

METHODOLOGY

This study consisted of two planting methods(bedded and flat), three nitrogen rates (0, 56,112 kg ha^{-1}), and two application timings (pre-plant and top-dress), making up 14 treatments which were arranged in a randomized block design (RBD) with the beds and flats block, replicated five times.

The study was established in September of 2019 at two locations; the Hajek Family Research Farm (HFRF) near Hennessy Ok, (36°06’58.60”N, 97°54’01.21”W) and the Cimarron Valley Research Station (CVRS) near Perkins Oklahoma (35°59’36.94”N, 97°02’36.94”W). Winter wheat was grown on the sites over three growing season 2019-2020, 2020-2021, and 2021-2022. The soil series and descriptions for both locations can be found in Table 1. Prior to establishment both locations had been managed as no-till systems for more than seven years. The beds were developed using a custom-built bedding tool used to pull the furrows of the beds. This bedding tool was set to pull beds that are 152 cm from center of bed to center of bed. Beds have an approximate width of 114 cm and an approximate furrow width and depth of 25 cm wide and 20 cm deep. Bedded treatments were reestablished twice a growing season, once prior to seeding and once in season preceding the wheat crop reaching the Feekes 4 growth stage.

The studies were sown with a 1.5 m wide Land Pride no-till drill model 3P606NT on a 19.05 cm row spacing. The planting dates, seeding rates, and cultivar can be found in Table 2. Plot sizes were 1.5 meters wide by 9 meters long, with 6.1 meter alleys between replications. Treatment design of this study was an incomplete factorial with four rates of nitrogen (0, 56, 112, and 168 kg N ha-1) applied across two timings (pre-plant and top-dress) across both bedded and flat management systems (Method). Nitrogen rates (Rate), nitrogen timing (Timing) and treatment descriptions are presented in Table 3. Nitrogen applications were made by surface spreading urea (46-0-0) by hand, flat-planted treatments urea was applied to the whole of the plot, whereas bedded treatments urea was only applied atop of the beds excluding the furrows. In season nitrogen applications occurred between 90-110 growing degree days (GDDs).

Throughout the growing season integrated pest management applications were made in accordance with Oklahoma State University best management practices. At crop maturity, harvest was conducted with a Massey Ferguson 8X-P small plot combine. This combine is outfitted with a 1.5 meter header and a Harvest Master unit. The Harvest Master system was used to collect plot weight as well as the average moisture percentage for each plot. Subsamples of the grain were collected for nutrient and quality analysis. Grain nitrogen concentration (GNC) was analyzed from subsamples using combustion analysis with a LECO model FP828 and a near infrared spectroscopy (NIR) Diode Array NIR analysis systems model DA 7000. Grain samples from growing season 2019-2020 as well as Perkins 2020-2021 were analyzed using the LECO and samples from the Hennessy location in the 2020-2021 and 2021-2022 as well as samples from Perkins 2021-2022 growing season were analyzed with NIR. Statistical analysis of grain yield

(GY),and grain nitrogen concentration (GNC) were conducted using statistical analysis systems (SAS 9.4).

Data collected was analyzed using Statistical Analysis Systems (SAS 9.4), comparisons were found significant at alpha=0.05. Data was first analyzed using an ANOVA to test for location, site year, and locations by site year significance (Tables 4 and5). After finding significance in location, site year, and location*site year analysis mean separation was conducted by site year. Data was next analyzed using an ANOVA to test for treatment significance (Table 6). During this analysis LSD tables were used to confirm N response between treatments (Tables 9-14). If no significance was found in N response no further analysis would be conducted on said site year. When N response was found further analysis was conducted without check plots (Table 7). The final ANOVA test was ran to test the main effects (Method, Rate, and Timing) and the interactions between the main effects. A total of 144 contrasts were ran to further compare the main effect of timing, however this data will not be discussed but is presented in the appendices

CHAPTER IV

RESULTS

This study was designed to evaluate the impact of permanent beds, N rate, and timing of N fertilizer application on winter wheat GY and GNC. ANOVA analysis was conducted to determine if location, year or the interaction of location and year had a significant impact on GY and GNC response to the treatments. The resulting analysis showed that there was a significant interaction between location and year on both GY ($p<.0001$) and GNC ($p= .0012$) see Table 4. Due to this interaction, statistical analysis was conducted on a site-year basis. As noted in the methods section, for each site-year the impact of N application on GY and GNC was evaluated to determine if a significant response to N fertilizer occurred. Five of the six site years GY had a positive response to N fertilizer application, the 2022CVRS site year did not, and GNC responded positively all six site years. Table 6 reports the ANOVA results of testing treatment and Tables 9-14 present Tukey LSD results of GY and GNC of all site years.

Following the documentation of significant response in N fertilizer application, zero N check plots were removed from further evaluation as the treatment confounded analysis. Utilizing the ANOVA procedure, the three-way interaction between the main effects of Method, Rate, and Time was found to be significant to GY once and GNC twice over the extent of the experiment. Three two-way interactions were tested of which two were significant to GY and all three were significant to GNC.

Hajeck Family Research Farm

The three growing seasons in which this experiment was implemented at the HFRF locations received a wide range in rainfall totals. In the first site year 2019-2020 the site received total rainfall for the growing season of 483 mm of rainfall, this is 119 mm less rainfall than the 30-year average for the area. Yet while the total was well below the 30 year average the distribution of the rainfall events were well spaced over the growing season. The second cropping season experienced an increase in rainfall; a season total of 556 mm of rainfall, but this was still below the 30-year average rainfall by 45 mm. In this season 147 mm of the 556 mm of rainfall was accumulated in the month of March, which corresponds with the Feekes 5 and 6 growth stage. The final growing season at HFRF experienced the least amount of rainfall over projects time frame with a total of 405mm of rainfall over the growing season. The 2022HFRF site year saw a total of 196 mm less rainfall than the 30-year average for the area. In this season 171 mm of the total 405 mm of rainfall accumulated in the site year occurred in the month of May, which corresponds with the growth stages 8-9.

2019-2020 HFRF

In the 2020 HFRF site year GY was significantly influenced by a three-way interaction between Method, Rate and Time (Table 7) with a p-value 0.0204. Table 8 shows that GYs in this site year ranged from 2.6 Mg ha^{-1} to 5.0 Mg ha^{-1} with a location average GY for this location was 4.1 Mg ha-1. The Bed0-112 yielded the greatest GY at

5.0Mg ha^{-1} but was not statistically different from five other treatments (Bed112-0, Bed112-56, Bed56-56, Flat112-56, Flat0-112). The lowest yield was a results of Flat0-0 at a GY of 2.6 Mg Ha-1, which was statistically equivalent to Flat56-0 and Flat112-0.

At the 2020 HFRF site year, GNC ranged from 1.78% to 2.51% with a location average of 2.03% (Table 8). The Bed0-112 treatment which had the greatest numeric yield, had the greatest GNC (2.51%) but statistically similar to Bed112-56, Bed56-56, and Flat0-112. The lowest numeric GNC resulted from the Flat0-0 treatment, however it was not statistically significant from eight other treatments, see Table 8. There was a significant main effect two way interaction of Rate and Time for this location ($p<0.0001$), and Method was significant at $p<0.0055$.

2020-2021 HFRF

At the 2021HFRF GY of the treatments ranged from 0.8 Mg ha^{-1} to 3.3 Mg ha^{-1}, with an average location GY of 2.3 Mg ha^{-1} see Table 9. For GY there was multiple significant two-way main effect interactions, Rate and Method at p=<.0001, Method and Time at p=0.0408, and while not significant at ($\alpha=0.05$) it should be noted the p value of the interaction of Method and Rate was p=.0769 (Table 7). At 2021HFRH the treatment Flat0-112 resulted in the highest GY but was not statistically different from the treatments Bed56-56, Bed0-112, Flat112-56 or Flat56-56. Both of the zero N treatments, Bed0-0 and Flat0-0 resulted in statistically lowest GY of 0.8 and 1.0 Mg ha^{-1} respectively.

Much like GY, the GNC at 2021HFRF showed multiple two-interactions of main effects, Rate and Method at p=<.0001, Method and Time at p=0.01053. The average

GNC across all treatments for this location was 1.82% with a range 1.70% to 2.04%. The treatment of Bed0-112 produced the statistically greatest GNC while the lowest GNC resulted from the Flat112-0. It should be noted that the treatments receiving the highest rate of N, Bed112-56 and Flat112-56 both had significantly lower GNC than the treatments receiving all 112 kg N ha^{-1} in-season (Table 9). Also, the Bed0-0 had statistically higher GNC than the treatments Bed56-0 and Bed112-0. Similar treatments sown on flats followed the same numeric trend but were not statistically different.

2021-2022 HFRF

The 2021-2022 cropping season resulted in the lowest yielding environment for the Hennessey location. Grain yields of 2022HFRF averaged1.7 Mg ha^{-1} with a range of 1.1 to 2.1 Mg ha^{-1} (Table 10) yield of this location were below average due to adverse weather conditions, as mentioned above. A dry fall followed by a very dry spring (Figure 2) impacted nearly the entire state. ANOVA analysis showed no significant main effect or interaction of main effects.

