MTF Challenge Project

A report on the effects of precipitation anomalies caused by climate change on soybean production in Missouri and its implications on the future of the agriculture industry and insurance policies.

"SO-YA-BEAN LOSING MONEY?

It's Pure Missouri!"

Team SANA

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Introduction

Executive Summary

Soybeans are used in food products, livestock feed, and many other commodities as an oil component. Soybeans were the top agricultural export of the United States in 2017, generating $21.6 billion in revenue.[1] Over 80% of the United States' soybeans are grown in the Midwest, with Missouri as one of the leading 10 states in soybean production.[2]

In 2018, $98.8 million were paid as indemnities by insurance companies for soybeans due to precipitation anomalies, including drought, excess precipitation, and flooding in Missouri; this amount accounts for approximately 87% of total indemnities paid for soybeans due to all causes ($113,396,727). This implies that much of the losses attributed to soybean production are due to precipitation anomalies, which will occur more frequently due to climate change.

Data from the National Oceanic and Atmospheric Administration (NOAA) clearly indicates that the number of floods increased over the course of 1991 to 2019. In addition, the data predicts an upward trajectory for total costs due to natural disasters, because the severity of floods and droughts will likely increase in the future and the damage will increase exponentially. Data from the NOAA statewide time series also indicates that the precipitation in Missouri will continue to increase by approximately 0.94 inches per decade[3].

To find the relationship between precipitation anomalies and soybean yield, we constructed a graph comparing percent yield for each year since 1991 with the corresponding precipitation anomalies for that year. We then created a quadratic regression line and the resulting graph followed the pattern of a negative parabola. This indicates an inverse relationship in which smaller precipitation anomalies correspond with higher yields, and larger precipitation anomalies correspond with lower yields.

We then identified the annual payment indemnities for soybeans due to precipitation anomalies in Missouri from 1991 to 2019. Using this data, we evaluated different models to estimate the increase in payment indemnities per year. Furthermore, we predicted the amount of indemnities that will be paid in 2050 after accounting for inflation.

We recommend improving irrigation systems, adjusting premiums, and reducing carbon footprints in order to combat the risks faced by the agricultural industry, insurance industry, and global economy due to climate change. These changes are expected to mitigate losses to the agricultural and insurance companies.

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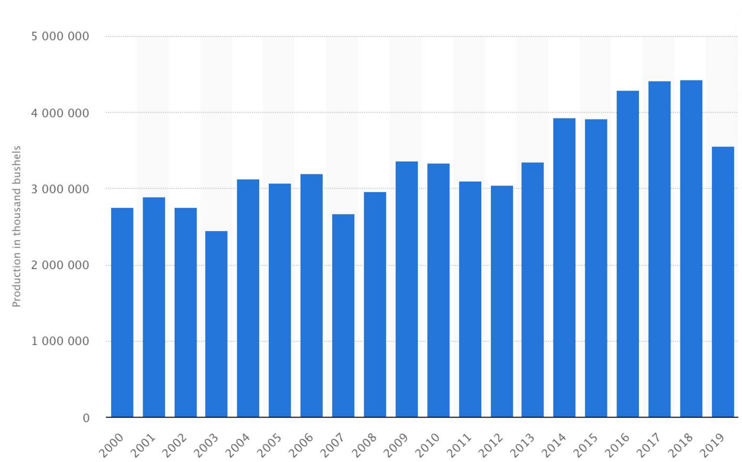
[1] United States Department of Agriculture
[2] Statista
[3] National Ocean and Atmospheric Administration

Background Information

Soybeans are an invaluable product in the agricultural industry as they are not only a major component of our diet but are also used as nourishing feed for livestock. The wide use of soybeans is largely due to the fact that it is 50% protein, making it highly nutritional. Soybeans contain bioactive compounds called isoflavones which are proven to lower diabetes and the risk of heart disease. Considering the fact that the number of Americans that suffer from diabetes is projected to triple by 2050,[4] the importance of soybeans will only grow in the future. The nutrition-rich soybeans also play a crucial role in the growing vegan lifestyle as a plant-based substitute in foods such as soy milk, plant-based meat products, and tofu. In 2019, plant-based food retails increased by over 11%, making it a 4.5 billion dollar industry.[5] Furthermore, soybeans are a versatile crop, and its components are often utilized in a variety of products such as margarine, paints, adhesives, fertilizers, and fire-extinguisher fluids.

The most significant role of soybeans is in the diet of livestock. More than 70% of soybeans grown are used as feed for poultry and livestock such as cattle and pigs due to their high protein content and availability year-round. Thus, the soybean industry directly affects the meat industry.[6] Consequently, the loss of soybeans would entail the loss of a major food source for livestock, causing humans to lose a major component of their diet as well.

The demand of the U.S. soybean crop has increased 3.05% since 1986 as evidenced by the bar graph of production in thousand bushels vs year to the right.[7] The United States produced 108 million metric tons of soybeans in 2018, accounting for 34% of the world's soybeans, and has a 42% market share, making it the largest exporter of soybeans on a commodity basis.[8]



Considering that the United States is responsible for a large amount of soybean production in the world, it is imperative to analyze how climate change may impact soybean production. Missouri ranks seventh among the top soybean producing states in the US, with 289,590,000 bushels harvested in 2018. With

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[4] Centers for Disease Control and Prevention
[5] *Newsweek*
[6] *ResearchGate*
[7] *Statista*
[8] *WorldAtlas*

approximately 95,000 soybean farms in Missouri, two-thirds of the state's total land acreage is allocated for soybean farmers[9]. Soybean meal is the second highest exported product in Missouri; in 2015 soybean meal exports generated $281,987,000, making soybeans the top agricultural commodity in Missouri. In 2016, Missouri produced 7% more soybeans than it did in 2015[10]. As demand for soybeans continues to grow, Missouri will need to find a way to address the challenges it faces due to climate change as their economy will depend on it.

