**The Alfalfa Crop’s Impact on Imperial County Water Usage** Joseph A. Guler  
  
**Introduction**: Imperial County in California possesses a longstanding agreement with the federal government, known as the Colorado River Compact. This compact allocates nearly 3.8-million-acre feet of water from the Colorado River each year to irrigate over 500,000 acres of farmland within the county. Signed by then Secretary of Commerce Herbert Hoover in 1922, seven western states including California benefit from the compact that allocates a total of 15-million-acre feet to the states annually. This small desert community of less than 180,000 residents receives over 86% of the state of California’s and over 25% of the entirety of the Colorado River’s annual water allocation, leaving the use of over 1.2 trillion gallons of water from the river at their disposal each year (3)(4). The Alfalfa crop, accounting for almost 10% of the Imperial Counties’ $2.3 billion a year agriculture industry, covers over 135,000 acres of farmland each year, making up nearly one-third of their annual water use (3)(9). The purpose of this project was to assess the impact of Alfalfa cultivation on Imperial County water usage by analyzing the relationship between relative evapotranspiration (ETo) and its’ defining variables to examine trends in water management practices and generate statistical averages on excess water use.   
 The question of: “How is Alfalfa cultivation impacting Imperial County water usage?” was used to hypothesize that there would be a negative correlation between relative evapotranspiration rates and relative humidity percentages, and a positive correlation between relative evapotranspiration rates and solar radiation, resulting in excessive water use on alfalfa crops that could otherwise be conserved. One rationale behind this hypothesis is that climactic factors within the desert southwest contribute to a more frequent need to irrigate crops in comparison to cooler regions that experience averagely lower rates of evapotranspiration (2). Another rationale includes the fact that the Imperial County possesses the ability to grow Alfalfa year-round, where in the case of other regions, the crop is only produced during one-half to two-thirds of the year. This results in an annual growing cycle for Alfalfa in the Imperial County, contributing to irrigation practices that may not firmly fluctuate with seasonal weather conditions but are instead based on regional climate (5). It should also be noted that the Imperial County averages 9-10 cuttings per year from their Alfalfa crops, as opposed to national averages of around 6.   
  
**Methods**: Data utilized for this project was derived from the CIMIS database, known as the California Irrigation Management Information System. CIMIS is a program within the California Department of Water Resources that manages a network of over 145 automated weather stations in California. These weather stations incorporate sensors that collect variable data on a minute-by-minute basis to calculate reference evapotranspiration rates (ETo) from standardized grass and/or alfalfa surfaces for the purpose of providing irrigators the ability to manage their water resources more efficiently (10).   
 After identifying relative evapotranspiration rates (ETo) as the observation necessary to analyze the project question, the dataset was generated from the CIMIS database and formatted into an excel spreadsheet. The spreadsheet was in an overall reproducible format but still tidied for use in R by camel casing column names, splitting dates into day, month, and year, freezing the first row as column headers, and removing any unnecessary descriptive text stemming from the CIMIS database. Once tidied, the dataset contained 365 days of relative evapotranspiration samples stemming from 17 variables, 4 of which included the date, day, month, and year. The remainder of the variables were explanatory and consisted of precipitation, solar radiation, average vapor pressure, maximum, minimum, and average air temperature, maximum, minimum, and average relative humidity, dew point, average wind speed, wind run, and average soil temperature. Correlations were then analyzed between the variables of interest which included the dependent variable of relative evapotranspiration and the explanatory variables of average relative humidity, solar radiation, and average air temperature (6).   
 To do this, an R script was generated using downloaded libraries tidyverse, ggplot2, and dplyr (8). Once the dataset was imported to R through a csv file, the dataset was then isolated to contain only the variables of interest as well as maximum relative humidity and month for statistical purposes. The relationships between each variable in the 12-month time frame were then plotted and used to analyze their distributions through linear regression models (1). After observing the models, the dataset was mutated using countywide statistics to create a data frame with three new variables which included required water, average water used, and excess water, all in gallons per acre. The excess water variable was then applied as an aesthetic to the graphs so that the data frame could continue to be observed and isolated within specific time frames (1)(8). The parameters for isolation included samples within the 6-month time frame of November-April and the 3-month time frame of November-January, which serve as the times of the year within this arid desert region where average air temperatures are at their lowest. The newly isolated data frames were then used to plot the variables and analyze their distributions through linear regression models once more. It is important to note that the data frames from the 6-month time frame contained 179 samples while the data frame from the 3-month time frame contained 92 samples. We then used these data frames to generate statistical data pertaining to our initial research question and hypothesis (6).  
  
