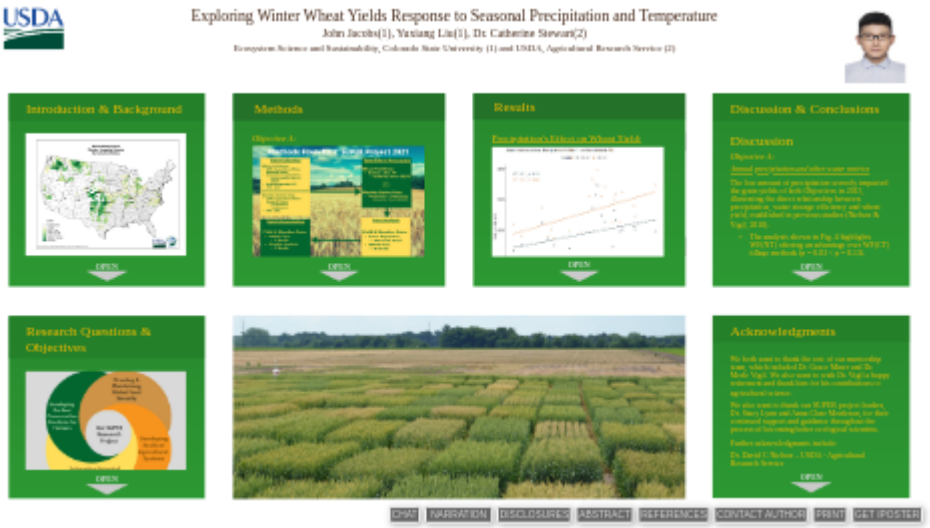
Exploring Winter Wheat Yields Response to Seasonal Precipitation and Temperature



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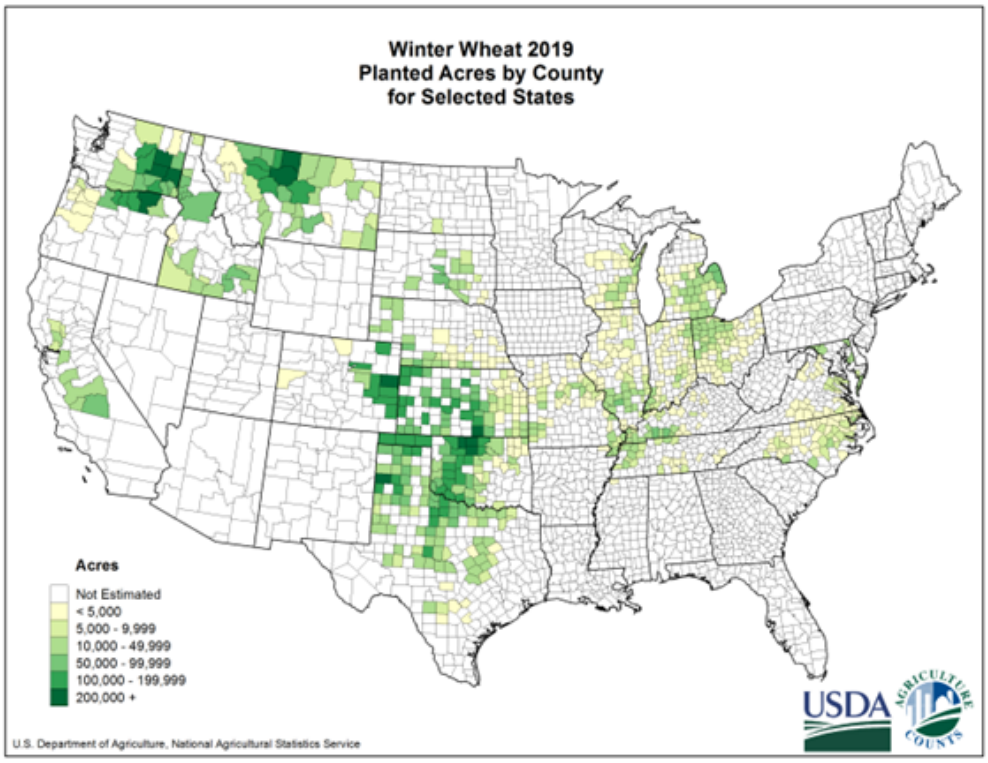
PRESENTED AT:

COLORADO STATE UNIVERSITY | CURC 2021 CELEBRATE UNDERGRADUATE RESEARCH AND CREATIVITY

INTRODUCTION & BACKGROUND



[Fig. 1. Winter wheat planted acres (1 hectare = 2.47 acres), 2010, by county in the United States. (https://www.nass.usda.gov/Charts_and_Maps/Crops_County/ww-pl.php, accessed 5 April 2021).]

Introduction:

Producing an adequate amount of food to meet the expected demand for a growing population requires a deeper understanding of the potential effects of climate change on global food staples like winter wheat (*Triticum aestivum* L.).

Concurrently, wheat yields and the rates of technology-driven improvement in yields are plateauing in major crop producing regions (Grassini et al., 2013). Climate trends are contributing to stalled yields in some regions (Hochman et al., 2017), yet the extent to which climate shifts are impacting yields in the U.S. Central Great Plains in not clear.

Wheat (Patel et al., 2018) is the most important crop species in the world. It is a critical food resource and has a constant yield. Colorado has a long rich, history of wheat growing.

