Aaron Piper

Geo 3426

Effects of Projected Weather on Arabica Coffee Production in Central America

Introduction

According to the international Coffee Organization in 2022 to 2023 more than 168.5 million bags of coffee were sold[1]. The ICO also states that coffee production has increased four out of the last six years (2017, 2018, 2020, and 2022) by more than 1% each year.[2] Of that coffee sold, arabica coffee made up more than 60 percent of the world's coffee production[3] meaning that the continued production of arabica coffee is not only financially but socially necessary for the continued functioning of the civilized world. While fascinating, the "civilized" portion of that statement is the important part, because as a civilized world it has majorly and perhaps irreparably changed the world's climate. These changes will have long-reaching impacts on the future of the world and of the crops and agriculture in it. What effects it will have are a portion of the research being described in this research project, explicitly it will look at "How will changes in climate potentially effect the production of arabica coffee in the Central Americas in the next 5, 10, and 50 years?"

Literature Review

Contemporary literature on the subject of coffee production acknowledges two key points. Firstly, there is a consensus that the demand for coffee will continue to rise.[4] Secondly, it is widely accepted that climate change will have a significant impact on the global coffee industry, particularly in relation to the production of arabica coffee. However, there are variations in the

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[1]International Coffee Organization, "Coffee Report and Outlook."
[2] International Coffee Organization.
[3] https://majestycoffee.com, "What is Arabica Coffee."
[4] Killeen, pg. 8.

literature regarding the degree to which these phenomena will occur, the timeframe in which they will occur, and the factors that will contribute to their occurrence. For example, Dr. Timothy Killean predicts that by the year 2050, only 100 square kilometers of land in Central America will be suitable for the growth of arabica coffee. However, it is important to note that not every square meter of this suitable land will be utilized for coffee production. On the other hand, a collaborative study conducted by multiple organizations suggests that there will likely be a shift from low to high probability of a net loss of suitable land for coffee production in Columbia, as well as a movement of suitable land within the region.[5] In addition to the aforementioned points, there are several factors that have not been thoroughly explored in the literature, which could be of interest for further research. [6]

These include the availability of sunlight and shade for coffee plants, the reduction in suitable land area due to climate change-induced shifts in planting to higher altitudes, and the impact of deforestation as individuals convert suitable land, previously used for wildlife or other purposes, into areas for cultivating cash crops. These aspects warrant further investigation to gain a comprehensive understanding of the potential challenges and opportunities that lie ahead for the coffee industry in the face of climate change.

Methodology

In order to answer the question of this project, initially the goal was to focus on elevation and weather (precipitation and temperature) to determine whether the suitable land for production of arabica coffee would increase or decrease, however, after research it became apparent that it was not necessary for arabica coffee to grow at a specific altitude, instead the altitude created the weather conditions necessary for arabica to grow. This means that while elevation does limit the amount of terrain and soil conditions necessary for growth, it would in theory grow at any altitude if temperatures and precipitation were available to accommodate it. And thus, elevation was taken from the equation.

The necessary requirements for arabica coffee to grow without elevation are:

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[5] Global Coffee Platform, "Coffee Production in the Face of Climate Change."

[6] Global Coffee Platform.

- Between 1500 mm and 2500 mm of precipitation each year to properly water the plants[7]
- Between 17 degrees Celsius and 24 degrees Celsius[8]

At first weather data was drawn from sources that kept worldwide data such as the National Oceanic and Atmospheric Administration. The resulting information was not viable in the long run as no common year in which weather was dutifully kept at the weather stations in the area of study. Ultimately, base historical weather data was found from the National Center for Atmospheric Research[9] drawn from the year 2005. This website also provided climate projections based on year for the world based on Representative Concentration Pathways (RCP) in shapefile format. RCP are designed to represent 4 different scenarios of varied radiative forcing, also called enhanced greenhouse effect, at 2.6, 4.5, 6 and 8.5 Watts per square meter.[10] This simply means the lower the number the lower the effect of greenhouse gas effect in the scenario. Two different RCP were used for this project the lowest (2.5) and the highest (8.5) to give different effects as to what human's actions have done. The process after gathering the information was as follows:

- From there the information was downloaded for five years, 2005 (the base year) 2022, 2028 (five years in the future), 2033 (ten years in the future) and 2083 (fifty years in the future) at both RCP levels. Each individual year was taken in and averaged for both air temperature and precipitation at RCP 2.6 and RCP 8.5.
- These were downloaded as geodatabases and needed to be imported then interpolated from points to create rasters showing the weather information.
- A Kriging Interpolation was used to complete all these as the Columbia Public Health suggested this method for accuracy over others for weather predictions, [11] with optimized settings, and eight points used to draw information from as weather is vary interwoven.

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[7]NOAA, "Climate and Coffee."
[8] NOAA.
[9] NOAA.
[10] UCAR, "Download NCAR System Models."
[11] https://www.publichealth.columbia.edu/research/population-health-methods/kriging-interpolation#:~:text=This%20helps%20to%20reduce%20bias,prediction%20error%20for%20that%20point.

- This process was completed several times as issues with the files, as well as errors with ArcGIS Pro resulted in incomplete/unusable files, often missing the attribute tables, making any statistical inferences impossible.
- These files were then converted into raster files using GN to Raster tool (again this process was done several times as they did not often contain attribute tables, or were not usable after closing and opening the program).
- From there the Reclassify Tool was used to reclassify the suitable growing conditions as 1 for suitable and 0 for not suitable for each map combination.
- These were then taken into raster calculator and each year/RCP map was created by multiplying the suitability of precipitation and temperature to create a success/fail map.
- The map symbology was altered to hide the unsuccessful growing areas while the successful were retained.
- Each year was compared to the base year as a reference point.

The final flow chart for this model is shown below in Figure 1.

Results and Findings

In looking at purely statistical components of the data there is a yearly decrease in suitable area, with the only exception being 2033 RCP 2.5. Even with the outlier year, there is a downward trend. When running a t-test on the results the resulting t stat is .504, which means that the chances that the effect that humans are having on the environment is not statistically significant in terms of output of arabica coffee, however, this was an extremely limited number of statistics so the accuracy of this is extremely questionable.

The lower suitability area is always RCP 8.5, displayed below in Table 1. This is expected as the increase in Green House Effect leads to the increase of air temperature which also increases the extreme weather an area sees, according to the National Resource Defense Council,[12] this effect would include the amount of precipitation. The greatest example of this effect would be Figure 6, labeled as “Worst case Scenario, shows a comparison between the base year (2005)

[12] https://www.nrdc.org/stories/are-effects-global-warming-really-bad#:~:text=Higher%20temperatures%20are%20worsening%20many,wetter%20and%20dry%20areas%20drier.

and the projected data for 2083 RCP 8.5. In the worst-case scenario, there is a change of nearly 1207 km. sq. This may seem insignificant when viewed on a global scale, but it is suggested that 3400 to 5000 plants can be planted per hectare,[13] meaning this is a loss of between 410 million and 603 million every year moving forward.

Conclusion

In general, the data gathered trends toward a decrease in suitable area for the arabica coffee, a vital cash crop, and the major strain of coffee grown and sold around the world, visible in Table 1 and Table 2. While perhaps human interactions do not play a significant role in this, based off the limited data, there is still a decrease overall. The decrease in suitability does not take into consideration elevation and the terrain available at those elevations. As the temperature increases in regions it drives the suitable window of temperature higher in elevation, thus decreasing the available area at an altitude further. Add into this terrain type (acidic soil) required to grow the plants given that higher altitudes see more rocky soil, this would further decrease the suitable area. Nor does this study take into account the prevalence of pests or disease. These factors may further decrease the overall area as well.

The conclusion of this research is that there is going to be a decrease in the suitable area of arabica coffee as time progresses. The extent to which the production of arabica coffee will decrease is still inconclusive and requires more research including the addition of a number of factors beyond the simple climate elements. This study was a good starting place but requires much more data and variables to give a more accurate picture of the actual effect.

Based solely on the information in this report alone, the outlook does not look good. In the worst-case scenario, production of arabica coffee in Central Americas could be cut close to half in the next 50 years.

