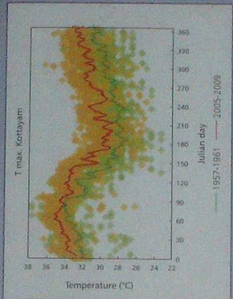

NATURAL RUBBER RESEARCH

Continuation of Indian Journal of Natural Rubber Research

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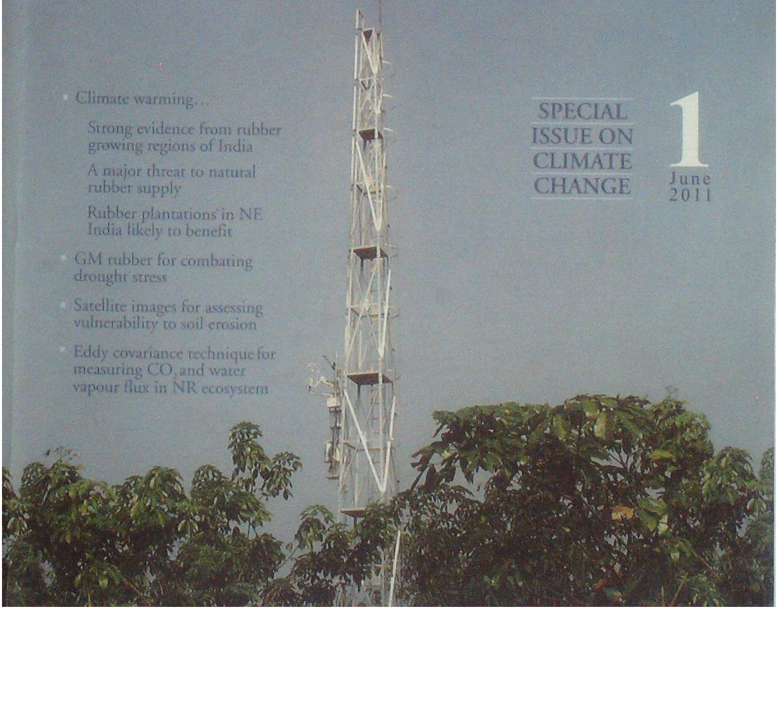
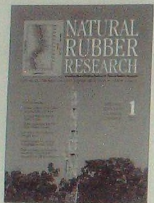


- Climate warming…
  - Strong evidence from rubber growing regions of India
  - A major threat to natural rubber supply
  - Rubber plantations in NE India likely to benefit
- GM rubber for combating drought stress
- Satellite images for assessing vulnerability to soil erosion
- Eddy covariance technique for measuring CO_2 and water vapour flux in NR ecosystem

SPECIAL ISSUE ON CLIMATE CHANGE

1
June 2011

NATURAL RUBBER RESEARCH



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- Articles in biological and technological disciplines of alternative sources of natural rubber, like guayule.
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In this issue

Natural Rubber Research is coming out for the first time with a special issue and the theme is Climate Change which is of topical relevance. The articles appearing in this special issue are important on two accounts: (i) According to the fourth assessment report of the Intergovernmental Panel on Climate Change, countries in South and South East Asia where most of the world's natural rubber (NR) is traditionally grown are highly vulnerable to the adverse effects of global warming and climate change. (ii) Due to the increasing global demand for NR, its cultivation is being extended to hitherto non-traditional areas that are often agro-climatically less congenial for its optimum growth and productivity. Thus, NR cultivation will increasingly experience climate stress, both in the traditional and non-traditional areas in the years ahead.

Several articles in this issue give evidence for climate warming in both the traditional and non-traditional areas of NR cultivation in India. The article by Satheesh and Jacob (page 1) shows how this will have a profound adverse impact on NR productivity. In parts of North East India where severe cold during winter is presently a limiting factor for NR cultivation, climate warming has a stimulatory effect on NR productivity. Moderate warming could make more areas in North East India suitable for growing NR in future.

The article by Jayashree *et al.* (page 18) explains the successful development of a transgenic rubber plant that over-expresses MnSOD, imparting protection against water deficit stress in nursery studies. This is the first such report in natural rubber. Several articles in this issue discuss agronomic practices for managing adverse climatic conditions in the field. These independent studies suggest that clone RRII 430 may have an edge over the other clones in the RRII 400 series in terms of survival under hot and dry conditions. The paper by Nair *et al.* (page 69) explains a fast and efficient method for screening large number of plants for intrinsic stress tolerance traits.

Carbon dioxide sequestration and water flux rates of a young NR plantation estimated by the eddy covariance technique is reported by Annamalainathan *et al.* (page 28). This is the first such report from a perennial crop grown in India. The article by Meti *et al.* (page 38) used satellite images for the first time to estimate the vulnerability of rubber soils to erosion. Extreme rainfall events are a likely fallout of climate change and rubber plantations which are generally grown in slopes need to take special care against soil erosion.

James Jacob MSc (Ag), PhD, DIC, PhD
Editor-in-Chief

Natural Rubber Research, **24**(1): 1-9, 2011

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

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Satheesh, P.R. and Jacob, J. (2011). Impact of climate warming on natural rubber productivity in different agro-climatic regions of India. *Natural Rubber Research*, **24**(1): 1-9.

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 ^{0}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 ^{0}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.

Key words: Climate warming, Maximum temperature, Minimum temperature, MLR models, Natural rubber productivity.

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 that of hot days per year increased. While we may be able to understand and appreciate

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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^{0}04′N, 72^{0}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 ^{0}C and during winter, the minimum temperature can be as low as 15.5 ^{0}C (Jacob *et al.*, 1999).

Agartala and Tura are situated in NE India, at 23° 50'N, 91° 16'E and 25° 30'N, 90° 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 °C or less and the maximum temperature during summer is 31 °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° 15'N to 12° 5'N and longitudinal range of 74° 5'E to 77° 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 °C and 25 °C and for the winter months, 31 °C and 22 °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 °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 °C per year and 0.03 °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 °C per year and 0.06 °C per year, respectively since 1986. In every study location there was a warming trend, but the extent of the warming was different (Table 1).

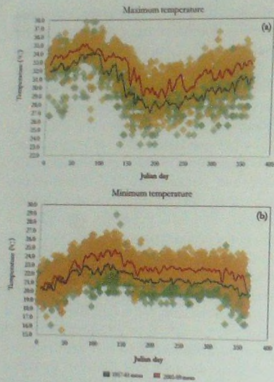

Fig. 1. Mean daily Tmax (a) and Tmin (b) in RRII, Kottayam during the periods 1957-61 (green) and 2005-09 (red)

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 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

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

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, 11^0 58′N to 75^0 36′N), Y = 204.98 - 1.01Tmax - 5.51Tmin (Dapchari, 20^0 04′N, 72^0 04′E), Y = 41.25 + 0.67Tmax - 1.13Tmin (Agarthala, 23^0 50′N, 91^0 16′E) and Y = -24.85 + 3.58 Tmax - 2.59Tmin (Tura, 25^0 30′N, 90^0 13′E). From these five models, the change in yield when both Tmax and Tmin concomitantly increased by 1 ^{0}C was calculated (Table 3). Reduction in yield in CES, Chethackal was to the tune of 16% for 1 ^{0}C rise in Tmax and Tmin. In Dapchari, the yield reduction for 1 ^{0}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 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).

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 (NE)	2003-08	Tmax	3.58	-24.85	0.23	3	11	35.8
		Tmin	-2.60					
Agartala (NE)	2003-08	Tmax	0.67	41.25	0.07	-1	-1	37.9
		Tmin	-1.13					
Chethackal (Traditional)	2003-08	Tmax	-7.87	433.43	0.29	-16	-7	73.0
		Tmin	-4.83					
Padiyoor (Traditional)	2007-08	Tmax	-2.54	171.01	0.19	-9	-4	48.6
		Tmin	-1.71					
Dapchari (Non-Traditional)	2007-08	Tmax	-1.01	204.98	0.50	-11	-4	57.7
		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 ^{0}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 ^{0}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				

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 ^{0}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 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

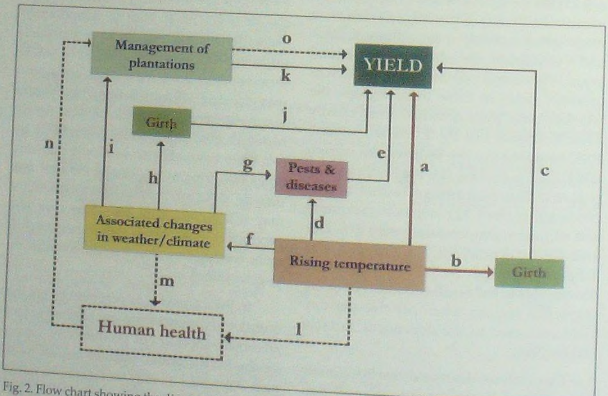

Fig. 2. Flow chart showing the direct and indirect effects of climate warming on growth and yield of rubber

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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ECOSYSTEM FLUX MEASUREMENTS IN RUBBER PLANTATIONS

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Annamalainathan, K., Satheesh, P.R. and Jacob, J. (2011). Ecosystem flux measurements in rubber plantations. *Natural Rubber Research*, **24**(1): 28-37.

