2019-20 Modeling the Future Challenge

Project Report

Effects of Future Climate Change on Almonds in the California Central Valley: Insurance Loss Projections and Risk Mitigations

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Submitted: 28 February 2020

Executive Summary

California's Central Valley produces 80% of the worlds' almonds in various forms, some of which include raw nuts, almond milk, and snack mixes. Because California is responsible for so much of the globe's almond production, a dramatic loss in the industry could not only negatively affect the world's almond needs, but the state's economy would be greatly damaged as well. Unfortunately, California's Central Valley experiences harsh weather conditions such as drought, excess precipitation, and temperature change, all of which can greatly detriment almond production.

In order to maximize almond production, data from the NOAA regarding past weather patterns in California were compared to almond production as reported by the USDA to create comparison graphs. We focused on the San Joaquin and Sacramento Regions where primarily all of the almond growth occurs. In this process, correlations between different weather conditions and almond growth became apparent. To ensure that California's economy maintains its stability, insurance policies and losses were also taken into account. Examination of correlations between almond production, indemnity losses, and weather and climate factors indicated that heat as measured by maximum temperatures and drought followed by extreme precipitation most adversely impacted almond growth as well as total indemnity losses in the past. After the key contributing climate factors were identified, the projected forecast of these parameters was obtained from Cal-Adapt. We then used a non-linear regression to establish trends between precipitation and total indemnity loss from past data and binary classification to assign indemnity losses to max temperature and drought trends. These models were then used to project future indemnity losses based on projected climate extremes.

Our results show that heat will have the most impact on almond growth over the next 30 years as indicated by projected indemnity losses, followed by drought and least impact by extreme precipitation. However, because of increased incidents of extreme climates, including high probability of such events, the total indemnity losses are projected to be increased by 4-fold to about \$2.1 billion compared to \$500 million over the last 30 years. Increased probability of extreme climate events combined with increased crop losses as well as increased indemnity losses puts the whole almond industry at risk in the California Central Valley.

To ensure stability for California's valuable almond industry, it is crucial that measures are adopted by the farmers industry, government and insurance companies. Insurance companies may have to consider increasing overall premiums, however, the overall impact to the farmer may be less given the potential growth of policy holders. Most importantly we recommend that the farmer industry and government work together to come with improved crop to withstand the cliamet extremes and/or invest in technology better manage water distribution systems and irrigation to protect against drought as well as structural elements to protect against extreme heat.

Technology Overview and Background Information

Almonds play a crucial role in both California's agricultural industry as well as in the global economy. These tree nuts have been California's top agricultural export for the past twenty years and generated 2.3 billion pounds of almonds and $10.5 billion in export value in 2018. In addition, California produces 80% of the worlds' almonds and 100% of the United States' almonds, exporting them to countries all over the world, with the European Union purchasing 35% of California's almond exports, leaving India (15%), China (11%), Canada (6%), and the United Arab Emirates (5%) to round out the top five consumers. Exports to Japan, Spain, and Germany have increased as well. Because so much of the world depends on the United States for its almond supply, California almond production, and consumer prices steadily increase. California's almond productions and exports are vital for both the state and the country's economics. In addition to preparing raw almonds, which make up 47% of all almond goods, handlers produce processed items, including cereals, energy bars, butter, chocolates, snack mixes, and dairy alternatives, just to name a few. Almond milk, for example, accounts for 64% of the world's plant-based milk, and its sales grew 61% in the last five years. Almond consumers all over the globe depend solely on California's almond industry for their share of the tree nut, thereby proving the industry's importance. Therefore, any impact on the almond crop in California would directly impact California's almond businesses leading to consumers' needs being unfulfilled.

To maximize the profits of the almond industry, one must analyze the almonds' growth cycle. California's 6,800 almond farmers plant trees in early February in the Central Valley, where the climate, soil, sunlight, and water acidity and salinity are perfect for almond trees. The farmers then cross-pollinate the trees with several other varieties of almond trees. Their buds bloom in late February or early March in time for bees to pollinate the orchards to begin the trees' growth. The almonds then develop until July or August when the hulls split, and harvesting begins. After using machinery to shake almonds out of trees and let them dry on the orchard ground for eight to ten days, farmers can reap their harvest.

Almonds are not easy crops to grow. Careful considerations of climate need to be given when calculating a year's harvest since changes in climate can easily cause increases or decreases in almond production. On May 10 of 2019, the United States Department of Agriculture forecasted that California would have an initial production of 2.5 billion pounds of almonds and a record high coverage of 1,170,000 acres. However, the almond crop experienced unusual weather in the early part of the season. A significant amount of rainfall during bloom hindered pollination; rainwater and cold temperatures deter bees from leaving their hives to pollinate. After experiencing the wet Spring, California's forecast was updated to a production of 2.2 billion pounds of almonds, respectively 12 percent lower than May's forecast.

Similar to excessive amounts of rainfall, lack of water would also decrease almond production. Almonds are crops that require a great deal of water to grow; on average, it takes about 1.1 gallons of water to grow just one almond. Since California supplies 80 percent of the world's almonds, the crop uses about 10 percent of the state's water. In July of 2014, during California's drought, almond production was forecasted to be at 2.1 billion pounds. In reality, California ended up producing only 1.87 billion pounds, and the value of production totaled at 7.39 billion dollars.

Today the majority of Almond production in California takes place in the central valley, with about two-thirds of the production coming from solely San Joaquin Region (Kern, Fresno, Stanislaus, Mader, and Merced counties) and most of the remaining production coming from the Sacramento Region.

Given the significant impact of almond production on the state's and the nation's economy as well as the world's needs, the following topic was chosen: "How does climate change and weather conditions affect almond growth in the state of California, specifically in the San Joaquin and Sacramento Regions, and what risks do insurance companies face in light of such impact?"

