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Observing climate impacts on tea yield in Assam, India

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A B S T R A C T

Tea is an important cash crop for the economy in northeast India. It also supports the livelihoods of a large proportion of the population. At the same time, tea growth is sensitive to climatic conditions making it vulnerable to climate change and variability. Identifying the tea yield response to climatic variability in operational plantations, and identifying the most important climatic variables that impact tea yield is critical to assessing the vulnerability of the industry and informing adaptation. Here, we developed a garden level panel dataset and estimated statistical models to identify the causal effect of monthly temperature, monthly precipitation, drought intensity, and precipitation variability on tea yield. We found decreasing tea yield returns to warmer monthly average temperatures, and when monthly temperatures were above 26.6 °C warming had a negative effect. We found that drought intensity did not affect tea yield and that precipitation variability, and in particular precipitation intensity, negatively affect tea yield. An increase in average temperatures as expected with global warming will reduce the productivity of tea plantations, all else held equal. Further, interventions to reduce the sensitivity of tea plantations to warming and precipitation variability will have immediate pay-offs as well as providing climate change adaptation benefits.

1. Introduction

Tea crops produced in northeast India are of major importance for the regional economy. India is the second largest producer and exporter of tea (Tea Board of India, 2014) with the northeastern state of Assam being a key producing region. The predominant tea variety produced in Assam is Assam-type var. *Assamica* (De Costa et al., 2007). On its own, Assam contributes around 17% of world tea production and annually produces more than 50% of India's tea (Dikshit & Dikshit, 2014). Tea also plays a pivotal role in supporting the livelihoods of approximately 1.2 million laborers in Assam (Dikshit & Dikshit, 2014). The tea bush grows in a specific climatic niche, thus making the industry vulnerable to climatic variability and climate change. Given the importance of the tea crop to the economy in northeast India, and as an employer, understanding its sensitivity to climatic variation is of paramount importance. Here, we estimated statistical models that identified the effect of various climatic variables, including monthly average temperature, monthly average precipitation, drought intensity, and precipitation variability on Assamese tea yield.

Tea yield is determined by the area harvested and the weight of the tea leaf plucked (De Costa et al., 2007). Typically two or three leaves and a bud are plucked from new shoots near the top of the tea canopy. The canopy is maintained at an optimal level for plucking, commonly referred to as a “plucking table”; a height much lower than tea bushes would grow to naturally. The number of tea shoots plucked is often determined by the land area of the plantation and the cultivar of the tea bush whereas the weight of the tea plucked is determined by the rate of shoot growth and growth of new shoots between plucking cycles (De Costa et al., 2007). Typically, tea bushes are plucked with a seven to ten day cycle. Environmental and climatic conditions within these plucking cycles determine the rate of shoot expansion and tea yield over short-to-medium timescales (De Costa et al., 2007).

Traditionally, laboratory or experimental field studies have been

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utilized to assess the impact of climatic variation on tea productivity and growth (Carr, 1972; Hadfield, 1975; De Costa et al., 2007). Recent studies suggest that increased water availability increases tea plant growth and growth of new leaves on tea bushes (Ahmed, Orians, Griffin et al (2013). These same authors also identify that climatic variation can influence the quality of tea production (Ahmed et al., 2013, 2014; Carr, 1972; Hadfield, 1975; De Costa et al., 2007). While experimental studies are useful to identify the effect of specific mechanisms through which climatic variation can impact tea productivity, they do not monitor the impact of climatic variation on tea productivity as it occurs in farmers' fields. Other approaches to assess climate impacts on crop productivity utilize crop simulation models; however, crop simulation model structure may not allow identification of the impact of climate extremes and such models require large amounts of data for calibration (White, Hoogenboom, Kimball, & Wall, 2011).

To address these shortcomings, the climate-impacts literature has undertaken econometric analysis of weather on realized crop yields. Lobell and Burke (2010) and Hsiang (2016) provide overviews of the econometric methods used. Typically, regression models are estimated using panel datasets of crop yield (Burke & Emerick, 2016; Lobell, Bänziger, Magorokosho, & Vivek, 2011; Schlenker & Lobell, 2010; Schlenker & Roberts, 2009). For example, Schlenker and Roberts (2009) and Burke and Emerick (2016) identify nonlinear heat impacts on maize and soy yield using county-level data in the USA. Burke and Emerick (2016) also use a long-differences model to capture potential effects of adaptation, and show little evidence of adaptation over the past 50 years. District-level panel data of drought intensity, rice yield, and irrigation from India identifies drought impacts on rice yield, but also decreasing sensitivity of rice yields to drought over time (Birthal, Negi, Khan, & Agarwal, 2015). Regression models trained with panel data have also been applied to experimental station crop yields for maize (Lobell et al., 2011) and remote sensing data for wheat (Duncan, Dash, & Atkinson, 2014; Lobell, Sibley, & Ivan Ortiz-Monasterio, 2012) to identify climate impacts on yield. A recent analysis has used panel data of tea production in China to identify the effect of monsoon dynamics and weather on tea production (Boehm et al., 2016). An increase in retreat date of the monsoon, and an increase in monsoon precipitation is associated with a decrease in tea yield (Boehm et al., 2016).

