INTERNATIONAL WORKSHOP ON

CLIMATE CHANGE AND RUBBER CULTIVATION: R & D PRIORITIES

28-30 July 2010

Rubber Research Institute of India, Kottayam-686 009, India

ABSTRACTS

Organised by

Rubber Research Institute of India

In association with

International Rubber Research and Development Board

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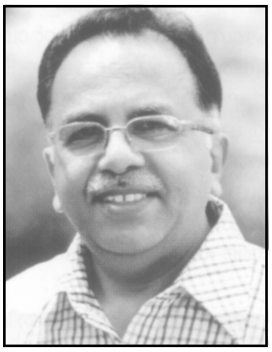

MESSAGE

We live in a world which is increasingly facing the threat of global warming and unprecedented climate change. According to the fourth Assessment Report of the Intergovernmental Panel on Climate Change, this is due to increase in the concentrations of greenhouse gases such as carbon dioxide, methane, nitrous oxide etc. in the atmosphere. However, there is a tiny minority of scientists - the so-called "climatic skeptics"- who still believe that climate change is not due to anthropogenic effects but this is due to natural causes such as changes in solar activity etc. Whatever be the cause or causes, there is a general consensus among scientists and political leaders, and it is common knowledge among ordinary people, that climate has been changing in their surroundings. Even as emission of carbon dioxide and other greenhouse gases is intricately linked to industrial activities and thus economic growth, the economic cost of climate change is substantial. We hear a lot about melting of polar ice, retreat of glaciers and occurrence of heat waves, flash floods, droughts, sea surge etc. in different parts of the world. The human and economic costs of these effects are beyond comprehension. Agriculture and food availability will be severely threatened and the poor masses living in the developing and least developed countries, mostly in the equatorial region will be highly vulnerable to the adverse effects of climate change.

Natural rubber is mostly cultivated in the developing countries in South and South East Asia, parts of South America and Africa falling in the equatorial belt. These are some of the most populous nations in the world and they are highly vulnerable to the adverse effects of climate change. Natural rubber cultivation will not remain immune to the adverse effects of global warming and climate change. There are more than 10 million small growers who depend on natural rubber cultivation for their livelihood in these countries and climate change has the potential to pose serious threats to their well-being. Adverse effects of climate change can seriously diminish the supply of natural rubber and thus jeopardize the rubber goods manufacturing industry. Shortage of natural rubber will eventually result in increased consumption of synthetic rubbers which will lead to increase in the emission of carbon dioxide into the atmosphere.

The importance of studying the impact of climate change on natural rubber supply was brought to the attention of the International Rubber Study Group (IRSG) by me during its meeting of its Industry Advisory Panel held in Brussels in October 2008. Since then, the Association of Natural Rubber Producing Countries (ANRPC) and the International Rubber Research and Development Board (IRRDB) have taken keen interest in the subject and I am glad that Rubber Research Institute of India is now hosting this important workshop under the auspices of the IRRDB. I congratulate all those who have been instrumental in organizing this workshop and coming out with this book of abstracts of the presentations. I am sure this workshop will help scientists to formulate meaningful research programmes for the future in which climate uncertainties will be major constraints for growth and productivity of natural rubber.

RRII **Sajan Peter IAS**

24 July 2010

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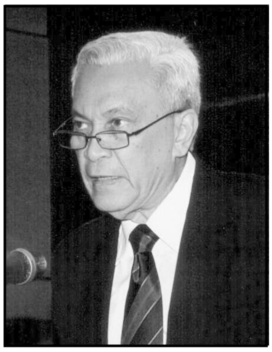

MESSAGE

The International Rubber Research and Development Board (IRRDB) has a long and rich history of bringing scientists and policy makers working in the area of natural rubber in various parts of the world to a common platform to discuss issues of topical importance. With a total membership of 21 rubber research institutes from 20 countries and 5 associate members, the IRRDB covers more than 95% of the natural rubber cultivated area in the world. In recent years, the IRRDB has become more active and visible by organizing various activities through its different specialist groups. In the Meeting of the Chief Executives and Directors of IRRDB and Meeting of the Board held in Bogor, Indonesia during October 2009, a decision was taken to organize an international workshop on "Climate Change and Natural Rubber Cultivation: R & D Priorities" under the auspices of the IRRDB Specialist Group on Physiology. The workshop will be hosted by the RRI India.