To approach this question, data of several parameters is necessary. It is vital to understand the almond production form the past several years and future projected growth of almonds. It is also crucial to evaluate the years in which almond production was impacted and the weather conditions during those years. This allows for a better understanding of critical weather conditions (precipitation, minimum and maximum temperature, drought, water availability, etc.) and their effects of the economic and agricultural aspects of almond production. The economic impact of any production losses can be assessed using the indemnity payments of insurance companies for almonds. The total indemnity loss in comparison to the years can be used as an indicator of economic loss in the region and to project future risk that insurance companies will face as a result of any projected adverse weather conditions. To predict future losses, projected weather forecasts from online data sets and the data that project indemnity losses were used. The probability of extreme weather conditions for the next 30 years (2020-2050) was used to calculate expected loss values to understand the possible risks to insurance companies. Based on this analysis, recommendations were provided to reduce the impact of extreme weather conditions on future almond production as well as to minimize the losses incurred by insurance companies.

Data Methodology

Table 1 shows the type of data used, the source of the data used along with rationale to approach our topic.

Table 1: Data type, data source and rationale for data use in current project

Data	Source	Rationale
Almond production in previous years	USDA Statistics by State: California	Provides info on Almond growth statistics from 1995-2019, used to project future growth
Total Indemnity Loss for almonds	USDA Risk Management Agency	Understand insurance payments to almond growers over last 31 yrs (1989-2019)
Weather Cause of Loss Viewer	USDA Risk Management Agency	Understand the weather factors that impacted Indemnity Loss values for almonds
Report Generator	USDA Risk Management Agency	Insurance Policy data for all years to project future risks
Historical weather data	Climate at a Glance | National Centers for Environmental Information (NCEI)	Understand historical weather patterns 1989-2019
Future weather trends/forecasts	Cal-Adapt.org	Project future weather patterns to understand impact on almond production and indemnity loses

Almond production has steadily grown over the years and is projected to double by 2050 to about 5 billion pounds (Figure 1, inset). Despite the continued projected growth, the overall production of almonds has seen fluctuations in net growth over smaller intervals. Almond production, like any other crop, is known to be impacted by weather conditions, for example, temperature, precipitation, and particularly drought conditions due to the high consumption of water by the almond crop. A closer examination of the almond production from 1995 until 2018 shows specific years indicating a decrease in overall growth compared to prior years identified as between 2002-2005, 2008-2010, and 2011-2015 (Figure 1). Therefore, we next examined the climate factors over these years (1995-2019), specifically focusing on precipitation, min and max temperatures, and drought conditions as measured by the Palmer Hydrological Drought Index (PHDI) for the San Joaquin and Sacramento Divisional regions to cover data for most almond-producing counties.