**Results:** The initial 12-month data frame proved to be quite successful in displaying specific trends associated between the variables of interest. Average relative humidity versus relative evapotranspiration possessed a negative correlation and an R2 value of 0.42 (Fig. 1A), while average air temperature versus relative evapotranspiration possessed a positive correlation and an R2 value of 0.69 (Fig. 1B). Solar radiation versus relative evapotranspiration possessed the most successful trend amongst the variables analyzed as there was a strong positive correlation between the two, resulting in an R2 value of 0.81 (Fig. 1C), indicating that solar radiation is the strongest factor when calculating rates of relative evapotranspiration in the 12-month data frame.  
  
Chart, scatter chart

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C

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A

**Figure 1**. 12-Mo. Relationship between ETo and (A) Rel. Humidity [R2 = 0.42], (B) Avg. Air Temp. [R2 = 0.69], and (C) Solar Radiation [R2 = 0.81]

Within the 6-month data frame, there were some key differences that began to provide answers to our initial project question. We observed an increase in the trend between average relative humidity versus relative evapotranspiration as the R2 value rose to 0.5 (Fig. 2A), while there was a significant decrease in the trend between average air temperature versus evapotranspiration, having its’ R2 value drop to 0.47 (Fig. 2B). An increase was also observed in the trend between solar radiation versus evapotranspiration as the R2 value rose to 0.88 (Fig. 2C).  
  
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**Figure 2**. 6-Mo. Relationship between ETo and (A) Rel. Humidity [R2 = 0.5], (B) Avg. Air Temp. [R2 = 0.47], and (C) Solar Radiation [R2 = 0.88]  
  
 The 3-month data frame displayed continued changes in the variable trends. Another increase in the trend between average relative humidity versus relative evapotranspiration occurred as the R2 value rose to 0.53 (Fig. 3A). The trend between average air temperature versus evapotranspiration also rose in this instance to an R2 value of 0.36 (Fig. 3B). The most significant change came between solar radiation versus relative evapotranspiration, as the R2 value decreased to 0.54 (Fig. 3C), which begged the question of what would cause such a sharp decline in its’ value.  
  
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 **Figure 3**. 3-Mo. Relationship between ETo and (1) Rel. Humidity [R2 = 0.53], (2) Avg. Air Temp. [R2 = 0.36], and (3) Solar Radiation [R2 = 0.54]  
  