I am extremely happy to note that more than 50 papers are being presented in this important workshop and wish to congratulate Dr. R. Krishnakumar, Liaison Officer of the IRRDB Specialist Group on Physiology who has worked very hard to organize the workshop.

The deliberations of this workshop will be useful to develop research strategies for cultivating natural rubber in a future climate which is expected to become less congenial in most of the traditional rubber growing regions of the world. Considering the importance of climate change and its impact on natural rubber cultivation, the IRRDB has set up a Task Force on Climate Change and I believe the recommendations of this workshop would be reviewed by the Task Force for further course of action.

Kuala Lumpur
24 July 2010

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FOREWORD

The Bogor meetings of IRRDB held during October 2009 decided to organize an International Workshop on "Climate Change and Rubber Cultivation: R & D Priorities" as an activity of the IRRDB Specialist Group on Physiology. Given the significant amount of research done in this area, Rubber Research Institute of India offered to host this workshop. India is perhaps the only country in the world where natural rubber is cultivated in extremely diverse agroclimatic zones where the summer maximum temperature can be above 40 ^{0}C or the minimum temperature during winter can be below 4 ^{0}C. RRII has successfully developed clones and farm technologies suitable for these diverse conditions.

About 60 papers are presented in this workshop. These papers are organized into different technical sessions such as (i) Climate Change and its Impact on Natural Rubber Productivity (ii) Projected Climate Scenarios and Natural Rubber Supply in Future (iii) Natural Rubber Cultivation in Stressful Environments (iv) Climate Change and Prevalence of Diseases in Natural Rubber and (v) Innovations in Rubber Processing and Manufacturing Industry for Mitigating Climate Change.

The extended abstracts of these papers are presented in this booklet for quick reference. Several studies indicate that climate has been undergoing significant changes in the natural rubber growing regions of the world. Temperature has risen, number of hot days and warm nights per year has gone up and unexpected break in monsoon and prolonged dry spells have been occurring in many palaces. While rise in temperatures can significantly reduce productivity in most of the traditional regions, this may have only little impact in cooler regions such as North East India or parts of China where rubber is cultivated. Warming temperatures may make more areas available for rubber cultivation in these regions. Climate change can bring new pest and disease incidences. Weather-induced instability in the supply of natural rubber can have significant impact on price formation. Studies presented in this workshop show that innovations in rubber processing and manufacturing can help in reducing emission of carbon dioxide and other greenhouse gases. Possibilities of applying remote sensing and GIS in climate change studies and identifying areas that are vulnerable to adverse effects of climate change are also discussed. Thus, this book of abstracts is a rich repository of highly valuable scientific findings. I hope and expect that the contents of this book will lead to meaningful research for successful cultivation of natural rubber in areas which are vulnerable to the adverse effects of global warming and climate change.

I wish to thank Sri. Sajen Peter, IAS, Chairman, Rubber Board for all the efforts he has taken to project the importance of climate change to the natural rubber sector at various national and international platforms, including IRSG, ANRPC, IRRDB etc. He has always shown keen interest in all activities of RRII. He is demitting the office on 5th of August 2010 after completing his term as Chairman of Rubber Board. All of us at RRII wish him the best in his next assignment.

I would also like to thank Datuk Dr. Abdul Aziz Bin S.A. Kadir, Secretary General, IRRDB for all the support and encouragement that he has given for the workshop. I thank Dr. Stephen V. Evans, Secretary General, IRSG for attending this important workshop and delivering a special lecture. I also thank all the invitees, delegates and my colleagues from RRII for their whole hearted support and hard work in making this workshop so beautiful. I also thank Travancore Rubber & Tea Co. Ltd, Thiruvananthapuram, Harrisons Malayalam Ltd, Kochi, Midas Mileage, Kottayam, Rehabilitation Plantations Ltd., Punalur, Vadakkel Nursery, Perumbavoor, Rubber Asia, Kochi, Mars Agency Pvt. Ltd, Bangalore, Spinco Analytica (P) Ltd., Chennai and Eastern Treads Ltd., Ernakulam for their financial support for the workshop.

RRII **Dr. James Jacob**
28 July 2010

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WHY SHOULD WE WORRY ABOUT CLIMATE CHANGE?

