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Precipitation Impact on Crop Yield

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Disclaimer: The following thesis was produced in the Environmental Studies Program as a student senior capstone project.

Precipitation Impact on Crop Yield

By Ian Ritchie

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Thesis Advisor: Jeff Peterson

Thesis Reader: Fabio De Mattos

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Abstract

Climate change is a massive force impacting and changing many weather trends, including precipitation rates. This thesis will study the relationship between crop yield and changes in precipitation. Understanding crop yield is important in determining overall crop supply every year as well as crop prices. Many factors can have either a negative or a positive impact on crop yields. One of these many factors is precipitation. This thesis looks directly at the impacts of changes in precipitation on corn yield in Iowa from 1991-2020. To do this, a regression analysis was performed to compare changes in yearly precipitation rates for the water year (October through September) from 1991 to 2020 and the average corn yield at the end of each crop season. This study did find a relationship between the corn yield and changes in precipitation rates.

Acknowledgments

I would like to thank Jeff Peterson and Fabio De Mattos for the support, time, and knowledge provided throughout the entire process of writing this thesis. Without them, it would not have been successful.

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Introduction

The grain industry is a large market that spans the globe. There are not many places in the world that are not impacted by the grain industry. Not only is the grain market responsible for keeping your car running, but it is also responsible for keeping *you* running. Grain commodities range from corn to wheat to soybeans. Wheat is responsible for creating the flour used in your bread. Soybeans feed the cattle that later become your steak. Corn is used to make ethanol, which is mixed with gasoline to run your car.

Just like gasoline, the prices for grain commodities vary every day. Many factors affect these prices, such as a change in demand to a shortfall in supply. Demand can be influenced by a variety of different factors, ranging from a change in trade policy to new industries being created. Weather has a large impact on supply. Droughts can prevent entire crops from growing while large floods can take out cropland in one sweep or prevent them from even being planted. Cold temperatures during certain times of the year can impact crops as well. Global reductions in supply can increase the prices for food, ethanol, and all the other products grain commodities provide (Williams). Over the past two centuries, carbon dioxide emissions and pollution in the Earth's atmosphere have created a slow but steady rise in the global average temperature. The rise in global temperature has had many disastrous impacts on the global environment and around the United States. The impacts of climate change range from a rise in sea level, acidification of oceans, changes in precipitation, and differing temperature trends (European Union).

This thesis will look at a small sliver of the relationship between climate change and grain prices. This thesis will determine the correlation (if any) between corn yield in Iowa and precipitation over the past 30 years. The relationship between yield and precipitation was picked for a variety of reasons. Regarding weather, precipitation data was picked over other weather events due to its quantitative nature. In addition, water access is a core part of plant health, whereas changes in atmospheric pressure are not. Other climate data sets, such as the frequency of severe storms, are less quantitative and usually more localized. A storm can easily only impact a small area of the state, whereas average precipitation is more likely to accurately represent the entire state.

The yield was picked as the representative dataset for crops over other sets, other data sets like production and price. Grain prices can be impacted by many factors including supply and demand. Weather, for the most part, only determines supply availability and does not impact demand. Production can be impacted by a variety of factors beyond plant health, such as a farmer’s decision to plant a certain number of acres in a year. Yield represented in harvested bushels per acre can accurately represent how productive the crop was and how well it did on average. For corn, a bushel is equal to 56 pounds.

Iowa was chosen to be the representative state because it is one of the largest agricultural states in the United States. In addition, Iowa has consistent weather across the whole state because its area has similar elevation and latitude. Other states such as North Dakota and Minnesota have a wider range of overall temperature patterns, including regular freezes, that can impact crop yield. Nebraska was specifically not chosen because of its heavy reliance on irrigation. Iowa, on the other hand, relies more heavily on precipitation to water crops. Corn was picked as the commodity of choice because it is Iowa’s most produced crop and corn requires a fair amount of water to grow, thus making it is more likely to be impacted by changes in precipitation.

Background

What Makes Up the Price of Grain

Grain prices are determined by a plethora of different contributors. Some of these different contributors include the amount of supply, the demand for the grain, how much it costs to store, how much it costs to transport, how much it takes to ensure the grain, and any additional taxes on imports and exports. All of these factors can be represented with a few different prices' values. These values are represented by the futures prices and the basis price (Hargrave).

The futures market is a market that provides a place to sell and buy a standardized contract. Here, national supply and demand are the driving factors that determine market equilibrium and commodity prices. The futures contract is standardized in many ways. It indicates a set grade (quality) of the commodity, amount, delivery period, and place of delivery. The only negotiable factor is the price. Because it is a standardized market, many participants play a role in finding the value of a commodity (Hargrave).

Another important price factor in grain is the basis. The basis is the difference between the spot market and the futures market. The spot market is specific to each buyer and their location. It indicates how much someone is willing to pay under or over the futures price to have grain delivered to them instead of the futures market. The basis indicates how much it will cost to store and transport grain around the country. Unlike futures prices, basis prices vary across the country (Kagan, J.).

Supply and Demand

Supply and demand are arguably the two most fundamental parts of economics. They are the two core pieces that will determine the price of any good. Both supply and demand can be represented on a graph, relating to quantity and price. Supply has a direct relationship between the two and demand is inversed. What this means for supply is that the higher the prices are, the more a producer will be willing to produce. Inversely, for demand, the more quantity of a product is, the lower the price will be. These two curves will always meet somewhere on the graph. This point is where the price is in equilibrium. As factors change supply and demand, the supply and demand curves will move left and right. This movement will move to the point where they met and price equilibrium (Law of Supply and Demand).

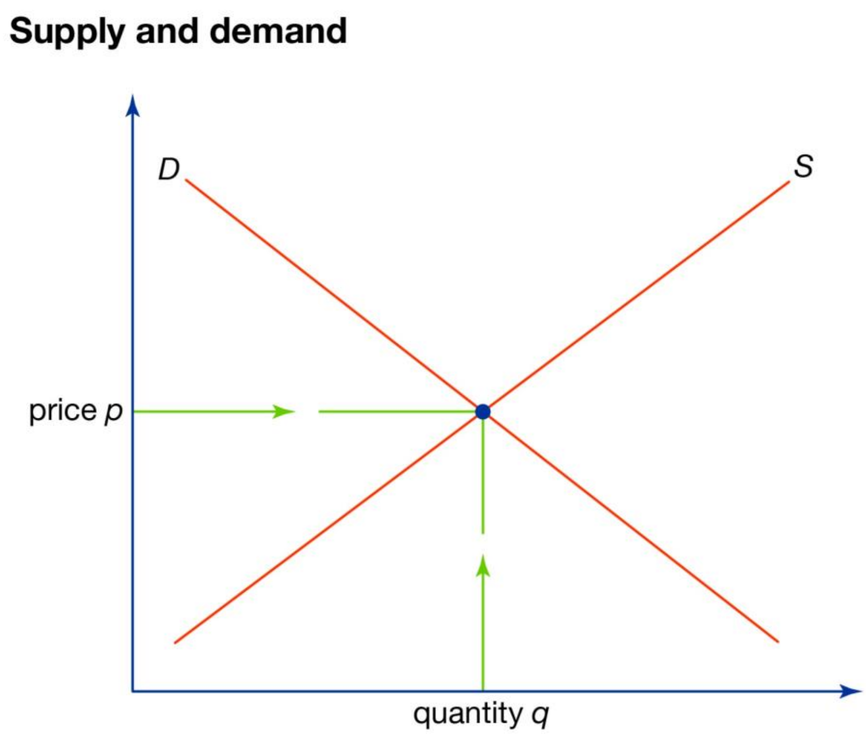

Figure 1. The figure demonstrates the relationship between demand, supply, and price. Augustyn, A. (Ed.). (n.d.). Supply and demand. Encyclopædia Britannica. https://www.britannica.com/topic/supply-and-demand.