Study Location:

The data used for analysis was from a USDA agricultural research facility located in Akron, Colorado.

- Akron is in the north eastern corner of Colorado.
- Used as a proxy for the Central Great Plains based on the location's precipitation and climatic variability.
- The soil type found in the area is Weld silt loam, (fine, smectitic, mesic Aridic Argiustoll).

Low precipitation in the Central Great Plains encourage a wheat-fallow (WF) rotation to store precipitation and maintain economically feasible wheat yields (Nielsen & Vigil, 2010).

- The long-term average annual amount of precipitation in the area is approximately 16.4 inches.

- The evaporative demand that is 4 – 6 times the average precipitation.

Previous work at this site has examined the precipitation storage efficiency (PSE) of no-till (NT) vs. conventionally tilled (CT) wheat-fallow systems (Nielsen & Vigil, 2010).

Wheat and Management Practices:

The fallow period for winter wheat is 14 months long, from wheat harvest in July until a September planting the following year.

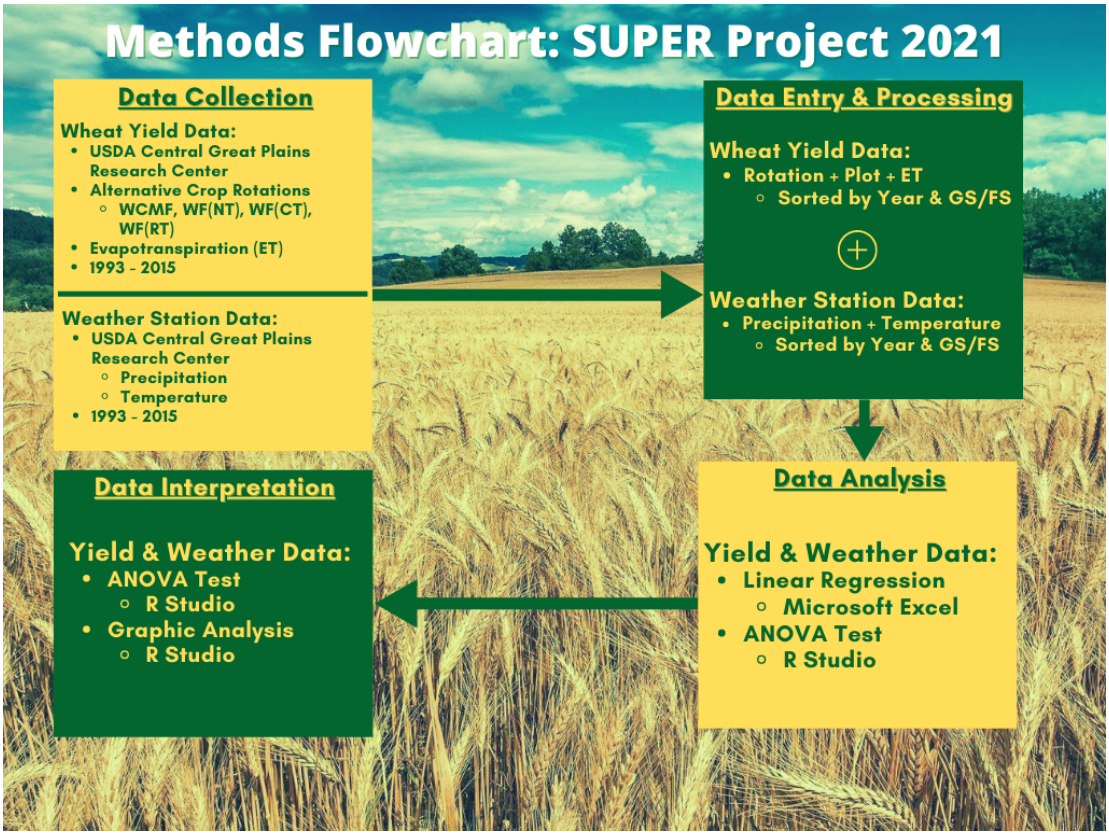
The growing season for winter wheat starts with a fall planting in September, with harvest the following July.

The WF rotation only provides 1 crop every 2 years.

Best management practices in these dryland cropping systems include no-till and residue retention on the soil surface, which can, potentially increase water storage and translate into increased yields.

METHODS

Objective A:



[Fig. 3: The flowchart illustrated above details the methodology used in this experiment. The green arrows highlight the order in which the experiment was performed.]

1. Wheat yield data from previous long term rotation and tillage research was combined with temperature and precipitation data.
2. The combined data was initally analyzed using Microsoft Excel then prepared for further analysis using R Studio.
3. Linear regression and ANOVA analysis was performed on the data using R Studio.

