Effects of Climate Change on Wheat Yields in the Central Great Plains

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Table of Contents:

List of Figures and Tables:

Abstract: Effects of Climate Change on Wheat Yields in the Central Great Plains

By 2100 the global population will be between 10 and 11 billion people (the Guardian). Climate change, meanwhile, is worsening and threatening our current food supply, particularly wheat. Wheat is plagued by chronic underperformance, and is not gaining enough in yield year-to-year to feed the population. A statistical analysis was performed using data from existing databases on yield, days to heading, temperature and precipitation from 1970-2010 for the State of

Nebraska, representing the Central Great Plains. The results indicate that yield in the Great Plains (a major growing region of the world) is increasing at a rate of 1% annually since 1970, far less than the 2% increase required to sustain population growth (Ray et al). Statistically significant changes in average growing season temperature and precipitation were not observed. In the range of temperature and precipitation analyzed, no significant effect on yield was noted. However, more research should be done to examine the effects of climate on yield outcomes for both different crops and different places.

Introduction

With wheat a major ingredient in everything from pasta to bread to animal feed, it is imperative that we do everything possible to protect our food supply for the next generation. However, with severe climatic events expected to rise in both severity and frequency in the next hundred years (www.epa.gov), as well as the world population projected to be at nearly eleven billion by the year 2100 (www.theguardian.com), agriculture and the humanity that relies upon it face a huge challenge. We must adapt our crops to meet the rigors of a new climate, or face the ultimate tragedy: not being able to feed our world. Given that the United States is the largest wheat exporter in the world, the third largest producer in the world, and given that Nebraska is a major wheat producing state in particular, this information is vital to our food security (Ag. Marketing Resource Center, 2012). Climate change could have a significant effect on wheat yield. For example, one recent drought in Texas (USA Today, 2013) halved the wheat harvest that year. While we can't control the weather, we can examine how the weather affects us, and we have a uniquely 21st century opportunity to do this. With our newfound understanding of the climate, we can foresee the effects of climate change on wheat in the Great Plains, where two thirds of the American crop is grown (Agriculture Marketing Research Center).

The average person consumes over eighty kilograms of wheat each year, and wheat alone is grown worldwide on an area the size of Greenland (wheatworld.org). Climate change is already affecting the North American wheat crop. In fact, according to a 2008 study, the overall area where most wheat can be grown will shift north by 2050 (Ortiz, et al). Ortiz et al. predicted drastic changes to climate patterns. Using climate projections, Ortiz sought to examine what higher global temperatures in general would do. Notably, Ortiz predicted that the area where wheat can be grown will shift north to Canada and away from the United States. Ortiz maintained that much of the Central Great Plains will be completely inhospitable to agriculture, and the optimal temperatures for harvesting will be found in parts of Canada and even Alaska. Another study by Semenov et al., looked at effects of climate change on the United Kingdom and saw similar results (2008). Semenov's study, using climate models like Ortiz's and Semenov's, predicted arid climates and less rainfall in the future, while the overall area where it is possible to grow wheat will shift north to parts of Scotland currently inhospitable to wheat. The models used incorporated current climate patterns, and used current and past climate data to predict the future. If the Semenov and Ortiz models indeed apply to the United States, some of the most fertile and productive areas of our nation will become inhospitable to wheat. Conversely, a 2013 study by Ray et. al established an important threshold for wheat production in the United States. The authors looked at yield and population data and determined that an annual yield increase of 2% is necessary in order to sustain our growing global population. Shifts in where wheat can be grown coupled with this increased demand could threaten our future food security.