Many variables are considered when determining what demand will be each year for grain. Just a few of these variables include exports, food, seed, ethanol, industrial use, and feed for livestock. Like supply, each variable can be impacted differently. Some of the variables can move quite quickly, while others typically stay fairly static and predictable. Typically, our demand for food, feed for livestock, and seed stays constant (Price Determination Factors for Corn and Wheat). However, they are growing as overall demand and population grows. Some demand can change quickly, such as ethanol. For example, when COVID-19 shut down much of the world, transportation came to standstill. This greatly reduced the demand for ethanol, and in turn, the demand for corn and other commodities used for ethanol production (Irwin, S.).

Similar to demand, numerous components are used to determine how much grain supply there will be each year. A few of those pieces include how much will be produced, the ability to transport the crop, and what the ending stocks are from the previous year. Each piece is directly impacted by different factors. Acres farmed can either be a choice of the farmer or limited by nature. Farmers can decide what crop they want to plant, and how much of it. On the flip side, nature can prevent acres from being planted by other factors such as flooding. Crop supply can be limited by the ability to transport it. If truckers go on strike, there will be no way to get the supply where it needs to go. Lastly, ending stocks, which is how much grain was stored from the previous year, can impact supply. Ending stocks are determined by the difference in supply and demand from the previous year (Price Determination Factors for Corn and Wheat).

Yield: A Piece of Supply

Crop yield is a core component used in determining overall production and supply. Crop yield is defined as “standard measurement of the amount of agricultural production harvested—yield of a crop—per unit of land area” (Hayes). One of the most common units of measurements of yield is bushels per acre or tons per acre in the United States. Yield is a critical piece in determining how much a farmer or area can produce. Once the total yield is known, and the acres planted, the total production of an area can be calculated.

Crop yield is estimated by harvesting a measured sample area of land and then weighing the harvested crop. This data is extrapolated from the sample across the whole field. As an example, an acre of corn is harvested and weighed and the total weight of corn comes in at 100 bushels, then it is predicted that the field's yield will be 100 bushels per acre. The National Agricultural Statistics Service (NASS), which is a part of the US Department of Agriculture (USDA), surveys producers every year to determine local, state, and national crop yields of almost two dozen different types of crops.

Yield Trends

Over the last 80 years, corn yield has increased every year. This overall upward trend was caused by a variety of factors, primarily due to an improvement in crop genetics and improvements in crop production technologies. Since 1860, when yield data first started being collected, there have been two dramatic shifts in the crop productivity trend. The yield started improving every year starting in the late 1930s with the adoption of double-cross hybrid corn. This massive improvement in genetics has allowed the genetic potential of the crop to grow every year, thus improving the corn yield every year. The second dramatic shift in corn yield improvement happened in the mid-1950s as a result of the use of N fertilizer, chemical pesticides, agricultural mechanizations, and a continued increase in genetic potential. These improvements are a result of advancements to crop technology. Over the last 25 years, yields have improved almost 2 bushels per acre. Figure 2 shows the two different shifts in trends over the 1860s. This trend has remained fairly constant and predictable. All fluctuations from the trend line can be contributed to changes in the growing conditions such as weather and pests (Nielsen).

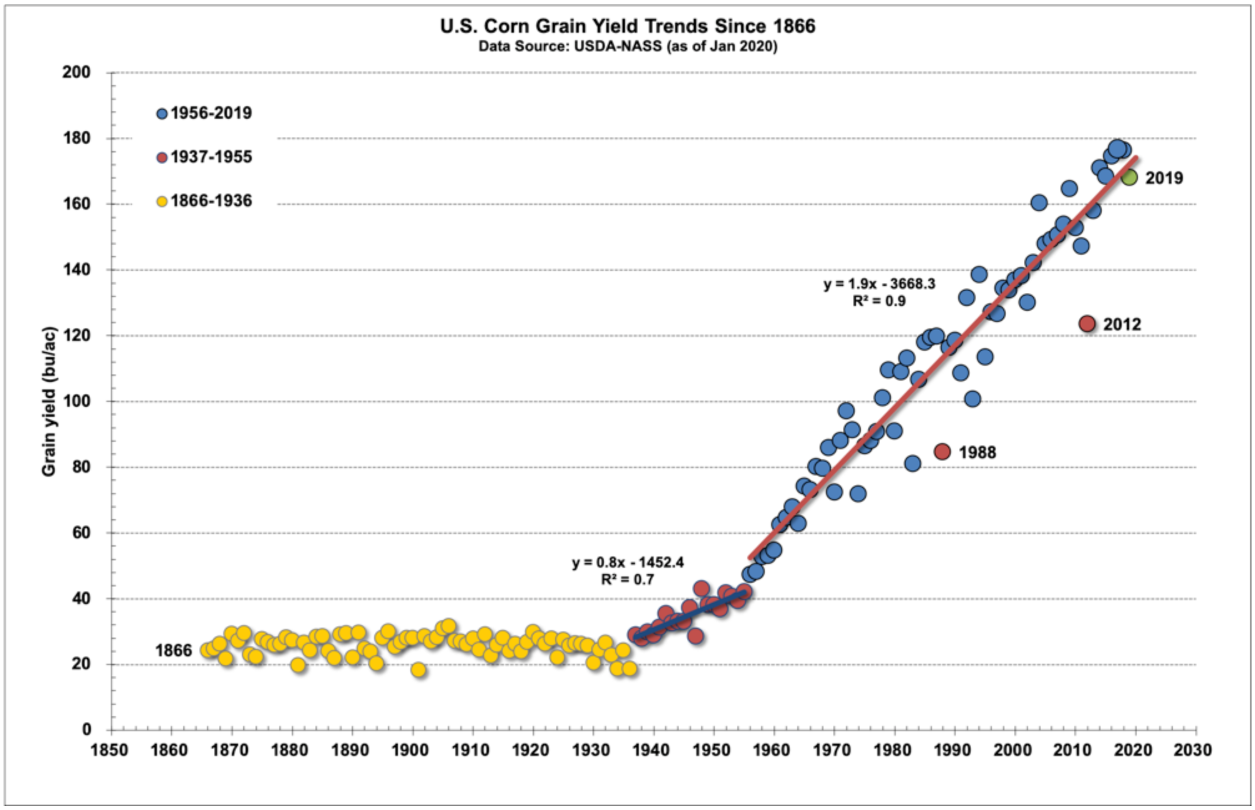

Figure 2. The figure shows yield data in the United States since 1866 and the two linear time trends. Nielsen, B. (2020, April). Historical Corn Grain Yields in the U.S. Historical Corn Grain Yields in the U.S. (Purdue University). https://www.agry.purdue.edu/ext/corn/news/timeless/YieldTrends.html.