As climate change increases globally, so do its effects on other climate factors such as temperature, natural disasters, air quality, and precipitation. After examining the different elements that affect soybean production[11], we found that precipitation irregularities have the greatest repercussions on indemnities and thus, decided to focus on it. Missouri has been faced with greater precipitation anomalies in recent years, which pose a threat to soybean production. Studies show that there has been a significant increase in extreme precipitation occurrences from 1948 to 1978, specifically in the Central United States as, "53% of the total precipitation increase was a result of positive trends in the upper 10th percentile of the distribution". On the other end of the spectrum, "drought is expanding during the summer to cover 39% of the contiguous United States (PDSI ≤ −3.0), which is the largest extent since the 1950s."[12] This shows that there is a trend of increasing dryness in the United States.[13] The Trends in Flood Magnitude figure[14] to the right supports this. Soybean yield is sensitive to both wet and dry extremities as during the reproductive stage, soybean yield can decrease as a result of either water deficit or water inundation.[15] Furthermore, for optimal growth, soybeans require adequate exposure to oxygen. Excessive flooding decreases soybean yield as water has a lower oxygen content than air. After 24 hours in flooded soil, oxygen concentration can be close to zero. Flooded soils also contain 50 times more toxins than non-flooded soils, which can contaminate soybean plants and reduce yield as well.

Trends in Flood Magnitude

With the frequency of precipitation anomalies in Missouri that are showing upward trends due to climate change, it is necessary to predict how this will affect the agricultural industry and identify ways to minimize losses attributed to decreases in soybean yields.

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[9] *Missouri Department of Agriculture*
[10] *United States Department of Agriculture: National Agricultural Statistics Service*
[11] *USDA RMA*
[12] *American Geophysical Union Publications.*
[13] *American Meteorological Society*
[14] *Peterson et al. (2013)*
[15] *Iowa State University, Department of Agronomy*

Modeling

Assumptions

1. We consider a correlation coefficient of 0.5 to 0.7 to represent a moderately strong relationship.
2. We assume that the upward trends in flood and excess precipitation will continue in coming decades, through 2050.
3. From 2019 to 2050 the mean precipitation value will remain 43.59 inches or possibly increase, as it has remained this value for the past 30 years.[16]
4. We consider precipitation anomalies to be any irregularities in precipitation that deviated from the mean precipitation per year in Missouri, which was 43.59 inches.
5. We consider soybean yield to be sensitive to precipitation anomalies, including but not limited to droughts, excess precipitation, and flooding.
6. We acknowledge that there are other factors such as pesticide use, genetic engineering, fertilizers, and other natural disasters, which could affect soybeans and thus affect our percent yield.
7. Since farmers are insured when natural disasters have negative impacts on soybean yield, we assume that higher indemnities will be paid when soybean percent yields (number of acres harvested divided by acres planted) are lower.
8. We consider that claims filed for loss indicate a lower percent yield, meaning that a farmer has lost money. It also indicates that the insurance company will lose money if the claim exceeds their premium values.

[16] *NOAA*

Data Methodology

Climate Data

In order to find trend lines for precipitation in Missouri, we used data from the National Oceanic and Atmospheric Administration (NOAA), a scientific agency within the United States Department of Commerce. First, we acquired data that demonstrated the increasing irregularity of precipitation patterns in Missouri through the statewide time series tool. We also obtained precipitation anomaly data from the NOAA, which took each year's precipitation measure's departure from the mean of 43.59 inches. These anomaly values were necessary in order to model the main relationship of our project: climate change and the monetary losses of the agricultural industry and insurance companies. The precipitation anomaly values obtained were used to create a linear regression model comparing precipitation anomaly values from the years 1991-2019.

In order to model the effects of climate change on the agricultural industry, it was imperative to first find data regarding the effect of climate change on water anomalies, our area of focus. To do so, we utilized Volume II of the Fourth National Climate Assessment from the US Global Change Research Program, which provided a plethora of antiquated information as well as trends in recent years. We obtained our information from Chapter 7, which focused on water access, floods, and droughts. Through this source, we were able to confirm an upward trend in the occurrence of floods, droughts, and excessive precipitation as the years went on due to climate change, specifically in the Midwest region of the US. This validated the basis of our report, as it proved that excessive precipitation has become a common occurrence in recent years due to climate change, posing a potential risk to soybean farmers in Missouri.

Soybean Data

To find percent yield for soybeans, we utilized data from the United States Department of Agriculture (USDA) National Agricultural Statistics Service's Quick Stats, in which we obtained data for both acres harvested and acres planted each year from 1991-2019. Noting the source's credibility, we decided to use the annual survey option instead of the 10 year - census option to obtain more data points. For both of the "Acres Harvested" and "Acres Planted" data sets, the domain was set to "total", and the period type was set to "annual", as those were the only available functions for the two settings; the period was set to "year", as we quantified based on whole years rather than seasons or months. This data was used to calculate percent yield, which was necessary to model the relationship between the magnitude of precipitation anomalies and percent yield.

Indemnity Data

We used the USDA Risk Management Agency (RMA) Cause of Loss Viewer to find the payment indemnities per year from 1991 to 2018 in Missouri, for soybeans due to precipitation anomalies. The categories were set to soybeans, Missouri, and precipitation anomalies. This step was required to accurately predict the indemnity value in 2050 for money lost due to precipitation. The USDA RMA provided information regarding the overall climate of the region as well as the specific causes of loss. Using the payment indemnities per year from the Cause of Loss Viewer, we created a regression model. However, it was imperative to take into consideration the monetary inflation that will occur from 2019 to 2050; therefore we utilized "Inflation Data" in order to obtain the standard inflation rate of 3.22%. Using the value from the data source, we were able to predict a more accurate range of values for indemnities paid.