Perennial trees like natural rubber plants sequester large quantities of atmospheric CO_2 into biomass and therefore, mitigate the increase in greenhouse gas (GHG) emission. In the present study measurements of CO_2 and water vapour flux of a natural rubber ecosystem were attempted for one continuous year. An eddy covariance (EC) flux measurement system was installed on an 18 meter tower inside a rubber plantation (4-5 years old) at the Central Experimental Station of the Rubber Research Institute of India (RRII) which is situated in the traditional rubber growing region of Kerala. The daily net ecosystem exchange (NEE) of CO_2 by the rubber ecosystem was in the range of 1-25 g/m^2/day during the study period. Most of the days recorded a net CO_2 sequestration. However, a few days recorded a net CO_2 efflux (R_{eco}) from the plantation to atmosphere. The mean annual NEE of the 4-5 years old rubber plantation was 11 g CO_2/m^2/day which works out to 33.5 tons CO_2/ha/year indicating that rubber plantation is a potential sink for atmospheric CO_2. The amount of carbon sequestered by the plantation as calculated from the EC data was compared with carbon sequestration of the trees calculated from biomass inventory method. The annual mean evapotranspiration was 3.5 mm/day as calculated from the EC data indicating the high efficiency of sequestering carbon per unit amount of water consumed.

Keywords: Atmospheric flux, Biomass, Carbon sequestration, Eddy Covariance, NEE.

INTRODUCTION

CO_2 is the most important anthropogenic greenhouse gas (GHG) causing global warming (Solomon *et. al.*, 2007). Agricultural and forest ecosystems act as major sinks for atmospheric CO_2 as these ecosystems can sequester large quantities of CO_2. The term "sink" is used to describe agricultural and forest lands or other systems that absorb and store CO_2 from atmosphere. Carbon sequestration is the removal and storage of atmospheric CO_2 by photosynthesizing organisms including terrestrial and aquatic vegetation, algae *etc.* in plant or algal biomass and soils (Kumar *et al.*, 2009). Sequestration of CO_2 by terrestrial plants helps prevent global warming (Suruchi and Singh, 2002). Marine algae are also a potent sink for atmospheric CO_2 (Takahashi *et al.*, 2002); however, terrestrial vegetation is obviously more amenable to human intervention than marine algae are.

Roughly between 45 and 55% of plant biomass is carbon (Malhi *et al.*, 2001). Some of this stored carbon in plants is transferred into soils when vegetation, litter and roots decay. In fact, there is more carbon stored in below ground biomass and soils than above

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ground biomass in boreal forests (Roger, 2001). In tropics, more carbon is stored in above ground vegetation than in soils (IPCC, 2000). Carbon stored in various components of an ecosystem can return to the atmosphere as CO_2 when the soil is cultivated. Agricultural tillage operations stir up soils resulting in oxidation of biomass carbon into CO_2. Decay or combusting of biomass also results in emission of CO_2 into the atmosphere. The movement of carbon in and out of trees and soils is integral part of the earth's carbon cycle.

While annual agricultural crops also sequester large amounts of CO_2 from the atmosphere, almost the entire amount of carbon stored in them is returned to the atmosphere at the end of the crop cycle when the crop is consumed by man or animal and the crop residues are used as cattle feed or they are incorporated into soil or burnt. This is not so in forestry or plantation agriculture with perennial tree species. For example, a plantation like natural rubber (*Hevea brasiliensis*) has an economic life cycle of 25- 30 years and therefore, the carbon sequestered in the biomass in rubber plantations will stay for this long.

Automobile tyres, whether they are made of natural or synthetic rubbers, are indispensable to man. Automobiles are responsible for emission of roughly 14% of the global GHGs (Stern, 2006). Natural rubber plantations help to mitigate the atmospheric CO_2 concentration in two different ways. First, it supplies natural rubber which can be used in place of synthetic rubbers that are produced from petroleum stocks. Production of synthetic rubbers results in huge emission of CO_2. Secondly, natural rubber plantations have the capacity to sequester significant quantities of CO_2 from the atmosphere. This study attempts to measure the capacity of a rubber plantation to sequester atmospheric CO_2.

There are several methods to study the CO_2 sequestration potential of a perennial plantation crop like natural rubber. Biomass inventory method is the most easily available and commonly used method which gives an estimate of the total amount of carbon stored in the various components over a period of time (Jacob and Mathew, 2004; Jacob, 2005). In the present study a state-of-the-art method known as eddy covariance (EC) technique was used for measuring CO_2 and water flux in a 4-5 year old natural rubber plantation in central Kerala continuously for a period of one year.

MATERIALS AND METHODS

Experimental site

The experimental site was situated at the Central Experimental Station (CES) of Rubber Research Institute of India (RRII) at Chethackal, Pathanamthitta District, Kerala (Fig. 1). The location is 9^0 26'N and 76^0 48'E. The study was carried out in an immature (4-5 year old) rubber plantation, with different *Hevea* clones namely, RRII 105, PB 260, RRII 430 and ten ortet selections, spread over more than five hectare area with almost uniform growth. The average height of the trees was 10 m and girth was 35 cm at 150 cm above the bud union of the plant when the study began in March 2009. Results given here are based on the measurements made between April 2009 and March 2010.

Eddy covariance technique for atmospheric flux analysis

Eddy covariance (EC) method is a sophisticated micro-meteorological method in which the fluxes of CO_2 and water vapour and three-dimensional wind velocities are measured on real time basis (Baldocchi, 2003). The EC system comprises of a three dimensional sonic anemometer (CSAT3, Campbell, USA) which is used together with an open path infra red gas analyzer (Li-7500, Li-Cor, USA). Additionally the system is equipped with a net radiometer (NR-Lite, USA) and temperature and relative humidity (RH) sensors (HMP 45, Vaisala, Finland) (Fig.2). Other weather parameters namely, rainfall, maximum and minimum temperatures, sunshine hours, *etc.* were collected from an adjacent weather station at CES, Chethackal. Carbon dioxide (Fc) and water vapour fluxes of the rubber plantation were continuously measured by eddy covariance technique for the above period. The EC equipments were commissioned on a flux tower of 18 m height and the various sensors were fixed on the tower at 4 m above the canopy (Fig. 2).

Raw data were collected and corrected by Edi Re software and processed into half-hourly values. There are several parameters necessitating correction of the measured signals (Massman and Lee, 2002). The planar fit corrections have been done for averaging the mean vertical wind by using Edi Re software. Data on CO_2 flux (Fc) and the water vapour flux which is measured as latent heat of vapourisation (LE) were corrected for density effects (Webb *et al.*, 1980). Daily diurnal net ecosystem exchange of CO_2 (NEE) and day and night flux rates were also calculated. The latent heat of vapourization (LE) was used to calculate evapotranspiration (ET) on a per day basis. The downloaded and corrected data table contains half hourly mean values of net radiation, air temperature, relative humidity (RH), fluxes of CO_2 (Fc), water (LE) and sensible heat (H). The rates of ecosystem photosynthesis, respiration and decomposition will vary diurnally and seasonally in response to interactions between the physical environment like irradiance, moisture and temperature and biotic factors like plant phenology, soil microbial metabolism and heterotrophic CO_2 release (Goulden *et al.*, 2004). Therefore, attempts were also made to correlate the CO_2 flux values with prevailing environmental conditions.