Objective B:

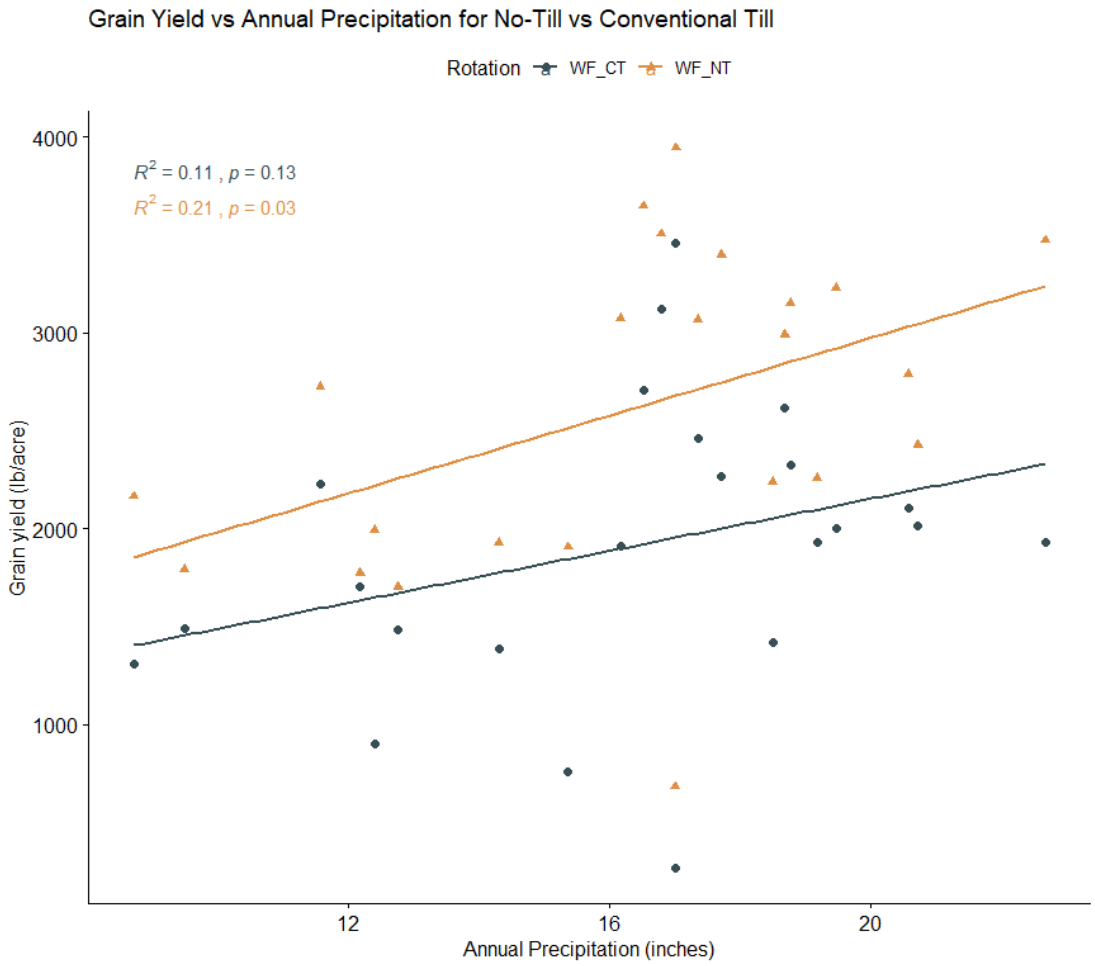
[Table 1: The table below contains an example of the different yield amounts from the wheat trial varieties used in this experiment objective.]

Row Label	Above	Akron	Alliance	Avalanche	Bond CL	Brawl CL P	Denali	Halt	Hatcher	Jagger	Prairie Rec	Ripper	Snowmass	TAM 107	TAM 111	Trego	Wichita	Yuma
1990														52.1			30.4	53.4
1991		63.1												70.3			48.2	60.7
1992		23.2												38.7			19.5	25.3
1993		57.2						54.6						57.2			46.9	61.6
1994		25.4						28.7						30.8			30.2	35.5
1995		60.7	62.4					59.8		75.4				54.8			33.6	70.3
1996		87.7	86.1					83.3		90.3	77.4			82.5			72.3	84.3
1997		51.3	47.9	42				47.5		35.8	43.9			43.9			34.9	46.8
1998		46.9	37.5	44.2				42.1		51.3	30.6			47.6			22.5	37.8
1999		75.9	81.6	74.5				64.3		71.9	73.7			75		67.7	56.3	72.4
2000	39.2	38.8	41.2	41.5				38.3		41.5	43			39		45.7	26.1	38.1
2001	45.3	52.9	45.1	47.3				49.6	60.9	56.1	47			45.2		56.5	34.5	54
2002	44.1	36.6	35.5	38.7	33.8			38.3	34.7	38.1	41.2				37.8	40.2		32.7
2003	93.1	88.4	92.2	89.9	97.3			85.4	97.6	93.2	88.5	87.7			101.3	92.8		93.4
2004	61.1	52.1	64	57.9	66.6			50.3	60	52.5	55.6	54.5			65	60.7		66.8
2005	27	20.7	25.1	26.4	33.6				26.5	31.4	26.6	31.3			22.8	20		18.9
2006	26.9	20.3	26.1	28.5	19.3				17.1	34.9	27.3	30.7			17.6	18.3		23.2
2007	61.8	64	61.2	56.3	67.9				57.8	63.6	54.8	56			65.5	52.4		60.3
2008	57.2	50.9			61.5				56.5	58.2	54.8	65.5	61.2		50.3	51.2		55.8
2009																		
2010	58.7					60.9	61.3		58.3				55.8		61			
2011	45.6				41.2	45.4	48.2		46.1	47.8	40.5	39.2	43.8					
2012	54.5				49.7	57.1	51.5		49.4			51.3	51.2		52.3			
2013	20.2				18.6	19.5	21.3		16.6			23.8	17.2		22.6			
2014	63.2	60.4			60.8	67.6	68.1		63.7		56.8	65	57.9		64.6			
2015	21.9	18.1				30.9	57.6		39		22.2	16.9	35.6					
2017						85.9	82.7		91.8				90.3					
2018						82.6	86.5		76.7				75.9					
2019						64.5	61.3		70.7				57.8					
2020						48	45.1		42.6				36.9					