 Solar radiation and average relative humidity being key factors in relative evapotranspiration rates is made clearer when taking their own relationship into consideration. As we observed the negative correlation between average relative humidity versus relative evapotranspiration, we can also form a relationship between average relative humidity versus solar radiation. We can see that as humidity increases, solar radiation decreases, resulting in a decrease in the rate of evapotranspiration that is able to occur and vice versa. This is due to increased moisture levels, resulting in solar rays being absorbed in the form of heat by water molecules in the air at a higher rate in comparison to days where humidity may be lower. The absorption of solar radiation by water molecules not only creates an environment that seems to be warmer than it truly is when analyzing the heat index, but it also reduces the amount of evapotranspiration that is able to occur in relation to the percentage of humidity at that given time. So, although average relative humidity is not as strong as solar radiations relationship with relative evapotranspiration in the 12 and 6-month data frames, we can see that in the 3-month data frame its’ role is just as significant as solar radiations being that it can at times dictate the rate of relative evapotranspiration that is able to occur.   
 This is more evident when observing the results from our statistical calculations, which were based on the relationships between our mutated variables and sample relative evapotranspiration rates. An average of 7,935 gallons of water per acre of alfalfa was used in relation to countywide statistics. This equates to 8.9 acre-feet of water used per acre of alfalfa grown in the county each year, whereas the average amount of water used per acre in the county sits at around 5.4 acre-feet (3)(4). We were then able to generate the average need in gallons of water per acre using the 12-month, 6-month, and 3-month data frames based on the rate of relative evapotranspiration and the number of gallons required in acre-inches. We were then able to determine that an average of 837,863 gallons of water per acre was used in excess throughout the entirety of the 12-month dataset, while 574,809 gallons and 498,030 gallons were used in excess throughout the 6-month and 3-month data frames respectively. In essence, 59% of the total excess water use in the county each year is grouped within the 3-month data frame, equating to almost two-thirds of the excess water being used in less than 25% of the year. In relation to this, average relative humidity rates within the 6 and 3-month data frames were found to have a daily average of 54%, with an average high of over 82%, exemplifying the role that humidity plays in solar radiation and evapotranspiration rates as temperatures decrease within the coolest months of the year.   
 The statistical data generated in conjunction with the relationships between these variables draws back to our initial hypothesis and rationale. Water management practices based on regional climate as opposed to seasonal weather conditions becomes more evident when looking at the disparity between average air temperature versus relative evapotranspiration rates in the 6-month and 3-month data frames. We can see that as relative evapotranspiration and solar radiation decrease, humidity increases, and temperature becomes less relevant in calculating the required amount of water for alfalfa cultivation. Thus, the support of our hypothesis and rationale behind it stand true when taking into consideration our research here. Temperature is not as significant of a factor in the rate of relative evapotranspiration during cooler months of the year in comparison to variables like solar radiation and humidity but is still traditionally considered by many cultivators to be the key factor in determining the quantity and frequency in which they need to irrigate throughout their growing seasons. These misjudgments have created an issue in the amount of over 113 billion gallons of water being used in excess each year, equivalent to over 9% of the Imperial Counties’ total water allotment from the Colorado River, on Alfalfa cultivation alone.   
  
**Discussion/Conclusion**: The analysis we conducted throughout this research project supported our initial hypothesis and prediction. We were able to conclude that there were both negative and positive correlations between average relative humidity and solar radiation versus relative evapotranspiration respectively. Although we saw solar radiation as the strongest factor in relative evapotranspiration rates within the 12 and 6-month data frames, we were able to determine that average relative humidity also plays a key role in the level of solar radiation and therefore the rate at which evapotranspiration occurs. Statistical data was generated to further support our rationale on this topic. This allowed us to conclude that excess water use is heavily dependent on unhealthy trends in water management practices that are not firmly based on seasonal weather conditions, contributing to the waste of over 113 billion gallons of water, or 9% of the Imperial Counties’ annual water allocation, on Alfalfa cultivation alone.   
 Furthering this research should include the study of desirable plant traits amongst different varieties of Alfalfa grown in the desert southwest, namely Imperial County. Research on water retention and capacity, rates of evapotranspiration during seasonal time frames, stress factors that indicate the capacity at which these varieties can continue producing equal volume in tonnage and protein content, and new varieties containing these desirable traits would be instrumental in the continued mass cultivation of this crop (2)(7). Other areas of research that this study could extend to include examining soil water capacity and soil colloid nutrient retention in Imperial County soil environments. This also relates to research on drainage and flow in soil plots for the study of hydrodynamics, mass flow rate, momentum, and irrigation and leaching technologies.   
 As agricultural water becomes more desirable, it also becomes more finite, increasing the need to be able distribute this resource as efficiently as possible while continuing to keep crop output the same. Advanced forms of irrigation technology continue to be developed each day, but extended research on forage irrigation technology that makes sense for both the cultivator and water as a resource has yet to be discovered. With the research done here, we hope to provide information to support more sustainable methods of water management and irrigation practices as well as a starting point for further studies on advanced irrigation technologies and the efficient cultivation of the Alfalfa crop within Imperial County.   
   
   
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
   
  
  
  
  
  
  
  
  
  
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