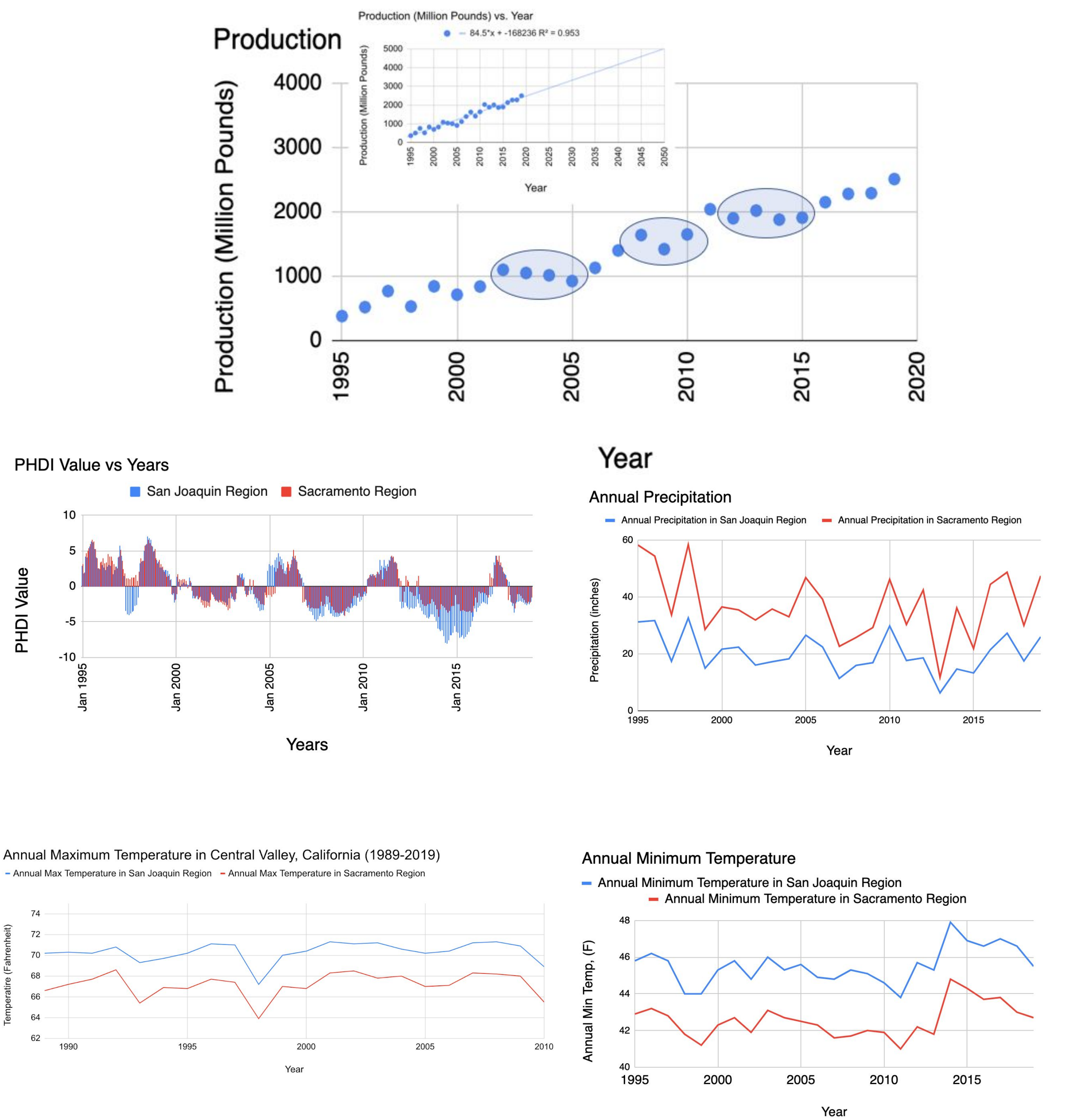

Figure 1. Top Panel: Total Almond Production in million pounds over 1995-2019 and projected forecast of Almond production up to 2050 (inset, top panel). The circles indicate years where Almond production was found to be slowed down or flat. Bottom Panels: Weather indicators over the years of 1995-2019 in the San Joaquin and Sacramento Regions. PHDI: Palmer Hydrological Drought Index.

In addition to the almond production over the years 1995-2019, Figure 1 shows the weather indicators of drought as measured by the Palmer Hydrological Drought Index, annual precipitation, annual (average) maximum temperature, and annual (average) minimum temperature in the San Joaquin and Sacramento Regions. Because the almond production overall shows an increase over these years, while the weather indicators fluctuate, a clear quantitative correlation could not be established. However, a qualitative examination of the data clearly shows the following patterns:

1. A high negative PHDI value of > -4, indicative of severe to extreme drought in the years 2007-2009 and 2013-2016 correlate with a decrease in the almond production over similar years
2. Warmer years are observed over 2013-2019 as shown by highs in the average max and average min temperatures; these years overlap with some of the extreme drought years (2013-2016), and also correspond to a reduction in almond production
3. A drop in annual precipitation is observed between the years of 2013-2016, which is consistent with the drought years.
4. No clear pattern of low minimum temperature was observed to be correlating with almond production growth.
5. It is noticed that a lack of growth in almond production over the years of 2003-2005 does not have a clear correlator in the weather pattern. Upon further literature search, we found that the years of 2004 and 2005 suffered from extreme frost (https://aic.ucdavis.edu/wp-content/uploads/2019/01/agmr-profile-Almonds-2005.pdf). Extreme frost is hard to capture with typical measures of weather and is more related to the dew point. We were not able to find any historical reliable dew point information to be used for our correlation studies. We also assume that the frost events would be low in probability and therefore, will have minimal impact in our future forecasts; nevertheless, these frost events cannot be ignored.
6. It is also noted that the weather patterns are very similar between the San Joaquin and Sacramento regions, with the difference being that the San Joaquin region is more prone to extremes of warm temperatures and drought. In contrast, the Sacramento region is more prone to extremes of precipitation.

Based on these observations, we next proceeded to understand the impact of weather patterns as related to almond production on the Indemnity Losses incurred by Insurance companies. Our ultimate objective is to be able to predict future indemnity losses for insurance companies due to the impact of weather on the almond crop.

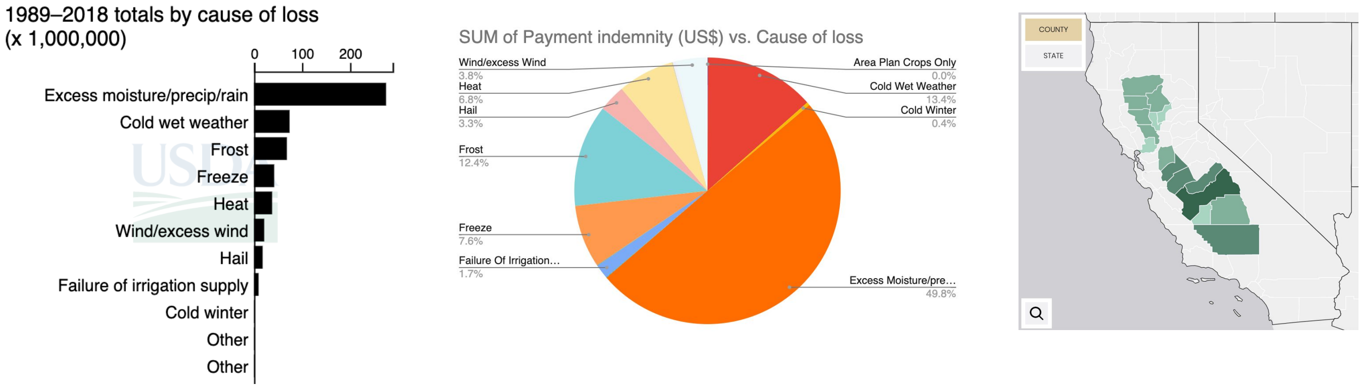

Figure 2. Cause of Loss for Indemnity Losses between the years of 1989-2018 (left pane) and the relative contribution of each cause of loss to total Indemnity Loss (middle pane). Indemnity Losses by county in San Joaquin and Sacramento regions, with a darker shade representing a higher loss.

The main data source used was the USDA Risk Management Crop Insurance data set. From this source, we isolated the almond crop insurance data but did not need to narrow it down further for the report, as all United States almonds are produced in the California Central Valley. The USDA data provided information for almond losses from the years 1989 to 2018. Interestingly, based on the relative contribution towards total indemnity losses, the following factors seemed to be the main contributors in decreasing order: Excess Moisture/Precipitation, Cold Wet Weather, Freee, and Heat. This is in contrast with our earlier examination of weather data where almond production seems to be more impacted by lack of rain, heat, and drought. To further understand the impact of historical weather conditions, we compared the almond production and Total Indemnity Loss to weather indicators over these years.