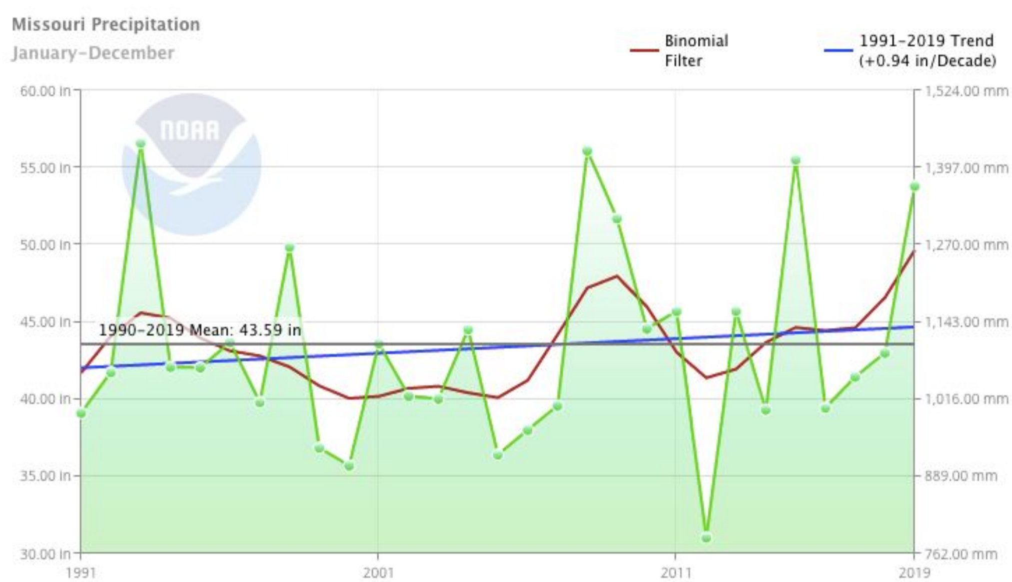
Utilizing all of these data sets, we were able to quantify the risks climate change and water access pose to soybeans, which enabled us to make recommendations to the agricultural industry and insurance companies in order to mitigate them.

Mathematics Methodology

P(x)	Average predicted precipitation in inches per year
Y(x)	Percent yield due to precipitation anomalies
A(x)	Predicted precipitation anomaly (absolute value of amount deviating from mean)
I(x)	Least Squares Regression Model of total indemnities due to floods, excess precipitation, and droughts
M(x)	Exponential Model between years and indemnities due to floods, excess precipitation, and droughts
W(x)	Power Regression Model between years and indemnities due to floods, excess precipitation, and droughts.

1) As shown in Figure 1, we see that as years go on, precipitation becomes more frequent and irregular, exemplified by the red moving average trendline. While examining soybean production in Missouri, we noticed that it is negatively impacted by precipitation, which we anticipate will increase in irregularity. This indicates that as climate change increases, the frequency of precipitation anomaly occurrences increases as well. To prove this, we first examined precipitation anomalies from 1991-2019 using data from the NOAA. With the given statewide time series tool, we found that the rate of change of precipitation per decade is a positive value(0.94 inches), indicating that precipitation is increasing in Missouri. Thus, we decided to examine if a linear regression was a fitting model to extrapolate the precipitation anomaly value in 2050.

Figure 1 : Precipitation Anomaly(inches) vs Years



2) Using an interval of decades, we created a trend line using the slope of 0.94 inches per decade, which was obtained from the NOAA statewide time series tool. We set the year 1991 to x = 1, making 2050 x = 5.9. We calculated our *y*-intercept by using the point from 1994, (1.3 decades, 42.08 inches), which was located on the regression line:

$$P(x) = 0.94x + b$$

$$42.08 = 0.94(1.3) + b$$

$$b = 40.858$$

Using this y- intercept value we are able to create the equation for average predicted precipitation in inches per year:

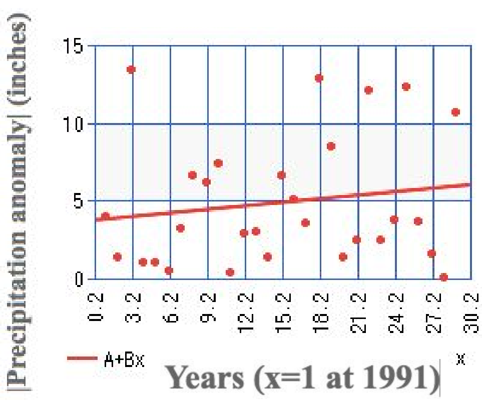
$$P(x) = 0.94x + 40.858$$

We then used this equation to predict the mean precipitation value in 2050, using an *x* value of 5.9 decades:

$$P(5.9) = 0.94(5.9) + 40.858 = 46.404 \text{ inches}$$

3) After using the linear regression model to calculate mean precipitation in 2050 (46.404 inches), we decided to estimate the precipitation anomaly value in 2050 based on the precipitation anomaly values from 1991-2019. We decided to use the absolute value of each precipitation anomaly value because we want to calculate the approximate deviation from the mean of 46.404 inches. We graphed a linear regression equation with years as the dependent variable and |precipitation anomaly| as the independent variable to predict the |precipitation anomaly| value in 2050.

Figure 2: Absolute Value of Precipitation Anomaly(inches) vs Years



function	value
mean of x	15
mean of y	4.873103448
correlation coefficient r	0.1571366668
A	3.736724138
B	0.0757586207

$A(x) = 0.0758x + 3.3767$, where $x = 1$ represents 1991

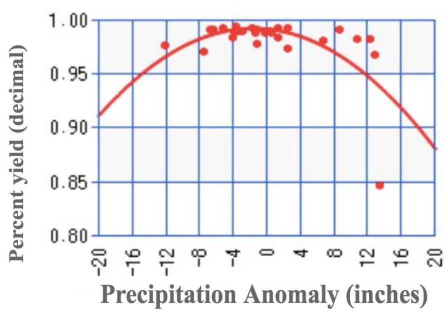
Looking at Figure 2, we saw a weak linear relationship between years and |precipitation anomaly|, with a correlation coefficient of 0.157. A low correlation implies that there is no set incremental increase or decrease of |precipitation anomalies| as years increase; this furthers our point that climate change will make precipitation anomalies even more erratic in the future. Despite the low correlation value, we still used our model as a baseline as we are underestimating the value. With this model, we are able to obtain an estimated |precipitation anomaly| for 2050 of:

$$A(59) = 0.0758(59) + 3.3767 = 7.8489$$

As seen in step 1, the precipitation in Missouri shows an increasing trend. As a result, we assumed that the precipitation anomaly in 2050 will be a positive value. Using this predicted precipitation anomaly along with our predicted mean precipitation from step 2, we are able to find the expected precipitation for 2050 as 46.404 + 7.8489 = 54.25 inches.