Despite the regional importance of the tea crop in Assam, and its potential vulnerability to climate change, limited assessment of the effect of climatic variability on tea productivity in operational plantations has been undertaken. Thus, we have little idea of the extent to which climatic variability is impacting tea productivity in Assam or the extent of the resilience or sensitivity of the real-world tea production systems to climate change (based on the assumption that yield response to contemporary weather is a proxy for response to climate change (Hsiang, 2016)). Further, if climatic variability is affecting tea yield we do not know which climatic variables are of importance and should be targeted with adaptation measures. To address this gap, we developed a unique panel dataset of tea yield from over 80 gardens, with monthly yield observations for 10 years. We combined this dataset with daily weather data to estimate several regression models to identify the impact of climatic variability on tea yield in Assam. Beyond providing useful results for stakeholders challenged with managing Assamese tea production under a changing climate, our analysis builds on the emerging literature of statistical analysis of climate impacts on tea productivity (Boehm et al., 2016). Specific advances include utilizing data at the garden level as opposed to aggregated data within administrative units, application to a new but important tea growing region with a different climate, and testing a different suite of climatic variables that theory suggests impact plant productivity.

2. Study site: Assam, northeast India

There are four main tea growing regions in Assam: Cachar, North Bank, South Bank and Upper Assam (Fig. 1). Tea yield data was collected from plantations in these regions in our analysis. In Assam, approximately 65% of tea crops are cultivated in plantations and the remaining 35% on smallholder plots (John & Mansingh, 2013). Assam experiences a subtropical climate with warm summers and heavy monsoonal precipitation; mean annual precipitation in Assam from 1871 to 2008 is reported as 2346 mm (Jain, Kumar, & Saharia, 2013). On average, Assam experiences the onset of monsoon precipitation in June (Duncan, Dash, & Atkinson, 2013; Moron & Robertson, 2014). The months which receive the largest precipitation totals, on average, are June, July, August, and September (Fig. 2). Long-term average monthly temperatures reported from the tea gardens used in this study show an annual warming cycle from cool average temperatures in January, warming through the pre-monsoon months, with the warmest months being June through to September (~27 °C), and then winter cooling (Fig. 2). Trend analysis of temperature data from 1901 to 2003 reports an annual warming trend for both maximum and minimum temperatures in northeast India (Kothawale & Rupa Kumar, 2005).

3. Data

3.1. Tea yield data

Monthly tea yield data was collected from 82 tea gardens across Assam with observations from 2004 to 2013. The tea yield data was generated for each plucking round which follows a seven to ten day cycle. The green leaf plucked by laborers from the pruned and unpruned sections are weighed separately and summed for the entire month. The data from each round is recorded on a daily basis by garden managers. From these records, tea yield can be calculated as the total green leaf weight (kg) divided by the area of the plantation (ha).

3.2. Temperature and precipitation data

The temperature data used in this study was obtained from the Indian Meteorological Department (IMD) gridded datasets (Pai et al., 2014; Srivastava, Rajeevan, & Kshirsagar, 2009). The IMD gridded data includes a daily temperature product at 1° spatial resolution. These datasets were derived from ground-based station data interpolated using a modified version of Shepherd's angular distance weighting algorithm (Pai et al., 2014; Srivastava et al., 2009). We used the Precipitation Estimation from Remote Sensing Information using Artificial Neural Network (PERSIANN) dataset (http://chrs.web.uci.edu/persiann/) to measure precipitation. The PERSIANN dataset provides daily precipitation estimates from 1983 onwards at 0.25° gridded spatial resolution. For each tea garden with corresponding yield data, we extracted all daily temperature and precipitation values from 2004 to 2013.

4. Methods

4.1. Regression models

To identify the effect of climatic variables on tea productivity, a monthly tea yield panel dataset was used. The panel data structure controls for time-invariant unobserved factors that could bias our estimates of the climate effect on tea productivity. Such variables could include soil type, tea cultivar, and plantation management practices. Tea garden fixed effects are used to account for such unobservables. Tea bushes are planted and plucked for several