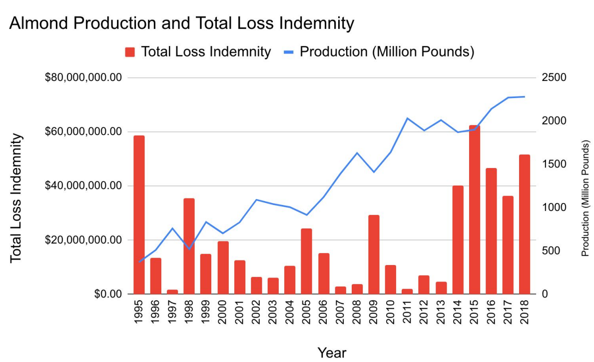

Figure 3. A comparison of the Total Almond Production and Indemnity Losses for the years 1995-2019.

Figure 3 compares the total almond production with total indemnity losses for the years 1995-2019. The almond industry significantly impacts insurance policies since a loss in almond crop due to natural causes has a direct impact on insurance companies, since these companies will end up making the payments due to indemnity losses. In fact, over the last 30 years, insurance companies have paid as much as 550 million dollars in towards indemnity losses for Almond crop in the State of California. It is clear from Figure 3 that the losses are unevenly distributed with the spikes of >20 million dollars observed over certain years, for example, 2014-2018, 2009, 2005, 1995, and 1998. On the other hand, a slow down of almond production is observed for the years 2012-2015, and 2002-2005. Therefore while a qualitative correlation seems to exist for some years of loss in almond production with indemnity losses, the role of weather still remains unclear based on this data.

For our climate data, we initially started using the Actuaries Climate Index to connect with the USDA data source. Although the Climate Index did separate values by season, we soon found that the Actuaries Climate Index data was not specific enough to the California Central Valley region, as the entire southwest Pacific was grouped into one category. Therefore, we relied on the National Oceanic and Atmospheric Administration's Climate at a Glance data. The NOAA collects information and provides data on weather trends and climate-related information down to the county level. Before we modeled into the future, this data provided valuable information on past climate statuses. The data provided went back to 1895, but for our purposes, we only needed to go back to 1989 to match with the USDA data. Out of the various forms of data presentation, we found the time-series data to be most significant for the report. We were able to change the time intervals for the climate outputs, to find the best times that correlated with our data. We specified the data down to the counties in the Central Valley, and based on Figure 1, we set the parameter to average temperature, minimum temperature, maximum temperature, and precipitation. This data was most helpful in analyzing past trends. Furthermore, for simplicity, we only compared the climate outputs of one region that represented the extreme for that weather output. Therefore, data for the San Joaquin region was used for drought and max temperature, while data for the Sacramento region was used for precipitation.

Similar to our previous process, we qualitatively compared the total indemnity loss over the years 1989-2019 to the historical climate data for drought index, max temperature, and precipitation only, since none other climate outputs provided any meaningful information. For comparison, we assigned loss >/= $20 million as a significant loss to insurance companies. Figure 4 shows the plots for this data. Several patterns are evident:

1. High indemnity losses in the years 2014-2018 strongly correlate with high temperatures (heat), high drought index, and somewhat lack of precipitation (2013-2015).
2. High indemnity loss in 2009 correlates with another severe drought event.

3. High indemnity losses in 1995, 1998, and 2005 correlate with excessive precipitation (>40 inches) in the Sacramento region.