Currently, some research on wheat breeding focuses on strains resilient to the effects of climate change. Genetic modification of wheat is not practical, as many global markets are unfavorable for GMO (genetically modified organism) products. Thus, wheat breeding and non-transgenic approaches present themselves as a feasible solution. Wheat breeding involves crossing wheat cultivars together to get an offspring that is genetically ideal. New knowledge about the wheat genome has allowed researchers to make great strides in improving our crops. We can now precisely plan and target our breeding approach in order to maximize effectiveness, and there are infinite genetic possibilities for breeders to investigate. Wheat breeding, however, can take up to ten years from start to finish. It requires many generations worth of trial and error, and it is imperative for researchers to do it as accurately as possible. Scientists try to utilize the newest understandings of wheat genetics in order to formulate breeds that can perform better in their environments. Different genes interact differently, and when breeding for drought, heat and disease resistance, we have to be prepared. Scientists working to create wheat resistant to climate change must know what climate change will bring, and how it will affect wheat yield. Already there exists a strong will to breed, and a comprehensive knowledge of the wheat genome.

Examining the correlation between weather conditions and the past yield is vital to ensuring breeding is effective. Breeders can use the information to refine their objectives and goals for research. For instance, a scientist breeding wheat to make it more drought resistant would now understand the effects drought has on wheat in a specific area, and could alter the wheat breeding to obtain more favorable genetics to meet those environmental conditions. Scientists have for years pored over climate and yield data, but rarely are they able to see refined precipitation, temperature, heading date and yield data statistically analysed to identify possible trends.

This research followed a similar course as Semenov and Ortiz, but looked at the U.S. Great Plains in particular, and used a multitude of different scenarios. This study incorporates new knowledge on climate change, including new data unavailable in 2008 when Ortiz and Semenov published their research. The two scenarios for climate change examined in the study (colder temperatures and drought) are both likely to occur more frequently with climate change. The occurrence of first and last frost with respect to flowering time was considered. Also, by being able to invent climate change scenarios, we were able to more effectively examine several possible effects of climate change, instead of the only one scenario investigated by Semenov and Ortiz. The purpose of this data was to illustrate the relationship between yield and climate conditions, including average temperature and precipitation.

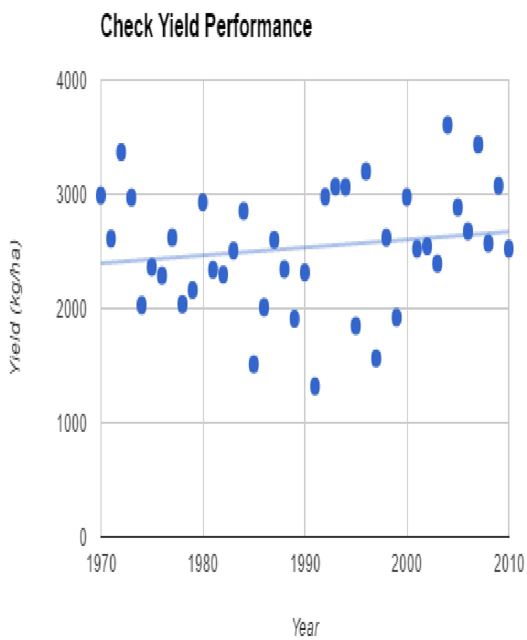
Materials and Methods:

Using the USDA Agricultural Research Service's (USDA ARS) Hard Winter Wheat Regional Nursery Database, and the University of Nebraska Regional Climate Center's CLIMOD database, data from 1970 to 2010 were aggregated, including data on total precipitation (in inches) between March 1st and June 30th of each year, average temperature between March 1st and June 30th of each year (from CLIMOD), as well as corresponding wheat yields (in kilograms per hectare) and days to heading (a measure of wheat growing time for which a low variation in days from year to year is necessary) for each entire season (from USDA ARS). The dates March 1st-June 30th were used because these dates generally represent the critical period of growth for the wheat crop. Using data for the entire year would not be able to show us as specifically if the climate had an effect on yield. For instance, a drought in August at the end of harvest would have a minimal impact on the yield, but it may be heavily reflected in a yearly average. For the yield/heading date data, the Northern Regional Performance Nursery database (NRPN) was used. The average yield data for the state of Nebraska, in kilograms per hectare (kg/ha), was examined in all NRPN entries between 1970 and 2010, and data was aggregated on the yields for the lowest, middle and highest performing cultivar. The check yield was the yield of the lowest performing cultivar for each year. The moderate yield was the median yield of the data provided, typically roughly the 15th cultivar out of 30 shown. The highest performing yield was the highest yield shown for that year. The moderate and highly performing cultivars varied considerably in terms of the actual cultivar.