While the GY for cropping season was below average, the GNC was well above, which corresponds with stressed growing conditions. The GNC ranged from 2.01% to 3.01% with an average of 2.56%. The treatment yielding the greatest GNC was Bed112-56 followed by Bed0-112 at 3.01% and 2.93% respectively. These two treatments were statistically greater than all others. As expected, the Bed0-0 and Flat0-0 resulted in the lowest GNC of 2.01% and 2.06%.

Cimarron Valley Research Station

The CVRS experimental location saw a similar variety in range of rainfall to HFRF. In the 2019-2020 season location accumulated a total of 624 mm of rainfall over the growing season, this is only 4 mm of rainfall less than the 30-year average. The next growing season accumulated more rainfall than the first; this year accumulated a total of 677 mm of rainfall, this is 53 mm more rainfall than the 30-year average. During 2020-21 241 mm of the 677mm accumulation occurred in the months of April and May. It should be noted that in the location experienced a period of freeze on February 9th through the 18th where temperatures dropped down to a low of -25.6°C. These freeze events were also accompanied by a heavy freezing rain with an accumulation of 0.6 to 0.75 cm of ice. The final growing season at the CVRS experimental location accumulated a total rainfall for the growing season of 608 mm, this was 20 mm less rainfall than the 30-year average for the area. The 2022CVRS site year accumulated 320 mm of the 608 in the month of May.

2019-2020 CVRS

The 2019-2020 resulted in the highest yielding season at the CVRS locations with yields reaching a high of 3.3 Mg ha^{-1}, in fact the lowest yielding treatment harvested 2.1 Mg ha^{-1} (Table 11) which was equal to or greater than any other treatment in the following two cropping season (Tables 11 and 12). ANOVA analysis of main effects and interactions reveled a two-way interaction with Rate and Time ($p=0.0175$) on GY, see Table 7. In this site year three treatments produced the same average GY of 3.3 Mg Ha^{-1} (Flat112-56, Flat56-56 and Bed56-56). These treatments were significantly greater than both 0-0 plantings and the Flat56-0 treatment.

Interestingly, a three-way interaction of the main effects was found at 2020HFRF with the GNC demonstrating the same three-way interaction with a p-value of p=0.0025 (Table 7). The 2020HFRF GY and the 2020CVRS GNC results are the only incidences of a significant Method by Rate by Time interaction was observed. Table 11 indicates GNC averages in the (2020 CVRS) site year ranged from 1.87% to 2.52%, where Bed0-112 treatment yielded the greatest GNC levels however was not different from Bed112-56 Kg nor Bed112-56. As seen in the GNC of 2021HFRF the trend of the flat sown treatments was for the 0-0 to have higher GNC than the 56-0 and 112-0 treatments. This trend however was not seen on the permanent beds where there was a positive linear trend from 0-0 to 112-0 with increasing N application.

2020-2021 CVRS

The GY for the 2021CVRS was the lowest of all six site years of this study with an average of 1.0 Mg ha^{-1} with a range of 0.3 Mg ha^{-1} to a high of 1.2 Mg ha^{-1} (Table 12). As stated above this site year experienced a series of freeze events after the stage of booting, this likely led to the reduction in GY. The ANOVA for 2021CVRS showed significant main effects of Rate and Time, p=0.0346 and 0.0463 accordingly. While the two-way interaction of Rate and Time was not significant at α=0.05 it did result in a p value of 0.0791. Three treatments recorded the same yield at 1.2 Mg ha^{-1}(Bed56-56, Flat112-56, and Flat56-56) while the two 0-0 treatments were statistically below all other treatments at 0.4 Mg ha^{-1}for the bedded wheat and 0.3 Mg ha^{-1} for the flat sown. All treatments that received 112 or 168 Kg N ha^{-1} produced statistically similar GY; with the exception of Flat112-0, as observed in table 12. In the evaluation of the main effect of Rate the 168 and 112 Kg N ha^{-1} were both statistically greater than the 56 Kg N ha^{-1} rate but not different from each other. The data also indicated significant effect of Time with the split applications and all in-season treatments yielding similar while the split applications was statistically better than all pre-plant.

The GNC from this site year ranged from 1.69% to 2.26% with a location average of 2.19% (Table 12). A Rate and Time interaction ($p<0.0001$) was also documented in the ANOVA analysis (Table 7). In general, a positive trend to GNC was found with both increasing N rate and delaying of N application timing. The highest GNC values came from treatments Flat0-112, Flat112-56, Bed112-56, and Bed0-112, as all four of these treatments resulted in GNC greater than 2.20% Table 12.

2021-2022 CVRS

As mentioned previously the 2021-2022 was characterized by a statewide drought, which likely led to a lack of response by GY to nitrogen fertilizer. The GY and GNC of 2022CVRS documents this with below average GY of 1.8Mg ha^{-1} and above average GNC of 2.96%. The GY ranged from 1.3 Mg ha^{-1} to 2.2 Mg ha^{-1}, see Table 13.

The three-way main interaction of Method, Rate, and Time on GNC had a p-value of $p=0.0573$ (Table 7), while the two-way interactions of Method and Rate along with Rate and Time had p values of 0.0483 and <.0001 respectively. As mentioned, the GNC was above average with a range of 2.26% to 3.36% (Table 13). The highest GNC was recorded in the 112-56 Bed and Flat treatments with values of 3.36% and 3.32% accordingly. While not statistically significant treatments, receiving all in-season N resulted in numerically lower GNC than those receiving all or a portion pre-plant.

CHAPTER V

DISCUSSION AND CONCLUSION

This study was designed to observe the effect of planting method, N rate, and application timing of N fertilizer. It was hypothesized that the permanent bedded planting method would produce more GY and a higher GNC than a conventional flat system due to an increase in efficiency of water and N use. While testing this hypothesis it was revealed that two locations presented a three-way interaction between the main effects of Method, Rate, and Time. The first site year to discuss this three-way interaction is the GY of 2020HFRF which can be seen in Table 8. When examining the data it can be observed that the bedded planting method out produced the flat treatments in the 2020HFRF site year, digging in further it can be seen that the timing of application had a significant effect on the amount of N fertilizer that was needed to obtain optimal GY. It can be inferred from these observations that when rates stay the same timing becomes critical to GY, it can also be inferred that at different rates of applications, timing of application either becomes more or less critical to GY. The 2020HFRF site year is the only site year in which the permanent bed planting method produced a higher average than the flat treatment. It was is hypothesized that the reasoning for this response is related to the treatments that were planted on beds producing more GY than flat treatments can tied to the Ortega and Sayre (2012) paper where it was concluded that GY in a permanent bedded system was determined by both rainfall and the distribution of the growing season’s rainfall. In the 2020HFRF site the rain accumulated during the growing season was characterized by rainfall that was distributed fairly throughout the year. Whereas in the following growing seasons rainfall through the growing season was characterized by heavy rainfall in both the beginning of the growing season and at the end of the growing season with relatively little rainfall in between (Figures2-3). Thus we can infer that when rainfall patterns are favorable and permanent beds are in place, rate and timing become less important.

As this study consisted of three main effects, three two-way interactions were tested, two of which had an impact on GY. The Method and Rate interaction was not significant at an $\alpha = 0.05$ for any of the six site years of this project.

The interaction of Method and Time on GY was significant at 2021HFRF. When evaluating this interaction, it was observed that the yields of treatments not receiving in-season N fertilizer applications were higher in the permanent bedded treatments as compared to those of the equivalent rates in the flat sown treatments. However, for all those treatments receiving any amount of N in-season the treatments in the flat-planted methods produced higher yields than the equivalent N rates in the bedded planting methods. The Flat0-112 treatment resulted in the highest yield of 2021HFRF, interestingly the treatments of 0-112 and 56-56 was statistically higher than the 112-0 treatment in the flat planted method. Within the bedded method, 56-56 was the highest yielding treatment, which was statistically greater than 112-0 in the bedded method with the 56-56 and 0-112 being statistically similar.

The two-way interaction between Rate and Time was shown to be significant in two of the six site years, 2021HFRF and 2020CVRS. This is even more significant when considering the 2021CVRS had a Rate and Time interaction p value of 0.0791, two of the six site years, 2022 HFRF and 2022CVRS, had no significant main effects or interactions with GY, and the sixth site year had a three-way interaction at a p-value of 0.0573 which was previously discussed. The interaction between rate and time can be examined in the differences in GY between treatments with applications of 112 Kg N ha^{-1} for both site years. At 2021HFRF the 112-0 was lowest of the 112 Kg N ha^{-1} treatments at 2.2 Mg ha-1 while 56-56 and 0-112 yielded 2.95 and 3.05 Mg ha^{-1} GY respectively. For 2020CVRS the lowest of the 112 Kg N ha^{-1} treatments was also 112-0 at 2.75 Kg N ha^{-1} as the 56-56 had a GY of 3.3 Mg ha^{-1} and 0-112 yielded 3.1 Mg ha^{-1}. And while the two-way interaction of 2021CVRS had p value of =0.0791 the same trend of 112-0 having the lowest GY was present. The treatments of 56-56 and 0-112 kg N ha^{-1} consistently outperformed the 112-0 treatments which supports the concept of when applying N at rates near optimal for maximum GY, the timing of applications becomes exceedingly more important. This observation is similar to the findings made in Cui et al. (2010) where it was found that when optimal N rate is applied as an in-season application GY can reach maximum.

