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Greater diurnal temperature difference, an overlooked but important climatic driver of rubber yield

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ABSTRACT

The increase of rubber demand has led to rapid expansion of rubber plantations from optimal environments in the humid tropics of Southeast Asia into suboptimal environments in montane mainland Southeast Asia. Nevertheless, rubber yields can be surprisingly high in sub-optimal environments. This paper investigates climatic factors which contribute to the higher than expected rubber yields in a sub-optimal environment in Jinghong, Yunnan, Southwest China. Two mathematical analysis methods were used to relate climate to rubber yield and dry matter content: partial least square regression and classification and regression tree models were used. Greater diurnal temperature difference was found to increase dry rubber yield, and has been previously overlooked as an explanatory factor. Average temperatures below 25.7 °C, and more sunshine hours in the day before tapping, were also found to significantly improve dry rubber yield, although more sunshine hours during the month prior to tapping were found to reduce rubber yield. Lower relative humidity was found to increase dry rubber content of latex and increase yield. Greater diurnal temperature difference and more sunshine hours in a day before tapping facilitate photosynthesis and rubber formation. Lower relative humidity reduces the water content in the latex, thus increasing dry rubber content of the latex.

In summary, this study finds that lower average temperature (within certain thresholds), greater diurnal temperature difference in both a day and a month before tapping, more sunshine hours in a day before tapping and lower sunshine hours in a month before tapping are the most important factors which promote dry rubber yield, and lower relative humidity in the day prior to tapping is the most important factor in determining dry rubber content of latex. Diurnal temperature difference has not been previously investigated as a driver of rubber yield. The case study site has a greater diurnal temperature difference than many other main rubber producing areas, which may contribute to explaining why rubber yields in Jinghong are higher than might be expected in a sub-optimal environment.

1. Introduction

The optimal environment of rubber trees (*Hevea brasiliensis*) is in the humid tropics (Raj et al., 2005). These regions are characterized by a high annual average temperature of around 28 °C, total annual precipitation varying between 1400 and 4000 mm, and humidity ranging between 67% and 82% (Priyadarshan, 2003a). The traditional, optimal locations of rubber plantation in South East Asia are Malaysia, Indonesia and Southern Thailand. As demand for rubber increased, rubber plantations have rapidly expanded into sub-optimal environments including southwest China, northeast India, highlands and coastal areas of Vietnam, northern Thailand, Laos, as well as the southern plateau of Brazil (Fox and Castella, 2013; Priyadarshan et al., 2005). A large portion of the expansion has been into areas with higher altitude than the traditional cultivated region (Nguyen, 2013). These areas are prone to climatic situations which cause stress to rubber trees: low temperature, dry periods, high altitude and typhoons (Hoa et al., 1998; Priyadarshan et al., 2001). The rubber plantations studied in this paper are representative of these sub-optimal areas of rubber expansion.

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Climatic factors are key determinants for rubber yield in these sub-optimal environments (Nguyen, 2013; Priyadarshan, 2003a). Studies have shown that temperature, precipitation distribution, sunshine hours, evaporation, humidity and wind velocity can apparently affect latex yields (Jacob et al., 1989; Priyadarshan, 2003b; Rao and Vijayakumar, 1992; Rao et al., 1998). According to earlier studies, temperatures ranging between 18 and 28 °C are optimal for rubber synthesis (Yang, 1989), while temperatures between 18 and 24 °C are optimal for latex flow (Shuogang and Yagang, 1990). Rubber yield decreases dramatically with temperatures above 28 °C or below 18 °C (Shuogang and Yagang, 1990). Zhou (2008) observed that rubber trees would be seriously affected when temperatures were lower than 5 °C or higher than 40 °C. Tapping panel dryness was seen to be high during periods of low temperature (<18 °C) (Raj et al., 2005).

In addition to the above factors, sunshine hours were also found to be correlated with weekly above-average yields (Rao et al., 1998). Evenly distributed monthly precipitation of more than 150 mm is considered optimal for rubber growth and production (Yang, 1989). Sufficient soil moisture and humidity was proven to be essential in supporting nutrient uptake and evapo-transpiration demand (Raj et al., 2005). Too much precipitation, however, makes tapping difficult (Rao et al., 1998; Yang, 1989). Priyadarshan (2003b) observed that higher wind velocity led to lower dry rubber yield. This may be because that stronger wind velocity reduces the vapor pressure and further decrease latex flow (Jacob et al., 1998).