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The global mean temperature of the earth has increased by almost one degree Celsius during the past 150 years. This warming did not cause any concern earlier because it was thought to be a part of natural variability of climate. During the past 30 years there has been a realization that most of the warming that has been observed is triggered by the release of carbon dioxide through burning of fossil fuels. The evidence of human induced climate change is accumulating every day. Most glaciers are retreating and there is increase in the incidence of heat waves and lower incidence of frost. The pace of climate change will accelerate in the 21st century if human beings continue to depend upon fossil fuels as the primary energy source.

Some developed countries have not taken the threat of climate change seriously because they think that they have the resources to adapt to a warmer world. The major impact of climate change will be, however, seen in the developing world wherein many people will not have the resources to adapt. A warmer world will increase heat stress in tropical countries and hence have an adverse impact on the performance of the workers in industries. The rise in sea level will affect a large number of cities located on the coast in Asian countries. The changes in pattern of rainfall and higher evaporation will lead to more water scarcity. The warmer night temperature will have an adverse impact on agricultural production. The higher temperatures will increase the incidence of attack by insects and pests on crops. The changing climate will also have an influence on the spread of diseases such as malaria and dengue. During the past 50 years the number of heavy rainfall events in India has increased by almost 50%. This has lead to urban flooding. If the global mean temperature increases by more than 2 degrees centigrade above that in the 19th century, then the threat of an abrupt climate change cannot be ruled out. Abrupt climate changes have occurred in the past due to natural causes but may be triggered by human actions in the future.

Many scientists and engineers have shown that we can move away from our addiction to fossil fuels and meet our energy needs through renewable energy technologies. The transition from the present fossil fuel based society to one dependent only on renewable energy will be slow and painful. We need, however, to take urgent actions now to promote this transition in order to avoid irreversible changes to the earth's climate

DEMAND AND SUPPLY RELATIONS IN A CHANGING CLIMATE

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The presentation gives an updated perspective on rubber demand, both natural (NR) and synthetic (SR) as it is affected by future developments in the Automotive/Tyre and General Rubber Goods industries. The focus is on the medium to long term up to 2020. Attention is also given to the supply side of SR with reference to butadiene feedstock availability and also to NR with reference to the future impacts of climate change, labour availability, alternative crops and land use for example.

The paper also focuses on the new planting of NR in selected producing countries, to analyse the impact on production, to develop assumptions for planting policies and to describe the consequences for future NR production potential. The conclusion being that a dramatic increase in total new planting area during 2005-2008 has occurred and the consequence is that normal production will significantly increase over the coming decade. The levels in 2015 and 2020 are expected to be around 30 per cent and 50 per cent higher than in 2008, respectively.

1. RUBBER GROWTH ANALYSIS USING A CLIMATE MODEL IN THE NON-TRADITIONAL AREA OF THAILAND

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Climate is an important factor that has affected plant growth and production. Due to extension of rubber planting area in Thailand, rubber plantations tend to extend towards the Northeastern and the Northern parts where they inevitably encounter climate variation. A crop modeling as a function of climate was used to simulate rubber growth in this study. The objectives were 1) to find the limiting factor of climate that reduces rubber growth and 2) to predict the tappable time. The results showed that the climatic conditions such as dry period and low temperature delayed rubber growth. This crop model is useful to predict growth and tappable time of rubber trees in these areas.

2. HAS CLIMATE CHANGED IN THE NATURAL RUBBER GROWING REGIONS OF INDIA?

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Information of long term trends in climatic factors influencing rubber cultivation is important in the context of the present climate change scenario. This will help in improving management strategies to cater to such long-term changes. The present study was focused on finding any long term temporal and seasonal changes with respect to important meteorological variables influencing rubber cultivation in the traditional rubber growing regions of India. Amongst the major climatic factors influencing rubber growth and yield, the meteorological variables of rainfall, temperature, and sunshine have been analyzed for four rubber research stations in the traditional rubber growing regions of Tamilnadu, Kerala and Karnataka with daily datasets ranging from 10 to 53 years. The stations considered for the study were Kottayam (09^{0}32'N 76^{0}36'E 73 m above MSL) in Central Kerala, Padiyoor (11^{0}58'N 750N 36'E 20m above MSL) in North Kerala, Parliar in South Tamilnadu (8^{0}26'N 77^{0}19'E 33 m above MSL) and Nettana in South Karnataka (12^{0}43'N 75^{0}42'E 110 m above MSL). Daily data on these variables was subjected to time series analysis to identify trends within the monthly, seasonal and annual periods. Trends were also found out for extreme meteorological events.