While 2021CVRS was discussed prior above due to the Rate and Time interaction at a p-value of 0.0791, the effect of both Rate and Time were significant at p values of 0.0346 and 0.0463 respectively. Analysis of Rate showed increasing yield with increasing N rates of 56, 112, and 168 Kg N ha-1, yielded 0.85, 1.08, and 1.15 Mg ha-1. Both 112 and 168 where statistically greater than 56, however not statistically different from each other. The timing of applications resulted in statistically different yields, pre-plant treatments showed lower response in yields as compared to the split and in-season treatments.

Recent work with winter wheat has shown that the crop will have accumulated 50% of the total N content at flag leaf, and 70% at heading (De Oliveira Silva, 2021). Which indicates that nitrogen rates in excess of crop demand will mask the efficiency differences that can be seen in timing on grain however, as GNC is correlated with soil N at grain fill there is an opportunity to see differences in GNC when GY was unaffected. As was mentioned above, the three-way interaction between the main effects of Method, Rate, and Time was observed once at both research locations. In the case of CVRS, the three-way interaction had impact on the GNC in the 2020CVRS site year (Table 11). At this location it can be observed that overall, the permanent beds produced greater GNC values in the fertilized treatments at 2.31% opposed the 2.08% average seen in the flat sown treatments. It is interesting to note that for both Methods the 0-112 treatment resulted in greater GNC than the 112-56 application pointing towards the residual availability of N that is applied later in the growing season. These findings are similar to those of Lollato et al. (2021) where it was found that greater N rates and Anthesis or Spring N timings increased GNC. It is hypothesized that the differences in GNC between the two planting methods may be a result of the fertilizer methods. The flat sown plots had urea evenly distributed across the entire plot area of 13.5 m^2, while the fertilizer was only applied to the tops of the bedded plots, a surface area of 10.26 m^2 resulting in a greater concentration of urea applied per harvested area.

The interaction of Method and Rate on GNC values was significant in the 2022CVRS site year. As seen in the 2020CVRS GNC results the bedded treatments averaged higher GNC than the flat treatments 3.76 and 3.32% respectively. Also in this site year, the bed treatments were shown to have greater average GNC than flat treatments regardless of the timing. It is hypothesized that these trends were observed due to the lower water holding capacity of this locations sandy loam soil, and the lack of rainfall during most of the growing season, and the bedded treatments having a higher concentration of N fertilizer per unit area.

The next interaction between main effects explored is that of Method and Time, which was significant once, 2021HFRF (Table 9.). The interaction between Method and Time is interesting as the data shows that within bedded treatments there is significant increase in GNC of the 112-56 over the 56-56 while that difference is not present in the flat sown treatments. In addition, the bedded treatments 112-56, 56-56, and 0-112 resulted in higher GNC than the corresponding flat sown treatments.

The interaction of Rate and Time on GNC was recorded in five of the six site years observed in this experiment, with the six year (2022 HFRF) not being significant due to an uncorrectable error in statistical analysis. However, based upon the data within Table 10., it is expected the interaction between Rate and Time would be significant. Considering that for each time a site years GY and or GNC responded to the application of N fertilizer the interaction of Rate and Time was significant (Table 7), this work documents the importance of timing of N application regardless planting method. Except for the 2021-22 season, which was characterized by drought during the timing of top-dress applications, for both locations in 2019-20 and 2020-21 the 0-112 out yielded 56-56 and 112-0 in terms of GNC, with 56-56 have better GNC than 112-0 treatments. We also see the 112-56 performing equal to or often less than the 0-112 in terms of GNC. The way timing impacting GNC is again similar to the finding of Souza et al. (2022) where it was viewed that winter wheat produced no less GY or GNC ; if not greater amounts, when applications of nitrogen were applied as an in-season application as compared to pre-plant applications. It was also stated in Souza et al. (2022) that applications of N applied after winter wheat crop dormancy can still maximize both winter wheat GY and GNC.

In this experiment it was observed that the bedded treatments did not produce statistically more GY or GNC in five of the six site years. While this lack of GY improvement is not as the authors hypothesized, it is noteworthy that GY of the bedded treatments was not consistently lower as the project was harvesting a smaller area in those treatments. As mentioned above the area harvested of the flat sown treatments was 13.5 m^2, while the bedded plots had an effective harvest area of 10.26 m^2. This is a 24% reduction in planted and harvested areas. In Freeman et al. (2007a) it was found that in three of the four site years bedded wheat systems did not produce more GY than traditional flat systems, this led to another experiment where the differences in row configurations were observed, it was found that in comparison to flat treatments bedded treatments with two and three row configurations increased yields (Freeman at al., 2007b). This suggests that even with a smaller harvest area than the traditional flat-planted treatments, that the bedded treatments increased wheat yield enough to make up for the differences in row configurations. One hypothesis is that the skipped row configuration allowed for more light interception of the lower canopy on the furrow edges.

This study was established to observe the effect permanent beds have on winter wheat production, it was hypothesized that permanent beds would produce more GY and GNC than the conventionally planted treatments. This experiment produced evidence that did not supports the hypothesis that was purposed, similar to the results of (Freeman et al., 2007a) where it was found that the bedded treatments did not produce more than the conventional flat treatments in three of four site years. Due to the lack of flat treatments with the same row configuration it cannot be proven that there is a distinct difference between the bedded and flat treatments. While investigating the differences between permanent beds and conventional flat, the trend of application Rate and Timing became most apparent. This trend between Rate and Time shows the importance N application timing on both GY and GNC. The application on all N in-season resulted in equal to or greater GY and GNC of equivalent pre-plant applications. Results suggest that with the use of in season N applications the rate of N fertilizer can be reduced while achieving optimal GY and GNC comparable to that of pre-plant applications. Taking this experiment forward, the permanent beds will be maintained however the N rate and timing treatments will be dropped so that row configurations can be evaluated on both a flat and bedded scenario. It is also planned to begin implementing a suitable crop rotation.

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APPENDICES

TABLES

Table 1. Soil series classifications of the two experimental locations the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF) utilized in the study evaluating the impact of planting method, nitrogen rate, and nitrogen timing on wheat grain yield and grain protein in Oklahoma over the 2019-2020, 2020-2021, and 2021-2022 growing seasons. Soil series and descriptions were gathered through web soil survey.

Location	Soil series	Description	Crop Residue
CVRS	Teller/ Konawa	(sandy loam)/ (fine sandy loam)	Wheat
HFRF	Bethany	(silty clay loam)	Wheat

Table 2. Planting date, seeding rate, cultivar, and harvest date for each of the experimental sites the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF) utilized in the study evaluating the impact of planting method, nitrogen rate, and nitrogen timing on wheat grain yield and grain protein in Oklahoma over the 2019-2020, 2020-2021, and 2021-2022 growing seasons.

Location	Year	Planting date	Seeding rate (Kg ha^{-1})	Cultivar	Harvest dates
CVRS	2019	10/12/2019	84.1	Double Stop	6/8/2020
HFRF	2019	10/16/2019	84.1	Double Stop	6/12/2020
CVRS	2020	10/6/2020	89.7	Smith's Gold	6/19/2021
HFRF	2020	10/7/2020	89.7	Smith's Gold	6/19/2021
CVRS	2021	10/20/2021	78.5	Green Hammer	6/15/2022
HFRF	2021	10/25/2021	78.5	Green Hammer	6/14/2022

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Table 3. Treatment structure implemented at the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF) locations for the 2019-2020, 2020-2021, and 2021-2022 growing seasons in the study evaluating the impact of planting method, nitrogen rate, and nitrogen timing on wheat grain yield and grain protein in Oklahoma

Trt	Trt ID	Method	Preplant N (kg ha-1)	Topdress N (kg ha-1)	Total N (kg ha-1)
1	Bed0/0	bed	0	0	0
2	Bed56/0	bed	56	0	56
3	Bed112/0	bed	112	0	112
4	Bed112/56	bed	112	56	168
5	Bed56/56	bed	56	56	112
6	Bed0/112	bed	0	112	112
8	Flat0/0	flat	0	0	0
9	Flat56/0	flat	56	0	56
10	Flat 112/0	flat	112	0	112
11	Flat112/56	flat	112	56	168
12	Flat56/56	flat	56	56	112
13	Flat112/0	flat	0	112	112

Table 4. ANOVA produced by SAS 9.4 testing the effect of the two experimental locations the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF), the three experimental years (2020, 2021, and 2022), and the combination of the two on grain yield utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting system

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
location	1	15113.675	15113.67504	148.26	<.0001
year	2	62504.7545	31252.37726	306.57	<.0001
loc*yr	2	10145.4035	5072.70175	49.76	<.0001

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Table 5. ANOVA produced by SAS 9.4 testing the effect of the two experimental locations, the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF), the three experimental years (2020, 2021, and 2022), and the combination of the two on grain nitrogen concentration utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
location	1	216.81	216.81	72.53	<.0001
year	2	1806.97	903.49	302.25	<.0001
loc*yr	2	40.99	20.50	6.86	0.0012

Table 6. ANOVA produced by SAS 9.4 testing the effect of the two experimental locations, the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF),the three experimental years (2020, 2021, and 2022), and the combination of the two testing the main effect of treatment on both grain yield and grain nitrogen concentration utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems

Site-Year	**Pr > F Yield**	**Pr > F Grain Nitrogen Concentration**
2020 HFRF	<.0001	<.0001
20221 HFRF	<.0001	<.0001
2022 HFRF	0.0029	<.0001
2020 CVRS	0.0081	0.0002
2021 CVRS	<.0001	<.0001
2022 CVRS	0.3594	<.0001

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Table 7. ANOVA produced by SAS 9.4 testing the effects of planting method, nitrogen application rate, timing of application and combination of the three main effects without zero nitrogen treatments over the six site years of this experiment utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems the Cimarron Valley Research Station (CVRS) and Hajek Farm Research Farm (HFRF).