Net ecosystem level flux of CO_2 and water vapor in real time was calculated. The net CO_2 exchange obtained from the EC system is the difference between photosynthetic assimilation by the vegetation and the total respiratory CO_2 efflux from the foliage, roots and soil (Lalrammawia and Paliwal, 2010). In the present study, ecosystem level net CO_2 sequestration rates (photosynthesis and respiration, including litter decomposition) and evapotranspiration for a one year period in a 4-5 year old rubber plantation is described.

Accounting of tree biomass

The above ground dry weight of a rubber tree was calculated using the Shorrock's regression model:

$W = 0.002604\ G^{2.7826}$ (Shorrocks *et al.*, 1965)

where, G is trunk girth (cm) at a height of 150 cm from bud union. 15-20% of the shoot biomass was taken as the root biomass.

RESULTS AND DISCUSSION

Diurnal pattern of net ecosystem exchange of CO_2 (NEE) clearly indicates two phases namely, a net fixation of CO_2 occurring during day time (influx) and net release of CO_2 from the system into the atmosphere during night time (efflux) (Fig. 3). By default,

Fig. 1. Map showing the location of the study area (Chethackal, Pathanamthitta District, Kerala, India, 9^0 26′N ; 76^0 48′E)

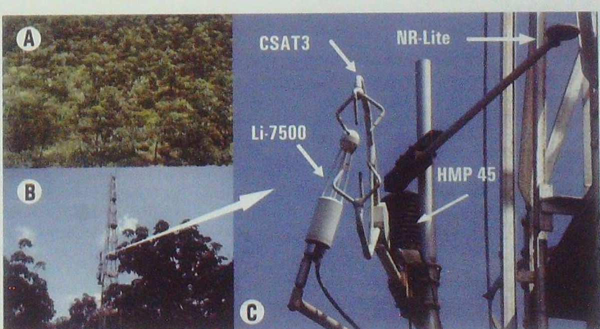

Fig. 2. (A) A bird's eye view of the young rubber canopy at Central Experimental Station (CES), Rubber Research Institute of India, Kottayam, Kerala State, India. (B) Eddy covariance system installed on an 18 meter tower inside a rubber plantation. (C) Various sensors of eddy covariance measurement system are indicated, CSAT3, Campbell's three dimensional sonic anemometer; Li 7500, Li COR's open path infra red gas analyzer; NR- Lite, Kipp and Zonen's net radiometer and HMP 45 temperature and RH sensors

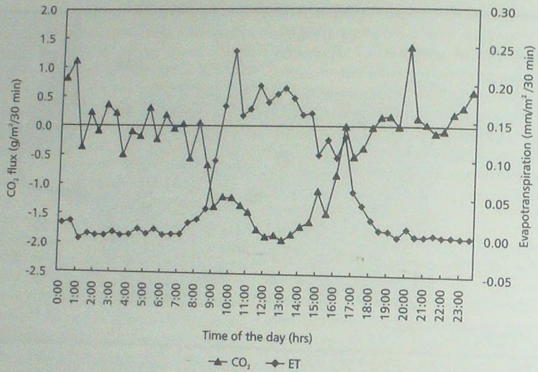

Fig. 3. A typical diurnal CO_2 and water flux (25th July 2009) pattern in an immature rubber plantation (4-5 years old)

net influx of CO_2 into the ecosystem (net photosynthesis) is shown as negative flux and net efflux of CO_2 (net respiration) is shown as positive flux which includes respiration from all living components and decomposition, collectively termed ecosystem respiration (R_{eco}). The difference between the amount of net fixation during day time and the CO_2 lost as R_{eco} during night time is the net fixation of CO_2 by the ecosystem for a given day. As sunlight intensity increases, net CO_2 flux gradually becomes negative (indicating net photosynthesis or CO_2 influx or sequestration into the ecosystem) and this generally remains negative until sunset. In the evening as light intensity declines R_{eco} becomes greater than CO_2 fixation (Fig. 3). Evapotranspiration followed an opposite pattern as that of CO_2 flux (Fig. 3).

During the study period, the daily NEE by the rubber ecosystem ranged 1-25g CO_2/m²/day (Fig. 4). Most of the days recorded CO_2 influx in to the plantation; however, a few days (around 25 days during the one year study period) recorded net carbon efflux from the plantation to atmosphere. On those days, around 1-7g CO_2/m²/day was released to atmosphere and during these days there was rain and relatively fewer sunshine hours. The net efflux on certain days would have included the possible high rate of total soil respiration (R_s) both by autotrophic (R_a) and heterotrophic (R_h) components of the soil in addition to the net CO_2 release from leaf respiration. The soil respiration rate generally depends on the soil moisture, temperature, organic composition, density of microbial population and rate of decomposition of organic contents (Stephen

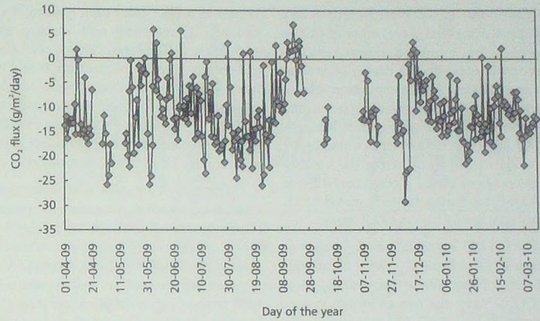

Fig. 4. Daily net CO_2 flux (Fc) in a 4-5 year old immature rubber plantation in central Kerala for a continuous one year period. Short gaps in the data are due to equipment failure from thunder storm, power failure *etc.*

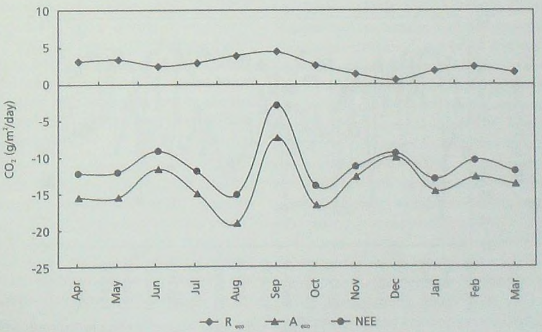

Fig. 5. Mean monthly ecosystem exchanges of CO_2 in a 4-5 year old rubber plantation. The mean ecosystem respiration (Reco), ecosystem CO_2 assimilation (A_{eco}) and net ecosystem CO_2 exchange (NEE) on per day basis are depicted

and Theodore, 1979). Intermittent heavy rainy days witnessed a net efflux of CO_2 to atmosphere, most probably, due to a low rate of canopy photosynthesis due to poor solar light and possible sudden spurts in release of locked up CO_2 from the air space in the soil. Sunny days (when soil moisture level was not deficient) were more favourable for sequestration of carbon by the rubber plantation. On an annual average, the NEE was 11g CO_2/m^2/day during the study period which is equivalent to 33.5 tons of CO_2/ha/year.

The net CO_2 assimilation (A_{eco}) and net respiratory CO_2 efflux (R_{eco}) were calculated for the entire year. While the mean R_{eco} was 2.5g CO_2/m^2/day, the net assimilation rate (A_{eco}) recorded was 13.5g CO_2/m^2/day (Fig. 5). Though there was considerable rate of ecosystem respiration at night, the CO_2 assimilation during daytime was much higher in rubber plantation making it a net sink of CO_2. In a study with mature rubber plantation in Thailand, Thaler *et al.* (2008) got similar rates of sequestration and they have suggested that ecosystem level EC measurement of CO_2 and water fluxes could be used to model gas exchange of rubber plantation according to prevailing climate and other environmental parameters.

The daily flux data were analyzed in relation to prevailing maximum temperature (Tmax) and sunshine hours of the day, but a clear relationship was not observed throughout the study period, most likely due to other factors such as soil moisture and VPD interfering with photosynthesis and respiration (Stephen and Theodore, 1979; Orchard and Cook, 1983). In general, days with lengthy sunshine hours recorded high rate of net ecosystem exchange (Fig. 6).