Tri-decadal area averaged rainfall data (obtained through the link www.tropmet.res.in) of the various sub-divisions of India (India Meteorological Department) within the natural rubber growing regions have also been analyzed to identify the changes if any. The statistical methods involved regression analysis of the anomaly from the long term average and significance of such trends were tested by adopting the standard Mann-Kendall test for time series data. Kottayam, situated in Central Kerala being the most important district representing the largest rubber growing region of Kerala, was studied in depth, since over three life cycles rubber cultivation had been taking place, and this station comprises the longest daily dataset of climatic variables. Trend analysis was carried out for the Standard Meteorological Weeks (SMW), months, seasons and annual periods. The four seasons considered for the analysis were Winter (January-February), Pre-monsoon (March-May), Monsoon (June-September) and the Post-monsoon (October-December).

No significant trends were noted in the annual rainfall amount and total number of rainy days over 53 years. However, the rainfall and number of rainy days showed a declining trend during the monsoon season. The month of December showed a declining trend in rainfall amount while the June and August months showed a declining trend in rainy days over a month. The decreasing trend in the monthly rainfall amount was noted to be 0.9 mm per year for December. The decline in June was mainly contributed by the 22nd SMW (1st week of June) and 26 SMW (4th week of June). A highly significant positive trend in the number of rainy days was noted in the 27th SMW. Negative trends in rainfall amount and rainy days were also noted in 34th SMW (2nd week of August) and 39th SMW (3rd week of September). The decrease in rainy days was observed to be 1 and 1.5 days in 10 years for June and August respectively.

Maximum temperature trends were significantly positive (99 % significance level) over all the periods of weeks, months, seasons and year. However, it was observed that week number 24 (2nd week of June) showed no trend at all. Positive trends in minimum temperature were highly significant when considered over an annual and seasonal basis. The annual increase in maximum temperature was found to be 0.04° C per yr and 0.02° C per yr for the minimum temperature. For both the maximum and minimum temperatures, the rate of increase over the month of May was highest at 0.06° C per yr & 0.04°C per yr respectively. This is unlike the reported warming trend seen in both global daily maximum and minimum temperatures, with minimum temperatures increasing at a faster rate than maximum temperatures. (IPCC, 2007). Week wise for both these parameters it was the 21st SMW (3rd week of May) which showed the highest rate in temperature increase of 0.06° C per yr & 0.039° C per yr respectively.

Yearly mean daily sunshine hours showed a very high significant negative trend over the years. A decrease of 0.03 hours per yr has been noted annually. Decline in sunshine hours was found to be highly significant during the winter and post-monsoon seasons. Consequent weeks during these periods also showed a significant decline. The month of January experienced highest decline at 0.06 hours per yr with all the weeks having values above 0.058 hours per year. The highest decline was noted during the 5th SMW or the last week of January.

Maximum temperature was positively significant for all seasons in Kottayam. The R^2 value was high during the post-monsoon period at 0.61. No significant trends during the pre-monsoon season were detected in the other regions of Padiyoor, Paraliar and Nettana. The highest increase in maximum temperature (0.04^0 C/year) was seen during all seasons for Kottayam. Significant positive trends were observed generally in the monsoon and post-monsoon months for all places except Padiyoor where positive trend was only seen during winter. Annual trends were not significant for stations other than Kottayam. Significant increase in minimum temperature was noted in Kottayam for all seasons, but were comparatively lower than that of the maximum temperature increase. The pre-monsoon season registered a high temperature of 0.30^0 C per year. During the winter season Paraliar showed a negative minimum temperature trend, while Nettana showed a positive trend. The monsoon and post-monsoon season minimum temperatures showed negative trends in Nettana. Kannur also showed negative trends in minimum temperature during winter. The winter average temperature showed a negative trend for Paraliar during winter with a slope of 0.08^0C per year. No significant trends were seen for Padiyoor in any season.

