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IMPACT OF CLIMATE WARMING ON NATURAL RUBBER PRODUCTIVITY IN DIFFERENT AGRO-CLIMATIC REGIONS OF INDIA*

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Long term changes in climate of major natural rubber (NR) growing tracts of India were quantified and their impact on NR productivity was estimated using multiple linear regression models. Day-to-day variations in productivity in terms of dry rubber yield per tree per tap (g/t/t) could be best explained based on the variations in daily maximum temperature (Tmax) and daily minimum temperature (Tmin) and variations in other weather variables did not contribute much to the variations in daily productivity. For unit rise in Tmax and Tmin, NR productivity was affected differently in different agro-climatic regions. If both Tmax and Tmin rose by 1 °C, NR productivity will reduce by 9-16% in the agroclimatic conditions of Kerala and by 11% in the hot and drought-prone North Konkan region. On the other hand, in the cold-prone North Eastern India, there is hardly any reduction in NR productivity if both Tmax and Tmin went up by 1 °C. Our analysis show that if the present warming trend continues, NR productivity in Kerala could be reduced by 4-7% and that in North East India could go up by as much as 11% in the next decade. North Konkan region may also register about 4% reduction in NR productivity in the next decade if the present warming trend continues; however, absolute yields will continue to remain high in Kerala.

INTRODUCTION

It is very likely that greenhouse gases (GHGs) accumulating in earth's atmosphere from anthropogenic emissions are warming the world's climate system (IPCC, 2007a). Climate change as a result of global warming can influence the growth and productivity of agricultural crops (Cynthia and Parry, 1994). Climate change can affect crop productivity in various direct and indirect ways (Cynthia *et al.*, 2001). For example, an extreme weather event like drought or storm directly impacts growth and productivity. Changes in weather pattern can affect the incidence of pests and diseases and thus indirectly affect the crop.

Natural rubber (NR) is mostly grown in South and South East Asia which is highly vulnerable to climate change (IPCC, 2007b). Studies show that temperatures have generally gone up in this part of the world in the recent decades (Manton *et al.*, 2001). Number of rainy days and number of cool nights per year showed a declining trend and

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that of hot days per year increased. While we may be able to understand and appreciate to what extent climate has changed in the traditional rubber growing regions of the world in the recent past, it is extremely difficult to predict how exactly these changes will continue in the years ahead and how these changes will affect growth and productivity of NR. Thus, the impact of change in future climate on natural rubber growth, productivity and supply will be complex and difficult to predict.

While warming conditions and associated changes in climate may adversely affect growth and productivity in the traditional NR growing tracts of the world, it is likely that new regions and countries could become suitable for NR cultivation in future. For example, regions where low temperature is presently a limiting factor for cultivating NR, such as parts of North East (NE) India could become suitable for NR cultivation in a future warmer world. Changes in climate may lead to changes in incidences of old and new pests and diseases in ways unknown today.

Between 2001 and 2008, consumption of NR in India increased at the rate of 0.035 million tons/year while its supply increased by 0.036 million tons/year (IRSG, 2009). Almost all studies show that in the years ahead, this kind of near-perfect harmony between demand and supply may not continue to exist even as consumption of NR is expected to increase at a faster rate than its supply, both nationally and globally (IRSG, 2009), provided there is sustained economic growth. Since 2006, India ranks first in the world in terms of NR productivity (IRSG, 2009). Despite the recent global economic crisis, India remained reasonably buoyant and the Indian economy is expected to grow at impressive rates in the coming years, and thus, the demand for NR also will be on the rise. But climate change is one important factor that may seriously jeopardize NR availability in India and other major NR producing countries in South and South East Asia, a region particularly vulnerable to the adverse impacts of climate change (Manton *et al.*, 2001). The present study examines how rising temperature may influence NR productivity in the different agro-climatic regions of India where NR is cultivated.

MATERIALS AND METHODS

Long term daily weather data collected from the weather station at the Rubber Research Institute of India (RRII) located in Kottaym, a typical traditional rubber growing region in Kerala, since 1957 were analysed for long term trends. Long term daily weather data were collected from the Regional Research Stations (RRSs) of RRII at Agartala, Tura and Dapchari (non traditional regions), and Central Experimental Station (CES) of RRII at Chethackal and RRS, Padiyoor (traditional region) representing the diverse agro-climatic regions in India where NR is cultivated (Jacob *et al.*, 1999) and their changing trends were worked out.