	2020HFRF		**2021HFRF**		**2022HFRF**		**2020CVRS**		**2021CVRS**		**2022CVRS**	
Model	**GY**	**GN**	**GY**	**GN**	**GY**	**GN**	**GY**	**GN**	**GY**	**GN**	**GY**	**GN**
Method	0.0002	0.0055	0.0656	<.0001	0.4527	-	0.9063	<.0001	0.5921	0.9324	0.5823	<.0001
Rate	0.0014	0.0028	<.0001	<.0001	0.5247	-	0.0045	0.0242	0.0346	<.0001	0.6393	<.0001
Time	0.0004	<.0001	<.0001	<.0001	0.3485	-	0.013	0.0008	0.0463	<.0001	0.8693	<.0001
*Method*Rate*	0.4636	0.4553	0.0769	0.1372	0.2979	-	0.104	0.5467	0.9559	0.7496	0.8162	0.0483
*Method*Time*	0.6479	0.9496	0.0408	0.0153	0.3585	-	0.7118	0.6853	0.8605	0.7756	0.4386	0.1121
*Rate*Time*	0.0026	<.0001	<.0001	<.0001	0.5803	-	0.0175	0.0081	0.0791	<.0001	0.8393	<.0001
*Method*Time*Rate*	0.0204	0.1503	0.408	0.408	0.611	-	0.5155	0.0025	0.9922	0.997	0.8399	0.0573

Table 8. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	**Yield Means (Mg ha^{-1})**	**Grain Nitrogen Concentration (%)**
Bed0-0	3.6 DEF	1.80 CDE
Bed56-0	3.9 CDE	1.81 CDE
Bed112-0	4.8 AB	1.92 CDE
Bed112-56	4.6 ABC	2.34 AB
Bed56-56	4.6 ABC	2.26 A
Bed0-112	5.0 A	2.51 A
Flat0-0	2.6 G	1.78 DE
Flat56-0	3.4 EFG	1.80 CDE
Flat112-0	2.8 G	1.84 CDE
Flat112-56	4.4 ABC	2.09 BCD
Flat56-56	4.1 BCDE	2.07 BCD
Flat0-112	4.3 ABCD	2.35 AB

Table 9. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	**Yield Means (Mg ha^{-1})**	**Grain Nitrogen Concentration (%)**
Bed0-0	0.8 G	1.76 EF
Bed56-0	1.7 F	1.73 F
Bed112-0	2.3 DE	1.72 F
Bed112-56	2.7 BCD	1.93 BC
Bed56-56	2.9 ABC	1.85 D
Bed0-112	2.8 ABCD	2.04 A
Flat0-0	1.0 G	1.82 DE
Flat56-0	1.5 F	1.71 F
Flat112-0	2.1 EF	1.70 F
Flat112-56	3.2 AB	1.83 DE
Flat56-56	3.0 ABC	1.77 DE
Flat0-112	3.3 A	1.93 B

Table 10. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	Yield Means (Mg ha^{-1})	Grain Nitrogen Concentration (%)
Bed0-0	1.2 CD	2.01 G
Bed56-0	2.0 AB	2.26 F
Bed112-0	1.9 AB	2.62 D
Bed112-56	1.5B CD	3.01 A
Bed56-56	1.8 AB	2.74B C
Bed0-112	1.8 AB	2.93 A
Flat0-0	1.1 D	2.06 G
Flat56-0	1.8 AB	2.22 F
Flat112-0	2.1 A	2.42 E
Flat112-56	1.9 AB	2.79 B
Flat56-56	1.9 AB	2.59 D
Flat0-112	1.7 ABC	2.82 B

Table 11**.** Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	Yield Means (Mg ha^{-1})	Grain Nitrogen Concentration (%)
Bed0-0	2.3 B	1.98 DEFG
Bed56-0	2.8 AB	2.05 DEFG
Bed112-0	2.7 AB	2.13 CDE
Bed112-56	3.1 A	2.46 AB
Bed56-56	3.3 A	2.40 ABC
Bed0-112	3.0 A	2.52 A
Flat0-0	2.2 B	2.05 DEFG
Flat56-0	2.1 B	1.87 EFG
Flat112-0	2.8 AB	1.99 G
Flat112-56	3.3 A	2.17 BCDE
Flat56-56	3.3 A	2.13 CDEF
Flat0-112	3.2 A	2.24 ABCD

Table 12. Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	Yield Means (Mg ha^{-1})	Grain Nitrogen Concentration (%)
Bed0-0	0.4 E	1.69 D
Bed56-0	0.9 BCD	1.80 CD
Bed112-0	1.0 ABCD	1.86 C
Bed112-56	1.1 ABCD	2.24 AB
Bed56-56	1.2 A	2.10 B
Bed0-112	1.1 ABCD	2.22 AB
Flat0-0	0.3 E	1.84 C
Flat56-0	0.8 D	1.81 CD
Flat112-0	0.9 CD	1.85 C
Flat112-56	1.2 ABC	2.25 A
Flat56-56	1.2 AB	2.12 AB
Flat0-112	1.1 ABCD	2.26 A

Table 13. Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

TRT	Yield Means (kg ha^{-1})	Grain Nitrogen Concentration (%)
Bed0-0	1.3	2.34 G
Bed56-0	2.0	2.86 E
Bed112-0	1.9	3.19 ABCD
Bed112-56	1.6	3.36 A
Bed56-56	1.9	3.22 ABC
Bed0-112	1.9	3.05 CDE
Flat0-0	1.3	2.26 G
Flat56-0	2.0	2.59 F
Flat112-0	1.9	3.02 CDE
Flat112-56	1.9	3.32 AB
Flat56-56	2.2	3.09 CD
Flat0-112	1.8	3.00 DE

Table 14. Treatment contrasts for the Hennessy location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	**Description**	**P Value Yield (kg ha-1)**	**P Value Grain Nitrogen concentration (%)**
3 vs 5	Bed 100pre vs Bed 50split	0.7246	0.054*
3 vs 6	Bed 100pre vs Bed 100top	0.6745	0.0013*
3 vs 12	Bed 100pre vs Flat 50split	0.1506	0.3814
3 vs 13	Bed 100pre vs Flat 100top	0.3802	0.0162*
5 vs 6	Bed 50split vs Bed 100top	0.4408	0.1649
5 vs 10	Bed 50split vs Flat 100pre	0.0004*	0.019*
5 vs 13	Bed 50split vs Flat 100top	0.598	0.6112
6 vs 10	Bed 100top vs Flat 100pre	<.0001*	0.0003*
6 vs 12	Bed 100top vs Flat 50split	0.0654	0.0157*
10 vs 12	Flat 100pre vs Flat 50split	0.0107*	0.1892
10 vs 13	Flat 100pre vs Flat 100top	0.0022*	0.005*
12 vs 13	Flat 50split vs Flat 100top	0.5691	0.1159

Table 15. Treatment contrasts for the Hennessy location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	Description	P Value Yield (kg ha-1)	P Value Grain Nitrogen concentration (%)
3 vs 5	Bed 100pre vs Bed 50split	0.0317*	0.0015*
3 vs 6	Bed 100pre vs Bed 100top	0.0862	<.0001*
3 vs 12	Bed 100pre vs Flat 50split	0.0179*	0.2005
3 vs 13	Bed 100pre vs Flat 100top	0.0009*	<.0001*
5 vs 6	Bed 50split vs Bed 100top	0.65	<.0001*
5 vs 10	Bed 50split vs Flat 100pre	0.0026*	0.0005*
5 vs 13	Bed 50split vs Flat 100top	0.1972	0.0244*
6 vs 10	Bed 100top vs Flat 100pre	0.0091*	<.0001*
6 vs 12	Bed 100top vs Flat 50split	0.4919	<.0001*
10 vs 12	Flat 100pre vs Flat 50split	0.0013*	0.1014
10 vs 13	Flat 100pre vs Flat 100top	<.0001*	<.0001*
12 vs 13	Flat 50split vs Flat 100top	0.2894	<.0001*

