The Impacts of Temperature and Precipitation on Tea Leaf Production in India, Bangladesh, and Sri Lanka

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Abstract

It is important to explore the impacts of climate change on temperature and precipitation throughout the growing and off-seasons of tea. Tea leaf production is "strongly determined by local environmental conditions…of seasonal and inter-annual climate variability" (Raj et al., 2019). This is especially relevant to India, Bangladesh, and Sri Lanka as they face both extremes of climate variability while remaining top tea producers worldwide. Despite the abundance of rain provided to tea plants during their growing season, the lower precipitation during the off-season creates a moisture deficit in tea bushes, which heavily decreases tea leaf production and crop health (Tea Research Association, n.d.). This study uses statistical modeling to show a negative relationship between production growth and precipitation and a positive relationship between production growth and temperature. In addition, by using linear regression modeling, this study quantifies the aforementioned relationships with a projected maximum decrease of 1.01% in production for every one month of suitable precipitation and estimated 0.467% increase in production for every one month of suitable temperatures.

Significance Statement

There are few studies conducted on tea leaf production that focus on off-season climate or regional comparisons. This study adds to existing research by analyzing the impacts of climate change on multiple countries from the same region, as many studies often analyze only one country or multiple geographically-different countries. This will place each country's relationship with climate change and tea leaf production in the context of its surrounding countries. In doing so, this study concluded that Sri Lanka faced the highest climate variations, which positively impacted its production trends whereas India and Bangladesh's lower climate variability negatively impacted their production. Analyzing the temporal variability of precipitation and temperature throughout the growing and off-seasons will provide non-generalized insight into yearly trends.

Introduction

It is significant to understand the effects of climate change on tea leaf production, not only because tea is the second-most consumed drink in the world compared to water, but also because the ideal climate for tea renders it vulnerable to common factors of climate change, such as rising temperatures and varying precipitation rates. Tea leaf production relies on suitable temperatures and evenly distributed rainfall.

India and Sri Lanka are among the 4 highest tea-producing countries. Along with Bangladesh, these three countries are significant tea producers in South Asia, and their monsoonal climates allow for tea plants to gain the necessary moderate to high precipitation during the growing season. These countries are vulnerable to climate change, in particular by prolonged heat waves and higher frequencies of rain storms despite decreases in annual rainfall. This concentrated precipitation has contributed to a 10% increase every decade in storms with at least 100 millimeters of rainfall per day (Sivakumar & Stefanski, 2011). Temperatures outside the suitable range of 21 to 28 degrees Celsius can inhibit the rate of photosynthesis and can slow down plant growth (Tea Research Association, n.d.). Uneven rainfall distribution, such as the excess precipitation during the peak of monsoon season, can cause drainage problems and decrease soil quality via erosion. The impacts on tea leaf production are substantial and cause for more research, as some models predict that under stronger climate change scenarios, there could be production losses of 20 to 30% (Beringer et al., n.d.).

This study aims to explore the relationship between temperature and precipitation variability and tea leaf production using statistical and linear regression modeling. I will examine the rate at which production increases or decreases based on how many months in a year are within the ideal range for each climate factor. I will also compare the differences in temperature and precipitation during the off-season and the growing season.

Results

My research first explored the patterns in temperature and precipitation during the growing season, comparing it to climate factors during the off-season. In Figure 1, the fitted lines for each country's data indicate that monthly precipitation during the growing season is generally decreasing but increasing during the off-season. For both seasons, temperature is increasing at similar rates for each country. Because precipitation is shown to vary more than temperature, it can be concluded that changing precipitation rates will have a stronger effect on tea leaf production. Figure 2 highlights this, as the trendlines for the precipitation graphs are steeper and have a larger range than those of the temperature graphs.

Linear regression models, shown in Table 1, were created to examine the relationship between production growth and the number of months each year that were within suitable precipitation and temperature ranges. Although the R-squared significance is low, these models provide useful insight with the signs of the coefficients. The positive coefficient in the first model indicates that for every month above the ideal precipitation range, production increases by 0.265%. Furthermore, for every month below this range, production is projected to decrease by that same percentage. The combined precipitation coefficients are greater in magnitude than that of temperature. In line with the trends seen in Figures 1 and 2, the modeling suggests that precipitation has a stronger association with production growth than temperature does.