4) In order to confirm that precipitation anomalies negatively affect the soybean industry, we examined the relationship between the two from 1991 to 2019. Considering the data, we presumed that years with large anomalies —or years where there is a larger deviation from the mean precipitation —would produce a smaller yield, while years with an optimal amount of precipitation would produce a larger yield. If this was the case, it would result in a negatively oriented parabolic curve. For this reason, we chose to create a quadratic regression model with precipitation anomaly as the independent variable and percent yield (acres harvested divided by acres planted) as our dependent variable.

Figure 3: Precipitation Anomaly vs Percent Yield in Missouri, including Great Flood of 1993



function	value
mean of x	0.2151724138
mean of y	0.9813334318
correlation coefficient r	0.6170656
A	0.991067738
B	-7.5186763E-4
C	-2.39206267E-4

$$Y(x) = 0.991 - 0.000752x - 0.000239x^2$$

After plotting, in Figure 3, we saw a moderately strong relationship with a correlation coefficient of 0.617; however, we noticed a potential outlier in 1993, where the percent yield was relatively low and the precipitation anomaly was unusually high. Interestingly, that year was marked by the Great Flood of 1993 that devastated the Midwest, including Missouri. During this flood, precipitation exceeded the mean by 13.47 inches of rain, and cost almost 15 billion dollars in total losses for the country[17].

[17]US Department of Commerce, & NOAA

Thus, we decided to re-examine the strength of the relationship between precipitation yield and precipitation anomaly by excluding the year 1993. In doing so, we observed a slightly lower correlation coefficient of 0.572. This, paired with the fact that extreme floods would increase in the future[18] as global warming persists (points such as 1993 would occur with increasing frequency), helped us decide to keep 1993 in our data set.

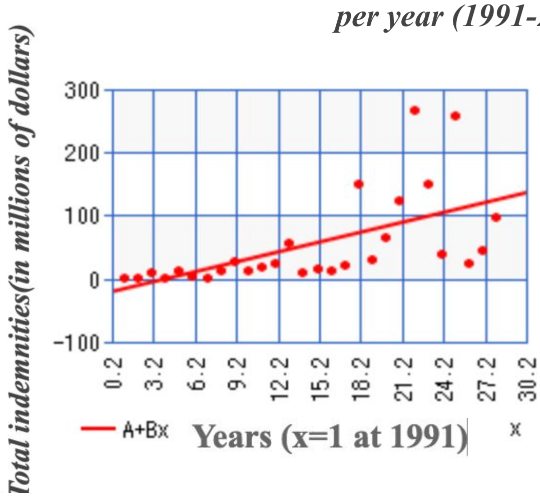
5) Using the precipitation anomaly found in step 3 and the model for percent yield from step 4, we predicted the soybean percent yield for 2050 to be approximately 97.04% soybeans harvested/total amount of soybeans planted.

$$Y(x) = 0.991 - 0.000752x - 0.000239x^2$$

$$Y(7.849) = 0.991 - 0.000752(7.849) - 0.000239(7.849)^2 = 0.9704$$

6) Overall, we were able to see that high precipitation anomalies generally reduce soybean yield; we predicted that lower yield would indicate an increase in indemnity cost as well. Using data from USDA RMA, we created a scatterplot and least squares regression line of indemnities paid due to precipitation anomalies against years.

Figure 4: Indemnities paid in millions of dollars (due to precipitation anomalies) per year (1991-2018) for soybeans in Missouri



function	value
mean of x	14.5
mean of y	54.5261
correlation coefficient r	0.589047
A	-21.19
B	5.22177

$$I(x) = 5.22177x - 21.19$$

[18] Climate Science Special Report: Droughts, Floods, and Wildfire

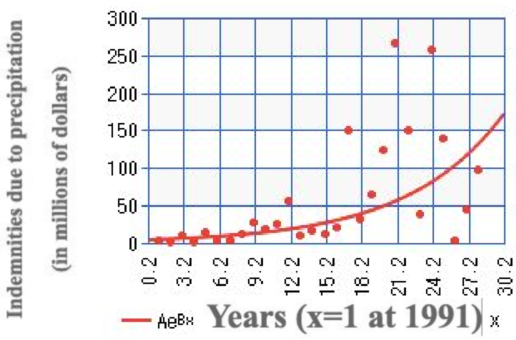
Examining figure 4, we see a moderate positive linear relationship between years and total indemnities paid due to precipitation anomalies, with a correlation of 0.589. Using this correlation, we made an estimate for 2050:

$$I(59) = 5.22177(59) - 21.1 = 286.98$$

We estimate the total indemnities paid for precipitation anomalies to be approximately $286,984,430 in 2050.

7) Since the correlation coefficient for the linear model was only 0.589, we examined the pattern further and decided to explore how an exponential regression curve would fit years and total indemnities paid due to precipitation anomalies.

Figure 5: Indemnities paid in millions of dollars (due to precipitation anomalies) per year (1991-2018) for soybeans in Missouri



function	value
mean of x	14.5
mean of y	25.1277837
correlation coefficient r	0.7123478238
A	4.22631261
B	0.1229409837

$$M(x) = 4.226e^{0.123x}$$

This exponential model in Figure 5 seems to be a better fit to the data as compared to the linear model because the correlation coefficient is 0.712. Using this exponential model we can predict the indemnities paid due to precipitation:

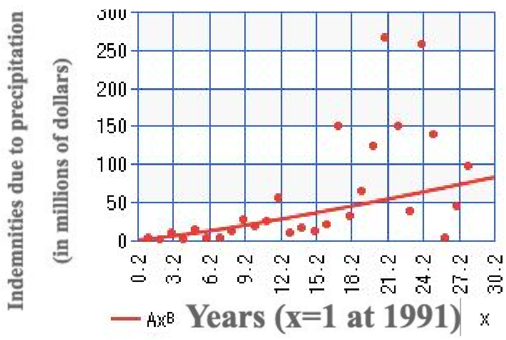
$$M(59) = 4.226e^{0.123*59} = 5992.45$$

The value $5,992,451,778 is most likely an overestimate since it is unlikely for the exponential pattern we see from 1991-2018 to continue all the way until 2050.