Climate Change

Climate change is a continuous problem and is growing at an exponential rate. As the composition of the atmosphere changes, the effects of climate change become more noticeable. Even in Nebraska, the climate has shifted and is predicted to keep shifting (Williams). The average temperature has gone up, and droughts and floods have become more frequent. The transportation, production, and storage of agricultural products, which are impacted by the increasing temperature, droughts, and flooding, also play a role in creating more pollutants.

Earth's climate has always been changing and shifting. The Earth has gone through many warming and cooling phases over its vast lifetime. These trends are normal and are what lead to many extinction-level events such as the Ice Age. While some species have not survived these climate changes, it has given rise to new species, such as humans. Over the past several centuries, humanity has lived through a relatively calm era in the Earth's climate. Based on historical trends, the Earth should be cooling ever so slightly. However, over the past two centuries, humans have been burning fossil fuels at abnormal rates. This, in turn, has changed the makeup of the atmosphere's chemical content dramatically, releasing more gases into the air, such as carbon dioxide. The shift in the atmosphere's content has led to a change in many climate patterns like temperature and precipitation (Williams).

Human Involvement in Climate Change

Currently, humans impact the environment and climate in many ways. Specifically, humans are accelerating the rate of this natural process to an unnatural point. Humans have been releasing more greenhouse gasses into the air. Greenhouse gasses include carbon dioxide, methane, nitrous oxide, and fluorinated gasses. Greenhouse gasses act like a blanket around the Earth, trapping more of the sun's energy and heating up overall atmosphere temperatures. There are a variety of events that contribute to the emissions of greenhouse gasses. Burning coal, oil, and gas release previously buried carbon dioxide and nitrous oxide. An increase in livestock farming also causes increased methane expulsion from cows and sheep digesting their food. Fertilizers used on crops create more nitrous oxide emissions. Trees are responsible for pulling carbon dioxide out of the air. Additionally, humans are cutting down trees leading to massive, deforested areas and keeping trees from acting as a carbon sink (pulling carbon dioxide out of the atmosphere and expelling oxygen back into the atmosphere). The increase in these greenhouse gasses trap the heat from the sun and reduces the Earth's ability to cool off, increasing its overall average temperature (European Union).

Climate Change's Impact on Agriculture

The impacts of climate change are far-reaching. Some of those impacts including increasing the amount of atmospheric carbon, the rise in temperatures, and the frequency and intensity of extreme weather. All of these pieces can impact the production and yield of a crop for better or worse. Depending on the crop, an increase in average temperature may be a move toward the crop's optimal growth and reproduction temperature. A temperature change can open new areas of land that had been previously too cold to produce the crop. However, extreme temperatures and precipitation will prevent crops from growing. For example, in 2012, increased temperatures at night caused cherries in Michigan to bud prematurely causing a large loss of the crop. A temperature change creates a more inhospitable environment for crops and creates a more favorable environment for weeds, insects, and fungi. Weeds and other pests create more competition for sunlight and nutrients that crops need (Environmental Protection Agency). Overall, changes in trends in the climate in weather can have many consequences on agriculture.

Climate change impacts crops and grain which directly impacts livestock. A large portion of corn and soybeans go into producing livestock feed. An increase in temperature has one of the largest direct impacts on livestock. Heatwaves stress the animals, leaving them more vulnerable to disease and reduces their fertility. Warmer winters allow more parasites and pathogens to survive and infect livestock. A reduction in rainfall decreases the amount of grazeable land for livestock. Increases in carbon dioxide do increase the productivity of pastures, but it decreases the quality of the plants in the pasture (Environmental Protection Agency.) Not only does climate change affect grain production, but it also influences livestock production, which is important when considering how much grain should be going to feed the livestock throughout the year.

Climate change reaches many parts of the supply chain, in fact, "Climate change can disrupt food availability, reduce access to food, and affect food quality" (Environmental Protection Agency). An increase in temperature makes it more difficult to preserve food. It can increase spoilage and contamination. Many countries, including the United States, rely on waterways to transport grain. High temperatures and a reduction in rainfall can severely impact the water height of the Mississippi River, which is the major transcontinental shipping route for almost all Midwestern agriculture. Droughts will reduce barge traffic and the ability to carry high volumes of goods through the United States. Climate change reaches all parts of the supply chain around agriculture.

Climate Change's Impact on Precipitation

Climate change is currently impacting all parts of weather, including one of its fundamental pieces, precipitation. On average, global precipitation has increased about .08 inches every decade as shown in Figure 3.

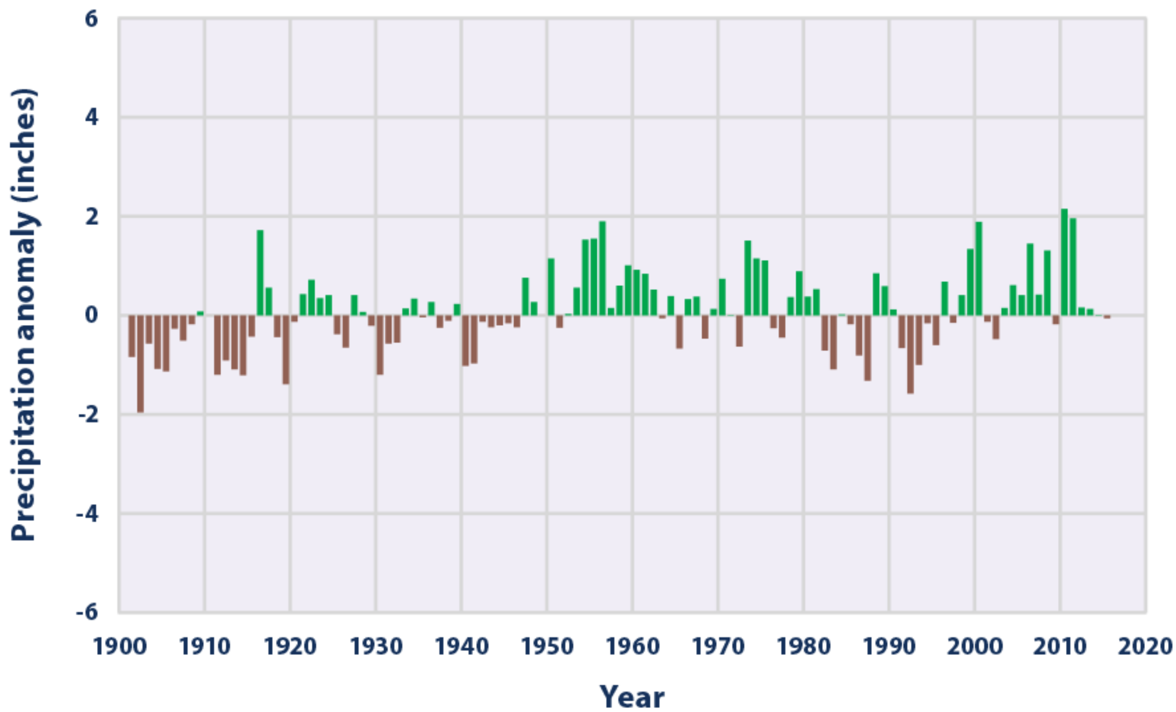

Figure 2. The figure shows the United States precipitation anomalies since 1900. The baseline is the average from 1900-2000. Environmental Protection Agency. (2021, January 30). Climate Change Indicators: U.S. and Global Precipitation. EPA. https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation.