The climatic conditions of these regions range from extreme dry and hot conditions in Dapchari to severe winter conditions in NE. Dapchari is situated at 20°04'N, 72°04'E with an average elevation of 48 m above MSL in the North Konkan region of Maharashtra. During the monsoon season, this region gets around 2400 mm rainfall. During peak summer days, the maximum temperature goes above 38 °C and during winter, the minimum temperature can be as low as 15.5 °C (Jacob *et al.*, 1999).

Agartala and Tura are situated in NE India, at 23^0 50'N, 91^0 16'E and 25^0 30'N, 90^0 13'E, with an altitude of around 30 and 1100 m above MSL, respectively. The annual rainfall in these regions ranges from 2000-2400 mm. During peak winter days, the minimum temperature may be as low as 5 ^{0}C or less and the maximum temperature during summer is 31 ^{0}C (Jacob *et al.*, 1999). Compared to these two non traditional regions, the weather conditions in the traditional NR growing regions of India are more moderate. These traditional regions are situated at a latitudinal range of 8^0 15'N to 12^0 5'N and longitudinal range of 74^0 5'E to 77^0 30'E with an altitude of approximately 20-500 m above MSL and are represented by RRII, Kottayam, CES, Chethakkal and RRS, Padiyoor. Mean annual rainfall in these regions ranges from 2000-4500 mm. The mean maximum and minimum temperatures during the summer months are 33 ^{0}C and 25 ^{0}C and for the winter months, 31 ^{0}C and 22 ^{0}C, respectively. India is perhaps the only country where NR is cultivated in such extremely diverse conditions. In all cases, we regressed NR yield with different weather parameters to determine the quantitative effect of each weather parameter on yield.

Three different approaches were adopted in analyzing the data. In the first approach, we regressed mean annual productivity in these diverse agro-climatic regions together with the prevailing weather parameters and made one single multiple linear regression model (MLR) for all the locations. In the MLR model, we used weather parameters like mean annual temperature (Tann), mean annual maximum temperature (Tmax), mean annual minimum temperature (Tmin), mean annual rainfall (RF) and mean number of annual rainy days (RFday) as independent variables and mean yield over the year *i.e.* g/t/t as the dependent variable. Variables from all the different experimental locations representing the diverse agro-climatic regions were regressed together in one single MLR model so as to get maximum variability in the independent (weather) variables. In the second approach, daily per tree yield (g/t/t) for several years was regressed with the corresponding daily weather parameters for these years, separately for the different agro-climatic regions. In a third approach, we regressed the per hectare productivity with maximum and minimum temperatures for three locations from within the traditional areas, namely Kottayam, Kanjirapally and Taliparamba and estimated the impact of rising temperature on productivity. After getting a model for each location, we predicted the yield for 1 ^{0}C rise in Tmax and Tmin. We also predicted the yield for the next 10 years by incorporating the current warming trends in these regions in the models.

RESULTS AND DISCUSSION

Long term temperature trends

The mean Tmax and Tmin on almost every day in an year during 2005-2009 have been higher than the same for the period 1957-1961 at RRII, Kottayam (Fig. 1). Liner regression analyses showed that the mean annual Tmax and Tmin have been increasing at the rate of 0.05 ^{0}C per year and 0.03 ^{0}C per year, respectively since 1957 at RRII, Kottayam (Table 1). At the Regional Research Station of RRII in Agartala, Tmax and Tmin increased at the rate of 0.02 ^{0}C per year and 0.06 ^{0}C per year, respectively since 1986. In every study location there was a warming