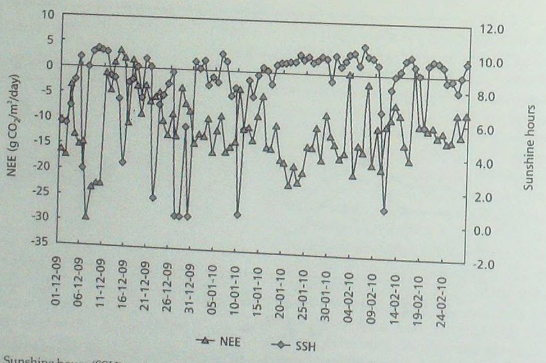

Fig. 6. Sunshine hours (SSH) and net ecosystem exchange of CO_2 (NEE). Days with lengthy sunshine hours recorded high rate of net ecosystem exchange (NEE)

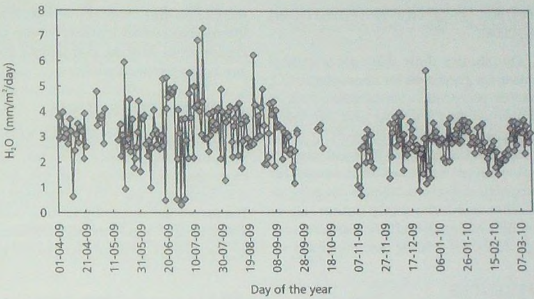

Fig. 7. Water flux in a 4-5 year old rubber plantation in central Kerala for a continuous one year period

During summer months sunlight was plenty but soil moisture deficit and high atmospheric VPD could restrict canopy photosynthesis and hence NEE. The NEE was relatively higher during pre-monsoon period when the soil is fully recharged with moisture after the initial showers. During continuously cloudy and incessant rainy days, either NEE was very low or the net ecosystem respiration rate was higher than net assimilation.

The rate of evapo-transpiration (ET) was calculated from the downloaded data on latent heat of vapourization (LE). The mean ET was 3.5 mm/day during the study period (Fig. 7). Earlier studies with lysimetric method in the traditional rubber growing areas of Kerala showed that the mean ET was 4.4 mm per day (Jessy *et al.*, 2002).

The amount of carbon sequestered by the rubber plantation was estimated during the same period by estimating the annual shoot biomass increment during this period using Shorrock's method. From the shoot biomass estimation, the amount of CO_2 sequestration was calculated as 13.5 t CO_2/ha/yr which does not include root biomass, soil respiration, litter decomposition and sequestration by weeds and other vegetation inside the plantation such as cover crops. Carbon stock in rubber plantations has been worked out earlier by biomass inventory method (Jacob and Mathew, 2004; Wauters *et al.*, 2008). The amount of carbon stored in one hectare of a 33 year-old stand was 596 mt. Total carbon sequestered by rubber plantations under Kerala conditions for a 21 year period was estimated to be 67 t C/acre and it was reported that the sequestration capacity of rubber plantation was much higher than most other terrestrial ecosystems (Jacob and Mathew, 2004). A 14 year old rubber holding had a carbon stock of 76 t C/ha in its above ground biomass which is equivalent to 19.9t CO_2/ha/yr (Wanters *et al.*, 2008). The contribution of the soil organic carbon pool amounted to 135 t C/ha (Wauters *et al.*, 2008).

Our studies show that natural rubber plants are a good sink for atmospheric CO_2 round the year. Cultivation of rubber trees on non forested land is a good land use option to mitigate rising concentration of CO_2 in the atmosphere. Under Kyoto Protocol, forestry or plantation activities that sequester atmospheric carbon into biomass can generate CO_2 offset credits that could further help in reduction of fossil fuel use (Suruchi and Singh, 2002), but existing plantations are not eligible for this credit. However, there are alternative carbon markets where carbon credits from existing plantations are also getting greater acceptability.

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COMPARISON OF ROOT TRAINER AND POLYBAG GROWN PLANTING MATERIALS OF *HEVEA*

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A propagation technique which will promote deep growth of taproot and well-developed lateral roots, is very important under a warmer and drier agro-climate influenced by global warming. Polybag plants with improper root system may not be able to withstand the various stresses characteristic of dry agro-climate. Vigorous seedlings of polycross origin propagated by means of seed-at-stake planting seem to be the best planting technique for the future. Advanced planting materials produced by the new propagation technique of *in situ* budding of stocks raised in root trainers may also perform well under an agro-climate influenced by global warming.

Keywords: Global warming, Plant propagation, Polybag plant, Root trainer, Seed-at-stake planting, Young budding.

INTRODUCTION

Climate is expected to get warmer and drier in the coming years in most of the traditional rubber growing tracts in the world. Developing appropriate technologies for cultivation of rubber under these climatic extremes will be one of the most important challenges before the rubber plantation industry in the immediate future. A propagation technique which will promote deep growth of taproot and well-developed lateral roots, is very important under a hot and dry climate influenced by global warming. At present, rubber is commercially cultivated mostly by using advanced planting materials raised in polybags. Despite various advantages, polybag plants were noticed to have certain drawbacks like coiled taproot, meager development and deformed growth of lateral roots etc. (Soman and Saraswathyamma, 2005). Taproot coiling was reported to adversely affect wind fastness and drought tolerance of plants in several crop species (Sharma, 1987; Josiah and Jones, 1992). The present communication is an evaluation of different propagation techniques being practiced for rubber with particular reference to their comparative efficiency to survive under a warmer and drier agro-climate.

MATERIALS AND METHODS

The experiment was conducted during 2007 (Cheerakuzhy Nursery, Mannarkad)

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and repeated during 2008 (HBSS, Paraliar) and 2009 (Vadakkel Nursery, Perumbavur). The propagation techniques included were *in situ* young budding, *in situ* green budding and stump planting of rubber in root trainers and polybags. A randomized block design with four replications and a plot size of 40 plants was adopted. Root trainers used for young budding had a length of 22 cm with a holding capacity of 350 cc and that used for green budding by direct seeding and stump planting had a length of 30 cm with a holding capacity of 800 cc. Cured coir pith mixed with powdered rock phosphate (5 g), neem cake (5 g), bone meal (5 g), pesticide (Phorate –10G @100 mg) and fungicide (Dithane M-45 @100 mg) was used as the potting medium per root trainers. Polybags of size 17.5 x 35.5 cm and thickness 250 gauge were used for young budding and of size 25 x 55 cm and thickness 400 gauge were used for green budding by direct seeding as well as for stump planting. Polybags were filled with topsoil mixed with powdered rock phosphate at the rate of 25 g for small bags and 50 g for big polybags.

Germinated seeds were planted directly in polybags and root trainers. Sufficient stock seedlings were raised in the ground nursery also for green budding and stump planting. After planting, the root trainers and polybags were stacked in trenches. Young budding was initiated at the age of 28th day onwards (on attaining maturity of the first whorl of leaves) on the seedlings raised in polybags (T_1) and root trainers (T_2) and continued up to 60 days (until it started emerging the second whorl of leaves), with bud wood of the same age. Budding tape of width 1.2 cm, length 25 cm and thickness 100 gauges was used for young budding. Green budding on stocks raised in polybags (T_3), root trainers (T_4) and ground nursery were initiated at the age of three months and continued up to 4½ months following standard practice. Budding success was enumerated 21 days after budding and successful bud grafts of both young budded and green budded plants were cut back at the age of five months. Successful green budded plants in the ground nursery were pulled out, stumped and planted in polybags (T_5) and root trainers (T_6) on the same date. Root trainer plants raised by stump planting were initially stacked in trenches till they attained two whorls of growth and then subjected to hardening by hanging in stand made of iron rods. Young budded plants raised by *in situ* budding on stocks raised in root trainers were stacked in stand right from the beginning. The plants were irrigated daily and fertilizer was applied with NPKMg (10:10:4:1.5) at the rate of 5 g for small polybags and 10 g for big polybags. Fertilizer was applied in root trainers in the form of 2% solution of the same fertilizer mixture at weekly intervals. Observations on height, diameter, number of whorls, number of leaves *etc.* were recorded just before transplanting to the field. Roots were examined by destructive sampling of ten plants each from every treatment. Data were analyzed statistically following Rangaswamy, 1995.

RESULTS AND DISCUSSION

High ambient temperature, low humidity, extended soil moisture stress and low ground water table are supposed to be the major climatic constraints anticipated under the influence of global warming. A bud grafted young plant is a two partite structure consisting of scion of an improved cultivar bud grafted on a rootstock of unknown genetic constitution. An agro-climate characterized by climatic extremes may demand a root system consisting of a deeply grown taproot with well-developed lateral roots. Since breeding for better rootstock is not easily practical in rubber, rootstocks are required to be improved by adopting appropriate plant propagation techniques.