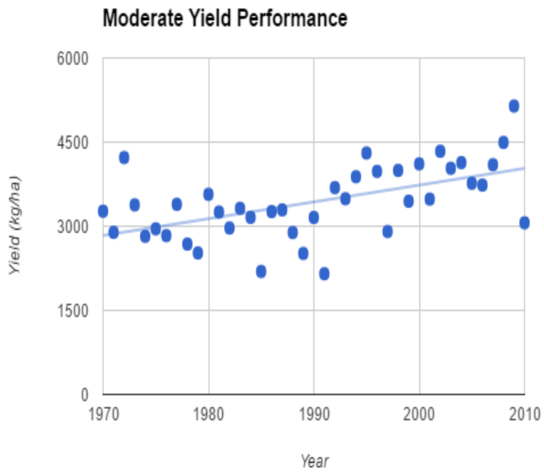
Multivariable regression analyses were performed comparing the temperature to the wheat yield for all three cultivars, temperature to heading date, temperature to year, precipitation to year, yield for all three groups; types to year, precipitation ro heading date, and precipitation to all three cultivars. The data was analysed for statistical significance and graphs were compiled. A regression is a test to examine the effects of “predictor variable” on an outcome. As such, the r and r^2 were calculated. The r value is a coefficient between -1 and 1 that determines the correlation of data in the positive or negative direction. An r^2 value is a measure of the percent of the data explained by the linear model. The p value was also calculated. The p value serves us by telling us the chance a certain result occurred by chance. Generally, 0.05 is the threshold for a P value: lower than 0.05 means there is a less than 5% probability the results were by chance. This helps us understand trends present in the data and whether they’re a result of climate change.

Results:

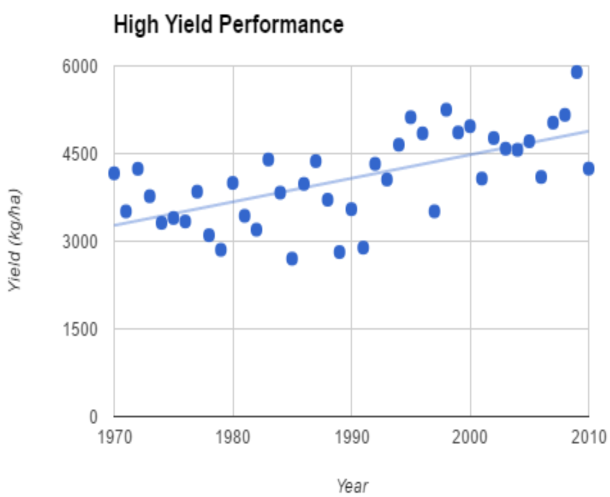
Figures 1a,1b and 1c show the increase in the yield over time for low, moderate and highly performing wheat cultivars. Figures 1a, 1b, and 1c show the increase in the yield over time for low, moderate, and highly performing wheat cultivars. While the correlation shown in Figure 1a is insignificant (p=0.423), this is expected, as check yield should not increase over time since this crop is meant as a control and does not change genetically from year-to-year. While 1a is insignificant, this is expected, as check yield shouldn’t grow over time since there is purposely no genetic improvement. The trend line clearly shows an increase over time in wheat yield, especially relating to the high yielding cultivars. With this information on the positive increase in moderately/high performing wheat yields (but no significant increase in check yields, as expected), further analyses were done. Considering the slope of the line for high performing yield was 40.288 kg/ha and the average yield was 4076 kg/ha, the average increase yearly was calculated at approximately 1%. This means that on average, the yield for highly performing cultivars went up by 1% year to year. For moderately performing cultivars, the actual percent increase was lower. This increase over time is illustrated in *Figure 1* for moderately performing cultivars and *Figure 1b* for highly performing cultivars. *Figure 1a* and *Figure 1b* both had low r^2 values, indicating that the results deviated somewhat significantly from the line of best fit. However, both values had clear and convincing evidence for a trend over time. In *Figure 1b*, the line explains 30% of the change in time, meaning that year has a relatively large effect on yield. The same is the case with *Figure 1c*, but with a higher correlation (40%).