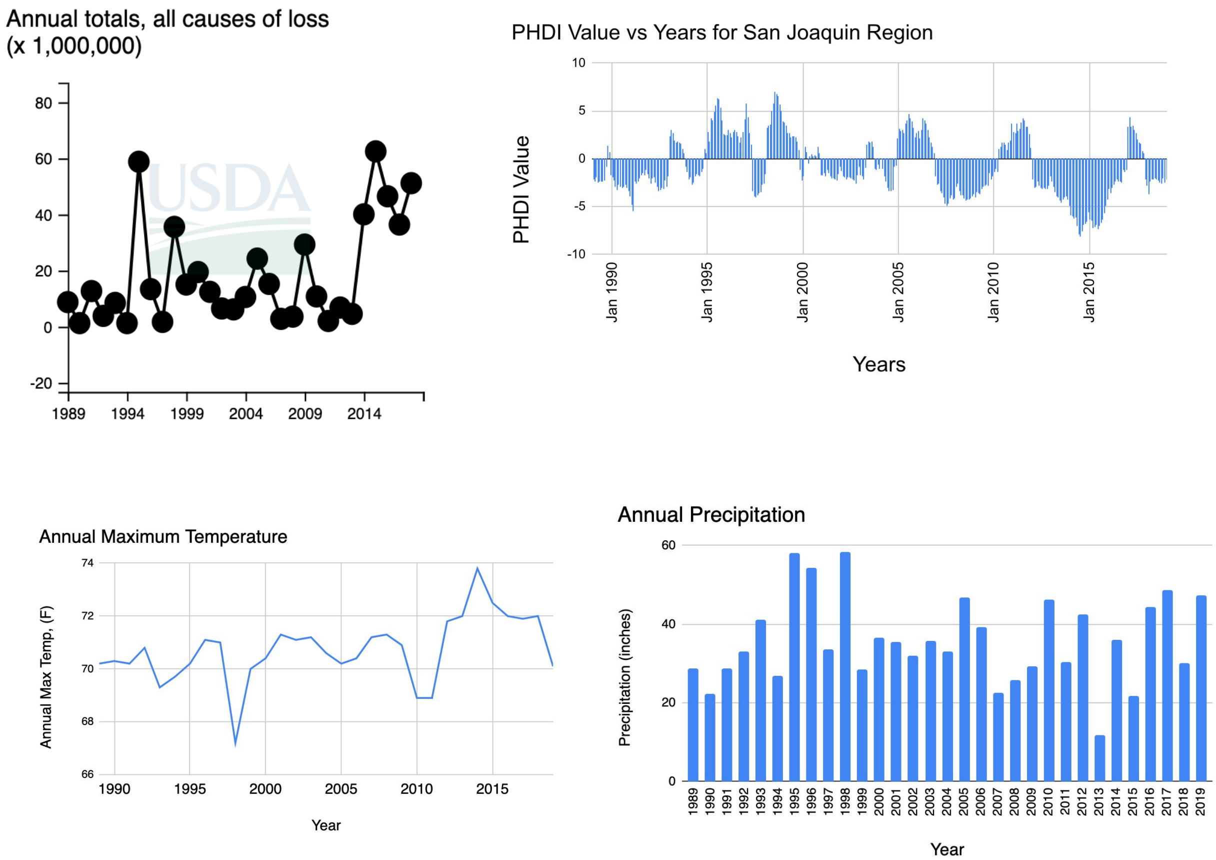

Figure 4. Total indemnity loss (top left panel), Palmer Hydrological Drought Index for San Joaquin Region (top right panel), Annual maximum temperature averaged for San Joaquin Region (bottom left panel) and Annual precipitation for Sacramento Region (bottom right panel) for the years 1989-2019.

Based on these data and qualitative comparisons, we conclude that the occurrence of severe to extreme drought (PHDI < -4.0), high max temperatures of > 72ºF, and excessive precipitation of > 40 inches are highly likely to impact almond crop damage and hence will lead to excessive total indemnity loses. We next used these observations and qualitative correlations to model indemnity losses for the future using existing climate forecasts for the years 2020-2050.

Mathematical Modeling and Projecting Trends

Before modeling future trends for indemnity losses, we wanted to understand the average indemnity losses for a given extreme weather event (drought, precipitation, and heat) along with the probability of such event for the past years. The reason was to understand the overall financial impact to the insurance companies as well as to be able to compare the severity of losses of past years to future trends.

Table 2 compares the average indemnity loss for each extreme climate output, where the term “extreme” is defined by a specific climate output to the average indemnity loss when the extreme climate event is absent. Due to the presence of overlapping extreme climate events, certain assumptions were made, especially for precipitation, where the years with extreme precipitation also impacted with drought were excluded, since it cannot be distinguished whether indemnity losses were due to excessive precipitation or drought.

Table 2: Summary of average indemnity loss for each climate output for the years 1989-2019 along with the probability of a specific climate event

Weather Condition and Impacted Years	Average Total Indemnity Loss impacted by a given Extreme Weather condition and Probability Extreme Weather	Average Total Indemnity Loss NOT impacted by an extreme Weather condition	Average Total Indemnity Loss impacted including all Extreme Weather conditions	Average Total Indemnity Loss NOT impacted by any extreme Weather condition
Drought (Extreme, PHDI > -5.0), 2013-2016	$38,401,475 (p= 0.13)	$15,529,102 (p=0.87)		
Drought (severe/Extreme, PHDI > -4.0), 2007-2009, 2013-2016	$27,036,802 (p=0.23)	$15,984,752 (p=0.77)		
Heat, Years > 72C in San Joaquin Valley, (including Drought Years), (2013-2019)	$40,286,988 (p=0.23)	$13,246,789 (p=0.77)		
Precipitation, >40in Annual average in sacramento valley (excluding drought/heat years), 1995-1996, 1998, 2005-2006, 2010, 2012 (excluding 2007-2009, 2013-2019)	$23,554,998 (p=0.23)	$7,873,356 (p=0.77)		
Total of Drought, Heat or Precipitation			$27,215,570 (p=0.55)	$7,873,356 (p=0.45)

In general, it is observed that the average indemnity loss for years impacted by an extreme climate event ranged from approximately $23 million to $40 million, with the higher average losses associated with severe drought conditions or heat. Average indemnity loss for years not impacted with extreme climate events ranged from $7 million - $16 million. In addition, the overall probability of a single extreme climate event ranged from 0.13 - 0.23, whereas, in general, the probability of any extreme climate event was as high as 0.55. Interestingly further analysis of the probability of extreme climate events for the first half of the last 31 years (1989-2003) was found to be only 0.2, whereas this probability increased significantly to 0.88 for the later half of the previous 31 years (2004-2019). This indicates that almost 9/10 years, the weather was impacted by high heat, drought and/or extreme precipitation.

In order to model the USDA cause of loss for the future, we needed to find future climate models pertaining to precipitation, extreme temperatures and severe droughts. The supplemental data sources did not provide us with easy to use extractable data, so we sourced the data from Cal-Adapt. Cal-Adapt provided California specific downscaled climate trends backed by historical data. To create their models, Cal-Adapt used the Localized Constructed Angles (LOCA) statistical analysis tool, which was pioneered by the Scripps Institution Of Oceanography, and the CMIP5 global models. The state's Environmental Protection Agency and Department of Public Health use the data to prepare for future, dangerous climate conditions. While Cal-Adapt is used to show the effects of climate change on California, we used Cal-Adapt for their future extreme weather event projections. Cal-Adap classifies extreme weather as an event that shows a substantial increase or decrease from the usual weather at that location. Initial examination of data indicated that California has noticeable extreme weather patterns in precipitation, heat, cold, and wildfires. We chose to focus on precipitation and heat for our report and extrapolated conditions of low precipitation and high heat as representative of extreme drought conditions. Cal-Adapt provided time-series graphs and the raw data for us to develop our models.

Precipitation model

Data from the past 31 years was first used to develop a model that correlates precipitation with the total indemnity loss. To make sure that only precipitation is used as the input variable, we excluded from the model those years where the contributing cause of loss was frost/freeze and heat. Therefore the following years were excluded: 1999 (frost), 2009 (frost), 2013-2019 (heat). A non-linear regression analysis of the precipitation in inches in the Sacramento region versus the total indemnity loss yielded a reasonable predictive model with a high correlation coefficient $r^2 = 0.79$ (Figure 5). The equation can be represented as:

$$Total\ Indemnity\ Loss\ (million\ USD) = 0.021 * P^3 - 0.21 * P^2 + 7.41 * P - 81 \qquad \text{Eq. 1}$$

where P = precipitation in inches in the Sacramento region.