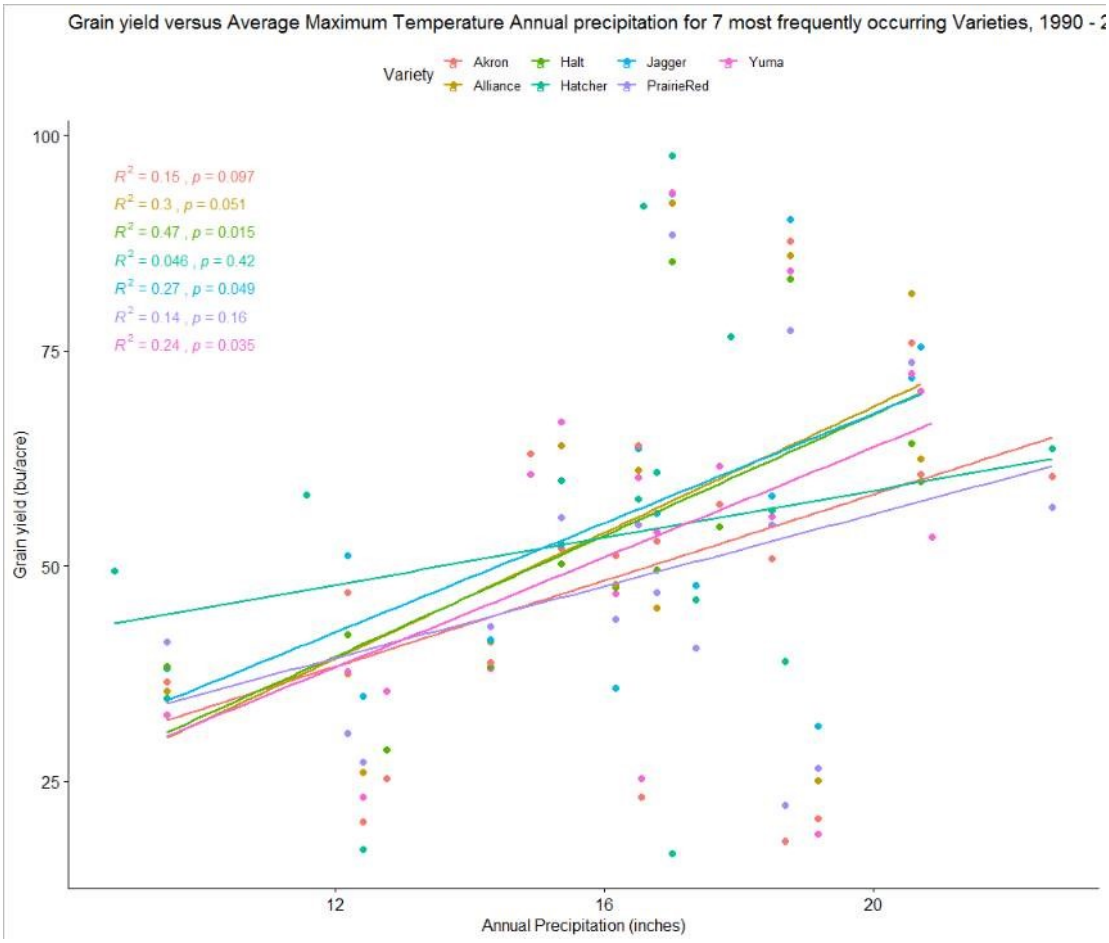
1. Yield data from previous wheat variety trials held from 1990 to 2020 in Akron, CO were downloaded from: http://ramwheatdb.com/database.php
2. The wheat yield data from the variety trials were combined with the weather data (Tmax and Annual Precipitation).
3. R Studio was used to plot the charts used for analysis.