y = 6.888 *x -11175.054 r^2 = 0.025. P value=0.423
Figure 1a



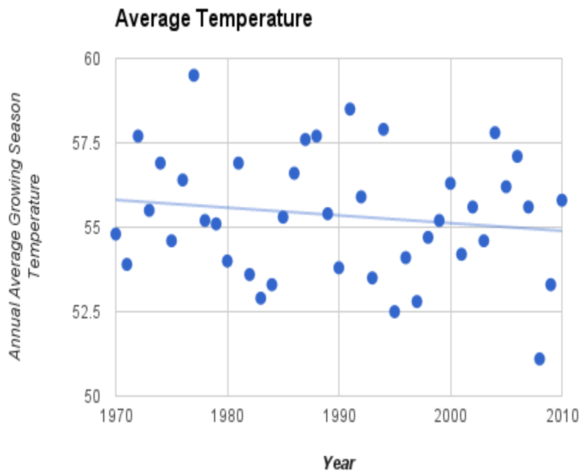
y = 29.932* x -56130.943 r^2 = 0.302. P value=0.00039
Figure 1b



y = 40.288* x -76096.96 r^2 = 0.4. P value 0.000020
Figure 1c

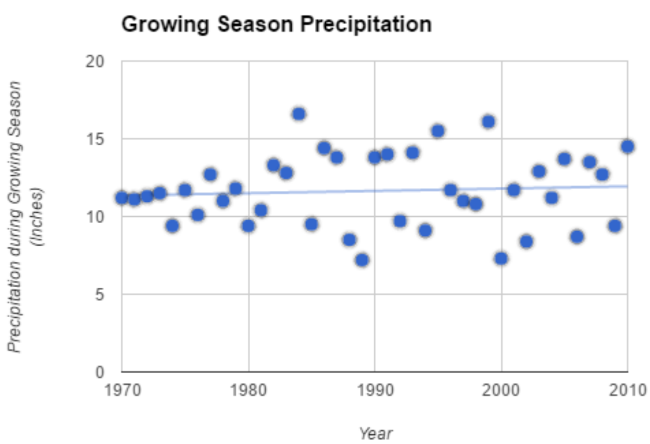
Figures 2a,b and c have year correlated with temperature, precipitation and days to heading.

Figure 2c shows a marked decline in days to heading over time, but this is likely due to the outlier data points. The P value here was well above 0.05, as with 2a and 2b. This indicates that the results were insignificant of an actual trend.



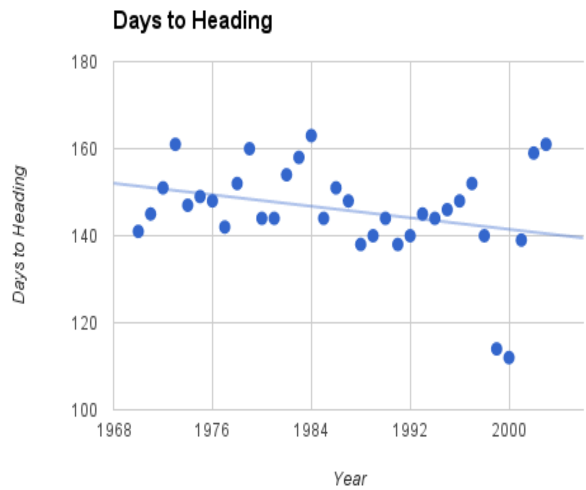
y = -0.023* x +100.941 r^2 = 0.023. P value 0.348