[13] Wikifarmer, “Coffee Trees Planting and Plant Spacing.”

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Appendices

Table 1

Year	RCP	Suitable Area (km2)	Change from base year (km2)
2005	N/A	2676	0
2022	2.6	2395	281
2022	8.5	2379	297
2028	2.6	2127	549
2028	8.5	2425	251
2033	2.6	2244	432
2033	8.5	2325	351
2083	2.6	2334	342
2083	8.5	1469	1207

Table 2

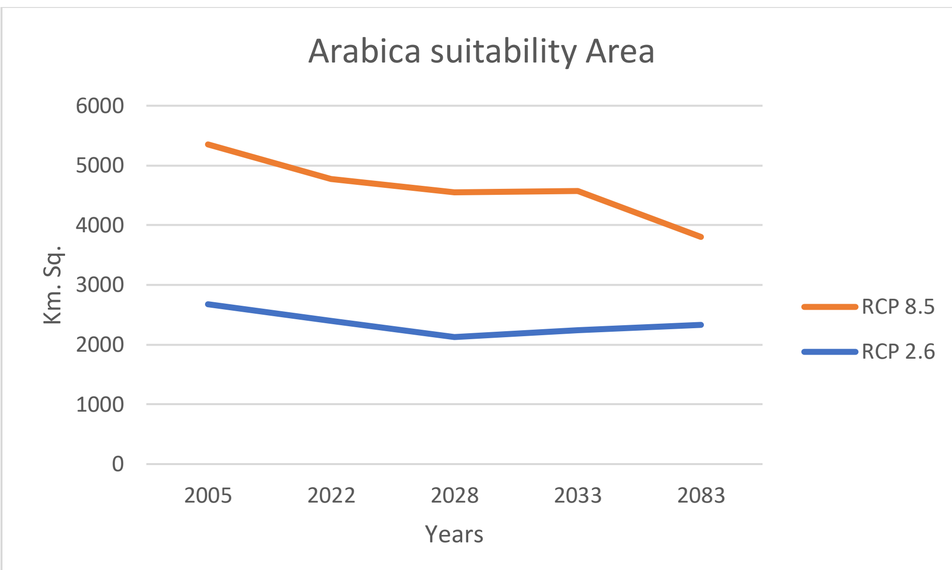

Figure 1 Workflow for Model

Figure 2: 2005/2022 Comparison

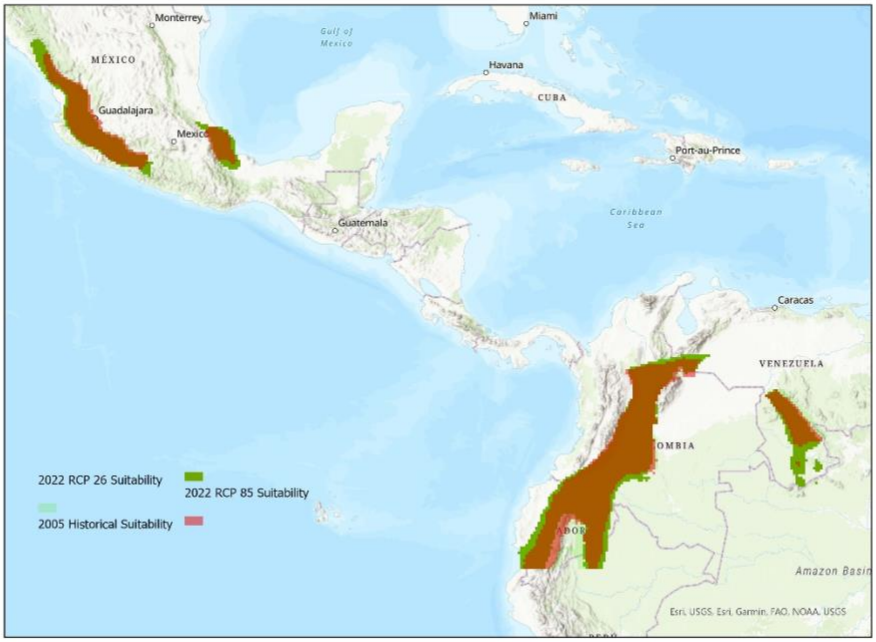

Figure 3 2005/2028 Comparison

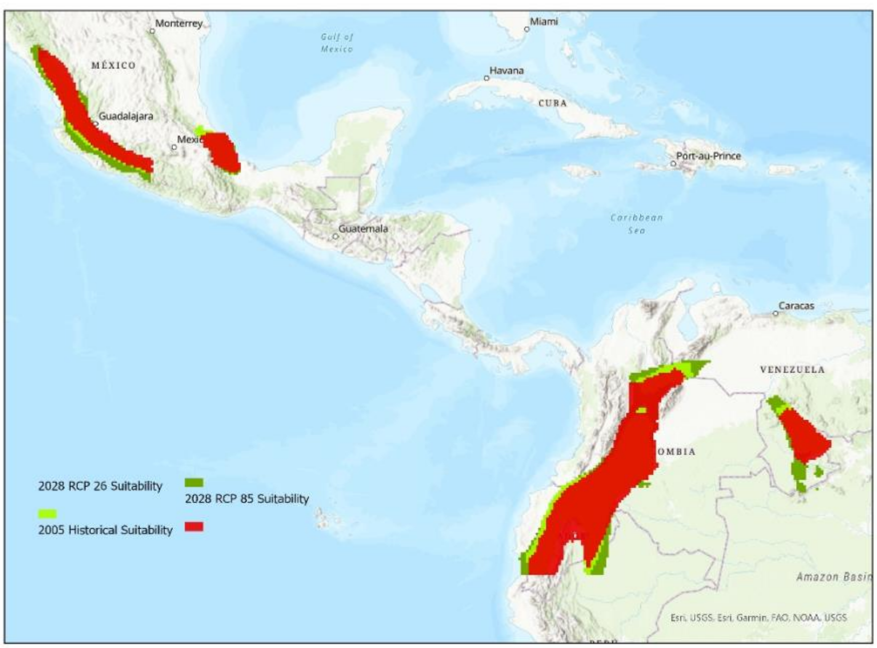

Figure 4: 2005/2033 Comparison

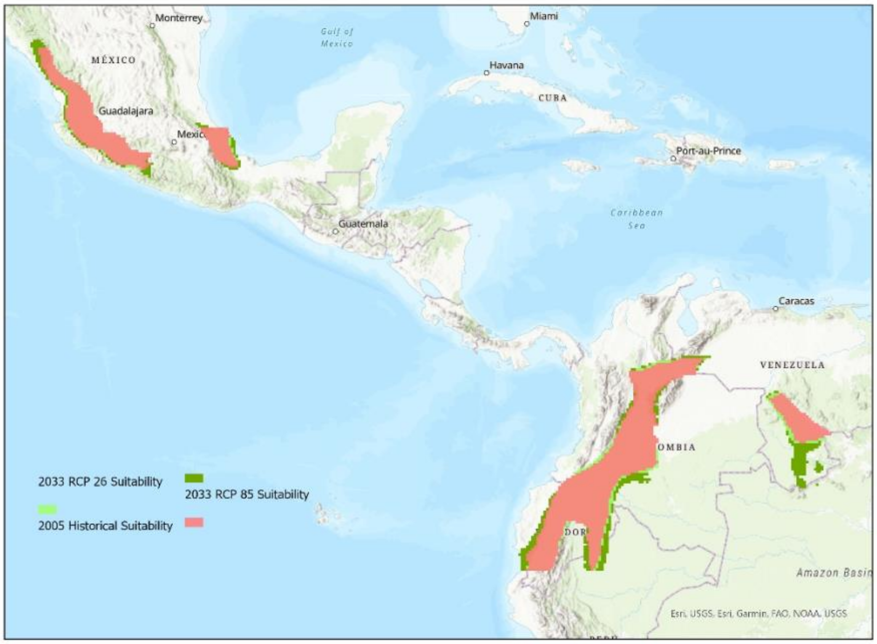

Figure 5: 2005/2083 Comparison

Figure 6: 2005/2083 RCP 8.5; Worst case scenario