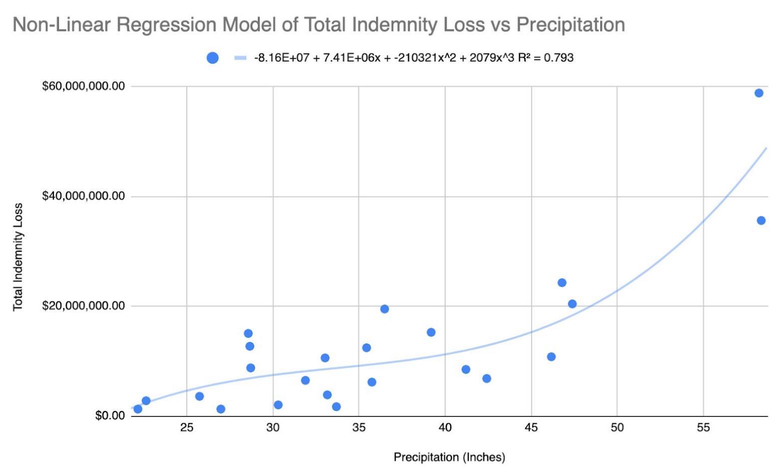

Figure 5. Non linear regression analysis of Total indemnity loss versus precipitation (inches) in larger Sacramento region excluding the years impacted by heat or frost.

Using Eq1 and the precipitation forecast for 2020-2050 as obtained from the cal-adapt.org for the sacramento region, we can now predict the total indemnity loss attributed to precipitation for the next 30 years (Figure 6.)

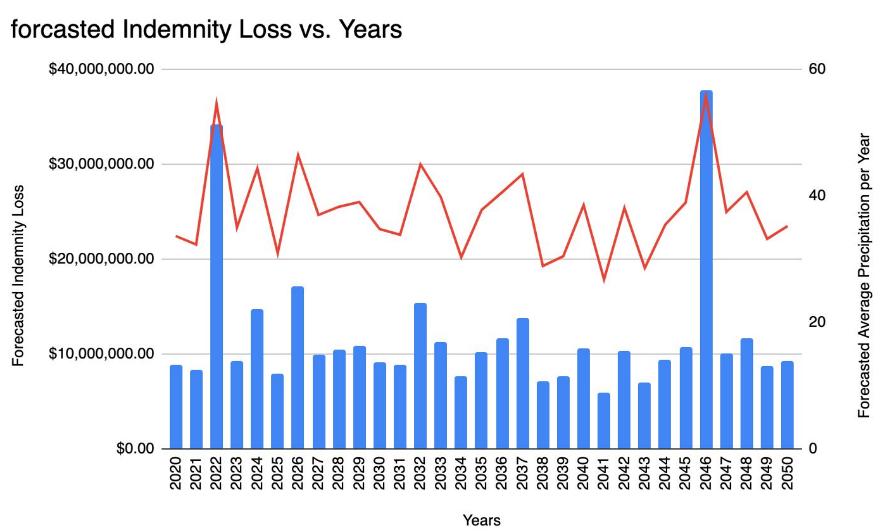

Figure 6. Predicted Annual Indemnity Losses based on precipitation forecast for the Sacramento region for 2020-2050

Based on our earlier analysis (Table 2) that a total indemnity loss of > $20 million dollars is considered significant, we can see that excessive precipitation will only less frequent impact on total indemnity losses impacting only 2/30 total years.

Table 3: Forcasted years for total loss indemnity for greater than and less than $20 million based on precipitation forecasts for the years 2020-2050.

	Years Impacted by Excessive Precipitation	**Probability**
Number of Forecasted Years with Indemnity Loss < $20 million	29/31	0.94
Number of Forecasted Years with Indemnity Loss >/= $20 million	2/31	0.06

Heat (High Max Temperatures) Model

While a linear correlation could not be established between annual max temperatures and total indemnity losses, we used a max temperature cut of 72ºF in the San Joaquin region to correlate extreme temperatures with high total indemnity losses.

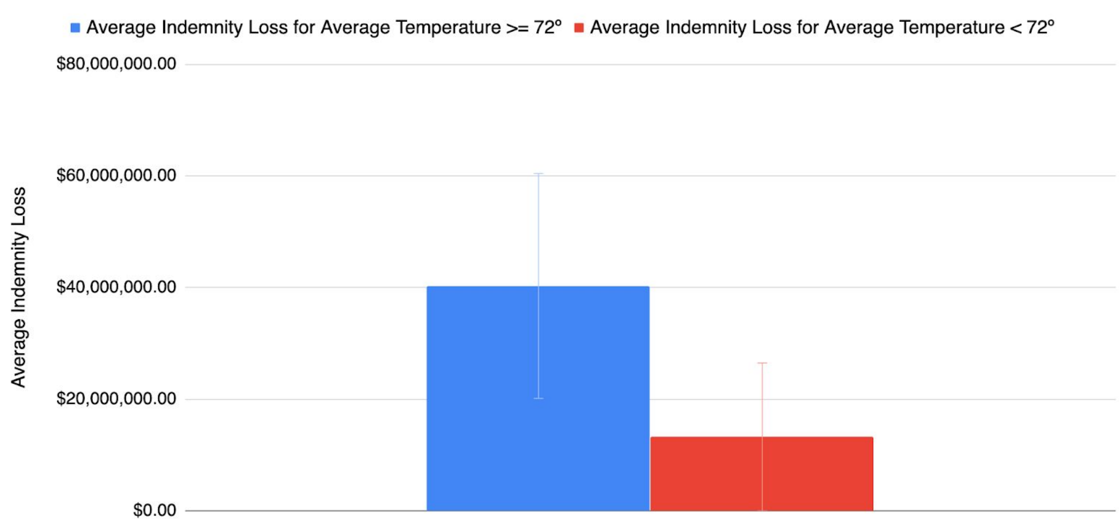

Figure 7. Average Indemnity losses for years impacted by extreme heat (max temperature >/= 72C) versus those no impacted by extreme heat in the San Joaquin Region.