Figure 2a



y = 0.015 *x - 17.642 r^2 =5.769E-3. P value 0.636

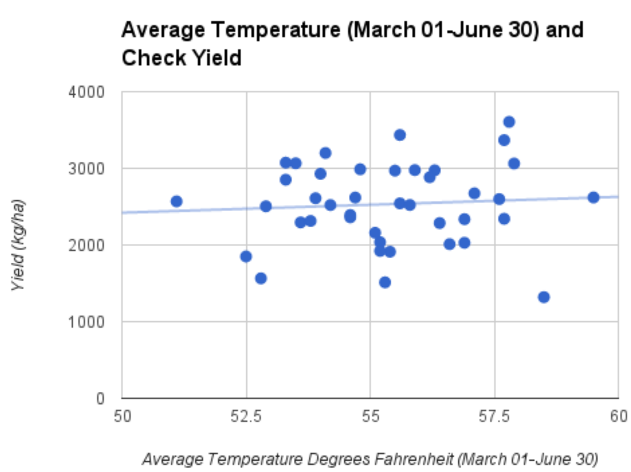
Figure 2b



$y = -0.33 * x + 802.139$, $r^2 = 0.09$. P value 0.085

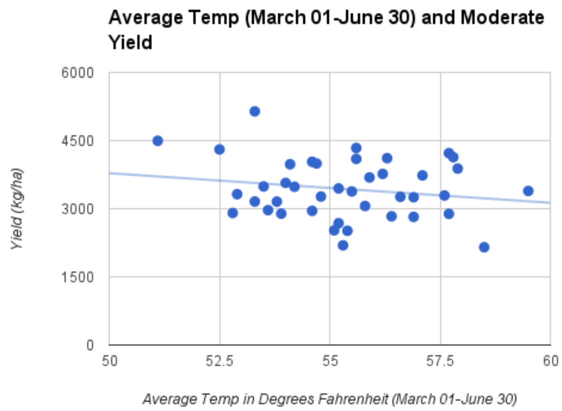
Figure 2c

Figures 3a, 3b, and 3c show correlations of check yield, moderate yield, and high yield versus average growing season temperature. Although the correlations for Figures 3b and 3c show a slight decrease in yield with increasing temperature (65 hectares per degree fahrenheit for moderate and 83 hectares per degree fahrenheit for high yield), none of the relationships is statistically significant. This could be because the relationship between yield and temperature is not that simple, and other factors may be affecting the results. For example, was there greater precipitation during the growing seasons with a higher average temperature?



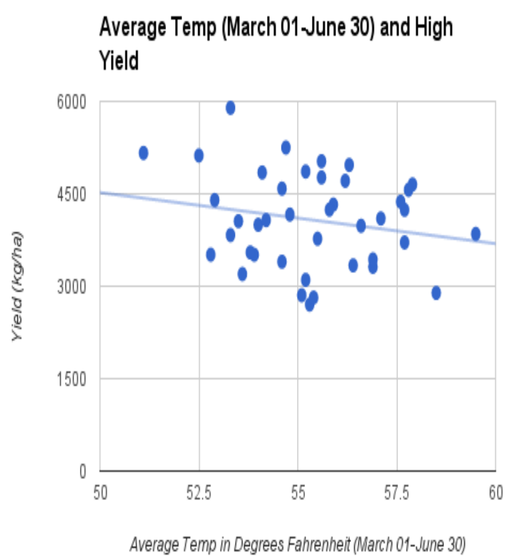
$y = 20.719* x + 1385.185$, $r^2 = 5.175E\text{-}3$. P value 0.654