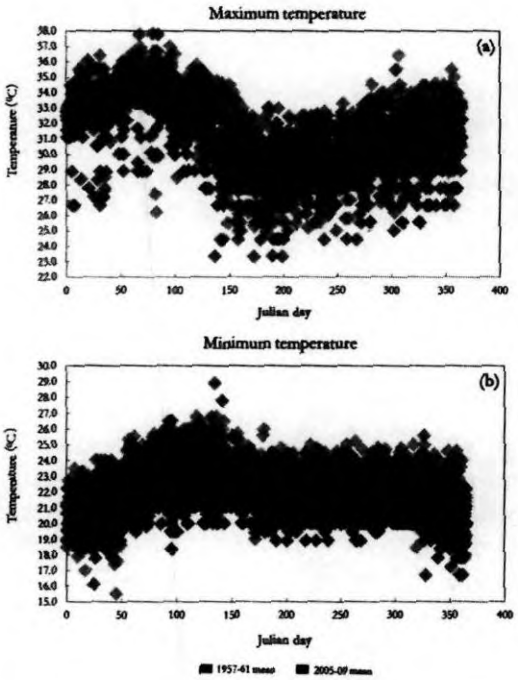

Fig. 1. Mean daily Tmax (a) and Tmin (b) in RRII, Kottayam during the periods 1957-61 and 2005-09

trend, but the extent of the warming was different (Table 1).

Multiple liner regression analysis of annual yield data and different weather parameters (all locations together)

Mean annual weather data (mean temperature, mean Tmax, mean Tmin, mean rainfall and mean number of rainy days/year) were used as the independent variables (X variables) and mean annual productivity of the tree (g/t/t) was taken as the dependent variable (Y variable) to work out a single MLR model in which data from all study locations were pooled together in order to catch maximum variations in the independent variables (approach 1). In the last step of MLR, only three independent variables were left in the model, namely, mean annual Tmax, mean annual Tmin and mean annual RF ($Y = 96.94 - 7.05$ Tmax + 7.45 Tmin + 0.008 RF, R^2=0.71) (Table 2). This

Table 1. **Climate warming trends based on liner regression analysis in different locations of the study representing different agro-climatic regions where NR is cultivated in India**

Station	Period	Annual mean temperature (^{0}C)		R^2	Warming rate (^{0}C/year)
Tura	1995-2008	Tmax	29.3	0.30	0.12
(NE)		Tmin	16.9	0.30	0.05
Agartala	1984-2007	Tmax	30.6	0.07	0.02
(NE)		Tmin	19.9	0.30	0.06
Padiyoor	1998-2009	Tmax	32.8	0.05	0.01
(Traditional)		Tmin	21.8	0.60	0.11
Dapchari	1987-2009	Tmax	33.2	0.40	0.08
(Non-traditional)		Tmin	20.6	0.16	0.03
Kottayam	1957-2009	Tmax	31.2	0.66	0.05
(Traditional)		Tmin	22.7	0.30	0.03
Chethackal	1987-2009	Tmax	32.5	0.10	0.02
(Traditional)		Tmin	21.8	0.21	-0.03

Table 2. **MLR (backward) models obtained between the annual yield and different weather parameters for all stations together (approach 1).**

Model		Unstandardized coefficient		Standardized coefficients	t	p
		B	Std. Error	Beta		
1	(Constant)	-26.4	152.224		-0.173	0.871
	Tann	2.787	2.628	0.284	1.061	0.349
	Tmax	-4.922	6.459	-0.607	-0.762	0.488
	Tmin	6.203	5.56	1.145	1.116	0.327
	RF	5.68E-03	0.009	0.449	0.625	0.566
	RFday	8.94E-02	0.305	0.21	0.293	0.784
2	(Constant)	-0.195	111.345		-0.002	0.999
	Tann	2.642	2.333	0.269	1.132	0.309
	Tmax	-6.419	3.572	-0.791	-1.797	0.132
	Tmin	7.647	2.327	1.412	3.286	0.022
	RF	8.13E-03	0.003	0.643	2.58	0.049
3	(Constant)	96.938	72.647		1.334	0.23
	Tmax	-7.053	3.61	-0.869	-1.954	0.099
	Tmin	7.452	2.375	1.376	3.138	0.02
	RF	8.11E-03	0.003	0.641	2.515	0.046

model (in which the independent variables from various agro-climatic regions were pooled and incorporated in one single MLR model) had a fundamental flaw; in the different regions, the different independent variables had qualitatively and quantitatively different impacts on yield (see approach 2 below). For example, in the NE where very low winter temperatures prevail, an increase in Tmax had a positive effect on yield unlike in other places where the effect was the opposite. This became evident when MLR analysis was made separately for the different regions (see approach 2 below). Therefore, approach 1 was rejected.