RESULTS

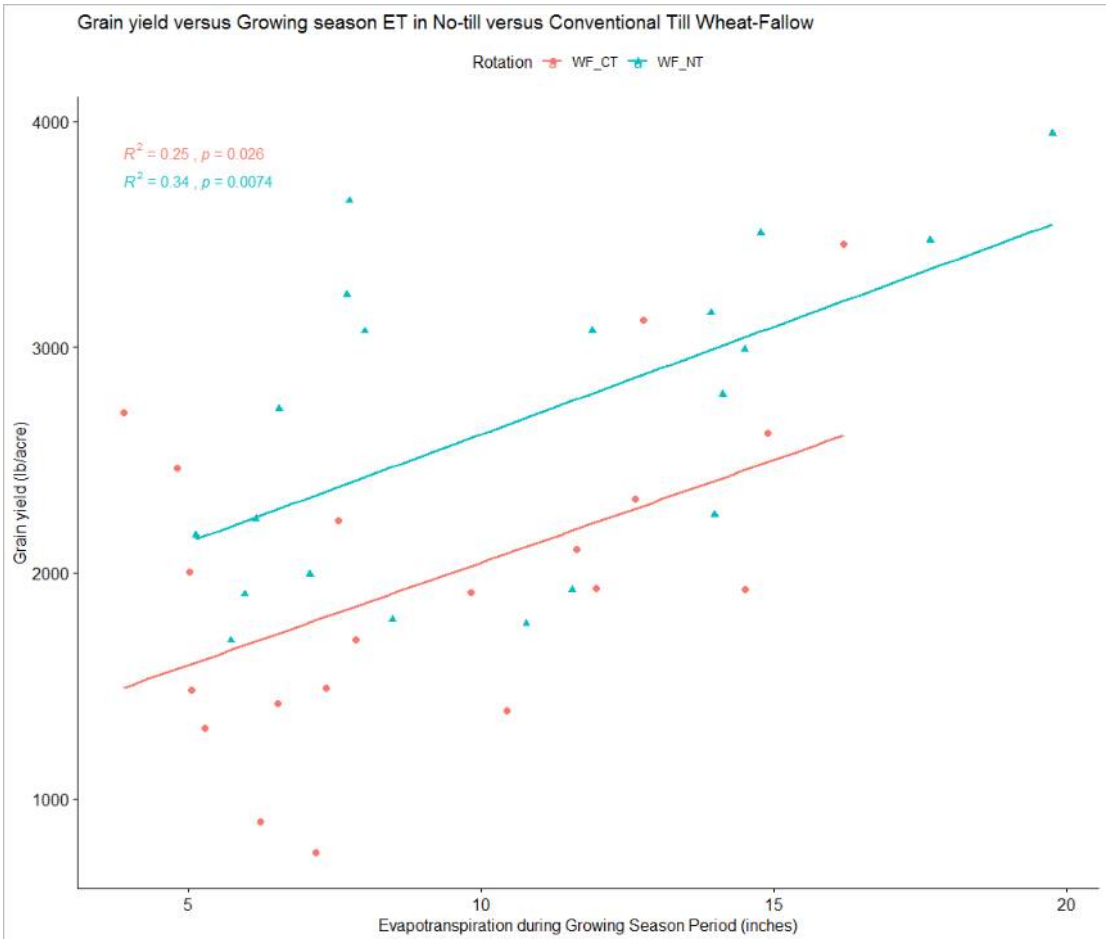
Precipitation's Effect on Wheat Yield:



[Fig. 4: The scatterplot above compares grain yield from both WF(NT) and WF(CT) tillage techniques against annual precipitation, used in Objective A.]



[Fig. 5: The scatterplot above compares grain yields from seven varieties of winter wheat against annual precipitation, from Objective B.]



[Fig. 6: The scatterplot from Objective A above compares grain yield from both WF(NT) and WF(CT) tillage techniques against growing season evapotranspiration.]

Yields:

For Objective A, the wheat yield data highlighted the high variability of region, with yield volumes ranging from:

- 265.81 lbs./acre in 2019 [WF(CT)].
- 3946.33 lbs./acre in 2003 [WF(NT)].

For Objective B, the wheat yield data volume ranged from:

- 20.3 lbs./acre in 2006 (Akron).
- 92.2 lbs./acre in 2003 (Alliance).

Annual precipitation and other water metrics:

Precipitation ranged 13.95" during the period used in Objective A.

- The largest amount of precipitation was 22.66" in 2014.
- The lowest amount was 8.71" in 2012.

For Objective B, the precipitation ranged 35.44".

- The largest amount was 57.56" in 2014.
- The smallest amount was 22.12" in 2012.

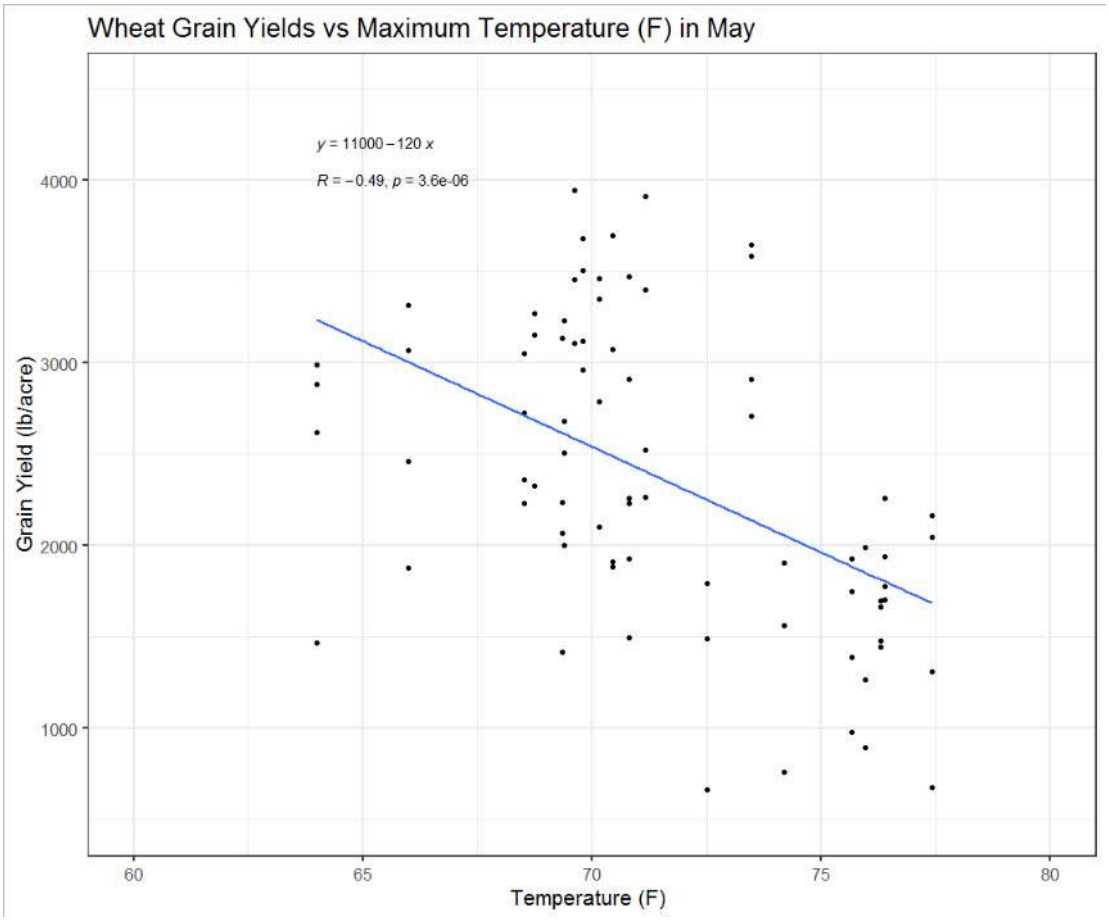
Evapotranspiration:

For Objective A, the ET ranged 18.26" for FS-ET and 18.76" for GS-ET.

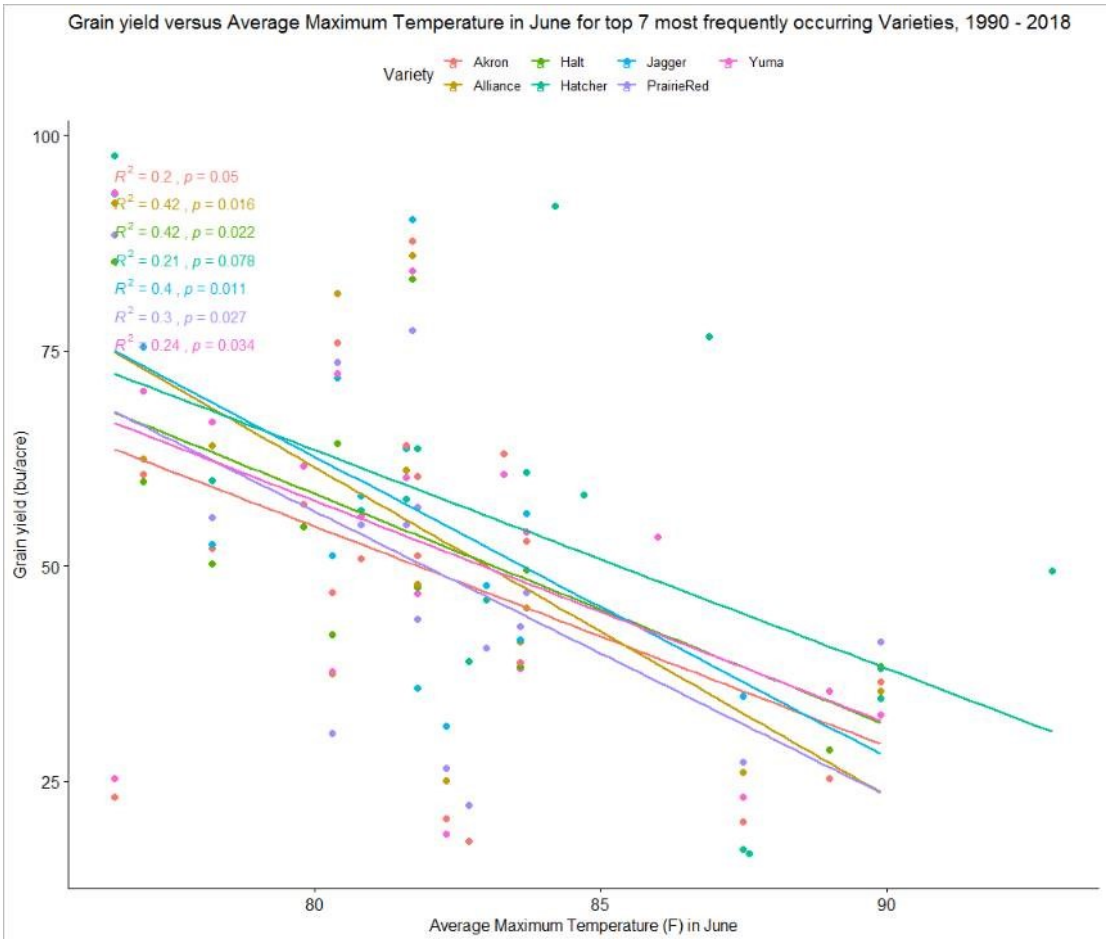
- The highest FS-ET value was 22.9" in 1995 [WF(NT)].

- The lowest FS-ET measurement was 4.64" in 2007 [WF(CT)].
- The highest GS-ET value was 19.75" in 2003 [WF(NT)].
- The lowest GS-ET measurement was 0.99" in 2006 (WCMF).

Temperature's Effect on Wheat Yield:



[Fig. 7: The scatterplot above from Objective A compares overall grain yield against maximum temperature in May.]



[Fig. 8: The scatterplot above compares grain yields from seven varieties of winter wheat against average maximum temperature, from Objective B.]

Temperature:

Temperature analyses for both Objectives were performed using TMAX values for the growing season (May – June – July).