Discussion

The overall trend from this research is that variant precipitation rates lead to a decrease in tea leaf production whereas tea leaf production increases as temperatures increase. Table 1 showed that production would increase and decrease at the same rate if the precipitation each month was too high or too low, respectively. Ideally, both extremes of precipitation should negatively impact tea leaf production because of dryness and overwatering. These results can be seen as inconclusive because Figure 2 showed that precipitation was only negatively correlated with production growth for every country but Sri Lanka.

Future research should re-examine the monthly trends for temperature and precipitation to only account for the tea-producing regions in each country as opposed to the whole country. This can be done by using more specific climate data and then isolating it to only the tea-growing regions. In addition, each country's climate could be further analyzed based on the conditions unique to the country, rather than applying one general ideal temperature and precipitation range for all three countries. The linear regression modeling can be extended to predict production values based on future climate projections by using said predictions as explanatory variables.

This study estimates that variations in precipitation and a continuing increase in temperature could be applied to harm all forms of agriculture across the three countries and have vast socio-economic implications. It is estimated that the demand for agricultural irrigation will increase by 10% for every 1 degree Celsius rise in temperature (Sivakumar & Stefanski, 2011). With temperatures predicted to only increase, the growing demand for water resources will affect its allocation for agriculture and for the populations that rely on reservoirs and wells.

Materials and Methods

For all figures and tables created, the monthly precipitation and temperature data was collected from the Climatic Research Unit's database (Harris et al., 2020). Annual production data was collected from the Food and Agriculture Organization's FAOSTAT database (FAO, 2023). Coinciding data from 1976 to 2022 was used because that ensured consistency across all countries. The growing season was identified to be the months from March to November because it would cover the pre-monsoon, monsoon, and post-monsoon seasons.

Figures 1, 2, and 3 were created first to understand the trends in monthly precipitation and temperature. The distribution of months shown in Figure 3 was the basis for the explanatory variables used in the linear regression modeling. These monthly counts were calculated by conditionally checking each month's temperature and precipitation data to verify whether the values were within, above, or below the climate factor's ideal range.

For the linear regression model, in Table 1, the explanatory variables were the number of months with suitable climate values. This was chosen instead of using just the raw monthly temperature and precipitation data because the months would provide a more accurate depiction of how the climate varied over time. The dependent variable, production growth, was calculated by taking the logarithmic difference between the current year's production and the previous year's. This would ensure that time and other external factors did not affect how the model calculated the relationship between the variables, as it is possible for the linear model to assume a strictly positive relationship between production and climate. It is highly possible that the data for the explanatory variables brought in high residuals and low R-squared values because the available climate data contained averaged nation-wide values, and not by each country's subdivisions.

Future research could explore how regional climate trends and off-season climate variability impact tea leaf production and plant health.

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Figures and Tables

Table 1: These are the summary statistics for the linear models that measure the relationship between production growth and the number of months per year that fall into, above, and below the ideal range of temperature and precipitation. The explanatory variables are based on the distribution of months visualized in Figure 3. Months below the range for temperature were not explored because they were all 0. For months above the range, NA values were produced which is why it has no coefficient. This could signify that the relationship between temperature and production growth is not linear or strongly correlated.

Summary Statistics with Production Growth as a Factor of Climatic Months

	Dependent variable:		
	Production Growth Percent		
	(1)	(2)	(3)
Precipitation: Months in Range	-0.824	-1.089	
	(0.769)	(0.683)	
Precipitation: Months Above Range	0.265		
	(0.436)		
Precipitation: Months Below Range		-0.265	
		(0.436)	
Temperature: Months in Range			0.467
			(0.422)
Temperature: Months Above Range			
Constant	2.278	4.659*	-0.928
	(2.290)	(2.362)	(2.518)
Observations	132	132	132
R^2	0.021	0.021	0.009
Adjusted R^2	0.006	0.006	0.002
Residual Std. Error	7.109 (df = 129)	7.109 (df = 129)	7.123 (df = 130)
F Statistic	1.366 (df = 2; 129)	1.366 (df = 2; 129)	1.226 (df = 1; 130)
Note:			*p<0.1; **p<0.05; ***p<0.01

Figure 1: This shows how precipitation rates vary more during the growing season than during the off-season. Temperatures for each country are distinctly lower during the off-season than during the growing season.