Polycross planting materials are derived from specially designed polyclonal seed gardens. Plants raised using polycross seeds were noticed to posses a strong root system with sturdy shoots (Simmonds, 1989). There are several documented evidences for better performance of polycross planting materials under stressed agro-climate. So, seed-at-stake planting raised with polycross planting materials seems to be the most suitable propagation technique for warmer agro-climatic conditions. However, the plants derived from polycross seeds may exhibit high variability with respect to growth and yield. So, the plants raised out of polycross seeds may be test tapped at the age of 1-2 years. A stringent selection based on test tap yield followed by field budding of poor yielders may improve yield potential of a polycross stand significantly. Under conditions of extreme climatic stresses, the entire polycross populations could be used as rootstocks and field budding could be attempted with high yielding clones having proven track record for drought tolerance.

Though polycross planting materials can bring about considerable improvement of rootstock, this planting technique is a laborious process necessitating much care and additional expenditure while the yield potential is relatively low (Simmonds, 1989). The cultural operations in the field are required to be initiated one year in advance and the climatic conditions in our country are reported to be not suitable for adoption of this practice on a large-scale (Rubber Growers Companion, 2011). So, a comparative study on various propagation techniques being practiced in rubber was made with an emphasis on roots, with the assumption that a well-formed and well-oriented root system would have better adaptive value under a changing agro-climate.

The important observations recorded on advanced planting materials generated by adopting various propagation techniques are furnished in Table 1. Lateral root formation was observed to be significantly higher when the stock seedlings were raised by direct seeding in containers (T1 to T4) compared to stump planting (T5 and T6). Successful bud grafts, when lifted from the ground nursery, were noticed to possess an average of 30 to 60 lateral roots, but all these laterals were pruned before planting in containers. It could be seen from Table 1 that approximately only ¼ of these lateral roots were regenerated in polybags (T5) and the others remained dormant. In this respect, the planting materials produced by young budding and green budding *in situ* in polybags (T_1 and T_3) were found to have the advantage that roots were not pruned or lost at any stage.

The taproot of rubber is capable of growing up to a couple of meters deep into soil, but due to the limitation of space inside the bag, taproot was seen coiled in 79.1% and 87.7% of plants in T_1 and T_3 respectively. A coiled taproot in rubber was observed to never attain its normal growth even several years after transplanting to the field (Soman and Saraswathyamma, 2005). In a tree crop like rubber, which grows very tall with heavy canopy, taproot coiling (Fig. 1a) can have a catastrophic effect as has been pointed out by several workers in various tree crops (Wilson, 1986; Sharma, 1987; Shankar, 1994; Chadurvedi, 1994; Khedkar and Subrahmaniam, 1996; Nanhorya *et al.*, 1999; FRI, 1999; Ginwal *et al.*, 2001). In due consideration of the above mentioned drawbacks of polybag plants, the Agricultural Division of the Asian Technical Department of the World Bank recommended root trainer planting technique as an alternative to polybag plants for tree crops (Josiah and Jones, 1992). Polybag plants with coiled taproot and under-developed lateral roots may not withstand a warmer and drier climate.

The propagation technique of raising advanced planting materials by planting green budded stumps in root trainers has widely been employed in the traditional belt. In this technique, the root trainers are filled with cured coir pith, planted with green budded stumps and the containers are stacked in trenches. On attaining two whorls of growth, the plants are subjected to hardening. For this, the plants are lifted from the trench, the roots outgrown the containers are carefully pruned with a knife and the plants are stacked in carriers made of iron rods. In this suspended condition off the ground, the taproot resumes growth in a few days and undergoes natural air pruning on contact with air. This natural air pruning exerts a temporary stress on the plant, and some of the root primordiae which remained dormant, are induced to sprout again under the influence of the stress. The vertical ridges on the container wall direct these roots downwards and these lateral roots are also subjected to air pruning. As a result, a hardened root trainer plant raised with budded stump as the initial planting material possess an average of 14.4 lateral roots as against 7.8 laterals observed in polybag plants of the same age (Table 1). So, in addition to avoiding the coiled growth of taproot, the natural air pruning is found to be helpful to improve the lateral root formation in root trainer plants. However, it could be seen from Table 1 that almost half of the lateral roots removed from the budded stumps still remained dormant and hence the root trainer plants raised with budded stumps as the initial planting material could also be not considered as an ideal propagation technique under a stressful agro-climate.

Table 1. **Mean values of budding success, scion establishment, growth and root parameters**

Treatment	Budding success (%)	Scion establishment (%)	Growth parameters			No. of leaves	Plants with coiled taproot (%)	No. of lateral roots
			Height (cm)	Diameter (mm)	No. of whorls			
T_1	96.1	92.3	68.1	7.93	1.86	13.0	79.1	33.8
T_2	95.6	91.8	59.6	8.66	1.68	11.4	–	47.7
T_3	88.3	92.1	71.0	8.31	1.74	12.1	87.7	30.7
T_4	86.6	90.0	62.9	8.49	1.69	11.8	–	58.6
T_5 (Control)	90.3	86.6	67.9	8.95	1.81	12.6	73.2	7.8
T_6	89.1	82.7	62.2	8.11	1.66	11.6	–	14.4
G. mean	91.0	89.3	65.5	8.41	1.72	12.1	–	32.2
CD (P=0.05)	6.3	4.9	8.3	0.91	0.27	1.6	–	30.6

In situ young budding on stocks raised in root trainers was an improvisation of the root trainer propagation technique mentioned above. This technique was standardized with a view not to disturb the roots at any stage in the nursery. Germinated seeds were planted directly in root trainers and kept suspended in carriers right from the beginning and budding was initiated at the single-whorl stage. The taproot growing out of the drainage hole at the bottom of the container was subjected to natural air pruning on contact with air. This air pruning, in the absence of soil, was a stress to the plant and the plant responded to the stress by producing large number of additional lateral roots into the well-aerated potting medium. The vertical ridges on the container wall directed these lateral roots also downwards in to air. As a result, at the time of transplanting, the root system of a young budded root trainer plant (*in situ* budding) was seen transformed into a root plug consisting of a single air pruned taproot and innumerable lateral roots which were properly oriented inside the container (Fig. 1b).

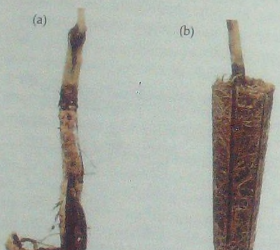

Fig. 1. (a) Root system of a poor quality polybag plant and (b) that of a hardened root trainer plant

Based on the observations made during the present study, it could be concluded that advanced planting materials raised in polybags using budded stumps as the initial planting material suffered from some serious drawbacks like coiling of taproot, insufficient number and deformed growth of lateral roots (Fig. 1a). A major portion of lateral roots pruned from the budded stumps failed to regenerate in polybags. Damage caused to the skin of the taproot during the process of uprooting and replanting the stumps could be one of the reasons for this meager lateral root formation observed in polybags. The poorly aerated topsoil used as the potting media in polybags was also reported to exert an inhibitory effect of the formation of lateral roots (Josiah and Jones, 1992). Relatively better lateral root formation was observed in root trainers, but a considerable number of lateral roots remained dormant in root trainers also when budded stumps were used as the initial planting material.

The propagation technique of *in situ* budding (both young budding and green budding) in polybags had the advantage that roots were not cut and lost at any stage, but the advanced planting materials were found to suffer from drawbacks like coiled taproot, strangled growth of lateral roots *etc.* The newly standardized propagation technique of *in situ* young budding on stocks raised in root trainers was an improvisation of the root trainer propagation technique using budded stumps as the initial planting material (Soman and Saraswathyamma, 2005). In this latest propagation technique, natural air pruning prevented coiling of taproot and this air-pruned root was noticed to grow deep into the soil on transplanting, just like the taproot of seedling trees. This deep growth of taproot may provide access to the much-needed moisture available in the deeper layers of soil during extreme drought. The full set of lateral roots, supplemented by additional numbers formed in response to natural air pruning, may help the plant to acquire additional absorption area. This additional absorption area may help the plant to absorb sufficient water and nutrients even under extended soil moisture stress. Roots were not disturbed during the process of transplanting and hence the naturally air pruned roots were noticed to resume growth within 24 hours after transplanting to the field. This quick growth of roots may help the plants to attain high establishment success even under prolonged dry spells.