- The highest temperature was 95.65° F, during July 2012.
- The lowest temperature was 38.61° F, in May 1995.

DISCUSSION & CONCLUSIONS

Discussion

Objective A:

Annual precipitation and other water metrics

The low amount of precipitation severely impacted the grain yields of both Objectives in 2013, illustrating the direct relationship between precipitation, water storage efficiency and wheat yield, established in previous studies (Nielsen & Vigil, 2010).

- The analysis shown in Fig. 4 highlights WF(NT) offering an advantage over WF(CT) tillage methods ($p = 0.03 < p = 0.13$).
- WF(NT) has a higher intercept than WF(CT), with an annual precipitation to yield starting at over 1000 lbs./acre per unit of water.

Concurrent with previous findings, practices like WF(NT) more efficiently use precipitation compared to WF(CT) (Nielsen & Vigil, 2010).

Temperature

The wide range of temperatures in the region that can occur during the most productive period for wheat may account for the large variability in yield.

The linear regression analyses performed using the TMAX values showed how the timing of high temperatures can have a negative impact on each tillage practice or rotation.

Crop rotations were grouped together for regression analysis for Objective A (Fig. 7):

- May had the strongest relationship with temperature overall [$Y = 11000 – 120$ x ($R2 = -0.49$, $p = 3.6e-6$)].
- This was just slightly more significant than June [$Y = 10000 – 95$ x ($R = -0.45$, $p = 2.9e-06$)].

High temperatures at critical growth stages can negatively impact wheat growth and grain filling (Asseng et al., 2015). In winter wheat, this is likely to be May and June.

Evapotranspiration

Evapotranspiration is an integrate metric of both temperature and water storage. The ET analyses used both full seasons (FS-ET) and growing season (GS-ET) to further compare WF(CT) and WF(NT) methods.

Higher ET values for both FS and GS appear to increase yield (Fig. 6). When GS-ET is used, the correlation for each tillage practice increases [$R2 = 0.34$, $p = 0.0074$ and $R2 = 0.25$, $p = 0.026$].

These results confirm previous research on PSE efficiency and soil water availability when working with WF systems (Nielsen & Vigil, 2010). Our results suggest that GS-ET is a better predictor of yield than FS-ET.

Objective B:

We selected different precipitation/temperature data to perform linear regression. However, we found that it is very important that too many varieties will greatly affect R^2. The yield of all varieties vs. the average annual precipitation graph. R^2 =0.096
But if we select the top 7 most frequently occurring varieties, R^2=0.18.
At the same time, we tried to plot the trendline of each variety(fig5). We can see the trend line more clearly. This also applies to the relationship between temperature and yield.

From the data we currently have, it is difficult for us to distinguish whether the yields of different varieties are different under the influence of changing climate.

For our result, the data of yield is not constant. So the problem is the inconsistency of yield data makes the plot looks unclear. Because not all the varieties that appear in same years. The different years introduce many external factors. So it is hard to evaluate the "quality" of varieties.

Besides, from (Donmez, E., et al. 2001) early maturity, resistance to lodging, leaf rust, and kernels spike, were all involved in the rise in productivity. But it may reflect on the yield directly. It may lead to the difference in the quality, pertain content of wheat.

Conclusions

Objective A:

Key Findings

The timing and amount of precipitation has a significant effect on the yield of winter wheat.

- When precipitation is plentiful, historical grain yields tend to be higher
- When temperatures reach extremes during the growing season, grain yields tend to be lower.

These results suggest that some simple measurements to predict yield could be:

- Maximum May or June temperature
- GS-ET is a better predictor of yield than FS-ET.

Objective Recommendations

Additional analysis is recommended with the following metrics included:

- A greater range of crop rotations to better determine the modification to yield rotation provides.
- Research into the regeneration and continued maintenance of soil health through best management practices.
- Continued research into the relationship between crop yield and extractable H2O resources.

The best management practices explored in this project may help mitigate the negative effects of climate variability.