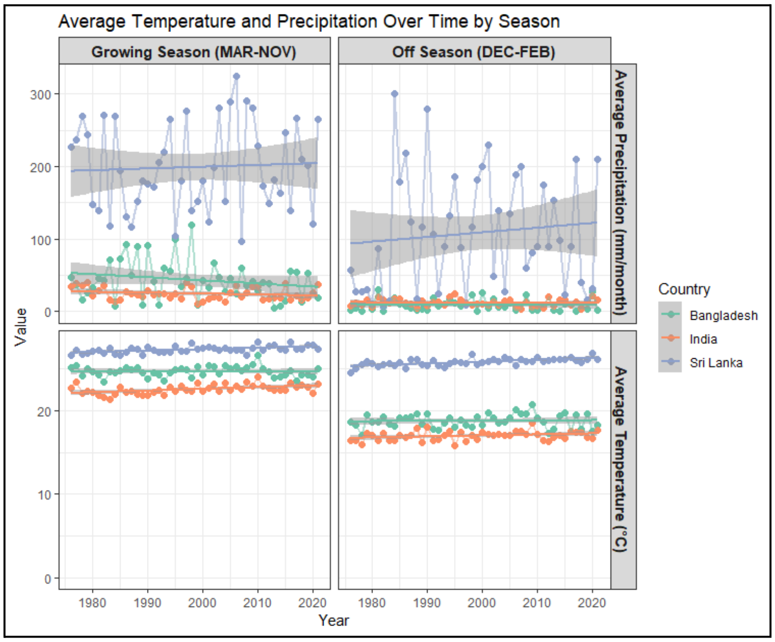

Figure 2: These scatter plots with fitted trend lines, in purple, show how production growth is generally negatively related with precipitation and positively related with temperature between the years 1976 to 2022.

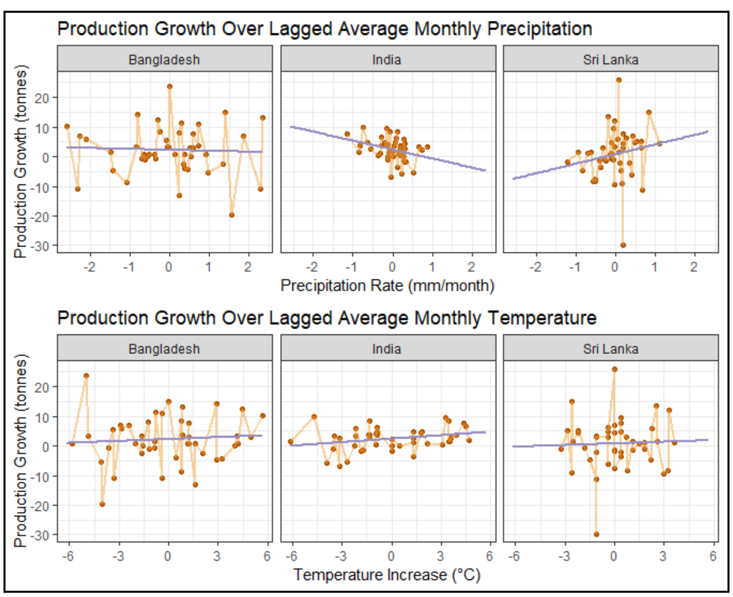

Figure 3: These graphs show the number of suitable months varies over time for each country and each climate factor. The ideal monthly temperature is a range from 21 to 28 degrees Celsius, and the ideal monthly precipitation rate was calculated based on the ideal annual precipitation range of 2000 to 3000 millimeters. The bottom three graphs do not include any months below the suitable range, indicating that temperatures have only gotten higher and more frequent as a result of climate change. The top three graphs show that the amount of months with suitable precipitation is less frequent than the other extremes of the range.