Figure 3a



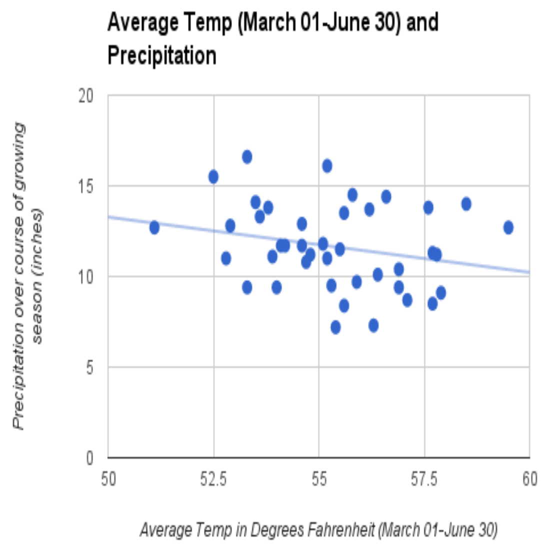
$y = -65.086* x + 7036.779$, $r^2 = 0.033$. P value 0.213

Figure 3b



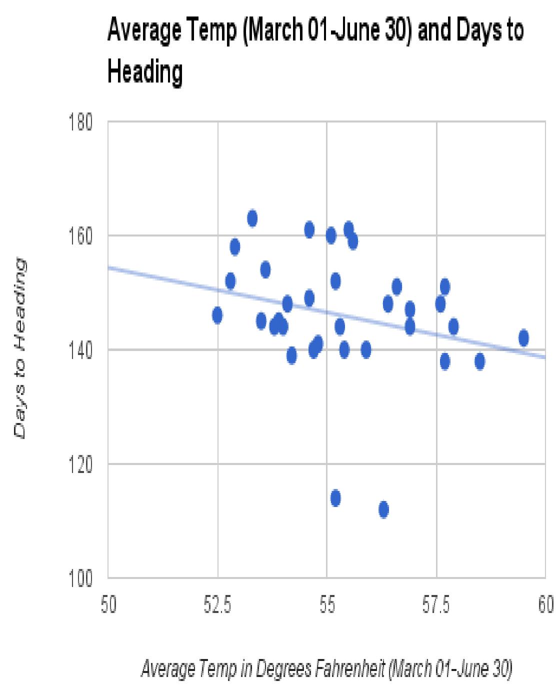
$y = -82.858* x + 8663.121$, $r^2 = 0.039$. P value 0.0129