Multiple linear regression analysis of daily yield data and daily weather data separately for different locations

Upon realizing that the weather parameters had different impacts on yield in the different study locations, MLR analysis was done for each study location separately (approach 2). For obtaining variations in yield (Y) and weather (X), daily data were collected round the year for several years. The MLR models obtained for the individual regions had only two independent variables in the last step, namely daily Tmax and daily Tmin. The MLR models for the different study locations were: Y = 433.43 - 7.87 Tmax - 4.83Tmin (CES, 9^0 26'N to 76^0 48'N), Y = 171.01 - 2.54Tmax - 1.71Tmin (Padiyoor, 11° 58'N to 75° 36'N), Y = 204.98 - 1.01Tmax - 5.51Tmin (Dapchari, 20° 04'N, 72° 04'E), Y = 41.25 + 0.67Tmax - 1.13Tmin (Agarthala, 23° 50'N, 91° 16'E) and Y = -24.85 + 3.58 Tmax - 2.59Tmin (Tura, 25° 30'N, 90° 13'E). From these five models, the change in yield when both Tmax and Tmin concomitantly increased by 1 °C was calculated (Table 3). Reduction in yield in CES, Chethackal was to the tune of 16% for 1 °C rise in Tmax and Tmin. In Dapchari, the yield reduction for 1 °C rise in Tmax and Tmin was 11% followed by 9% in Padiyoor. But in the other two regions, namely Agartala and Tura in NE India where winter temperatures are very low, the impact of warming was found to be negligible. In Agartala, the yield reduction was about 1% and in the case of Tura there was an increase in the yield by 3% for 1 °C rise in Tmax and Tmin. Thus, small rise in temperature in this region may not have much adverse impact on rubber yield. Sometimes this may increase the yield just like what happened in the Tura region. Warming of the region may help to expand NR cultivation to more parts of NE where low temperature is a limiting factor today.

During the last 52 years (1957-2009) Tmax and Tmin in RRII have increased at the rate of 0.05 °C/yr and 0.03 °C/yr, respectively at RRII, Kottayam (Table 1). Extrapolating this data, the rise in Tmax and Tmin in the next 10 years was calculated and the same was used to estimate the expected reduction in productivity after 10 years at the nearby CES, Chethackal using the MLR model developed for CES (Table 3). The yield reduction after 10 years will be about 7% in CES. In Padiyoor, the rate of increase in Tmax and Tmin during the period 1998-2009 were 0.01 °C/yr and 0.11 °C/yr, respectively (Table 1) and this may result in the reduction of yield by 4% after 10 years based on the MLR model for Padiyoor (Table 3). In the

Table 3. **MLR (backward) models, percentage change in NR productivity (on a per tree per day basis) for 1°C rise in Tmax and Tmin and predicted yield depression in the next 10 years with the current warming trends in the different study locations (approach 2)**

Station			MLR			% Change (for 1 °C rise)	% Change (in next 10 years)	Estimated present productivity from MLR (g/t/t)
			Coeff.	Intercept	R^2			
Tura	2003-08	Tmax	3.58	-24.85	0.23	**3**	**11**	**35.8**
(NE)		Tmin	-2.60					
Agartala	2003-08	Tmax	0.67	41.25	0.07	**-1**	**-1**	**37.9**
(NE)		Tmin	-1.13					
Chethackal	2003-08	Tmax	-7.87	433.43	0.29	**-16**	**-7**	**73.0**
(Traditional)		Tmin	-4.83					
Padiyoor	2007-08	Tmax	-2.54	171.01	0.19	**-9**	**-4**	**48.6**
(Traditional)		Tmin	-1.71					
Dapchari	2007-08	Tmax	-1.01	204.98	0.50	**-11**	**-4**	**57.7**
(Non-Traditional)		Tmin	-5.51					

Table 4. **MLR (backward) models, percentage change in the future productivity of rubber (on a per ha per month basis) for 1°C rise in Tmax and Tmin and estimated present productivity (kg/ha/yr) from the MLR models for three locations in Kerala**