8) Although the exponential model yielded a correlation coefficient of 0.712, we recognize that it is unrealistic to expect exponential growth for this length of time. For this reason,

we wanted to examine the relationship between years and indemnities due to precipitation using a power regression model.

Figure 6: Indemnities paid in millions of dollars (due to precipitation anomalies) per year (1991-2018) for soybeans in Missouri



function	value
mean of x	11.29808998
mean of y	25.1277837
correlation coefficient r	0.72138663
A	1.32772698
B	1.212762874

$$W(x) = (1.327727)\, x^{1.21276287}$$

The power model in Figure 6 seems to be the best fit for the scatterplot of indemnities paid due to precipitation against year, as the correlation coefficient is the strongest (of our models) at 0.721. Using the power model, we can make a prediction for 2050:

$$W(59) = (1.32772698)\, 59^{1.21276287} = 186.523$$

Therefore, the indemnity value in 2050, according to our power model, will be $186,522,981.30.

9) Looking at our three models(Figures 4, 5, and 6) for predicting indemnities paid due to precipitation (linear, exponential, and power), we decided that the linear and power models were more likely to give us an accurate prediction for 2050. In addition, we recognized that inflation is a major factor and decided to adjust our predictions to account for it. Assuming a 3.22% inflation rate per year[19], we are able to use the simple interest equation ($P \cdot (1+r)^{n-1}$) to evaluate the actual value of indemnities. For each equation, the principal amount used was the indemnity value calculated in our linear model and power model respectively. The number of years is 31 because there are 31 more years until from 2019 to 2050.

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[19] *Inflation Data*

From (6) we obtained the linear model prediction for indemnities paid of $286,984,430, and adjusted this for inflation:

$$I(31)_{adj} = 286{,}984{,}430(1 + 0.0322)^{31-1} = \$742{,}632{,}544.20$$

From (8) we obtained the power model prediction for indemnities paid of $186,522,984.10, and adjusted this for inflation:

$$W(31)_{adj} = 186{,}522{,}981.30(1 + 0.0322)^{31-1} = \$482{,}667{,}426.10$$

Using $482,667,426.10 ($186,522,981.30 before inflation) achieved from the power regression model W(x) as our lower bound, and 742,632,544.20 ($286,984,430 before inflation) achieved from the linear regression model I(x) as our upper bound, we can safely assume that total indemnity value due to precipitation anomalies in 2050 will be between $\$482,667,426.10$ and $\$742,632,544.20$.

$482,667,426.10 < Total indemnities due to precipitation in 2050 < $742,632,544.20.

Results and Discussion

The slope we found from the NOAA of +0.94 inches per decade indicates that there will continue to be a steady increase in precipitation in Missouri. Furthermore, Missouri can expect to see more extreme anomalies as seen by how the graph's moving average (the red trendline) shows drastic irregularities in recent years. Such extreme anomalies, specifically floods, will have negative impacts on soybean farmers.

Using the NOAA, we predicted the mean precipitation value in 2050 to be **46.404 inches** meaning the average amount of rainfall will increase from 43.59 inches. Regardless of the anomaly, the increase in precipitation will negatively impact the agricultural industry.

We found the |precipitation anomaly| value for 2050 using the linear regression model to be **7.849 inches**; however, we believe it is an underestimate of the actual anomaly as the linear model has a low correlation with many points above the trend line. With irregularities in precipitation becoming more frequent, Missouri should expect to see precipitation anomaly values either close to 7.849 inches or greater than 7.849 inches in the future as floods increase.

We found the average precipitation value in 2050 to be **54.25 inches**. However, this value is also an underestimate because it was calculated using the underestimated precipitation anomaly value. This means that Missouri can expect to see approximately 54.25 inches of rain or more in 2050.

After plotting the quadratic regression model for the relationship between soybean yield and precipitation anomaly, we saw a moderately strong relationship correlation coefficient of **0.617**. This value is significant because it indicates that precipitation anomalies have a negative impact on soybean yield. As anomalies become more extreme and unpredictable in the future, soybean farmers in Missouri will need to mitigate the risks posed by excess precipitation and floods.

The percent yield computed for 2050 is **97%** and serves as an indication of the negative impacts of the high precipitation values and anomalies on the industry. Although this may seem like a high percent, it is lower compared to the percent yields of other years which ranged between 98% - 99%. Looking at the percent yields for previous years, only the years 1993 and 2008 produced lower percent yields, which can be attributed to the Great Flood of ‘93 and the June Floods[20] of ‘08. This proves that in the future, farmers will need to invest more money on solutions to increase their yield in order to ensure that their profits and farms are not severely impacted by extreme precipitation anomalies.

Using the least squares regression line (LSRL), we estimated the total indemnities paid for precipitation anomalies in 2050 to be approximately **$286,984,430**. The estimated total indemnities paid using our exponential regression model will be **$5,992,451,778**. The indemnity value in 2050, according to our power model, will be $**186,522,981.30**. It is unrealistic that the indemnities paid will continue to increase at an exponential rate in future years, so Missouri should expect to pay an amount that is between the estimates found in the power model and the LSRL.

After adjusting for inflation, our prediction for total indemnities paid in 2050 due to precipitation is between **$482,667,426.10** and **$742,632,544.20,** where the lower bound is the adjusted value from the power model and the upper bound is the adjusted value from the LSRL. It was necessary to create a range, as on one hand, the power model is the most accurate and so a value closer to the lower bound is expected, however on the other hand, it is highly likely that total indemnities paid will be much greater due to the greater frequency of extreme precipitation anomalies.