Figure 3c



y = -0.305* x +28.514, r^2= 0.057. P value 0.131

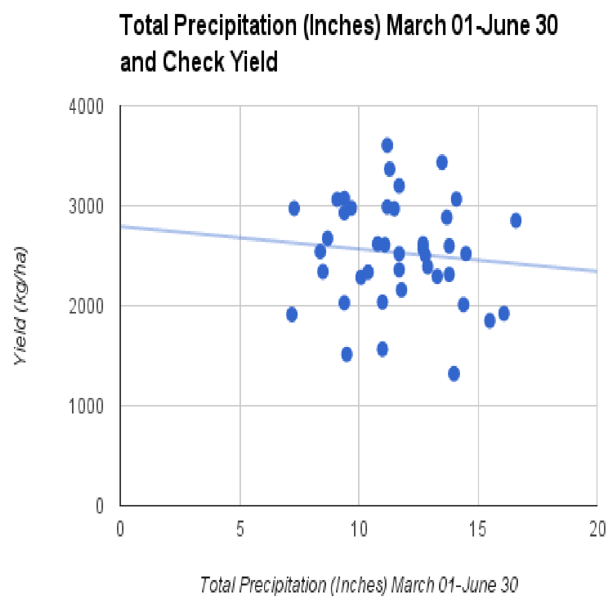
Figure 3d



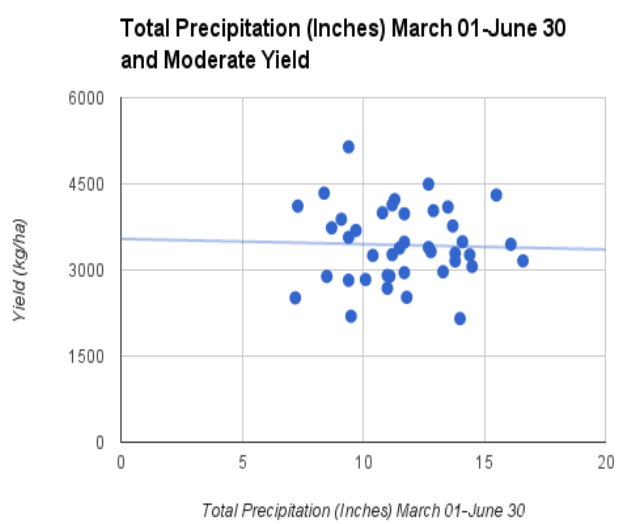
y = -1.567* x +232.706, r^2 = 0.062. P value 0.1547

Figure 3e

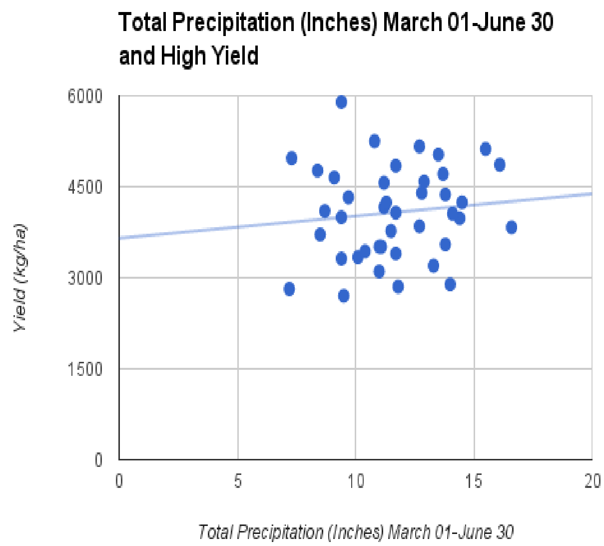
Figures 4a, 4b, 4c and 4d show correlations of check yield, moderate yield, and high yield versus total growing season precipitation. While Figure 4a shows a slight decrease in yield alongside precipitation, and 4c and 4d show increases, there is no statistical significance. The relationship between precipitation and yield may not be that simple, or other factors could be at hand. Outlier years may have a large effect on the data, and a longer time span might be needed.



y = -22.291* x +2791.63, r^2 =9.684E-3. P value 0.541
Figure 4a

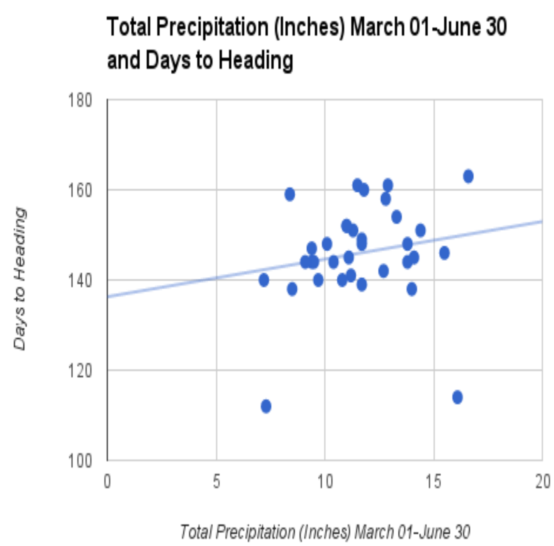


y = -9.192* x +3541.251, r^2=0.001071251456. P value 0.839
Figure 4b



$y = 36.533* x +3651.342$, $r^2 = 0.012$. P value 0.488

Figure 4c



$y = 0.834 *x +136.281$, $r^2= 0.03$. P value 0.309

Figure 4d

Discussion & Conclusion:

While not necessarily the results expected, this study raises some alarming questions about our world and its capacity to feed people. After starting out examining climate change's correlation with yield through 15 different regressions, the study's interesting results concerning yield gain over time came to light. Since there was a lack of significance for a correlation, this suggests that while global warming may be happening, it is not reflected by these variables. Yield has been increasing in both moderately and highly performing wheat, but is it increasing enough to feed the world? This increase is a result of improvements in agriculture, including a genetic gain for wheat as the crop becomes more advanced.