Budding success in rubber is highly influenced by atmospheric temperature and humidity. So, a dry weather due to a change in the agro-climate is likely to poise a serious threat to the vegetative multiplication of planting materials in rubber. The stock seedlings in the newly standardized *in situ* young budding are raised in root trainers and the plants were maintained over a stand, off the ground, till they are finally transplanted to field. The compact size of the container and the portable nature of the stock seedlings make it possible to take the rootstocks to a green house and carry out bud grafting under controlled environment. A stand containing as many as 75 plants could be taken to a green house and budding could be attempted conveniently on a wooden bench. In case of unfavorable agro-climate, budding success could be improved by retaining the bud-grafted plants under protected conditions till the scion buds are accepted by the stock. So, this planting technique makes it possible to derive the various advantages of bench grafting without uprooting the plants and hence without compromising the budding success and establishment.

This modern propagation technique is environment friendly, labor friendly and highly cost effective also. Due to the light weight and compact size of the containers, the cost required for planting operations like transport of plants, distribution, field planting *etc.* could be cut short drastically compared to polybag plants which also need large volumes of soil.

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SOME GOOD AGRICULTURAL PRACTICES FOR ADAPTING RUBBER CULTIVATION TO CLIMATE CHANGE

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Drought is one of the most important manifestations of climate change as far as the rubber growing regions in India are concerned. The effect of type of planting material and water conservation techniques like tillage, mulching and *in situ* water harvesting on growth of immature rubber and storage of soil moisture in two ongoing experiments are discussed. In the nursery experiments, growth parameters of planting materials raised through direct-seeding in polybags followed by *in situ* budding and planting budded stumps in polybags were compared. The results indicated significant difference in the growth performance depending up on the type of planting material. It was observed that the planting material produced through direct-seeding with an intact root system was significantly superior in stem diameter, plant height, number of whorls, fibrous root and dry matter compared to plants raised through budded stumps. In the field experiment, direct-seeded green budded plants were integrated with moisture conservation practices like tillage, mulching, silt pits and enhanced fertilizer application along with the use of organic manures. It was observed that the soil moisture storage during summer was significantly increased compared to the plots where plants were raised from budded stumps following the current package of practices. A significantly higher leaf area index (LAI) and root length density (RLD) were maintained by the direct-seeded green budded plants under integrated management. The growth of the direct-seeded green budded plants under integrated management was significantly superior to other treatments. Therefore introduction of planting materials with a good root system and adoption of good agricultural practices (GAPs) could play an important role in adapting plants to future extremes of climate change.

Keywords: Climate change, GAPs, Growth, Immature rubber, Soil moisture.

INTRODUCTION

Natural rubber is a prominent plantation crop of considerable significance to Indian economy, having a share of 8.9 per cent of world's production and 8.7 per cent consumption. Climate change has many facets including fall and rise in temperature, rainfall uncertainties, severe and prolonged droughts *etc*. Prolonged hotter, drier climate and uneven monsoon are a reality in the traditional rubber growing regions in India. Like other agricultural crops, the growth and productivity of natural rubber are also adversely affected by climate change (Jacob, 2010). Concern is growing among the natural rubber producing countries over the possible impact of climate change especially after the fall of NR output by 5.1 per cent during 2009

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available information, biomass gasifier is not being used in other major rubber producing countries for drying of block rubber. If, at least, 50 per cent of the production is dried with producer gas, 120 million liters of diesel can be saved which will in turn reduce 3,24,000 MT of CO_2 emission into the atmosphere per year.

The biomass gasification technology can replace diesel/kerosene/electricity in a conventional block rubber dryer. Its benefits are two fold; in addition to the savings made in the cost of production of block rubber, there would be considerable reduction in CO_2 emission. Globally, only a small quantity of block rubber is being dried with this technology and there exists further scope for contributing towards CO_2 emission reduction in NR processing by employing this technology.

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CLIMATE UNCERTAINTIES AND EARLY ESTABLISHMENT OF YOUNG RUBBER PLANTS IN TRADITIONAL RUBBER GROWING REGIONS OF INDIA

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Observations indicated that climate uncertainties are increasing the number of casualty of young plants immediately after field planting. Symptoms of drought are manifested on young plants during summer and life saving irrigation is increasingly being practiced in very young holdings even in the traditional rubber growing regions to tide over drought. In addition to the already recommended summer management practices, tilling of the plant basin at the end of the rainy season increased soil moisture storage, reduced casualty during summer and enhanced growth of young plants. This may be a good practise to manage drought in young plantations.

Keywords: Casualty, Climate uncertainty, Drought, *Hevea brasiliensis*, Life saving irrigation, Soil moisture, Tillage.

The impact of climate change on agriculture varies with crop, region and cultivation techniques. Variabilities in local climate rather than global climate patterns are more relevant in determining the impact of weather events on crop production. Daily, monthly and seasonal patterns of temperature and precipitation are likely to be affected by climate change (Reilly *et al.*, 2000). Rainfed crops are more vulnerable to the variations in climate such as changes in precipitation regimes, temperature, sunshine hours and relative humidity. Reddy and Hodges (2000) emphasized the need for altering cultural practices and engineering techniques to tackle climate change effects on crop production. Considering the changing climatic scenario in the rubber growing regions of the world, the current agronomic practices being followed in rubber cultivation may be inadequate to meet the challenges of future climate.

The impact of uncertain weather pattern will be more pronounced during the establishment and early growth of young rubber plants. Traditionally monsoon season is the ideal planting season of rubber in India. In recent years, uncertainty in rainfall and other weather factors is making the scheduling of various farm operations like planting, difficult even in traditional rubber growing regions. Occurrence of unexpected

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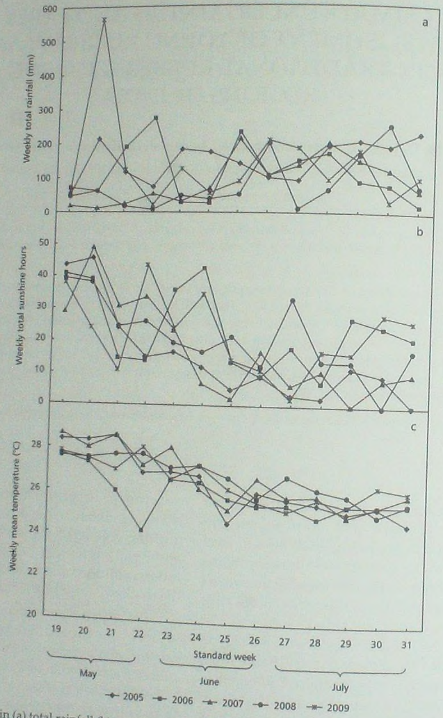

Fig. 1. Variability in (a) total rainfall (b) sunshine hours and (c) mean temperature during monsoon season

dry spells and bright sunny days with warm temperature during the monsoon season also increases casualty. The present study was carried out to assess the impact of changing weather pattern on planting and establishment of young rubber plants.

The extent of casualty after planting was assessed in field experiments initiated during consecutive years with varying weather pattern during planting season in Central Kerala. The extent of casualty was assessed in one hectare plantation during 2007 and 2008. During both years, planting was carried out during the first week of July and casualty was assessed during September.

A field survey was carried out to find out the extent of life saving irrigation adopted by smallholders during the summer season of 2010. The traditional rubber growing region mainly covering the central Travancore and south Malabar regions of Kerala was sub divided into eight regions for the survey. A total of 161 holdings were visited for the assessment of drought intensity in the first year of planting.

A field experiment was conducted at Puthukkad Estate, Trichur, which is a comparatively drought prone area in Kerala. The experiment was initiated during 2008 with three treatments *viz.*, control, tilling the plant base and life saving irrigation. Rubber (clone RRII 105) was planted during June 2008 and subsequently vacancy filling was carried out during September 2008. At the end of the rainy season (October, 2008) the base (radius 1.0 m) of 100 rubber plants were tilled to a depth of 10 cm. Hundred plants were given life saving irrigation weekly twice from December 2008 onwards and another hundred plants were retained as control without irrigation or tillage. The base of the plants in all the three treatments were mulched as per the standard practice and stem of the rubber plants were protected from sun scorch by contact shading with dried grass. Soil moisture was recorded periodically during summer and stem diameter was recorded at the end of summer (April 2009). The data was analyzed with t-test. Extent of casualty at the end of the summer was also recorded in all the first treatments.