The case study used in this paper is located in Jinghong, Xishuangbanna prefecture, Yunnan province, Southwest China. The location is considered as the sub-humid tropics (lower annual temperature and less precipitation than humid tropics), and suffers from cold damage (Wang, 1996) and drought (Qiu, 2010). The rubber plantations in Xishuangbanna yield well despite these undesirable climatic factors. From 1994 to 2004, the average rubber yield in Xishuangbanna of 1800 kg ha^{-1} year^{-1} was amongst the highest global yields (Deng, 2005). There is no existing explanation as to why such high yields can be achieved in what should, according to the literature, be a suboptimal environment. Analysis of the relationships between rubber yield and antecedent climatic factors provides an explanation to this question.

2. Materials and methods

2.1. Study area

Yunnan is the province with the second highest total rubber production (accounts for 35%) in China (Huang and Wang, 2004). Xishuangbanna is the main rubber producing prefecture in Yunnan. The sixth branch of Jinghong Farm (21°48′ N, 100°46′ E), a state-owned farm located in Jinghong (the prefectural level city of Xishuangbanna), was chosen as the research site for this study due to good data availability and topography and climate which is representative of the region. There are 1813 ha of rubber plantations on the farm. The average dry rubber yield (1673 kg ha^{-1}) from 2004 to 2010 in research site was higher than the national average yields in Malaysia, Indonesia, Vietnam and China, and slightly lower than Thailand and India for the same period (see Table 1). Among these countries, Malaysia and Indonesia are generally considered to be optimal environments for rubber production (because the climate is similar to that within the natural range for rubber crops); some parts of Thailand and India are considered optimal environments, and Vietnam and China are mainly considered to be sub-optimal environments. Table 2 summarizes the main geographic and climatic features of the 'optimal' and 'sub-optimal' environments. Jinghong generally falls outside of the 'optimal' climatic ranges for most parameters.

2.2. Rubber yield data

The rubber yield data was gathered from records in sixth branch of Jinghong Farm and includes daily dry rubber yield (kg ha^{-1}) and five-day-average dry rubber content (DRC, in percentage) from 2004 to 2010. Total daily dry rubber yield for the farm was measured before export from the farm and averaged across the whole farm area. Dry rubber content was measured by the DH925A microwave measuring instrument, which is widely used in China. The measurements are rarely affected by the environment and tapping regime. This method is rapid, repeatable and with an error of ±0.5%. Both dry rubber yield and dry rubber content are compared to climatic factors throughout this study.

The major clones cultivated in this study area are RRIM600, GT1, PR107, and YUNYAN1. The clone RRIM600 is used worldwide in both optimal and sub-optimal environments (Priyadarshan et al., 2005); GT1 is planted widely in sub-optimal environments prone to chilling (Ping et al., 2012); PR107 is a less widely planted clone, especially resistant to wind breakage (Obouayeba et al., 2010); and YUNYAN1 is a locally developed variety. All clones except YUNYAN1 have relevance to locations in other rubber cultivated region. The tapping regime are(s/4 + s/4↑)d/4 + ET2∼3% and (s/2 + s/2↑ + s/4↑)d/4 + ET2∼3%. The tapping age of the rubber trees are more than 20 years. Typically, rubber tapping takes place from 4:30 to 7:30 am. Tapping begins when temperatures exceed 15 °C in the early morning and usually starts between March and April, and ends in late November.

2.3. Climatic data

Daily climatic data (2004–2010) was collected from the China Meteorological Data Sharing Service System. Data selected for comparison to rubber yields was: daily average (T_{avg}), minimum (T_{min}) and maximum (T_{max}) temperature, diurnal temperature difference (TD), daily average (RH_{avg}) and minimum (RH_{min}) relative humidity, precipitation (P), mean wind velocity (WV) and sunshine hours (SH). The antecedent climatic factors of one day and one month prior to tapping were prepared for analyzing their relations with rubber yields.

2.4. Statistical analysis

The relationship between daily rubber yield and DRC to climate factors was evaluated using partial least square (PLS) regression in XLSTAT software and also using classification and regression tree (CART) analysis with rpart package in R software (Breiman et al., 1984). Daily dry rubber yield (total 1612 records) and five-day average DRC (total 314 records) from year 2004 to 2010 were used as dependent variables, respectively. The antecedent climatic factors in both one day and one month before the tapping day from 2004 to 2010 were used as the independent variables (total 18 independent variables).

This PLS regression first determines latent factors, a variant of principal components, to reduce the dimensionality of the independent (and optionally also the dependent) variables (Wold, 1995). Partial least square regression is thus beneficial for highly autocorrelated variables, such as climatic variables. It then uses these factors as independent factors in a linear model to explain variation in the dependent variables (Yu et al., 2012). Two major outputs are produced, namely, indication of which independent variables are useful for explaining the variation in the dependent variable (variable-importance-in-the-projection), and of the direction in which that influence is exerted (model coefficients of the centered and scaled data) (Yu et al., 2010).

The CART method used is based on Breiman et al. (1984). The variable importance of drivers of interest is calculated, and the