Significant negative trends in sunshine hours were seen annually and also for all seasons except monsoon season in Kottayam. In all locations except Padiyoor (data not available) a high decrease in winter sunshine hours were noted. Rainfall did not show any trends for Kottayam. But Padiyoor showed an increase in monsoon rainfall. Nettana showed a decrease in rainfall during the post monsoon period.

The days with extreme temperature events were found out from the number of days having temperature values equal to or higher than the threshold temperature. The threshold is considered from the long-term mean. This has been calculated month wise for Kottayam for both hot days utilizing the maximum temperature and warm nights utilizing the minimum temperature. Increase of hot days was noted in January and December with 0.46 and 0.45 days/year respectively. Warm nights increased during the monsoon season. It was earlier found that a minimum of 5.6 hours of sunshine is necessary for optimum rubber yield (Rao *et al.*, 1998). Extreme sunshine events below 5.6 hours and more than 9.0 hours were calculated for Kottayam. It was found that days with less than 5.6 hours of sunshine per day was on the increase and days with sunshine hours greater than 9.0 hours were on the decrease.

Stations were compared for extreme climatic events based on the total annual number of days above respective threshold limits for temperature, sunshine and rainfall. Increase in the hot days was observed only for Kottayam while decrease in warm nights was seen for Paraliar and Nettana. In the case of extreme sunshine hours in Kottayam, there was an increase of days with >9.5 hours of sunshine within a year while Paraliar and Nettana showed negative trends from their respective thresholds. Extreme rainfall trends (>50 mm/day) showed a high significant increase only for Padiyoor at the rate of 1.2 days per year. No change was seen in other stations.

The tri-decadal monthly rainfall dataset was observed for changes from the rainfall series spanning 1871 to 2006. The all India rainfall series indicated a decrease in the peak rainfall amounts in the last decade. This was more prominent for the Konkan and Goa subdivision during the south-west monsoon season. Lowering of peak amounts during the south-west monsoon period with increase in peak amounts during the north-east monsoon was observed for the long-term data over the Kerala subdivision.

Monthly datasets for the maximum and minimum temperatures were plotted for the first decade and last decade for Kottayam and Paraliar stations. A difference of 2^0 C was noted between the two sets of decades for the maximum and minimum temperatures in Kottayam. In Paraliar, the difference was noted to be around 0.5^0C for the maximum temperature datasets while no difference was observed in the minimum temperature.

The above study shows that there is an indication of climate change in the natural rubber growing tracts, the most prominent being that of maximum temperature. The optimum sunshine hours of 5.6 per year for rubber were found to decrease, which can affect rubber growth and yield in future. Variability in climatic extremes is another factor influencing rubber cultivation. The study emphasizes the fact that agromanagement practices will have to be modified in future to cater to this change.

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3. HAS THE CLIMATE CHANGED IN NE INDIA?

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The study analyzed the climate of Agartala and Guwhati using different tools and indices. The database corresponds the period 1984-2008 for Agartala and 1989 - 2007 for Guwhati. An increase in mean annual minimum temperature was observed in Agartala at a rate of 0.05^o C per year over a span of 25 years. No change was noticed in mean annual maximum temperature. Trend analysis on seasonal basis revealed that the minimum temperature increased at a rate of 0.04° C during SW monsoon while the decadal trend for 2000 - 2009 showed an increase for minimum temperature except during post monsoon.

Cusum plot for seasonal minimum temperatures in Agartala indicated 1994-95 as the year in which a shift to warming occurred. It is of interest to note that though not significant, maximum temperature showed an upward trend only during SW monsoon. A downward trend was observed in the winter and post monsoon maximum temperatures during the last decade (2000 - 2009). Cusum plot for maximum temperature during SW monsoon indicated that the change to the warming phase occurred during 1990 and continued up to 1998. It is interesting to note that there was the increase in T_{max} during SW monsoon in Agartala.

Cold nights decreased at a faster rate (-1.7 days per year) than the increase of hot days (0.9 days per year) at Agartala which is in concordance with the result obtained for minimum temperature. The cusum chart for cold nights indicated a sudden change in direction towards warming during 1994. The year 1994 as the major change point for T_{min} is reconfirmed here.