Objective Limitations

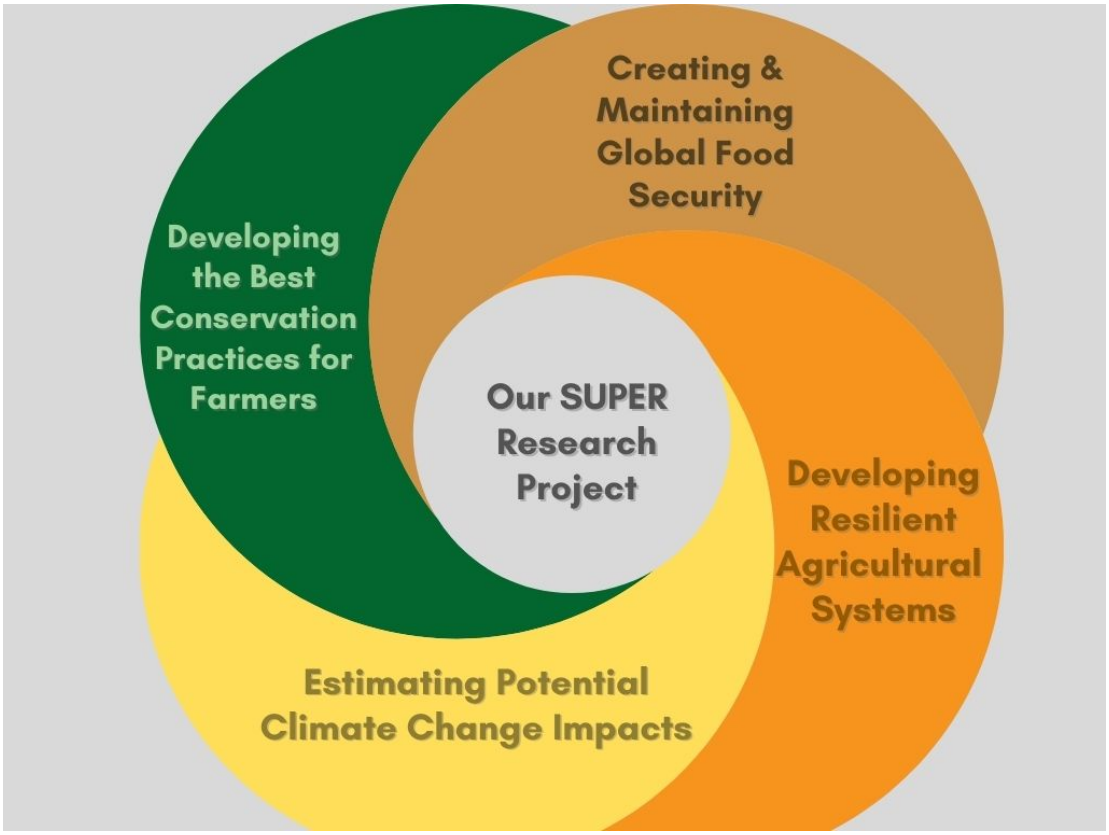
Our project encountered time limitations.

Objective B:

Our team research result (the impact of changing climate to different rotations and different varieties) would help farmers, landowners have a better understanding of crop management. People can choose the best variety and rotation for long-term cultivation based on the trend of climate change.

- Temp & precip have an overarching effect on all genotypes, genotype variety not as significant as thought.
- Variety trial data is powerful but underutilized, hard to compare or generalize because same varieties are not used in same period of record.

RESEARCH QUESTIONS & OBJECTIVES



[**Fig. 2**: The diagram above illustrates the dynamic mission and nature of our research project.]

Research Objectives:

Objective A:

The purpose of this study was to evaluate the historic climate effects on winter wheat yields in differing tillage systems and cropping rotations [WF(NT), WF(CT), WF(RT), WCMF] to help recommended improved practices for creating resilient agricultural systems and maintaining consistent wheat yields. Our project hopes to gain new inference about temperature and precipitation relationship with winter wheat yield.

Objective B:

The purpose of our group project is to identify the relationship between yield and climate winter wheat grown in Akron, CO. Why do we need to analyze the yields? (Yousif et al., 2015) indicates that the yield of wheat is one of the most critical factors affecting the commercial benefit.

Research Questions:

Research Question A:

How does precipitation and temperature impact dryland winter wheat yield under typical and best-management practices at Akron, CO?

Hypothesis A:

Warmer temperatures and extended periods of drought will negatively impact wheat yields. Conservation practices like no or reduced till will positively impact wheat yields.

Research Question B:

How does the difference of varieties impact dryland winter wheat yields in different climates at the Akron, CO farming location?

Hypothesis B:

Different varieties yield different responses for the changing of temperature and precipitation.

Core Ideas:

- Best management practices in dryland systems like no-tillage can increase precipitation storage efficiency & crop yield.
- Best management practices can reduce erosion, retain soil organic matter, and improve water infiltration & retention.
- Crop yield in the region is driven primarily by the timing & amount of precipitation.
- Higher temperatures during the wheat's reproductive period can negatively impact crop yield.
- Temperature and precipitation have an overarching effect on genotype.

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ACKNOWLEDGMENTS

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DISCLOSURES

J. Jacobs authored Objective A. Y. Liu authored Objective B.

ABSTRACT

Climate change will continue to impact agricultural production worldwide by modifying the amount and timing of precipitation and altering temperature patterns. In the U.S. Great Plains, yields of wheat (Triticum aestivum L.) are already highly variable due to limited regional precipitation and high evapotranspiration (Nielsen, Vigil and Benjamin, 2011). Best agricultural management practices like no-till farming and retention of crop residues may mitigate climate variation by increasing soil water infiltration and storage. Long-term datasets of crop production, management practices, and climate metrics can be used to evaluate historical impacts of climate on crop productivity, to identify management practices that may mitigate climate-induced yield declines, and to model and project future climate impacts to crop production and food security.

Long-term wheat yield data from an experiment located in Akron, Colorado was used to explore how agricultural management practices like tillage intensity (no-till, reduced tillage, conventional tillage) and rotation (Wheat-Fallow and Wheat-Fallow-Corn-Millet) have historically impacted grain yields. Linear regression analyses were used to explore the relationships between wheat yields, tillage intensity, rotation, annual average and monthly growing season temperature, annual precipitation, and evapotranspiration. Wheat yields declined in relation to decreased annual precipitation, and slightly declined with increased maximum temperatures. The month of May; a crucial reproductive period for wheat, saw the greatest negative consequence to yield [Y = 11000 – 120 x (R2 = -0.49, p = 3.6e-6)], although this was also evident in June. Our results suggest the need for continued analysis of regional yield trends with climate to understand and project how wheat yields in the Central Great Plains will be impacted by climate change in the coming decades.

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