Table 16. Treatment contrasts for the Hennessy location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	Description	P Value Yield (kg ha-1)	P Value Grain Nitrogen concentration (%)
3 vs 5	Bed 100pre vs Bed 50split	0.5254	0.0711*
3 vs 6	Bed 100pre vs Bed 100top	0.5756	<.0001*
3 vs 12	Bed 100pre vs Flat 50split	0.8885	0.5906
3 vs 13	Bed 100pre vs Flat 100top	0.3406	0.0043*
5 vs 6	Bed 50split vs Bed 100top	0.9398	0.0067*
5 vs 10	Bed 50split vs Flat 100pre	0.1264	<.0001*
5 vs 13	Bed 50split vs Flat 100top	0.7485	0.2607
6 vs 10	Bed 100top vs Flat 100pre	0.1456	<.0001*
6 vs 12	Bed 100top vs Flat 50split	0.4844	<.0001*
10 vs 12	Flat 100pre vs Flat 50split	0.4436	0.0104*
10 vs 13	Flat 100pre vs Flat 100top	0.0662	<.0001*
12 vs 13	Flat 50split vs Flat 100top	0.2752	0.0009*

Table 17. Treatment contrasts for the PERKINS location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	Description	P Value Yield (kg ha-1)	P Value Grain Nitrogen concentration (%)
3 vs 5	Bed 100pre vs Bed 50split	0.1087	0.1565
3 vs 6	Bed 100pre vs Bed 100top	0.3797	0.0355*
3 vs 12	Bed 100pre vs Flat 50split	0.1106	0.9692
3 vs 13	Bed 100pre vs Flat 100top	0.2222	0.5371
5 vs 6	Bed 50split vs Bed 100top	0.4596	0.4757
5 vs 10	Bed 50split vs Flat 100pre	0.2092	0.0008*
5 vs 13	Bed 50split vs Flat 100top	0.6938	0.4184
6 vs 10	Bed 100top vs Flat 100pre	0.601	<.0001*
6 vs 12	Bed 100top vs Flat 50split	0.4651	0.0325*
10 vs 12	Flat 100pre vs Flat 50split	0.2124	0.0437*
10 vs 13	Flat 100pre vs Flat 100top	0.3855	0.0086*
12 vs 13	Flat 50split vs Flat 100top	0.7004	0.512

Table 18. Treatment contrasts for the PERKINS location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	Description	P Value Yield (kg ha-1)	P Value Grain Nitrogen concentration (%)
3 vs 5	Bed 100pre vs Bed 50split	0.173	0.001*
3 vs 6	Bed 100pre vs Bed 100top	0.503	<.0001*
3 vs 12	Bed 100pre vs Flat 50split	0.2129	0.0005*
3 vs 13	Bed 100pre vs Flat 100top	0.5055	<.0001*
5 vs 6	Bed 50split vs Bed 100top	0.483	0.0992
5 vs 10	Bed 50split vs Flat 100pre	0.0355*	0.0006*
5 vs 13	Bed 50split vs Flat 100top	0.4805	0.0322
6 vs 10	Bed 100top vs Flat 100pre	0.1531	<.0001*
6 vs 12	Bed 100top vs Flat 50split	0.5603	0.1599
10 vs 12	Flat 100pre vs Flat 50split	0.0467*	0.0003*
10 vs 13	Flat 100pre vs Flat 100top	0.1542	<.0001*
12 vs 13	Flat 50split vs Flat 100top	0.5576	0.0568

Table 19. Treatment contrasts for the PERKINS location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems. Significance indicated by *.

TRT Contrast	Description	P Value Yield (kg ha-1)	P Value Grain Nitrogen concentration (%)
3 vs 5	Bed 100pre vs Bed 50split	0.9824	0.7543
3 vs 6	Bed 100pre vs Bed 100top	0.8297	0.2136
3 vs 12	Bed 100pre vs Flat 50split	0.287	0.3823
3 vs 13	Bed 100pre vs Flat 100top	0.8599	0.1011
5 vs 6	Bed 50split vs Bed 100top	0.8126	0.1214
5 vs 10	Bed 50split vs Flat 100pre	0.9487	0.0735
5 vs 13	Bed 50split vs Flat 100top	0.8773	0.0525
6 vs 10	Bed 100top vs Flat 100pre	0.8628	0.8023
6 vs 12	Bed 100top vs Flat 50split	0.3941	0.7073
10 vs 12	Flat 100pre vs Flat 50split	0.3063	0.5319
10 vs 13	Flat 100pre vs Flat 100top	0.8268	0.8756
12 vs 13	Flat 50split vs Flat 100top	0.2157	0.435

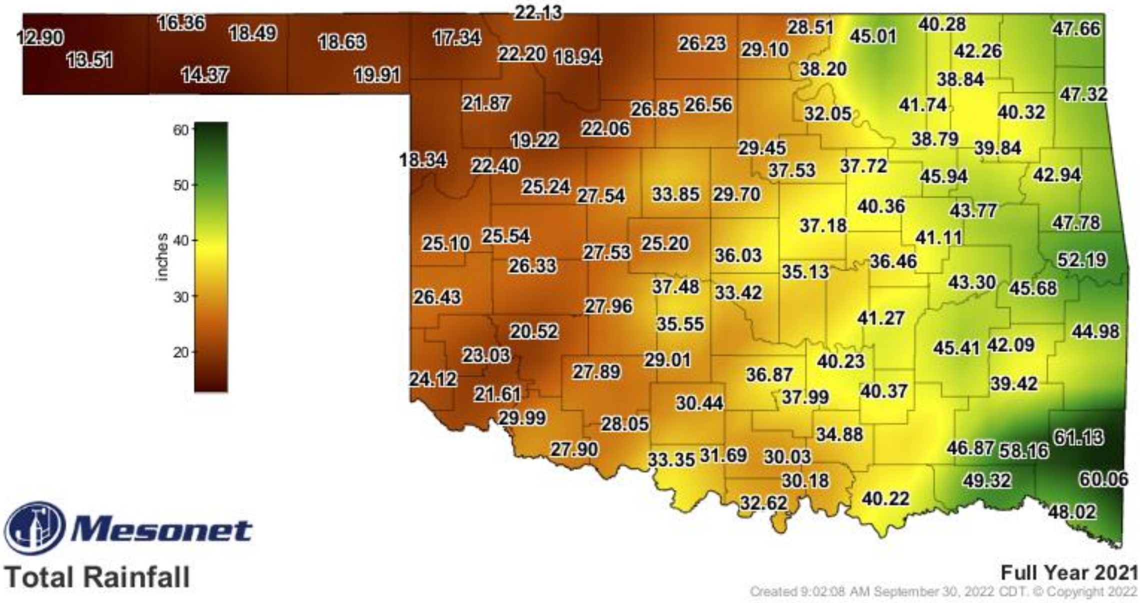


Figure 1. Total annual precipitation for Oklahoma in the year 2021 (Mesonet)

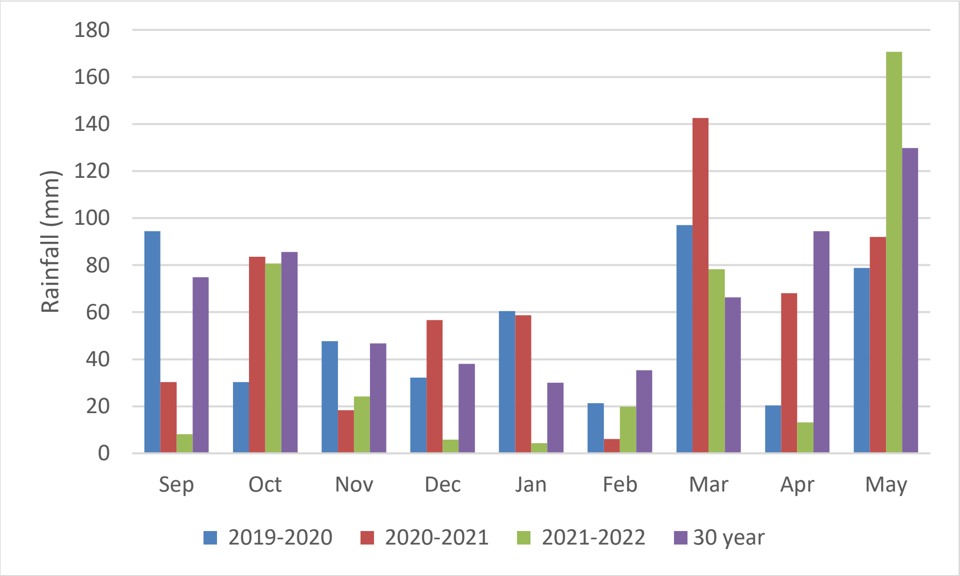


Figure 2. Total precipitation for the Hijack Family Research Farm over the growing seasons of 2019-2020, 2020-2021, 2021-2022, and the 30-year average of the area.