Seasonal trends for hot days indicated that hot days did not increase during summer, which is to be taken care of. All the other seasons depicted an increase in hot days though not significant. Decrease of cold nights during SW monsoon at a rate of 0.8 days per year is to be noted which is well in agreement with the earlier results obtained for the season. The number of days where T_{max} exceeded the thresholds were observed to be increasing over the years during SW monsoon. Number of days with $T_{max} > 33.8°$ C increased at a rate of 0.56 days per year. Over a span of 25 years the number of spells of threshold where $T_{max} > 33°$ C increased at a rate of 0.16 spells per year.

In Guwhati, annual hot days increased at a rate of 1.7 days per annum . Mean minimum and maximum temperature recorded a per year increase at the rate of 0.09 and 0.05° C respectively. Cusum plot for hot days indicated a variable cusum with the direction of change difficult to interpret. Hot days did not show any increase during summer over the years which were similar to the result obtained for Agartala. Increase of hot days during winter is to be noted.

Analysis of moisture regime revealed that monthly distribution of rainfall during the two halves at Agartala indicated a shift in the distribution. Observed rainfall peak was May-June during the first half (1984-1995) and June-July during the second half (1996-2008). Two rainfall peaks (May-June and Sep-Oct) were observed during first half which was changed to one during the later half.

Annual rainfall did not show any trend in Agartala. Seasonal trends in rainfall indicated a decline in rainfall during post monsoon and winter season though not significant. Rainy days during SW Monsoon declined at a rate of 0.4 days per year. Extreme rainfall events during the season increased at a rate of 0.15 days per year over a span of 25 years. Decline of rainy days during summer is notable. Extreme rainfall events during summer indicated a decline of 0.03 days per year.

Onset and withdrawal of SW monsoon as an index of climate change was studied. Pentad rainfall of fourth spell (May 30th to June 3rd) was the onset during the first half (1984-1995) and pentad rainfall of third spell (May 25th to 29th) was the onset during the second half (1996-2008) in Agartala. Onset was found to be more stable during the second half. When the two periods were joined together pentad rainfall of 3rd spell was found to be the onset. In Guwhati pentad rainfall of fourth spell (May 30th to June 3rd) was observed to be the onset. Withdrawal of the monsoon has been extended to 46th week (Nov 12-18) during the later half instead of 45th week (Nov 5-11) during the first half at Agartala.

Evolution of T_{min} during winter at Agartala indicated the difference between the first and second halves widens up during December. An increase of more than 2°C observed for the second half, compared to the first half indicated that December is becoming warmer over the years. The observed decline in the T_{min} of second half during the beginning of February revealed a shift in the winter which was extended up to the middle of the month.

From the study an increase of minimum temperature in all the seasons and increase of maximum temperature during SW monsoon were observed. The trends in the hot days and cold nights, consistency in the non increase of hot days during summer in Agartala and Guwhati and identification of the year 1994 as the major direction of change to warming, the observed shift in the onset and withdrawl of monsoon in both the locations of Agartala and Guwhati, changes in the monthly distribution of rainfall in Agartala are some of the interesting observations to be noted.

4. IMPACT OF CLIMATE CHANGE ON NATURAL RUBBER PRODUCTIVITY IN DIFFERENT AGRO-CLIMATIC REGIONS IN INDIA

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Between 2001 and 2008, consumption of natural rubber (NR) in India increased at the rate of 35.03 tons/year while its supply increased by 36.39 tons/year. Almost all predictions show that in the years ahead, consumption of NR is expected to increase at a faster rate than its supply, both nationally and globally, provided there is sustained economic growth. 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 impact of climate change.

Climate has undergone significant changes in the rubber growing regions of India in the recent decades and this has certainly impacted productivity. However, as more and more area under the high yielding clone RRII 105 came into tapping, the national productivity of NR increased masking the actual impact of climate change on productivity during this period. Since 2006, India ranks first in the world in terms of NR productivity.

Climate change as a result of global warming can influence the growth and productivity of natural rubber in various direct and indirect ways. 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. While we may be able to understand 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. Thus the impact of change in future climate on natural rubber growth, productivity and supply will be complex and difficult to predict.

The objective of our study is to estimate the impact of climate variables on NR productivity. We adopted three different approaches. In all cases we regressed productivity with different weather parameters to determine the quantitative effect of each weather parameter on yield.