In the United States, the rate is even higher, at .17 inches per decade. As seen in Figure 4, some parts of the United States have increased at an even greater rate, while some areas such as the southwest have had a decrease in average precipitation (Environmental Protection Agency).

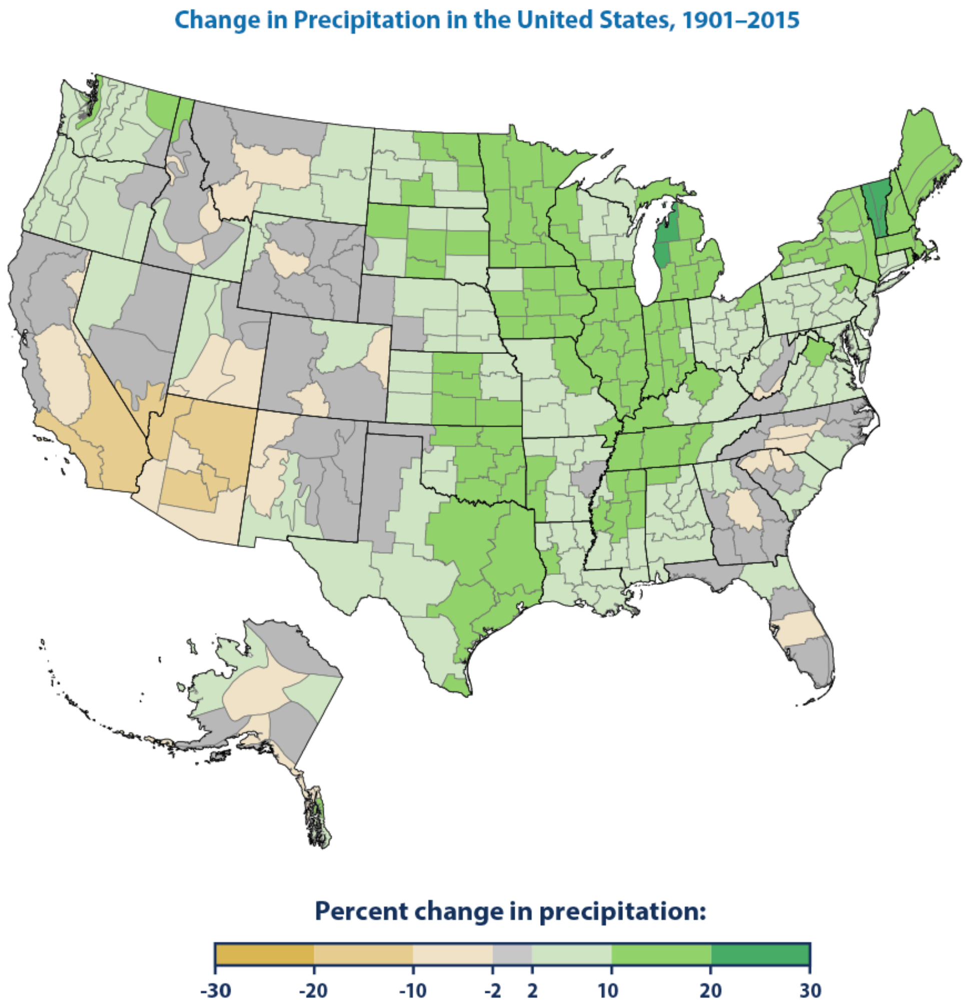

Figure 3. Figure show percent change in precipitation rates across the United States. Environmental Protection Agency. (2021, January 30). Climate Change Indicators: U.S. and Global Precipitation. EPA. https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation.

Overall, largely agricultural states in the Midwest have had an increase in precipitation. Climate change has also impacted wind patterns. Wind patterns are what are responsible for moving evaporated water. The shift in wind patterns have moved dry areas and wet areas to new zones. Even with the increase in precipitation, there are still downsides, in fact, "higher temperatures lead to more evaporation, so increased precipitation will not necessarily increase the amount of water available for drinking, irrigation, and industry" (Environmental Protection Agency). While this data does show an overall trend, it does have some imprecisions. The lack of weather stations in the early 20th century reduces the ability to create an appropriate average (Environmental Protection Agency).

Literature Review

Much of the research that went into designing this thesis was completed and outlined in the article *Weather, Technology, and Corn and Soybean Yields in the U.S. Corn Belt* by Tannura, Irwin, and Good. They studied and discussed a broader relationship between yield, weather, and technology. Specifically, the study used precipitation and temperature to represent weather. They compared changes in weather and technology to both corn and soybean yield in Illinois, Indiana, and Iowa. To complete the study, yield data was gathered from the National Agricultural Statistics Service database, Quick Stats. The weather data was collected for precipitation and air temperature by month from a combination of resources included the Cooperative Network, National Weather Service offices, and principal climatological stations.

From there, a regression model was created to determine the relationship between all of the variables to yield. Both precipitation and temperature data were grouped into monthly averages based on the growing season. So, precipitation was grouped into the following variable sets, September through April, May, June, July, and August. The individual months were given modeled in quadratic form. Temperature data from the following months was also variable in the model, May, June, July, and August. The temperature data was exclusively modeled linearly. Lastly, both a time variable and a technology variable were included in the model to account for changes due to independent trends from time and changes due to technology.

Overall, the model for each state and crop was fairly accurate. The R squared values ranged between .89 and .95, meaning 89% - 95% of the variations in yield could be explained by the model. While the model did explain a lot of the variations in yield, it did leave out a few key factors. To start, the model did not consider variations caused by insects, diseases, or pests. While outbreaks of insects or diseases are less common than variations in weather, they can still play a role in determining the yield of a crop. Additionally, the model did not study all the pieces of weather data, including temperature data for all of the months, nor any temperature or weather anomalies such as freezes or large storms.

This particular study is important to this thesis as it laid the groundwork in identifying trends between weather and changes in yield. However, this thesis will take a closer, more specific look at the impacts of precipitation and its impact on corn yield in Iowa. It is important to understand specifically how changes in precipitation can impact corn yield as climate changes challenge weather norms like average precipitation.

Methods

Design and Approach

The thesis was completed in two parts. The first part was the collection of the crop yield and precipitation data. The second part of the thesis used statistical analysis to determine the correlation between crop yield, precipitation, and the time trend. A regression analysis was used to create a quadratic line of best fit. A quadratic line of best fit was used over a linear line of best fit as both too much or too little rain could have an impact on crop yield. A quadratic relationship can consider the impacts of too little or not enough precipitation. A linear model could only look at one. A similar model was created by Michael A. Tannura, Scott H. Irwin, and Darrel L. Good in the paper that was discussed in the literature review.