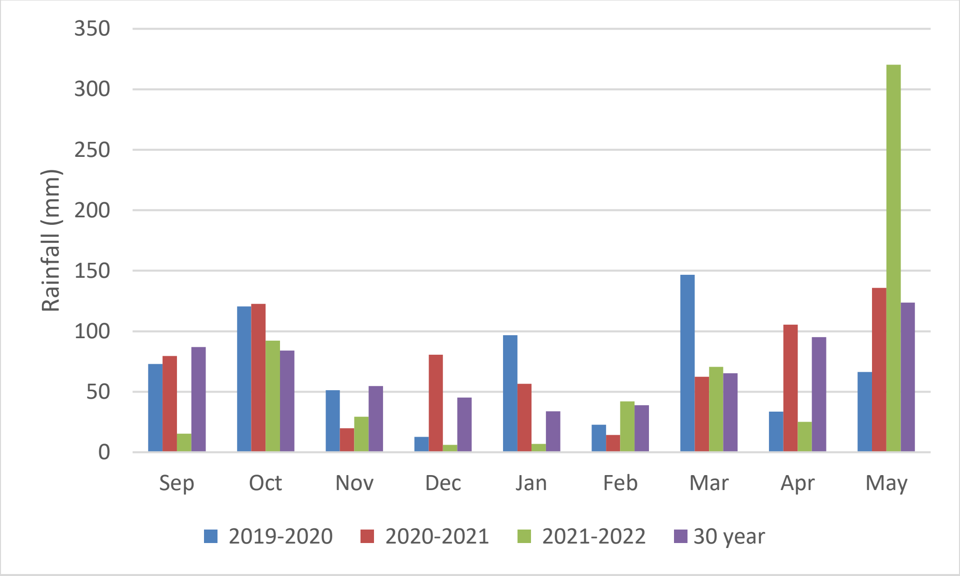


Figure 3. Total precipitation for the Cimarron Valley Research Station over the growing seasons of 2019-2020, 2020-2021, 2021-2022, and the 30 year average of the area.

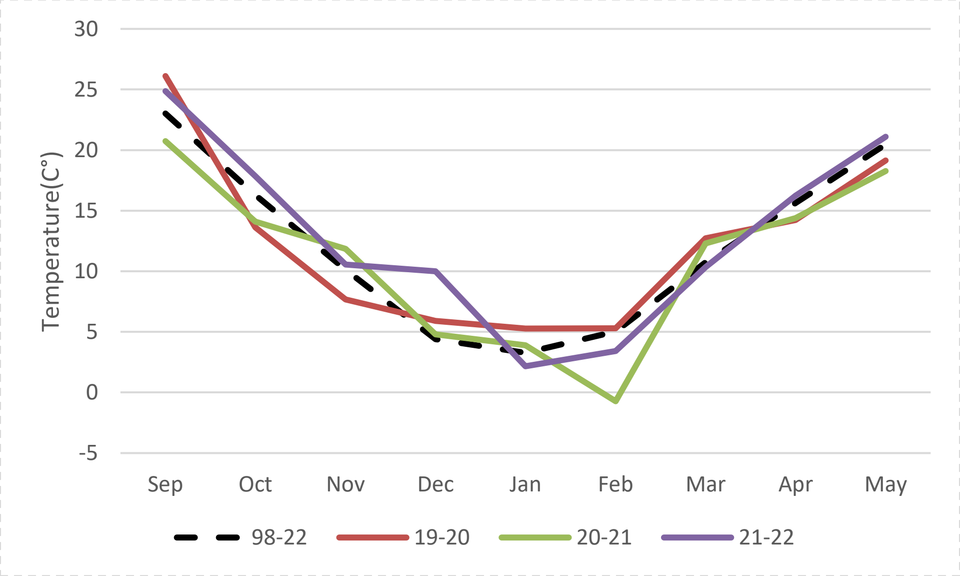


Figure 4. Monthly average temperatures for the Cimarron Valley Research Station during the 2019-2020, 2020-2021, 2021-2022, and the average from 1998-2022 growing seasons (1998-2022, MESONET).

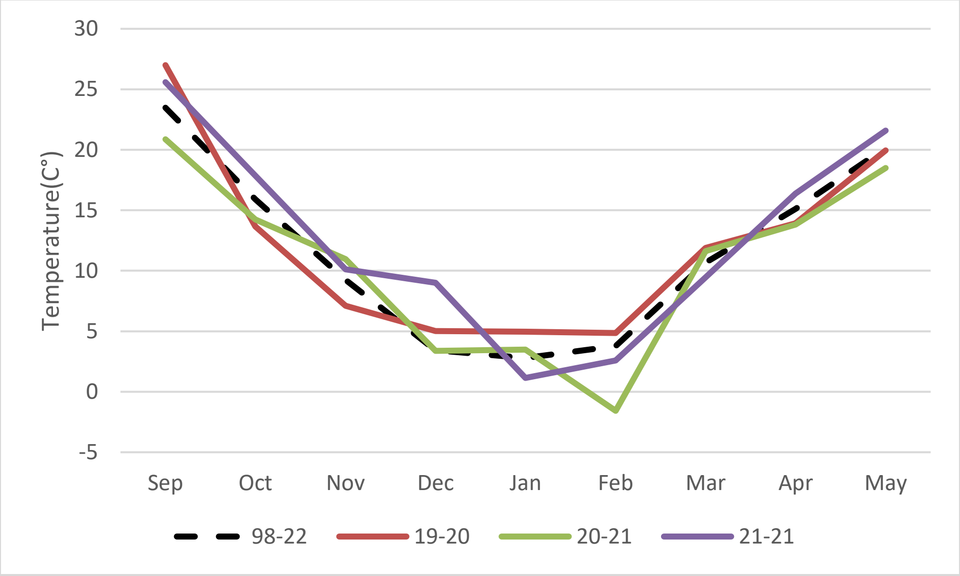


Figure 5. Monthly average temperatures for the Hajek Family Research Farm during the 2019-2020, 2020-2021, 2021-2022, and the average from 1998-2022 growing seasons (1998-2022, MESONET).

Figure 6. Treatment description and treatment averages for the Hajek Family Farm Research Farm location over all growing seasons utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final grain yield and grain nitrogen concentration when compared to traditional flat planting system.

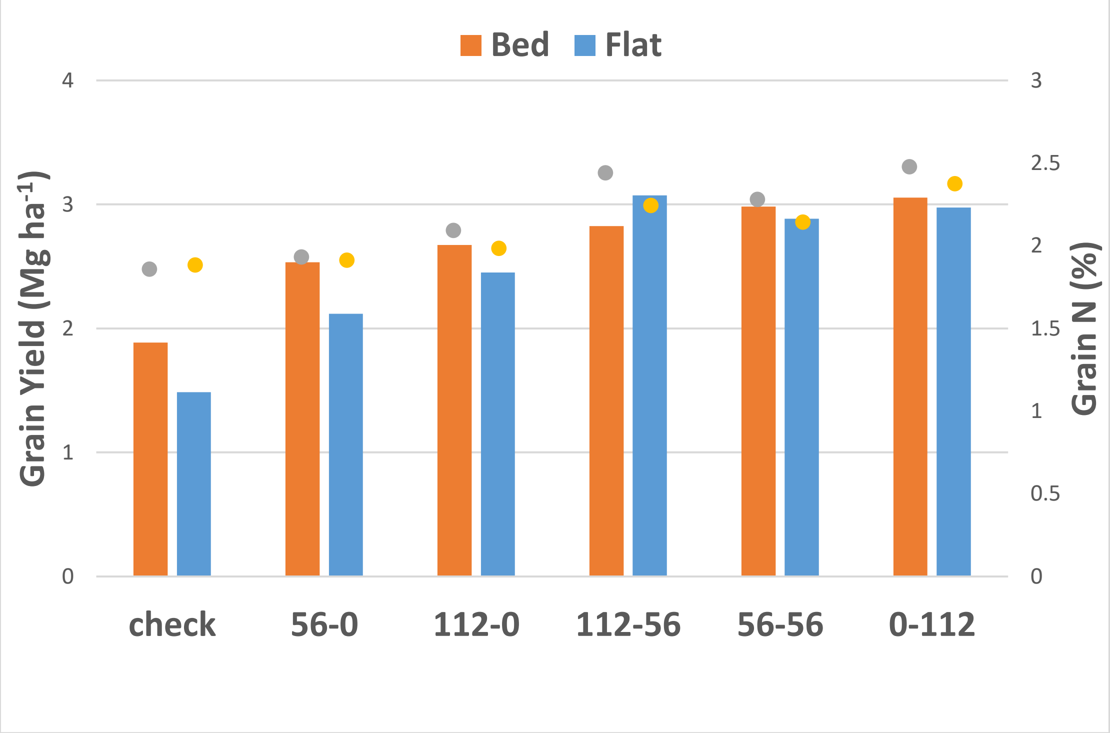


Figure 7. Treatment description and treatment averages for the Cimarron Valley Research Station location over all growing seasons utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final grain yield and grain nitrogen concentration when compared to traditional flat planting system.