[20] *NOAA*

Analysis

Reflection

1. We researched the effects of climate change on several states that suffered from severe losses to enhance our understanding of the varying climate of the midwest region and the fundamentals of the soybean crop.
2. Our projections are based on historical climate patterns, so they may not be accurate predictions of future climate patterns since future climate patterns will be affected by factors such as the amount of carbon emissions released into the atmosphere and new regulations that may address climate change.
3. We only considered the positive anomaly value in order to account for floods and high precipitation, but not the negative anomaly value that could account for droughts as excess precipitation is a more prevalent issue in Missouri.
4. Although our calculations considered all the acres to be grown under the same conditions, we also realize that different areas grow soybeans differently, at different times throughout the year, and with different amounts of soil.
5. Many soybeans are genetically engineered to be resistant to precipitation anomalies, and irrigation systems are implemented to limit losses due to precipitation, but this was not taken into account when calculating percent yield.
6. We created many models in order to procure the most accurate estimate for indemnities, considered over and under estimation, and accounted for the rate of inflation, which led us to make our proposed predictions. However, we are using extrapolations to make these predictions, so they may not be accurate.

Risk Analysis

Risks to the Agriculture Industry

The implications of climate change on soybean farming affect a variety of industries ranging from agriculture to insurance. The agricultural industry as a whole will face an impact in both monetary and gross aspects. The yield will fluctuate greatly over the years due to the varying weather patterns and the percent yield is predicted to be approximately 97% in 2050, which is 1.1% less than the average percent yield from 1991 - 2019. Considering that one acre of land generates approximately $567[21] and that there are 5,000,000 acres of land dedicated to producing soybeans in Missouri[22], a 97% yield would result in a loss of $85,050,000. Furthermore, the precipitation anomaly is predicted to be very high, at 7.8 inches in 2050. Since precipitation fluctuations further deteriorate soil quality, farmers will encounter difficulties in finding viable soil to plant soybeans. Moreover, precipitation anomalies will cause farmers to be unable to plant soybeans during the prime season, spring. The delay in planting progress results in a decrease in acres planted. Spring 2019 began on March 1st and ended May 31st; however by mid-may, only 9% of the US soybean crop was planted, leaving 77 acres unplanted[23]. Future delays in planting due to unfavorable weather conditions will cause the total income of farmers to decline. Precipitation anomalies may also affect water access. Existing irrigation systems may not be up to par with the water access levels in 2050 as the flooding will ruin crops if preventative measures are not taken. Excess water may also erode irrigation systems, causing farmers to invest in newer, more advanced systems which will cost them a great deal of money.

Further monetary risks farmers may face include losing money due to increasing premium rates of insurance companies, without making sufficient profit from their crops. Additionally, soybean farmers will have to invest in solutions to prevent pest invasions. As the climate creates hotter environments as well as more intensive periods of precipitation, the pest population will increase. Although soybeans are fairly resistant to smaller variations in weather, they are not resistant to pests. Most farmers will have to invest in solutions such as genetically modified organisms (GMOs) or genetically engineered pesticides that are on the higher end of the price range. This will ensure the protection of soybeans, but the stigma surrounding GMOs in the public has not gone and will most probably require years of research to dispel. This means that the industry faces a possible loss in profit if consumers avoid GMO foods. The increase in awareness of local farmer markets may also pose a threat to profits. This is because most of the soybeans produced in the Midwest region are exported throughout the country and to the world. The movement to support local farmers can take away from the soybeans exported from the Midwest, as many consumers may prefer to purchase alternatives sold by local farmers.

Risks to the Insurance Companies

The losses suffered by the soybean farmers affect insurance indemnities as well as premiums. The indemnity paid by insurance companies in 2050 for soybeans in Missouri due to

[21] *University of Illinois*
[22] *University of Missouri*
[23] *American Farm Bureau Federation*

precipitation anomalies is predicted to be between $482,667,426.10 and $742,632,544.20 as seen in our least squares regression model and power regression model. Insurance companies are faced with the conflict of adjusting the premium prices in order to cover indemnities later; however, if they increase the price excessively, soybean farmers will not want to purchase the policies and it will affect the profit of the insurance companies as well.

As the United States continues to export soybeans to various countries, political relations between them also affect the revenue made by both farmers and insurance companies. Conflicts with nations such as China have resulted in as much as an 87% decrease in revenue, explaining why in recent years, we see that many policies have been sold for Revenue Protection Insurance Plans (RPIPs). These RPIPs have had loss ratios over 1, indicating that the insurance companies are losing money due to the fact that soybean farmers are not making enough revenue. The government has attempted to remedy the situation through closing deals that demand an increase from the already existing percent yield. As precipitation anomalies become more severe in the future, soybean farmers will likely face greater challenges in increasing yield, meaning that the revenue for soybean farmers will decrease further, which will pose a greater risk to insurance companies who will need to compensate their losses.

Risks to the Food Industry

Additionally, the food industry is at risk in a multitude of facets including grocery sales, restaurants, and fast food chains. The uses of soybeans vary from feeding livestock to vegan substitutes for meat. In the case of livestock, soybeans are one of the most used crops after corn in their diet, and so additional costs to soybean farmers will raise the price of soybeans to feed cattle and livestock. This will raise the prices of milk, meat, and additional dairy products used, illustrating the impact not only on vegans but on people who choose to maintain any other type of diet. Soybeans are also used in processed meat that are sold in the market. It is mixed into foods to increase protein content and the higher costs to attain soybeans may lead to higher prices for meat, or lower protein content. Furthermore, the number one substitute for milk for lactose intolerant people is soy milk. The growth of the soy milk market is projected to be approximately 28.6 billion dollars in 2026, approximately 7.8% greater than the 14.4 billion dollars in 2017[24]. The requirement for soybeans will raise prices for soy milk and may reduce profits after 2026 as the expansion of the market will result in overproduction with a deficit in customers to purchase the product and the market will face a loss in profits. In the case of

[24] *Research and Markets*

veganism, the innovation of Impossible Foods inc., meat substitutes, and vegan cheese require a substantial amount of soybeans. The market is not only advertised to those who have adopted a plant-based diet, but also to those who seek to make healthier choices or reduce their carbon footprint. As the demand for more sustainable food items is growing, it is imperative that the food industry produces more. However, the spike in prices will not only affect production costs of these products, but it will affect the consumer rates of purchase. If the issue of lower soybean yields is not addressed, the food industry will have to rely on another substitute for meat and protein that may be more scarce and expensive. The quality of food may also go down if the newer substance does not retain similar properties to soybeans.