In the first approach, we used data from the Regional Research Stations of RRII in various agro-climatic regions in India. These regions represent a wide range of climatic conditions ranging from extreme dry and hot conditions in Dapchari to severe winter conditions in North East (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. Agarthala and Tura are situated in the Northeastern region, 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. 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 20-840 m above MSL. Mean annual rainfall in these regions ranges from 2000-4500 mm. The mean maximum and minimum temperatures during summer months are 33 ^{0}C and 25 ^{0}C and for winter days, 31 ^{0}C and 22 ^{0}C, respectively. India is perhaps the only major NR growing country where NR is cultivated in such extremely diverse conditions.

The mean annual productivity in these diverse agro-climatic regions was regressed with the prevailing weather conditions on a daily basis with the objective of determining the relationship between yield and various weather factors. In the multiple regression model, we used weather parameters like mean annual temperature (Tann.), mean annual maximum temperature (T_{max}), mean annual minimum temperature (T_{min}), mean annual rainfall (RF) and mean number of annual rainy days (RFday) as independent variables and mean yield *i.e.* gram per tree per tap (g/t/t) as the dependent variable. In the last step of MLR, only three independent variables were left in the model, namely, T_{max}, T_{min} and RF (Y = 96.94 - 7.05 T_{max} + 7.45 T_{min} + 0.008 RF, R^2 =0.71). This model in which the X variables from various agro-climatic regions were incorporated in one MLR model had a fundamental flaw; in the different regions, the different X variables had qualitatively and quantitatively different impacts on yield. For example, in the NE where very low winter temperatures prevail, an increase in T_{max} 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.

In the second approach daily per tree yield (g/t/t) for several years was regressed with the weather parameters for the corresponding years separately for the different agro-climatic regions. The MLR models obtained for the individual regions were Y= 433.43-7.87T_{max}-4.83T_{min} (CES, 9^0 26'N to 76^0 48'N), Y=171.01-2.54 T_{max}-1.71T_{min} (Padiyoor, 11^0 58'N to 75^0 36'N), Y=204.98-1.01T_{max}-5.51T_{min} (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+3.58T_{max}-2.59T_{min} (Tura, 25^0 30'N, 90^0 13'E). From these five models, the change in yield when both T_{max} and T_{min} concomitantly increased by 1^0C was calculated. A reduction in yield was noticed in CES (16.23%) for 1 ^{0}C rise in maximum and minimum temperatures. In Dapchari the yield reduction for 1 ^{0}C rise in T_{max} and T_{min} was 11.25% followed by 8.43% in Padiyoor. But in the other regions like Agarthala and Tura in NE India where winter temperatures are very low the impact of warming was found negligible. In Agarthala the yield reduction was about 1.17% and in the case of Tura there was an increase in the yield by 2.72% for 1 ^{0}C rice in maximum and minimum temperatures. Thus, small rise in temperature in this region may not have much impact on rubber yield. Sometimes it may increase the yield just like what happened in the Tura region and expand NR cultivation to more parts of NE.

During the last 54 years (1956-2009) T_{max} and T_{min} in RRII have increased at the rate of 0.05 ^{0}C/yr and 0.03 ^{0}C/yr respectively. Extrapolating this data, the rise in T_{max} and T_{min} in the next 10 years was calculated and the same was used to estimate the expected reduction in productivity after 10 years at CES. The yield reduction after 10 years will be 6.90% in CES. In Padiyoor the rate of increase in T_{max} and T_{min} during the period 1998-2009 was 0.01 ^{0}C/yr and 0.11 ^{0}C/yr respectively and this may result in the reduction of yield by 4.23% after 10 years. In the case of Dapchari during the period 1994-2009 the rate of increase in T_{max} was much higher (0.08 ^{0}C/yr) but the minimum temperature increased by 0.03 ^{0}C/yr. The reduction in the yield in this region will be 3.70% for the next decade. In Agarthala, the reduction in yield in the next ten years will be very small (1.10%) extrapolating the rise in T_{max} (0.02 ^{0}C/yr) and T_{min} (0.06 ^{0}C/yr) during the period 1984-2007. For the last 12 years (1992-2003) T_{max} in Tura increased by 0.12 ^{0}C/yr. But the minimum temperature increased by 0.05 ^{0}C/yr in this region. The cumulative effect of the expected changes in T_{max} and T_{min} in this region could lead to an increase in the yield by 9.36% in the next ten years.