As shown in Figure 7, this criteria clearly establishes a significant difference between total indemnity loss > $20 million (avg. $ 40 million) for extreme temperatures versus total indemnity loss < $20 million for years with normal highs. To understand the total indemnity loss forecast we used the projected annual average max temperature forecast using data from cal-adapt.org for the years 2020-2050.

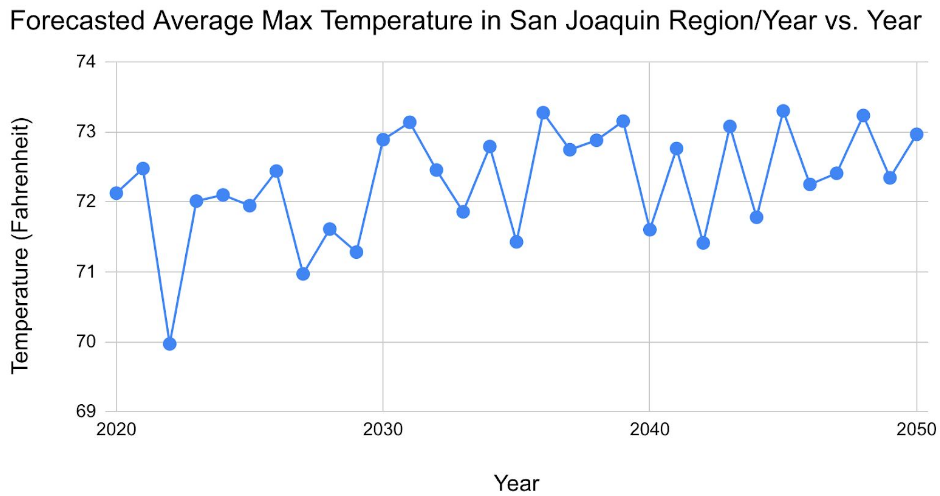

Figure 8. Projected forecast for the average max temperatures in the San Joaquin Region for the years 2020-2050.

We next converted this data to a tabular format to obtain a number of years impacted by extreme temperatures of > 72ºF and therefore resulting in high total indemnity losses (Table 4).

Table 4. Forecast of total indemnity loss based on max temperature forecasts for the years 2020-2050 and the assocaited probability of high temperature events

	San Joaquin and Sacramento Region	Number of Years Impacted by Max Temperature >= 72º	Total Loss	Probability
Avg Forecasted Indemnity Loss due to heat (Avg Max Temp >= 72º)/year	$40,286,988	18/31	$720 million	0.58
Avg Forecasted Indemnity Loss due to heat (Avg Max Temp < 72º)/year	$13,246,789	13/31	$156 million	0.42

It is clear that heat and extreme temperatures have significantly high probability of impacting total indemnity losses

Drought Model

We predicted extreme drought conditions essentially by observing low levels of precipitation (less than 20 inches) from Figure 6 and years with extreme temperatures from Figure 8. Based on these observations, prolonged drought is expected between years of 2038-2045 due to low levels of precipitation combined with high heat. Similar to the approach with heat above, we used the average indemnity losses from past years for those impacted by severe drought (Table 2) and the average indemnity losses from past years for those not affected by drought to obtain a forecast for future losses. The outcome is as follows:

Total predicted loss for years impacted by drought: 8 x $38.5 million = $308 million
Total predicted loss for years impacted by drought: 23 x $15 million = $345 million

Risks

Table 5 shows a summary of projected Total Indemnity Losses due to extreme weather conditions of drought, excessive heat or precipitation for the years 2020-2050.

Table 5. Projected losses 2020-2050 due to extreme weather conditions

Extreme Weather Conditions	**Years Impacted**	**Projected Total Indemnity Loss of Extreme weather impacted years, million dollars and probability of extreme weather event**	**Projected Total loss of Non Extreme Weather Impacted years, million dollars and probability of non extreme weather event**
Drought	8 (2035-2043)	$ 308 (0.27)	$330 (0.73)
Heat	18	$720 (0.58)	$156 (0.42)
Precipitation > 40 inches	2	$72 (0.06)	$293 (0.94)
Total		$1,336	$779
Grand Total			**$2,115**

Therefore the total projected total indemnity loss over the next years is estimated to be close top $2.1 billion due to weather-related damages to the Almond crop. Compared to the total indemnity loss of 550 million dollars for the last 30 years, this is a 4-fold higher increase to indemnity payments by insurance companies, a significant increase in costs. Clearly, there is a great risk for insurance companies to be able to pay for these losses while still staying profitable. In addition, examining data of Almond acres growth and the insurance policies issued by using the Report Generator database at USDA RMA, we observe that the almond acreage has continued to grow over the last 30 years. Projecting this trend over the next 30 years, we estimate the almond acreage to grow 2-fold. The projected total indemnity losses of $2.1 billion are based on current almond acreage. Taking into consideration the impact of acreage growth while assuming a constant factor to represent losses, this means that the total indemnity losses could double to as much as $4.2 billion over the next 30 years. This is an immense amount, and unless farmers, government companies, and insurance companies do not make any changes, the whole almond farming industry in the state of California would be at a huge risk of significant depletion.

This is further compounded by the fact that the severity of extreme climate conditions is only going to be worse, specifically concerning extreme temperatures. While only 7 out of the last 30 years have experienced extreme temperatures, the number is projected to grow 2.5 fold to almost 18 out of the next 31 years. This brings significant risk to the damage of almond crops over the next 30 years.