Other Risks

The increasing carbon emissions due to petroleum, diesel and other coal energy sources are contributing to the growth of climate change, especially contributing to the increase in precipitation anomalies. These irregularities are preventing soybeans from flourishing, ultimately affecting the global market. Globally, 34% of soybeans are sourced from the United States[25], making the U.S. the largest producer, with China as its largest consumer. During the trade war with China, the cost of soybeans was reduced to 9 dollars per bushel. In 2017, soybean exports generated 24 billion dollars for the US and accounted for just over 50% of all agricultural exports to China. However, after the trade war, soybean exports only generated 3.1 billion dollars[26]. The overall reduction in trade and exports affected both China and the United States, creating monetary deficiencies.

With soybean farmers suffering from heavy losses due to both heavy precipitation and falling prices due to the trade war, the Government had to compensate farmers. In 2019, farm subsidies raised immensely as the USDA gave $16 billion in trade-related aid to farmers on top of existing programs for government-subsidized crop insurance. However, independent economists have found that farmers received twice as much as they actually lost due to the trade war. The Government has been generous to soybean farmers when providing aid due to their losses. Precipitation irregularities will be a major cause of losses to soybean farmers in the future. The Government faces the risk of a deteriorating economy if they do not find an accurate way to measure how much compensation the farmers actually need for losses due to precipitation.

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[25] *FAOSTAT*
[26] *Forbes*

Recommendations

Agricultural Industry

In the case of droughts, which may become more frequent in the future, policies that encourage drip irrigation systems can be implemented. Additionally, using technology such as pivot control panels to remotely control and track systems, variable-frequency drives to optimize the speed and pressure of water pumps, and soil moisture sensors to monitor soil can be beneficial[27]. These technologies assist to control and monitor irrigation systems, allowing for a more conserved and effective use of water. In order to combat the losses suffered due to lower percent yields, farmers can choose to plant soybeans before corn which are usually planted together. Planting soybeans before corn, augments yield potential without increasing cost.[28] This will also remedy the problem for delayed planting due to heavy precipitation during growing seasons.

Farmers also must take measures after floods to retain nutrient levels of soil for soybean growth. After floods, fungi in the soil, such as Arbuscular mycorrhizae and phosphorus, are lost. These fungi are crucial to maintain the nutrient levels of the soil, and farmers must reestablish fungi populations after flooding[29]. One way to do so is to plant cover crops which provide protection from debris and stimulate microbial and fungal activity. In addition, wet soil can be harmful to growing crops as it is harder for oxygen to get into soil and can cause soil loss due to erosion. In order to manage the quality of soil it is important to implement solutions that deal with run-off properly and maintain correct drainage systems, such as loosening compacted soil beds to reopen pores and adjusting cropping patterns by splitting long fields to decrease erosion from wind[30].

Genetically modified crops (GMOs) are often implemented in order to increase pest resistance. While studies prove that GMOSs enable less use of insecticides, consumers are hesitant to purchase crops that have been genetically modified. Increased research and awareness on the actual effects of GMOs on human health should be implemented to dispel unwarranted stigmas[31].

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[27] *United Soybean Board*
[28] *DTN Progressive Farmer*
[29] *Science Society of America*
[30] *Farming for a Better Climate*
[31] *Harvard University*

Insurance Companies

As seen in our graphs, the frequency of precipitation anomalies, specifically occurrences of floods and excess precipitation, will continue to increase. Since there is no way to accurately predict the effects of climate change, insurance companies cannot rely solely on data that predicts future floods and irregular weather patterns. However, what insurance companies can do is design appropriate policies as preventative measures in order to protect themselves in the case that severe precipitation anomalies do occur and consequently decrease soybean yield.

One policy that may be created is a Rainy Day Fund, where insurance companies have a safety reserve for Emergency Farm Loans, specifically for high-risk areas that must be paid when rainfall passes a certain threshold. In other words, insurance companies can analyze historical data that shows which agricultural areas in Missouri are at a higher risk of flooding and excess rainfall. They can then set a predetermined amount of money that is to be paid as a one-time fee when precipitation exceeds a measurable parameter. This parameter can be set by evaluating what amount of rainfall preceded severe storms or severe floods. In creating this policy, insurance companies can ensure that when farmers file claims for loss due to excess precipitation or floods, they will have enough money from the Emergency Farm Loan to compensate for the damage. Recently, Missouri's governor called for a $100 million Rainy Day Fund, which could help bring state savings up to 10% of general revenue, along with Missouri's existing Budget Reserve Fund[32]. As Missouri has its own safety reserve, insurance companies could help mitigate their own risks.

Another policy that can be created is to provide discounted premiums when farmers take preventative measures to protect soybean yield in the case of natural disasters. Often, after floods, farmers see new sets of weeds because old weed seeds buried deep in the tillage are revealed as flood waters wash away the top layers of soil. Insurance companies can encourage farmers to develop weed management plans to be employed after floods occur to prevent new weed growths from harming soybean yield. Farmers who do develop weed management plans can be rewarded by insurance companies through cheaper premiums. Through this policy, farmers will be less likely to file claims for loss due to floods since farmers will have already planned methods to prevent new weed growth. Discounted premiums can also be given to farmers who develop adequate drainage systems. This involves creating water courses so that the flooded water can quickly drain into rivers and creeks. Another method would be to ensure that

[32] *KY3*

sediment that has accumulated over time is cleared to prevent flooded water from collecting and harming soybean yield. Encouraging farmers to have adequate drainage systems guarantees that they are better prepared to deal with damages from heavy precipitation which will prevent excessive claims filed for loss.