Data Collection

A. Corn Yield

Crop yield data was gathered from the National Agriculture Statistics Services (NASS), which is a part of the United States Department of Agriculture (USDA) at https://quickstats.nass.usda.gov. Thirty years of corn yield from 1991 to 2020 was collected for the state of Iowa. Quick Stats database from NASS fields were narrowed as followed for the data collection: Program: Survey; Sector: Crops; Group: Field Crops; Commodity: Corn; Category: Yield; Data Item: Corn, Grain – Yield, Measured in Bu / Acre; Domain: Total; Geographic Level: State; State: Iowa; Year: 1991 – 2020; Period Type: Annual; Period: Year. The data was then downloaded as a CSV file. From there it was imported to Excel.

B. Precipitation Data

The average precipitation data was collected from the National Oceanic and Atmospheric Administration's (NOAA) at https://www.ncdc.noaa.gov/cag/statewide/time-series. Specifically, it was pulled from the Climate-at-a-Glance database under the statewide time series. Thirty years of yearly total precipitation data ranging from October of 1991 to September of 2020 was pulled. The total precipitation data for each year from October-September instead of the typical calendar year, January- December was downloaded. October- September is considered to be the water year. From there, a CSV file was downloaded and then converted into a Microsoft Excel Workbook.

Data Analysis

The data for this thesis was compared similarly to the data from the study *Weather, Technology, and Corn and Soybean Yields in the U.S. Corn Belt*. A regression analysis was performed in Excel to determine if there was a relationship. To do so, the yield data and precipitation data were placed in the same Excel sheet, matching up data to their appropriate year. From there, the year column was replaced with a time count from one to thirty to account for the long-term time trend in yield. Another column was created and labeled precipitation squared. From there, the squared value of the precipitation was calculated in that column. This allowed the quadratic model to be analyzed over a linear model. Once the data is set up properly, using the data analysis tool in Microsoft Excel, a regression analysis was performed. Yield data was entered as the y-value (dependent variable) and the time count, precipitation, and precipitation squared data were entered as the x-values (independent variables).

Once the regression analysis was completed, the following model was created with the results:

$$(yield) = \beta_0 + \beta_1(time\ trend) + \beta_2(October\ through\ September\ Precipitation) + \beta_3(October\ through\ September\ Precipitation)^2$$

From there, values such as the R squared value, the p-values, and the upper and lower 95% values were used to determine how well the data fits the model. The derivative of the modeled equation above was derived to determine the relationship between a change in precipitation and a change in yield as demonstrated in the following equation:

$$\frac{d(yield)}{d(precipitation)} = \beta_2 + 2 * \beta_3(October\ through\ September\ Precipitation)$$

Results

Below, the graphs demonstrate the raw data collected. Additionally, they represent the analysis and models created as described in the methods.

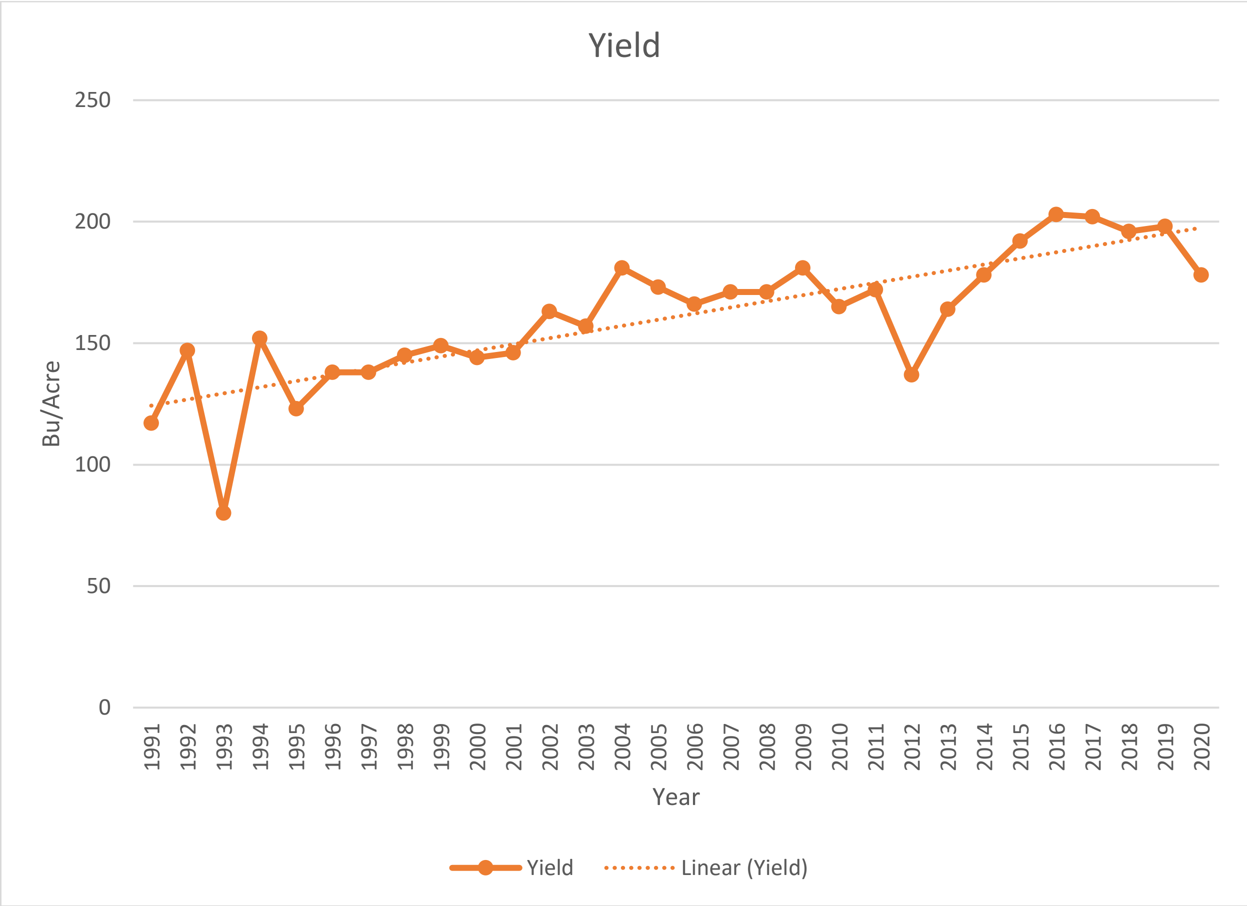

Figure 4. The figure shows yield data collected as well as a linear time trend line.