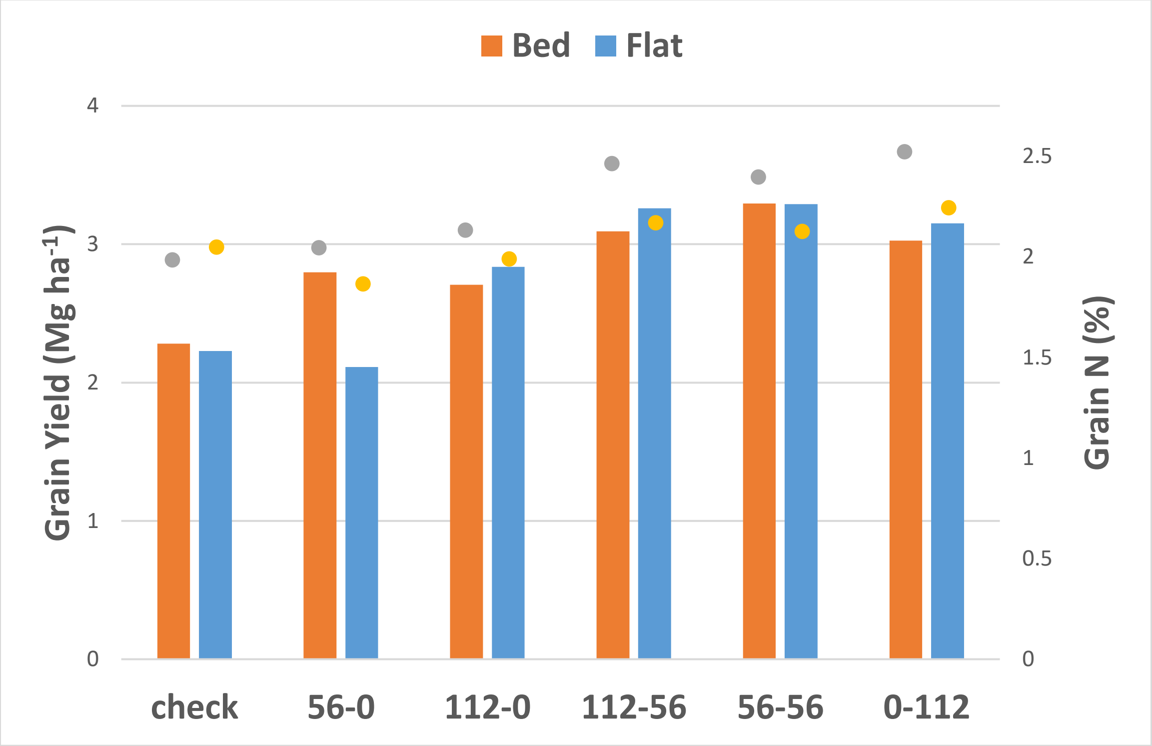


Figure 8. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

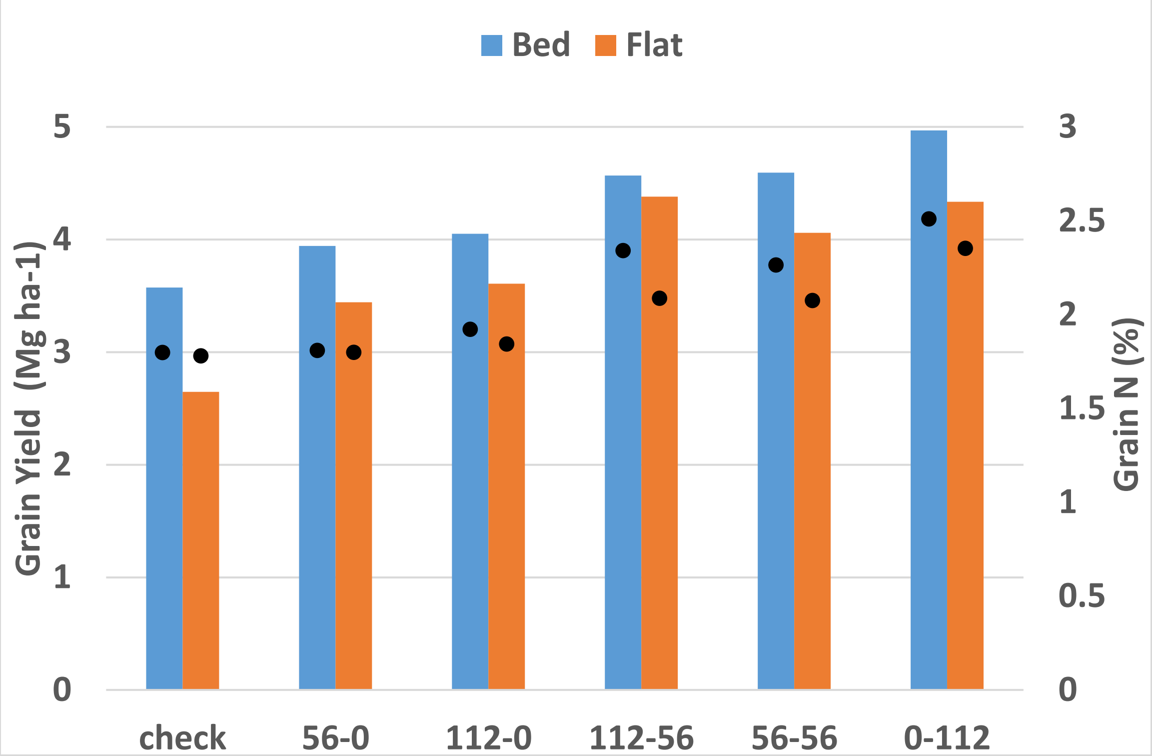


Figure 9. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

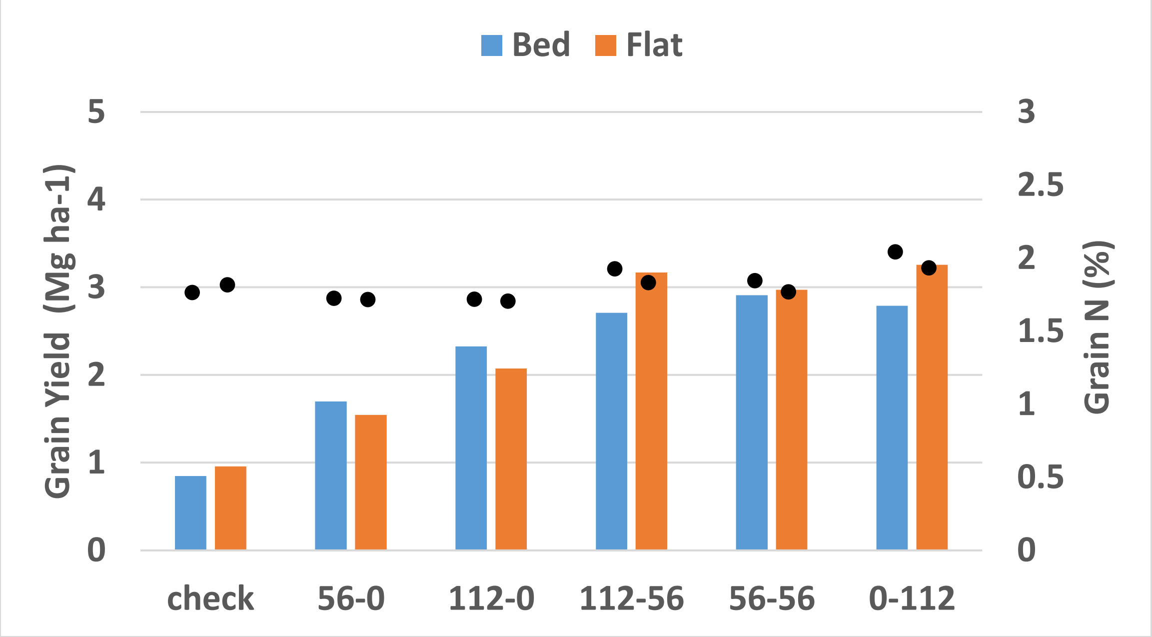


Figure 10. Treatment description and treatment averages for the Hajek Farm Research Farm location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

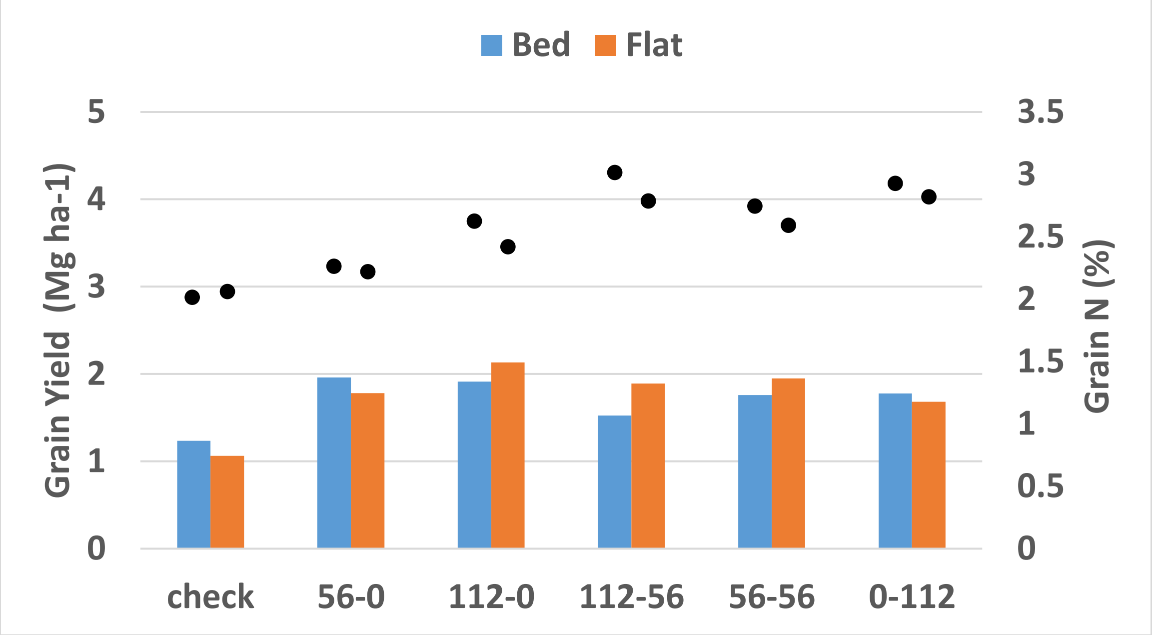


Figure 11. Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2019-2020 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