Region			MLR			% Change (for 1°C rise)	Estimated present productivity from MLR model (kg/ha/yr)
			Coeff.	Intercept	R^2		
Kottayam	2008-09	Tmax	-6.14	999.53	**0.24**	**-19**	**1965**
(close to RRII)		Tmin	-27.68				
Taliparamba	2008-09	Tmax	6.14	-7.30	**0.12**	**-4**	**1950**
(close to Padiyoor)		Tmin	-1.37				
Kanjirapally	2008-09	Tmax	-11.33	798.36	**0.25**	**-15**	**1902**
(close to CES)		Tmin	-12.68				

case of Dapchari, during the period 1987-2009 the rate of increase in Tmax was much higher (0.08 °C/yr) but the minimum temperature increased by only 0.03 °C/yr (Table 1). The reduction in the yield in this region will be 4% for the next decade. In Agartala, the reduction in yield in the next ten years will be very small going by the present warming trend (1%) which is 0.02 °C/yr for Tmax and Tmin 0.06 °C/yr for Tmin (during the period 1984-2007). For the period 1995-2008 Tmax in Tura increased by 0.12 °C/yr (Table 1). But the minimum temperature increased by 0.05 °C/yr in this region (Table 1). The cumulative effect of the expected changes in Tmax and Tmin in this region could lead to an increase in the yield by 11% in the next ten years (Table 3).

Multiple linear regression analysis of per hectare productivity and temperature

The MLR model obtained for per hectare productivity (kg/ha/month) was Y = 999.53 - 6.14Tmax - 27.68Tmin for Kottayam (close to RRII), Y = 789.36 - 11.33Tmax - 12.68Tmin for Kanjirapally (close to CES) and Y = 281.91 + 4.13Tmax - 11.26Tmin for Taliparamba (close to Padiyoor). These MLR models were made using monthly mean values of the Y and X vaiables for the whole year for several years. While mean yields were obtained from growers' fields in these three regions, the weather data were obtained from nearby RRII, Kottayam (for the Kottayam region), RRS, Padiyoor (for the Taliparamba region) and CES, Chethakkal (for the Kanjirappally region). The percentage reductions in productivity (for 1 °C rise in both maximum and minimum temperatures) were 19%, 15% and 4% for Kottayam, Kanjirapally and Taliparamba, respectively. These results were comparable to the results obtained from the respective regions when per tree per day yield was used as the dependent variable (Tables 3&4).

Our analyses clearly indicate that climate has warmed in the traditional and non traditional rubber growing tracts of India and that this will have qualitatively and quantitatively different impacts on NR productivity in the different regions. Kerala and the Konkan regions are going to be relatively more affected by the adverse effect of climate warming than NE India (Table 3) where warming conditions may increase productivity even as the prevailing cold conditions are a limiting factor at present (Jacob *et al.*, 1999). Rise in temperature, especially in Tmax would have a positive impact on NR cultivation in NE India, unlike in other places. For these reasons, approach 1 was rejected. Extrapolating the present warming trends, the MLR models clearly indicate that NR productivity will be relatively more affected in Kerala than any other NR growing regions in the next one decade, although the absolute productivity may still remain high here. However, NR productivity may see an improvement in NE in the coming decade as the region continues to get warmer.

In this context, it is pertinent to ask the question if the past warming has had in fact adversely affected NR productivity. Going by the MLR models, such an impact must have happened already. But it may be noted that statistical data clearly indicate that NR productivity in the country has gone up in the past decades (Rubber Board, 2009). This has been due to increased adoption of high yielding clones, particularly RRII 105, the flagship clone released by RRII during 1980. RRII 105 has been one of the highest yielding clones anywhere in the world. As a large share of the mature plantations came under RRII 105, NR productivity (based on statistical data from growers' fields) also increased over the years, masking the actual impact of climate warming on productivity.