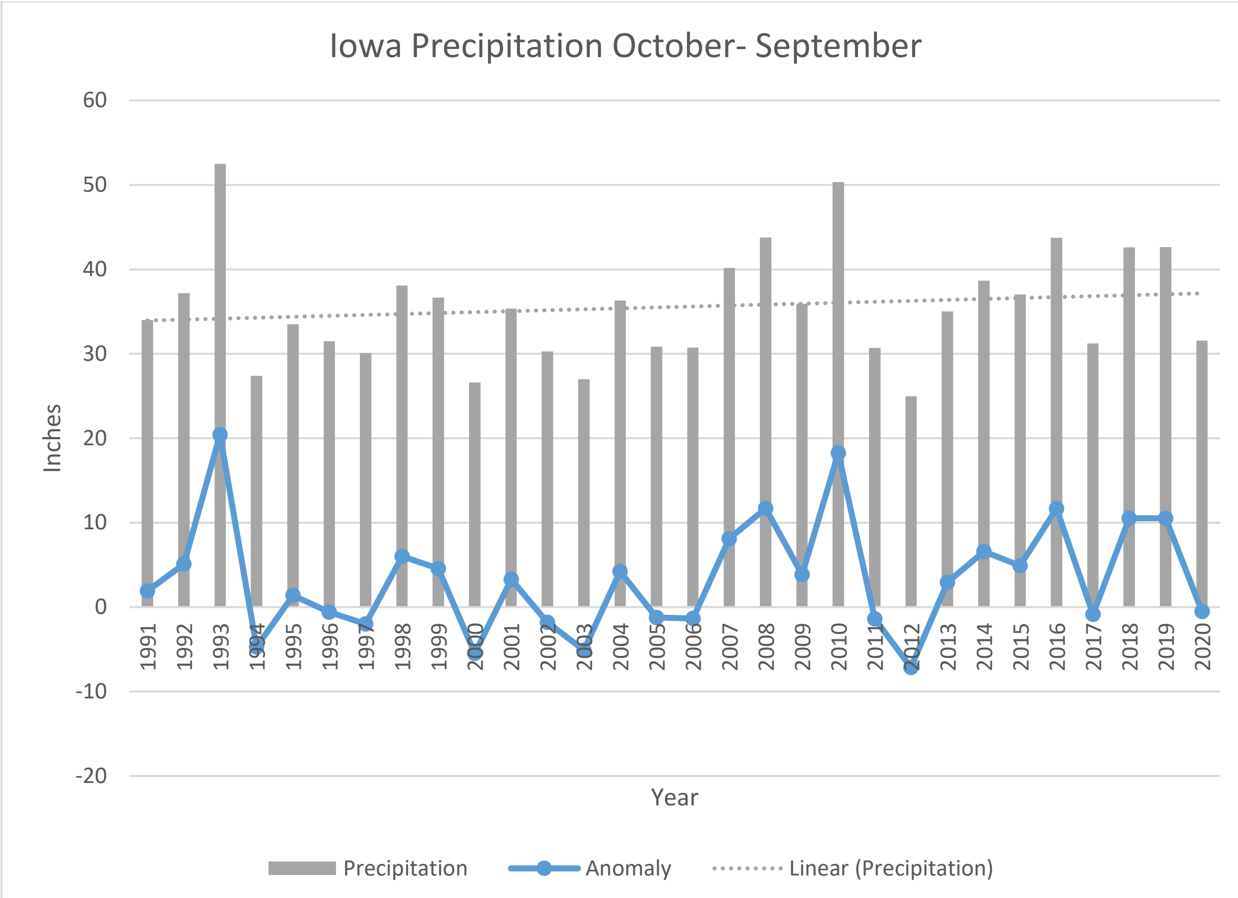

Figure 5. The figure shows precipitation data collected and the anomaly per year, t the baseline for the anomaly is set from 1900-2000. Additionally, a linear time trend line of precipitation is included.

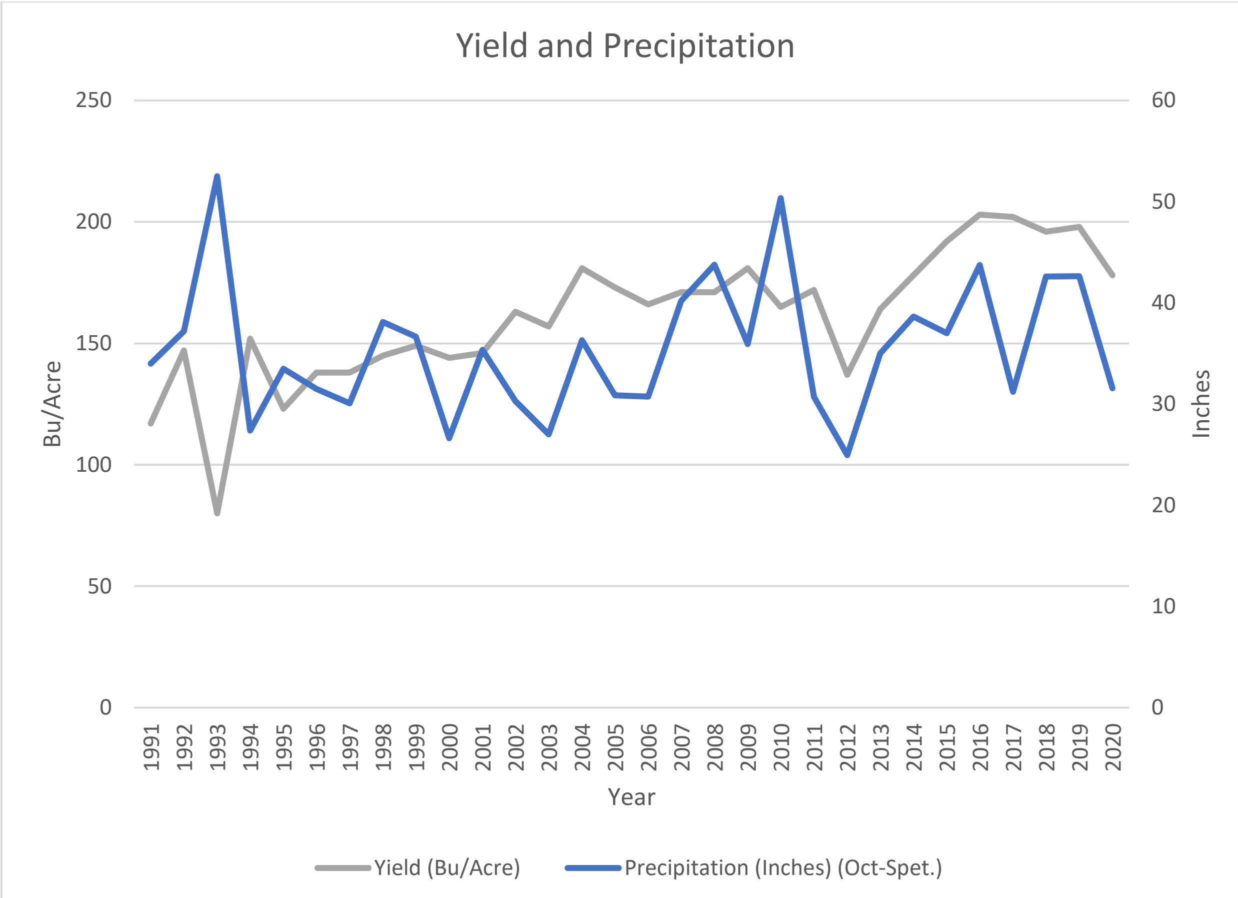

Figure 6. The figure shows yield data and precipitation data laid over each other.