Table 1. **Casualty of young plants two months after planting in the main field**

Year	Date of planting	No. of plants observed	Casualty (%)
2007	July 6	450	2.6
2008	July 3	450	4.7

Casualty of young plants immediately after planting was 2.6 per cent during 2007 whereas it was 6.7 per cent during 2008 even after providing life saving irrigation to the plants which showed wilting symptoms. Planting was done during the first week of July which is the middle monsoon season in both years. Although soil moisture status was sufficient in both years, atmospheric drought due to bright sunshine hours and high temperature (Fig. 1a-c) during the first week of July 2008 might have resulted in the higher casualty (Table 1). It is recognized that as the climate warms and as the hydrologic cycle intensifies, it is likely that there will be an increase in the temporal and spatial variability of precipitation and in the intensity and duration of storms and droughts (Huntington, 2010). The occurrence of dry spell with bright sunshine and warm temperature during monsoon season observed in this study may or may not be related to climate change. However, new management strategies to mitigate the resulting adverse effects should be developed if such aberations continue to occur. Soil moisture conservation alone is not sufficient and the possibility of enhancing the ability of plants to tide over transient drought by nutritional manipulations or other cultural methods need to be explored.

In the field survey in traditional rubber growing region, it was observed that in addition to the recommended management practices like mulching and shading, life saving irrigation is increasingly practiced in certain holdings, although this has not been a recommendation in the tradidtional areas.

Table 2. **Percentage of farmers adopting life saving irrigation in the first year of planting in traditional rubber growing region**

Sl. No.	Region	No. of holdings surveyed	% of holdings irrigated
1	Adoor	20	20
2	Kottayam	22	18
3	Pathanamthitta	25	16
4	Erattupetta	19	16
5	Kothamangalam	20	18
6	Muvattupuzha	19	21
7	Mannakkad	25	16
8	Thalassery	11	16
	Total farmers contacted		161

Almost 18 percent of the rubber holdings where planting was taken up in 2009 in the traditional belt where the survey was taken up, were irrigated at least once during the summer season of 2010 (Table 2). Life saving irrigation was never needed in the traditional rubber growing regions. However, in the recent years due to scorching sunlight and high temperature, life saving irrigation is being provided to tide over drought conditions. In most cases basin irrigation was adopted.

Visual assessment indicated chlorophyll bleaching and leaf scorching in the rainfed unirrigated young plants. Severe drought induced mediated symptoms in leaf have been reported only in non-traditional areas of rubber cultivation in central India (Devakumar *et al.*, 1998: Jacob *et al.*, 1999). Heat stress caused by increasing temperature has already been reported as a major concern for crop production in association with projections of increase in the number of days with high temperature (Trenberth *et al.*, 2007) and in young rubber plants also, it appears that climate change is warranting alterations in cultural practices.

The experiment area on tillage did not receive rains during December to February 2009. Tillage enhanced soil moisture content significantly during January and February (Table 3) and the growth of plants was significantly superior to that of control and was on par with that of plants with life saving irrigation (Table 4). Surface tillage has been reported to enhance soil moisture storage considerably (Jalota and Prihar, 1998; Payne,

Table 4. **Growth and survival of plants 10 months after field planting**

Treatment	Diameter (mm)	Casualty (%)
Control	18.34	4
Tillage	19.81*	Nil
Life saving irrigation	19.72*	Nil

* Significant at P=0.05

Table 3. **Soil moisture status during summer (%)**

Treatment	January			February		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Control	10.74	14.65	15.65	10.44	13.68	16.05
Tillage	12.98 *	16.47 *	18.69 *	13.67 *	15.12 *	17.04 *

* Significant at P=0.05

1999). The extent of casualty was 4% in the control whereas there were no vacancies in the other two treatments during summer season of 2009 (Table 5). The data indicated that additional measures to conserve soil moisture will help to enhance growth of young rubber plants and reduce casualty. Both tillage and life saving irrigation were found effective; however, tillage is a comparatively more economically viable and feasible management practice.

These observations indicate the necessity of adopting additional *in situ* moisture conservation measures and developing appropriate management techniques to increase the ability of plants to tide over drought which may become more adverse in a future warmer world.

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POTASSIUM AND SILICON HELP YOUNG RUBBER PLANTS TIDE OVER TRANSIENT DROUGHT

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A glass house experiment was conducted with polybag plants of clone RRII 105 to study the effect of potassium and silicon in alleviating the adverse effects of soil moisture stress in young rubber plants. The experiment consisted of two treatments, *viz*, irrigated and unirrigated. Under each treatment, there were four sub-treatments *viz*, control (standard practice), silicon (Si), potassium (K) and silicon + potassium (Si+K). Silicon was supplied as rice husk ash, and incorporated into the soil, two weeks after planting. In treatments with potassium, 2.5 times the recommended dose of K was added so that N:K was maintained as 1:1. Observations on leaf water potential and chlorophyll content index indicated positive effect of silicon and higher dose of potassium in overcoming soil moisture stress.

Keywords: *Hevea brasiliensis*, Moisture stress, Potassium, Silicon.

Variations in annual monsoon pattern and increasing frequency of dry spells during monsoon season adversely affect establishment and initial growth of rubber plants even in traditional rubber growing regions. Increasing severity of drought during summer season also augments the casualty in the field. Scarcity of water for irrigation and manpower limit the large-scale adoption of irrigation in young rubber plantations, though life saving irrigation for young plants is increasingly adopted in recent years.

Status of mineral nutrients in plants plays a critical role in increasing plant resistance to drought stress (Marschner, 1995). It is known that potassium (K) has a specific role in alleviating the adverse effects of soil water stress, by decreasing the loss of water from the plant by reducing transpiration (Mengel and Kirkby, 1980). K^+ maintains the osmotic potential and turgor of the guard cells and regulates the stomatal functioning under water stress conditions (Lindhaur, 1989). Potassium enhances photosynthetic rate and plant growth under stress condition (Marschner, 1995). The compensating effects of high levels of added K in overcoming moisture stress effects in young rubber plants was reported by Samarappuli *et al.* (1993).

Silicon (Si) also plays an important role in enhancing tolerance to environmental stresses like drought and cold in plants (Lux *et al* 2002; Ma and Yamaji, 1999). Silicon improved water use efficiency and

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maintained high rates of photosynthesis under water stress (Epstein, 2001). Silicon helps to maintain lower hydraulic resistance under water stress and increases water uptake (Hattoiri, 2005). Besides this, silicon has been reported to alleviate aluminum toxicity, which increases the susceptibility of plants to water stress by formation of aluminum silicates (Marschner, 1995).

In young rubber, the current recommendation of K is low compared to nitrogen and phosphorus (N : K = 2.5 : 1). A low quantity of K was recommended since there was no measurable effect of K on growth of young rubber plants (Ananth, 1966). Beneficial effects of silicon in young rubber plants have not been studied so far.

Uncertain rainfall pattern as a result of climate change has been reported to increase casualty of young plants immediately after planting (Jessy *et.al.*, 2011). Bright sunshine and high temperature are being experienced even in the middle of the monsoon season in recent years adversely affecting establishment of young plants in the field (Jessy *et al.*, 2010). The objective of the present study was to find out if silicon and potassium supplements increase the ability of young plants to tide over transient drought. The experiment was conducted in a glasshouse, since uncertain weather pattern makes testing in the field difficult.

Brown budded stumps of clone RRII 105 were planted in polybags (60x35 cm) and raised in glass house conditions. The soil used for filling the polybags was acidic in reaction (pH 5.2), medium in organic carbon status (1.02 per cent) and low in available P (0.5 mg/100g) and available K (4.5mg/100g) (Jackson, 1958).

There were two treatments, *viz.*, irrigated and unirrigated. Under each treatment, there were four sub-treatments *viz*, control (standard practice), silicon (Si), potassium (K) and silicon + potassium (Si + K). Silicon was supplied as rice husk ash, and incorporated into the soil (1g/kg soil), two weeks after planting the budded stumps. N:P:K:Mg mixture (10:10:4:1.5) was applied twice at the time of maturity of first and second whorls. In treatments of higher dose of potassium, 2.5 times the recommended dose of K was added (N:K=1:1) and both N and K were applied in two splits. Treatment imposition was completed 15 days prior to withholding irrigation.