However, if large scale adoption of RRII 105 had not happened and the area under this high yielding clone had not

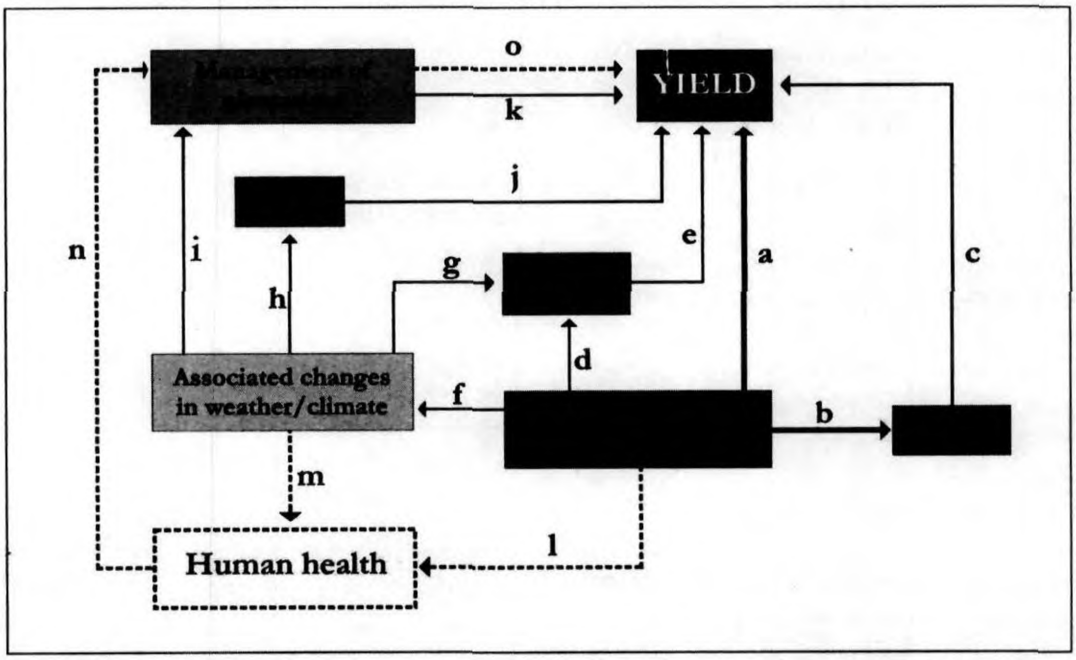

Fig. 2. Flow chart showing the direct and indirect effects of climate warming on growth and yield of rubber

increased, there was every possibility that NR productivity would have gone down over the years as a result of climate warming. The MLR models clearly suggest that the potential NR productivity must have come down in the recent decades; thanks to climate warming. During the late 1970s and early 1980s, the mean productivity of RRII 105 under the best management practices of our research farms in the traditional regions have been in the range of 60-65 g/t/t, but of late, this is mostly in the range of 50-55 g/t/t or even less (RRII, 1988 & 2010). Since the genetics (clone) was the same and the management practices were constant (as can be expected as the trials were in our own experimental farms where management practices did not under go any substantial change over the years), the most persuasive reason for this reduction in productivity seems to be the appreciable temperature warming that has happened during this period. There might have been other factors too, such as likely deterioration in soil productivity or other unknown factors, but the high rate of rise in both Tmax and Tmin in the traditional regions strongly indicates the significant role climate warming must have played in reducing productivity in the past.

This could have been true for other crops too – had it not been for the genetic and agronomic improvements, productivity might have been adversely affected, or at least the potential productivity of a new variety might not have been fully realized in the field as temperature rose. This points to the need to evolve cultivars and clones that are climate (temperature) resilient.

The present analysis has been the first attempt of its type to assess the direct impact of climate warming on NR productivity. Our results clearly indicate how Tmax and Tmin have been increasing in the past, how it has adversely affected productivity in the past and what rising temperatures might do to NR productivity in future in the different agro-climatic regions of India where this crop is cultivated today. Climate change is obviously much more complex than daily variations in weather parameters such as daily Tmax or Tmin (See Fig. 2). Changes in cloud formation, wind, rainfall pattern, occurrence of extreme weather events like storms, floods, long dry spells, unexpected breaks in monsoon, spread of new and old pests and diseases *etc.* are important factors that can seriously influence NR cropping calendar in unknown ways which are the subject of our current research.

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