Table 1. The table shows results collected from regression analysis.

Regression Statistics						
Multiple R	0.881441683					
R Square	0.776939441					
Adjusted R Square	0.751201684					
Standard Error	13.6377064					
Observations	30					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	16843.03707	5614.345689	30.18675823	1.26102E-08	
Residual	26	4835.662934	185.9870359			
Total	29	21678.7				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-90.19061811	64.06578125	-1.407781445	0.17104031	-221.8797175	41.49848126
Precipitation (Inches) (Oct-Spet.)	11.97155003	3.467713637	3.452289111	0.001914386	4.843562564	19.0995375
Precip. Squared	-0.161906198	0.045338571	-3.571047662	0.001415484	-0.255100965	-0.068711431
Time Count	2.396689311	0.294441713	8.139775064	1.27641E-08	1.791455702	3.001922919

Below is the model created by the provided equation in methods using the collected data from Microsoft Excel's regression analysis.

$$(yield) = (-90.191) + 2.397(time\ trend) + 11.972(October\ through\ September\ Precipitation) + (-0.162)(October\ through\ September\ Precipitation)^2$$

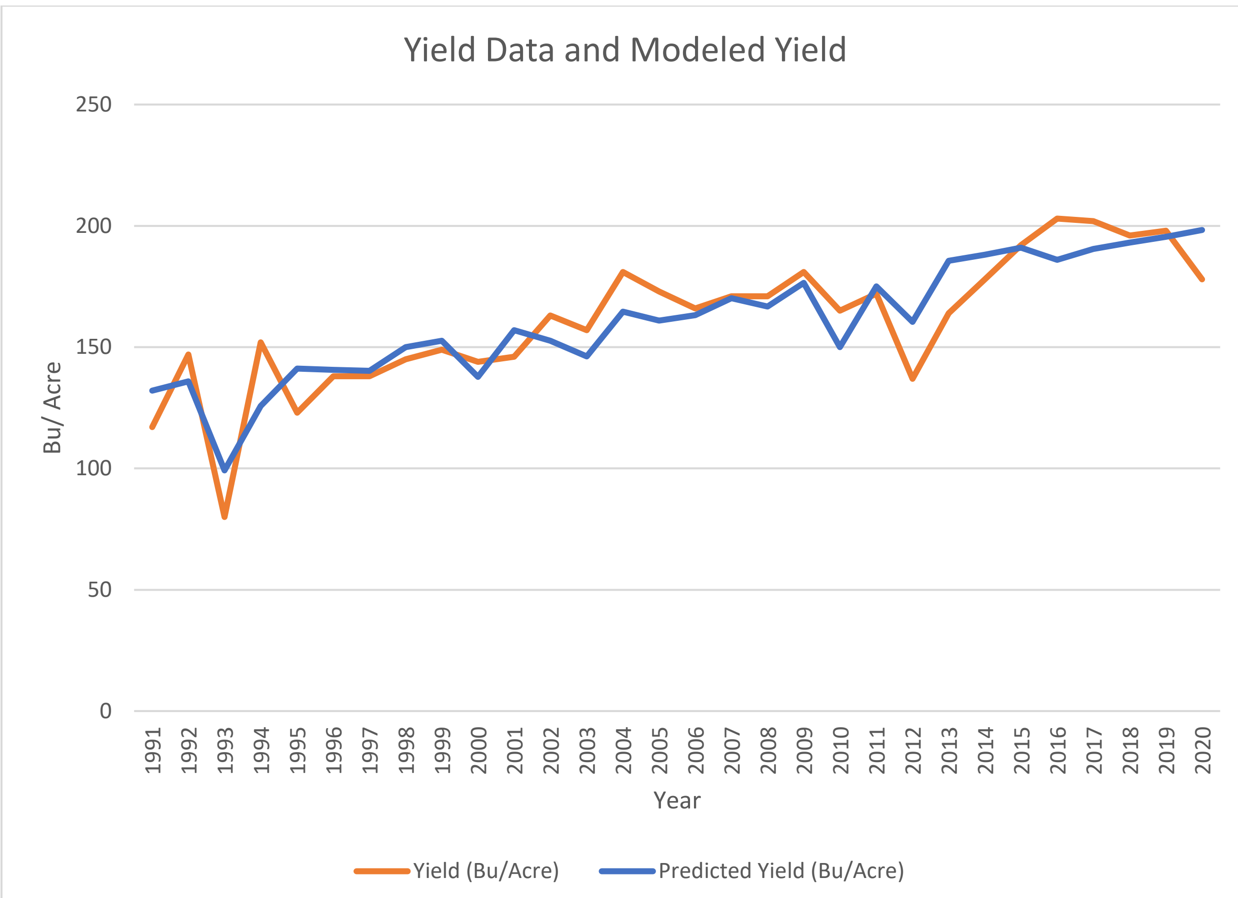

Figure 7. The figure shows collected yield data overlaid by the predicted yield from the model created.

The below equation is the derivative of the model, representing how the change in precipitation impacts the change in yield.

$$\frac{d(yield)}{d(precipitation)} = 11.972 + (-.324)(October\ through\ September\ Precipitation)$$

Figure 9 shows this equation on a chart, representing the relationship between a change in precipitations (x-axis) and a change in yield (y-axis).