There were 40 plants under each treatment, out of which 20 were kept un-irrigated, while rests of the plants were irrigated. Before initiating the experiment, water for irrigation was quantified so that no water drained outside the polybag. Water lost through evapo-transpiration was replenished by irrigation based on the canopy area and evaporative demand of the atmosphere. Soil moisture content in polybag was assayed by gravimetric method on the 30th day of withholding irrigation. chlorophyll content index was recorded after 10, 20 and 30 days of withholding irrigation with a chlorophyll content meter (CCM 200, Opti-science, USA). Leaf water potential was recorded with a Psypro water potential meter (Wescor Inc.) after 10 and 20 days of withholding irrigation. Leaf area was measured with LiCOR leaf area meter, 20 days after withholding water. After 35 days, plant diameter was recorded, and the plants were uprooted for the estimation of dry mater. The data was subjected to two-way analysis of variance.

Chlorophyll content index (CCI) recorded 10 days after imposing water stress in polybags showed significant reduction in

Table 1. **Chloroplyll content index – 10, 20 and 30 days after withholding irrigation**

Treatment	Chlorophyll content index					
	10 days		20 days		30 days	
	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed
Control	119.9	99.5	117.3	95.7	98.3	45.2
Si	115.1	115.9	119.7	110.9	103.2	65.1
K	119.5	119.5	117.2	116.2	95.6	73.3
Si+K	116.0	110.1	109.4	100.6	100.8	66.4
Mean	117.6	111.3	115.9	105.7	99.5	62.5
CD(A)	4.57		5.08		6.49	
CD (AxB)	9.14		10.16		12.99	

stressed plants compared to irrigated plants (Table 1). Among unirrigated treatments, CCI was significantly higher for treatments with Si, K and Si + K compared to stressed control. CCI recorded after 20 and 30 days also showed the same trend. After imposing water stress for 30 days, there was 54% reduction in CCI in the stressed control compared to the irrigated control. This reduction in CCI compared to irrigated control was only 25% for K, 34% for Si and 33% for Si + K treated plants, indicating a positive effect of potassium and silicon in retaining chlorophyll content under moisture stress condition.

Table 2. **Leaf water potential (-MPa) 10 and 20 days after withholding irrigation**

Treatments	Leaf water potential (-MPa)			
	10 days		20 days	
	Irrigated	Stressed	Irrigated	Stressed
Control	2.22	2.78	2.22	3.09
Si	1.98	1.96	2.58	2.69
K	2.03	2.36	2.30	2.69
Si+K	2.23	2.34	2.34	2.51
Mean	2.12	2.36	2.36	2.75
CD (A)	0.17		0.13	
CD(AxB)	NS		0.26	

Leaf water potential (LWP) recorded 10 days after imposing water stress showed a significant decrease in unirrigated plants compared to irrigated plants (Table 2), but did not show significant difference among sub-treatments. However, after 20 days, among the unirrigated treatments, significantly higher LWP was observed for Si, K and Si + K treated plants compared to stressed control, indicating a positive effect of potassium and silicon in maintaining a better water status in plants under soil moisture stress.

Bajehbaj *et al.* (2009) reported the beneficial effect of higher level of potassium in maintaining chlorophyll content and leaf water potential in sunflower (*Helianthus annuus*) under drought stress. Similar results in potato *cv.* Agria. was reported by Khosravifar *et al.* (2008). Samarappuli *et al.* (1993) studied the role of potassium on growth and water relations of rubber plants and reported that stem diameter and height of rubber plants when grown in a soil at 50 per cent field capacity with recommended level of K was almost equal to the stem diameter and height of plants when grown in a soil at 10 per cent field capacity with double the recommended level of K.

Ma and Yamaji (1999) reported the beneficial effect of silicon application in reducing water loss by cuticular transpiration in rice and sugarcane. Hattori *et al.* (2005) reported a positive effect of silicon application in maintaining the photosynthetic rate and stomatal conductance at a higher level in sorghum (*Sorghum bicolor* Moench) under drought stress.

Leaf area recorded 20 days after withholding irrigation showed a significant reduction in unirrigated plants, compared to irrigated plants (Table 3). Stem diameter recorded 35 days after withdrawing irrigation showed a significant decrease in water stressed plants compared to irrigated plants, and among the sub-treatments, no significant difference was observed (Table 4). Stem and root dry matter estimated after 35 days was significantly lower in stressed plants compared to irrigated plants, and among sub-treatments, no significant difference was observed (Table 5). The mean soil moisture content estimated on 30[th] day of drought imposition in the irrigated and unirrigated treatments were 21.24% and 14.33% respectively.

Data on CCI and LWP indicate that under soil moisture stress condition, supplementing silicon and a higher dose potassium helped the plants to retain chlorophyll content and maintain leaf water potential. Under short dry spells, both silicon and potassium were effective in reducing the adverse effects of water stress. However, as the water stress prolonged, potassium was more effective than silicon. In this experiment, after imposing water stress for 35 days, all the plants were irrigated uniformly and it was observed that plants supplemented with higher level of K recouped from wilting symptoms within two days and showed better survival percentage. Further experiments have to be conducted in the field to ascertain the beneficial effect of potassium and silicon in drought prone areas.

Table 3. **Leaf area (cm^2) 20 days after with holding water**

Treatment	Irrigated	Stressed
Control	63.24	43.35
Si	68.91	58.78
K	67.44	55.67
Si+K	65.78	54.77
Mean	66.34	53.14
CD(A)	2.92	
SE (AxB)	2.76	

Table 4. **Diameter of stem (mm)**

Treatment	Irrigated	Stressed
Control	8.55	6.18
Si	7.91	6.00
K	8.73	7.09
Si+K	8.64	6.18
Mean	8.46	6.36
CD(A)	0.41	
SE (AxB)	NS	

Table 5.: **Stem and root dry matter (g/plant)**

Treatment	Stem		Root	
	Irrigated	Stressed	Irrigated	Stressed
Control	7.95	4.77	5.64	3.47
Si	9.44	4.89	6.28	4.21
K	9.57	7.88	5.53	4.42
Si+K	8.11	5.97	5.62	3.91
Mean	8.77	5.88	5.76	4.00
CD(A)	0.86		0.50	
CD(AxB)	NS		NS	

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VARIATIONS IN LEAF FATTY ACID COMPOSITION OF DIFFERENT CLONES OF *HEVEA BRASILIENSIS*

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The increased unsaturation of lipids in plant cell membranes is considered as a necessary adaptation to cold stress. Fatty acid composition of leaf polar lipids in different *Hevea brasiliensis* clones was analyzed and the double bond indices computed. The main unsaturated fatty acids in the leaf polar lipids of *H. brasiliensis* were palmitoleic acid, oleic acid, linoleic acid and linolenic acid. Palmitic acid and stearic acid were the main saturated fatty acids. The double bond indices of leaf polar lipids in different *Hevea* clones varied significantly. Among the clones, the highest double bond index was noticed in RRIM 703, suggesting that it would be the most cold tolerant clone.

Keywords: Cold tolerance, Double bond index, *Hevea* clones, Leaf fatty acid.

In order to meet the rising demand for natural rubber, rubber cultivation is now being extended to the non-traditional areas in India including the low temperature stress prone states like Assam, Tripura, Meghalaya, etc. Tolerance to low temperature is a useful trait for plants grown in such areas. Plants respond to low temperature stress through a wide variety of biochemical and physiological changes, such as synthesis of many regulatory proteins, accumulation of compatible solutes etc. Over the past decade, a number of reports in different crop plants have shown physiological effects on cell membrane properties due to low temperature stress (Steponkus, 1984; Orvar *et al*., 2000).

Cell membrane undergoes both qualitative and quantitative modifications during low temperature stress which increase the membrane fluidity. The lipid composition, level of fatty acids and its level of saturation/unsaturation regulate the cell membrane fluidity (Hur *et al*., 2004). Lipids of plant cell membranes are characterized by a high content of polyunsaturated fatty acids (Wang *et al*., 2006). An increase in phospholipids unsaturation has been related to membrane fluidity at low temperature. Saturated fatty acids solidify much faster at lower temperatures than unsaturated fatty acids and hence tissues with high quantities of unsaturated fatty acids would have a low freezing point. The fatty acid composition of leaf polar lipids of cold tolerant and susceptible rice genotypes indicated that double bond index of lipid unsaturation is significantly high in the cold tolerant genotypes (Majumder *et al*., 1989). Gustavo *et al*. (1990) studied the fatty acid composition of leaf phospholipids of barley

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