A 2013 study by Ray et. al established an important threshold for wheat production in the United States. The authors looked at yield and population data and determined that an annual yield increase of 2% is necessary in order to sustain our growing global population. The results of this study suggest that wheat production in the state of Nebraska is only growing by 1% yearly in yield. A world food shortage may be on the horizon. Additionally, in a 2010 study, R.A Graybosch et al. concluded that the rate of genetic gain (yield gain as a result of improvements in genetics) is actually *slowing* as we exhaust all of our common methods of improving wheat yield via genetics. This study concluded that an urgent need to research wheat genetics exists: our food supply depends upon it. Better farming methods can only take us so far, and the growth in yield is fueled by genetic improvements.

Not many correlations can be drawn to research done by either Semenov et al and Ortiz et al. Since climate data turned out to be inconclusive, Semenov and Ortiz's data stands as the best research available on climate change's future effects on wheat, and should be heeded.

Several limitations hindered this study. By examining the entire state of Nebraska (a vast area with variable climates from East to West), data became less signifying of a trend. Also, the range of years (1970-2010) might have been too short to illustrate a trend in global warming. Future research could correct this by using a wider year range and a more specific/less variable geographic area. Future research could also examine the effects of climate change on other crops vital to food supply, including corn and soy. Facing population growth, climate unpredictability, and diminishing yield gains, actions need to be taken by policymakers and researchers to ensure the next generation is able to have food security.

Bibliography:

Graybosch, R. A., & Peterson, C. J. (2010). Genetic improvement in winter wheat yields in the Great Plains of North America, 1959–2008. *Crop Science*, *50*(5), 1882-1890.

Peterson, C. J., Graybosch, R. A., Baenziger, P. S., & Grombacher, A. W. (1992). Genotype and environment effects on quality characteristics of hard red winter wheat. Crop Science, 32(1), 98-103.

Koch, Wendy. "Climate Change's Heat Intensifies Drought In USA." USA Today. USA Today, 9 July 2013. Web. 24 Feb. 2016.

Peterson, J. C. (1992). Similarities among test sites based on cultivar performance in the hard red winter wheat region. Crop Science, 32(4), 907-912.

Peterson, C. J., & Pfeiffer, W. H. (1989). International winter wheat evaluation: Relationships among test sites based on cultivar performance.Crop Science, 29(2), 276-282.

Semenov, M. A. (2008). Impacts of climate change on wheat in England and Wales. Journal of the Royal Society Interface, rsif-2008.

"Understanding the Link Between Climate Change and Extreme Weather." Understanding the Link Between Climate Change and Extreme Weather. EPA, n.d. Web. 24 Feb. 2016.

"Fast Facts: National Association of Wheat Growers." *National Association of Wheat Growers*. National Association of Wheat World, n.d. Web. 25 Feb. 2016.

Carrington, Damian. "World Population to Hit 11bn in 2100 – with 70% Chance of Continuous Rise." *The Guardian*. The Guardian, 18 Sept. 2014. Web. 24 May 2016.

Ortiz, R., Sayre, K. D., Govaerts, B., Gupta, R., Subbarao, G. V., Ban, T., ... & Reynolds, M. (2008). Climate change: Can wheat beat the heat?.*Agriculture, Ecosystems & Environment*, *126*(1), 46-58.

"Related Topics." PRE 2010 NURSERY DATA : USDA ARS. USDA ARS, n.d. Web. 01 Sept. 2016.

Ray DK, Mueller ND, West PC, Foley JA (2013) Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS ONE 8(6): e66428. doi:10.1371/journal.pone.0066428

"Wheat." *Agricultural Marketing Resource Center*. Ag Marketing Resource Center, 1 Apr. 2012. Web. 18 Oct. 2016.