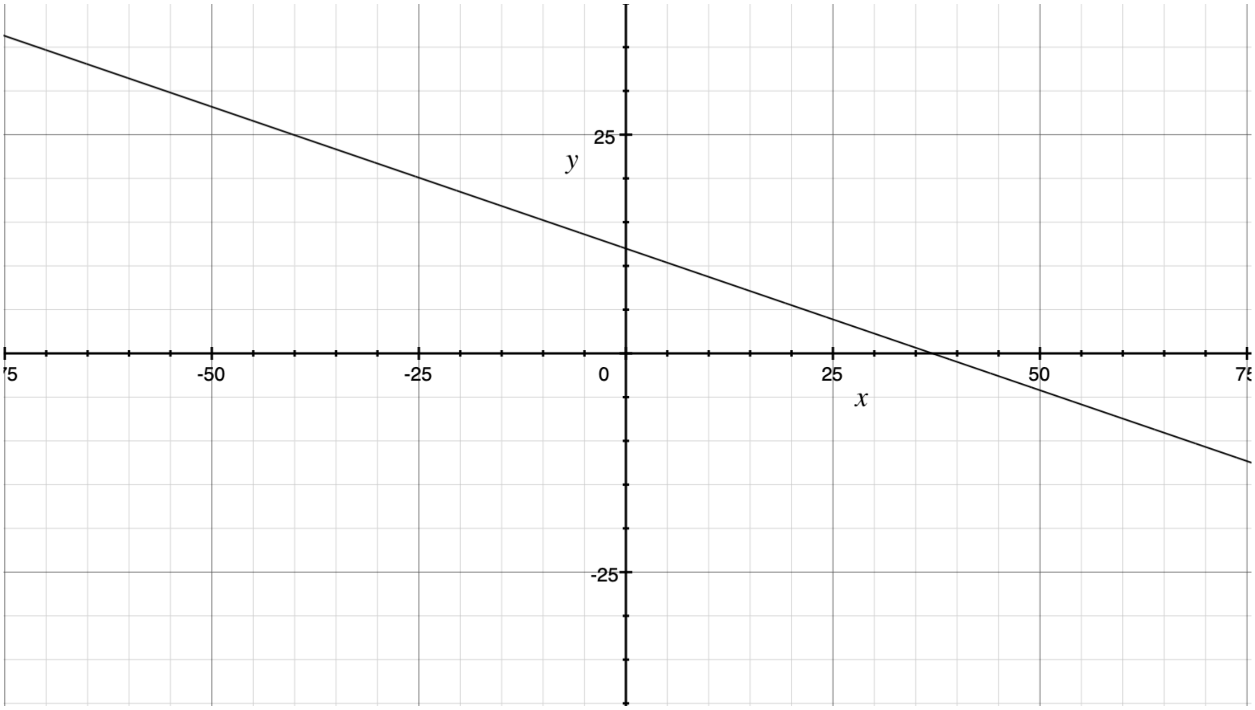

Figure 8. The figure plots the derivative of the model.

Discussion

Overall, the data collected and analyzed shows a strong correlation between changes in yearly precipitation and crop yield. To start, the adjusted R squared value is 0.751201684. This means 75.12% of the data can be explained by the model. Or to say it another way, 75.12% of the variation in yield can be explained by a change in precipitation and the time trend. The similarity of the actual yield data and the yield calculated by the model is shown in Figure 7. As shown by the graph, the two lines follow each other closely. This demonstrates the similarity between the modeled yield and the actual yield data collected

The significance F value, which is 1.26102E-08, represents the probability of how likely it is the model is wrong, or how likely the adjusted R squared value is incorrect. The smaller the number, the more probable the model is correct. This value shows there is a 1.26E-06% chance the model is incorrect. The small value strengthens the argument that there is a relationship.

Statistically, the next thing to note is the confidence intervals for each coefficient in the model. The coefficients in the model are as follows: intercept, -90.19061811; precipitation, 11.97155003; precipitation squared, -0.161906198; and time trend, 2.396689311. The upper and lower 95% confidence interval provides a range in which Excel is 95% confident that the coefficient lies within that range. The lower 95% and upper 95% for each coefficient respectfully are intercept, (-221.8797175, 41.49848126); precipitation, (4.843562564, 19.0995375); precipitation squared, (-0.255100965, -0.068711431); and time count, (1.791455702, 3.001922919). What is important to note is the signs (negative or positive) are the same within the upper and lower limit of the range for the precipitation, precipitation squared, and time trend. This guarantees the direction of movement (or slope) in the modeled equation. The intercept range does sit on either side of zero. The upper 95% is positive and the lower 95% is negative. This is less important as the intercept does not indicate a direction or slope, it simply moves the whole model up and down on the y axis.

The p-value sums up the importance of the upper 95% and lower 95% confidence intervals. It represents how likely the coefficient is equal to zero. The smaller the p-value, the less likely the coefficient is equal to zero and the smaller the confidence interval will be. The p-values are as follows: intercept, 0.17104031; precipitation, 0.001914386; precipitation squared, 0.001415484; and time count, 1.27641E-08. Except for the intercept, the p-values are all less than .2%. This means there is less than a .2% chance that the coefficients are equal to zero. The p-value of the intercept is fairly high at 0.17104031. However, it is insignificant and it does not impact the model nearly as much as a low p-value for the other coefficients.

The derivative of the model equation provides a lot of important information. As seen in Figure 9, the downward slope of the line represents the duality of the impact of precipitation. As you move to the left (there is a negative change in precipitation), the impact on yield increases. As you move right, the impact of precipitation decreases, until the line crosses the x-axis at 36.95. Once the line crosses the x-axis, more precipitation begins to negatively impact yield as well. Essentially, the model shows that if there is more than a 36.95-inch increase in precipitation every year, crop yield will be negatively impacted. This line demonstrates that drier conditions impact the yield of corn as does too much precipitation.

Overall, the statistical analysis does support a relationship between precipitation and corn yield. However, the model does have some room for error, specifically when looking at the p-value of the intercept and the adjusted R squared value. Comparable studies, such as the one from *Weather, Technology, and Corn and Soybean Yields in the U.S. Corn Belt*, had much higher R squared values. The R square values from this model varied between .89 and .95. This is likely because the model considered more variables than this thesis did. The model includes temperature data, in addition to splitting both precipitation data and temperature data out by month or groups of months based on growing periods. The study also accounted for changes in technology (Tannura).

It is important to note that there are variables beyond temperature and technology that could impact the results found in this study. Unusual weather events can go unnoticed in average trends, such as freezes or derechos, and have lasting impacts on crop yield. For example, a derecho in Iowa in 2020 destroyed more than 10 million acres of corn and soybeans. Over 43% of the soybean and corn crop suffered damage. This impact can go unseen by yearly precipitation and temperature data. In addition, insects, pests, and diseases can have a large impact on crop yield. For example, a blight epidemic in 1970 reduced yields in Illinois and Indiana by nearly 50% (Cappucci). Events like this go unnoticed by the model used in this thesis.

Some other trends to note are in the raw data. Both the precipitation data and yield data have an upward trend that can best be represented by a linear trendline. The upward trend in the precipitation data supports what was discussed in the introduction by the article "Climate Change Indicators: U.S. and Global Precipitation." The article states that climate change is causing the average amount of precipitation to increase. The precipitation trend line in this thesis model that trend. In addition, a linear trend line shows that yield on average increases every year. The increase in yield every year can be attributed to improved genetics of the crop and improvements in crop production technology. This trend demonstrates and helps predict how much corn will be produced. The article, *Historical Corn Grain Yields in the U.S. Historical Corn Grain Yields in the U.S* states, "Annual corn yields continually fluctuate above and below the historical trend line primarily in response to variability in growing conditions year to year (weather, pests)" (Nielsen). Moving forward to potential future studies, these variables should be included to create a more accurate yield model.

Summary and Conclusions

Overall, the model generated shows an important correlation between changes in precipitation and their impact on corn yield. Understanding this correlation is important because climate change continues to impact weather patterns such as average precipitation (Environmental Protection Agency). The adjusted R squared value shows that 75% of the yield changes are due to changes in precipitation and the time trend. This model could be used to determine trends in yield, based on predicted trends in precipitation. The model would be valuable in helping predict yield and the overall supply of corn in the future. Since the adjusted R squared value is 75%, this leaves 25% of the changes in yield to be determined by other variables. These variables, such as average temperature, extreme weather events (such as freezes or derechos), insects, pests, and infectious diseases, could be considered for future studies to create a more accurate yield model. It is important to consider the relationship that precipitation has with yield and how climate change is impacting precipitation rates as climate change could have an impact on corn yields in the future.

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