Therefore, if our projection for loss is underpredicted based on future weather that may not follow the forecasted climate trends, there will be greater risks on the insurance company because their total loss may be greater than their premiums. In addition, many farmers may lose profit and run out of business due to high loss in almond production. Bee health and pollination will also be heavily impacted as there will be a significant amount of loss in pollination due to low almond production, which can further impact the many companies that take care of bees for pollination make. Insurers may also go bankrupt if their loss substantially exceeds their premiums. The government may have to step in and subsidize if insures won't be able to insure almond loss, which creates another problem the government has to take care of. Finally, if the loss gets substantially worse, the state of California may no longer be able to sustain almond growth.

Recommendations

Given the large projected indemnity losses and impact to farmers, insurance companies, and the economy, steps must be taken now to minimize the risks described above. First, we determined how the farmers and insurance companies both can be protected against projected losses. To this end, we calculated the expected value of the losses. Based on the indemnity losses and the probabilities described in Table 5 and taking into account the 2-fold increase in acreage and losses, we calculated the total expected value using the following formula:

$$Expected\ Value = 2 * (\Sigma\ Loss\ due\ to\ a\ certain\ extreme\ climate\ event * probability\ of\ climate\ event)$$

Calculated expected value = 2.6 billion dollars for 30 years.

Therefore, insurance companies must collect at least 2.7 billion dollars over the next 30 years to compensate for projected indemnity losses. This translates to an annual total premium of $92 million/year. Based on the data provided in the Report Generator database at USDA RMA, the current annual total premium collected by insurance companies in 2019 was about $61 million. Insurance companies need to increase the total premium by about $30 million/year to stay even translating to about an increase in annual premium from $14,000/policy to about $21,000/policy. However, assuming that the number of policies has more than doubled in the last 30 years and will continue to grow over the next 30 years, the actual increase per policy may not have a large impact.

Despite the coverage for insurance, the actual loss of crop over the next years cannot be ignored. Therefore, measures must be taken to minimize the risks to crops from extreme weather. The following recommendations are made:

1. The government and industry must put more effort into research to develop a better crop that has less dependence on water. Given the huge water footprint of almonds, this will have a beneficial impact by making sure the damage can be minimized. The crop takes six years from planting before fruits can be collected; therefore, the effort needs to be accelerated.
2. More efficient irrigation systems will need to be developed to make sure that the loss of water during irrigation can be minimized.
3. Since heat is a significant factor projected to be the cause of loss, farmers and the government will have to invest in some kind of mechanism or system that can protect the crop from extreme heat. This could be installments of shades that can be brought up when necessary at defined times to minimize the heat from direct radiation. The initial cost of such a system may be high, but the long term benefits will be huge by decreasing

potential high indemnity loss of almonds from heat. Therefore investment should be made on cooling systems with intermittent dampened sunlight.

4. Since bees are the primary source of pollination for almond production, and the flowers also act as a food source for bees, farmers and bee holders will need to create additional food sources for bees so that their health is not compromised from high losses. This will allow bees to continue to pollinate almond blossoms even with little almond crops because they obtain other needed nutrients from other crops farms can grow to help sustain bee life. Measures will also be required to protect the Bee population from extreme weather.

References

“Almonds California .” United States Department of Agriculture Risk Management Agency, January 2017, https://www.rma.usda.gov/en/Fact-Sheets/Davis-Regional-Office-Fact-Sheets/Almonds-2017-CA

Hayley Boriss, Agricultural Issues Center University of California, Commodity Profile: Almonds. September, 2005. https://aic.ucdavis.edu/wp-content/uploads/2019/01/agmr-profile-Almonds-2005.pdf

“Climate at a Glance: Global Mapping.” NOAA National Centers for Environmental Information, February 2020, https://www.ncdc.noaa.gov/cag/

Cox, John. “Cold, Wet Weather Has Almond Growers Worried about This Year's Pollination.” *The Bakersfield Californian*, 20 Feb. 2019, https://www.bakersfield.com/news/cold-wet-weather-has-almond-growers-worried-about-this-year/article_2b7a339a-353f-11e9-92e2-6b89dacb4eec.html

Cox, John. “Rain, Cool Weather Bring down California Almond Production.” *The Bakersfield Californian*, 11 July 2019, https://www.bakersfield.com/delano-record/rain-cool-weather-bring-down-california-almond-production/article_615c7e8a-a1b1-11e9-ac80-ff2d2fb901be.html

“Exploring California's Climate Change Research.” Geospatial Innovation Facility at University of California, Berkeley https://cal-adapt.org/

“Helping Honey Bees.” *California Almonds - Your Favorite Easy Snack*, http://www.almonds.com/growing-good/research-innovation/helping-honey-bees

“Merlo Farming Group.” Edited by Christine Souza, *Almond Growers Check Effects of Rain at Bloom | Merlo Farming Group*, California Farm Bureau Federation., http://www.merlofarminggroup.com/almond-growers-check-effects-rain-bloom

“2019 California Almond Production.” *Statistics by State: California*, United States Department of Agriculture National Agricultural Statistics Service, 10 May 2019, www.nass.usda.gov/Statistics_by_State/California/Publications/Specialty_and_Other_Releases/Almond/Forecast/201905almpd.pdf.

Pathak, T.B.; Maskey, M.L.; Dahlberg, J.A.; Kearns, F.; Bali, K.M.; Zaccaria, D. Climate

Change Trends and Impacts on California Agriculture: A Detailed Review. *Agronomy* **2018**, *8*, 25.

David B. Lobell, Christopher B. Field, Kimberly Nicholas Cahill, Celine Bonfils, Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties, Agricultural and Forest Meteorology, Volume 141, Issues 2–4, 2006.