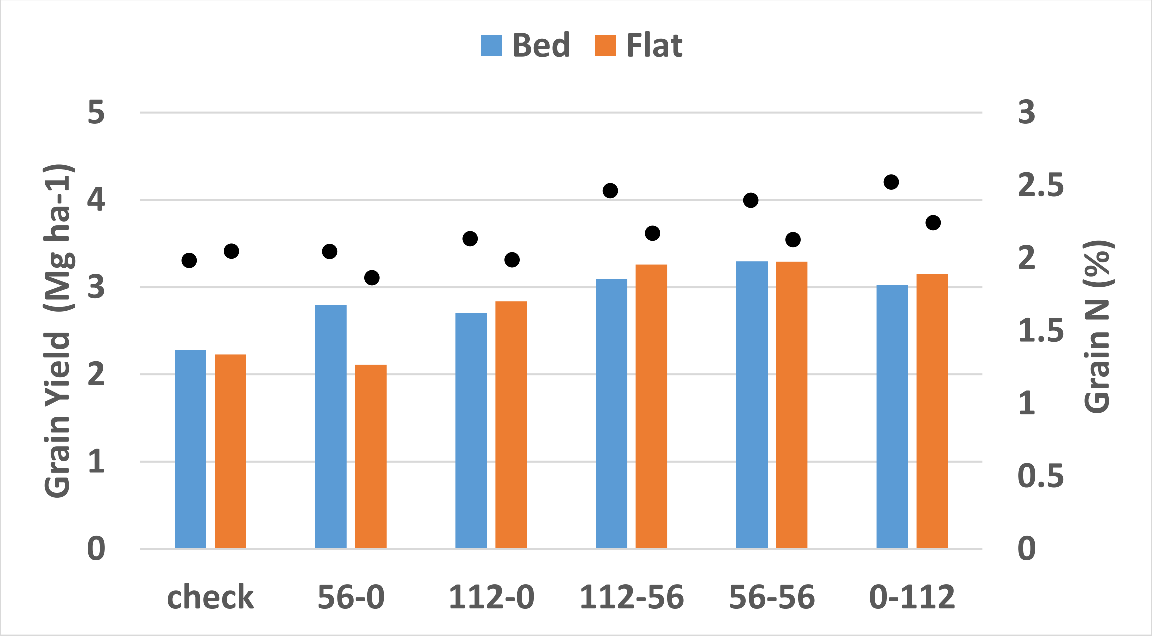


Figure 12. Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2020-2021 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.

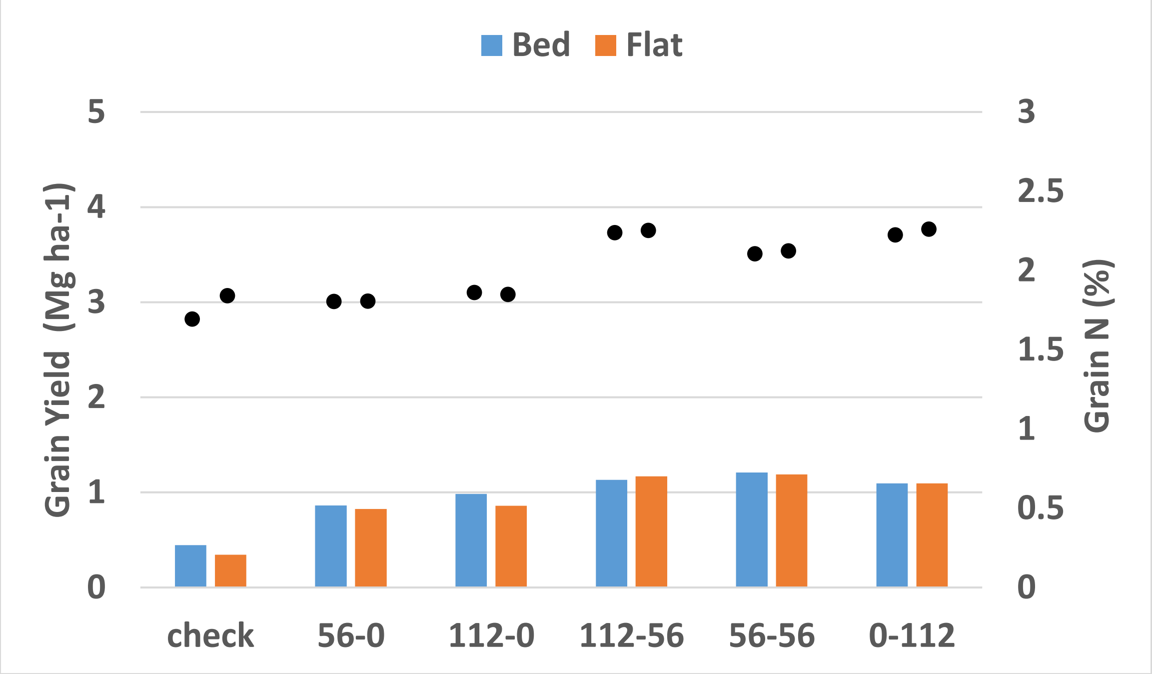
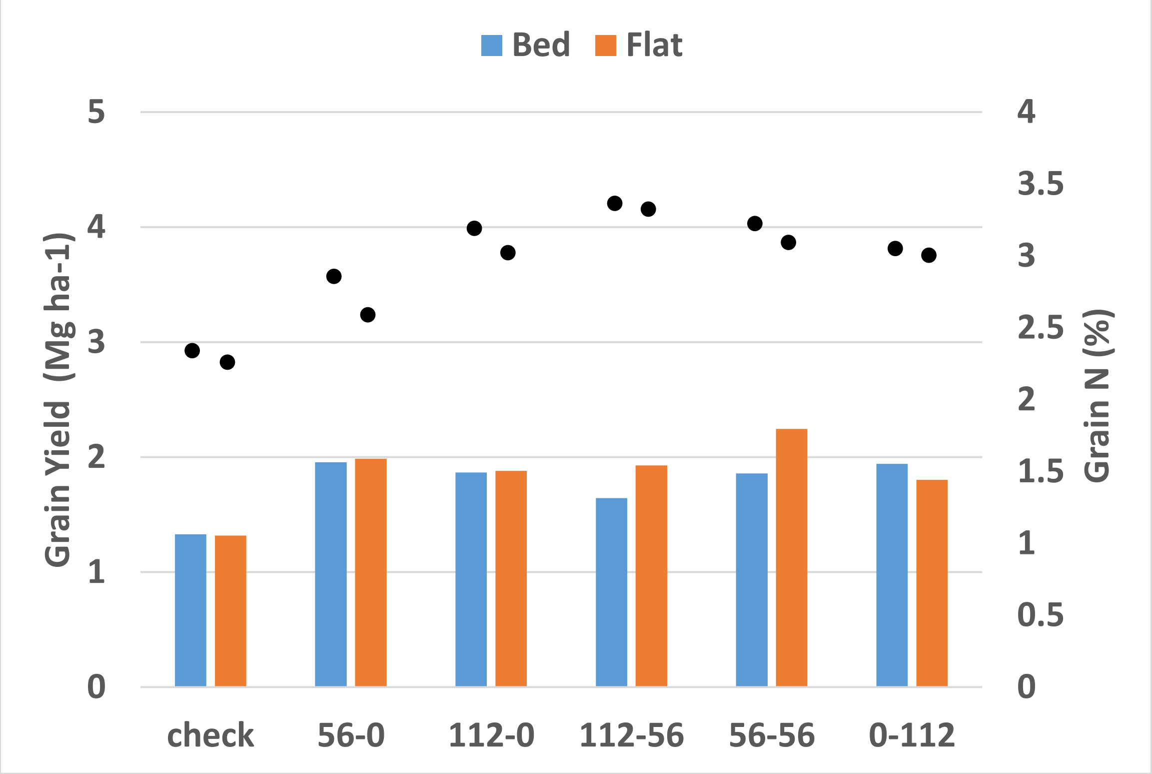


Figure 13. Treatment description and treatment averages for the Cimarron Valley Research Station location in the 2021-2022 growing season utilized in this study evaluating the impact of bedded planting methods, nitrogen rate, and timing of nitrogen had on final wheat grain yield and grain nitrogen concentration when compared to traditional flat planting systems.



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