In the past, the Government has shown that they are very accommodating when farmers lobby for greater subsidies to be paid. In 2019, for example, soybean farmers threatened to stop all trade due to the consequences that they faced from the tariffs that the US President placed on Chinese goods. Furthermore, due to the trade war, the EU, Mexico, and Canada retaliated with tariffs on soybeans from the US. When soybean farmers lobbied Congress, the Federal Government announced a new deal that entailed 16 billion dollars of aid to be given to soybean farmers. This aid, however, overcompensated farmers greatly, causing losses to the government. To prevent the Government from losing money due to excess subsidies, the best procedure is to develop a concrete method to quantify approximately how much farmers need to be compensated after floods. To avoid losing money in the future due to losses from floods, the Government needs to create criteria to ensure eligibility for the amount of aid farmers need after floods.

On the other hand, considering how supportive the Government has been towards soybean farmers, it is very plausible that insurance companies can benefit from this as well. Insurance companies can invest money to lobby Congress for increased subsidies on crop insurance policies, specifically yield protection policies, instead of Revenue Protection Insurance Plans. This would be an effective way to protect insurance companies in the future since the increasing precipitation anomalies will likely result in unexpectedly low yields for soybean farmers. Furthermore, lobbying for Congress allows for huge revenue returns which would be very beneficial to Congress. The average insurance company gains revenue not only from premiums but mainly from investing a small portion of the premiums in other organizations. By investing to lobby, many corporations received "22,000% in returns meaning 220 dollars for every dollar invested."[33]Although this is an overestimate considering many of the companies who lobby are multinational corporations, insurance companies can expect to earn a high amount of returns for every dollar invested.

Public Policies

One public policy that can be created is conducting frequent soil tests to ensure that soil that has been affected by floods or excessive rainfall has adequate infiltration and nutrients.

[33] *National Public Radio*

Flooded soil often changes the soil composition since it is exposed to new components from the flood water. Through soil tests, the Government can ensure that farmers are aware of the nutrients that the soil is lacking, which has a large impact on the quality of the yield as well as the types of fertilization used in the next season. Testing soil can also measure the amount of water that is held in the soil. When soil does not have proper infiltration, then flood waters can carry away nutrients and prevent soil from holding clean water. Furthermore, by carrying out frequent land examinations, the Government can find which regions are most conducive for soybean growth. Frequent soil tests can help to prevent damage from pest invasions as well. Plants grown in inadequate soil conditions such as in low pH or low nutrient levels, which are often results of flooding, have a difficult time resisting pest invasions. In months after flooding, farmers should frequently test soil to ensure that soybeans have the means to effectively tolerate insect feeding[34]. Certain areas in Missouri are at a higher risk of drought or floods and therefore may be at a higher risk of having low soybean yields. Examining the land will clarify which areas have the best soil composition and infiltration and will also identify which areas have the lowest risk of severe precipitation anomalies.

Lastly, the policies to develop infrastructure that protects farming lands from floods and droughts can minimize the costs of damage on soybeans due to precipitation anomalies by utilizing agencies such as the Inland Waterways Trust Fund. Flood walls can be built in high-risk farming lands to reduce the damage of severe floods in the future.

Other Recommendations

The agricultural industry can increase awareness of their needs through independent agricultural organizations. Institutions such as the American Soybean Association should cooperate with the government in order to develop practical solutions for environmental and food safety issues. Since farm and commodity organizations have the most experiential knowledge, their input should be highly valued by the Government. By working cooperatively, new policies can be created to protect soybean farmers and consumers through greater education on product safety and handling.

To minimize carbon emissions, which can intensify the effects of climate change, coconuts, starch, and sugarcanes can be used as the base of biofuel, which is a renewable energy source[35]. The implementation of biofuel would not only reduce the amount of carbon emissions

[34] *North Carolina State University*
[35] *Energypedia*

released into the atmosphere but would also reduce US dependence on foreign energy sources. Fossil fuels provide 80% of the US energy needs[36], and approximately 19% of US petroleum is imported from foreign energy sources[37]. By shifting to produce biofuels, such as corn ethanol, instead of nonrenewable petroleum, it could take as little as 15 years to offset the greenhouse gas emissions produced by liquid fossil fuels.[38] In addition, switching to biofuels could reduce the amount of particulates in the air, as diesel has an opacity percent of 2.9%, while biofuels such as B5 and B100 have opacity percents of 2.4% and 1.1%, respectively[39]. Lowering emissions and pollution can decelerate the effects of global warming and thus lessen the consequences it has on soybean yields.

For a more long-term solution, the Government, specifically the US Department of Agriculture, should collect accurate data and frequently update data on soybean yields. By updating data frequently, the USDA would more effectively monitor trends and make accurate predictions in the future. The NOAA should also frequently collect data on rainfall measurements and flooding incidents for this purpose as well.

If these recommendations are taken into consideration, farmers will be more prepared for damages from precipitation anomalies, insurance companies and the government will be less susceptible to monetary loss, and other institutions such as the food industry will benefit as well.

Conclusion

Based on our model, it is clear that severe floods and droughts due to precipitation anomalies will become a more alarming issue in the future for soybean farmers in Missouri, insurance companies, and other institutions. As precipitation anomalies increase, all parties must prepare to deal with extreme irregularities harming soybean yield. Considering the value that soybeans hold in the agricultural industry and in the US economy, it is crucial that all parties including insurance companies take preventative measures to reduce the risk of damage on soybeans. Soybeans are the foundation of a wide variety of sectors. As climate change heightens, it is imperative to address and prevent the destruction of this precious crop. The cultural, political, and environmental repercussions from soybean devastation can only be avoided through the cooperation and immediate response of all parties both domestically and globally.

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[36] *US Energy Information Administration*
[37] *American Geosciences Institute*
[38] *Interface Focus*
[39] *Consumer Reports*

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