In a third approach, the per hectare productivity was regressed with maximum and minimum temperatures for Kottayam, Kanjirapally and Thaliparamba and estimated the impact of rising temperature on productivity. The MLR model obtained for per hectare productivity was $Y= 999.53-6.14T_{max}-27.68T_{min}$ for Kottayam, $Y= 789.36-11.33T_{max}-12.68T_{min}$ for Kanjirapally and $Y= 281.91+4.13T_{max}-11.26T_{min}$ for Thaliparamba. The percentage reduction in productivity (for 1 ^{0}C rise in both maximum and minimum temperatures) for these regions was 18.83%, 15.06% and 4.15% for Kottayam, Kanjirapally and Thaliparamba, respectively. These results were comparable with the results obtained from the respective regions when per tree yield was used as the dependent variable.

5. IMPACT OF CLIMATE CHANGE ON NATURAL RUBBER CULTIVATION IN GHARO HILLS OF MEGHALAYA.

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Meghalaya is one of the potential areas in North East India where natural rubber can be successfully cultivated. However, the Sub-Himalayan conditions prevailing in this part of the country, particularly low temperature conditions during winter can be inhibitory to growth of young rubber plants. While the summer temperatures are congenial, the minimum temperature during winter is stressful to *Hevea.*

In the present study, we used temperature and rainfall data collected from the Meteorological Station attached to the research farm of Regional Research Station of Rubber Research Institute of India, West Gharo Hills Tura. The farm is located at an altitude of 600 m above MSL and lies at 25-26^{0}N latitude and 90-91^{0}E longitude. Survival of the young plants in the nursery and field and defoliation, refoliation and flowering were recorded from 1989 till March 2010.

In Gharo Hills, December to February is the winter time and January has the lowest minimum air temperature. The average minimum temperature 1995 was about 1 – 1.5^{0}C warmer than the average for the period 1989-1995. After 2006, the lowest minimum temperature during winter was always above 5^{0}C.

Significant number of budded stumps and young seedlings dry up during the month of January every year due to severe cold stress. Low temperature conditions during winter is responsible for prolonging the gestation period by two years or more in this non-traditional rubber growing regions of India. Between 1989-1995, 4% of the annual growth was contributed during winter period, where as after 2006 this has been as high as 8%. This must be a clear and direct effect of warming temperature during winter season.

Winter time always coincides with the leaf fall season. Gradual warming of winter days has lead to early leaf fall and refoliation which usually happens when the minimum temperature rises above 10^{0}C for at least a week. Earlier refoliaiton has helped to avoid incidence of *Oidium* which is a major disease in North East India.

Warmer winter conditions may increase survival rate and reduce gestation period. Early leaf fall and refoliaiton leads to early production of extrafloral nectar and easily seed production. This also helps in escaping from *Oidium* incidence. When the leaves are not affected by *Oidium* there is a better production of honey and more seed production and the canopy will be thick which will increase the rate of growth. Early production of good quality seeds helps to establish healthy seedlings nursery early giving the seedlings slightly longer period of growth before they are budded and cut beck before the onset of the next winter. Thus small shift in the climate can have significant impact of rubber cultivation in North East India. Gradual warming may make winter less severe and more areas in the North East may become suitable for rubber cultivation in the years ahead.

6. CHANGES OBSERVED IN CLIMATIC PARAMETERS IN RUBBER GROWING AREAS OF SRI LANKA

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In Sri Lanka, rubber is grown under different climatic conditions. Hence, understanding the vulnerability of rubber plantations to climate change impacts is a basic necessity under these situations. In this regard comprehensive analyses employing fairly long historic time series data is a must to identify vulnerable areas to develop adaptation measures to combat adverse impacts of climate change on rubber plantations. This paper reveals observed changes in rainfall and temperature in some selected sites representing the rubber growing areas of Sri Lanka.

This study employed rainfall records of 15 and temperature records of five meteorological stations representing intermediate and wet zone areas for the period 1941-2006. The annual and monthly changes in rainfall, shifts in rainy seasons, extreme rainfall events and dry spells were investigated in this study. Temporal changes in minimum, maximum and average temperatures were also studied. Descriptive analyses, trend fitting and probability theory were employed in data analysis.

Negative trends in total annual rainfall were found for the rubber growing areas, where the trend is significant in nine out of 15 locations studied. In several locations significant changes were observed in monthly rainfall for March and December. An understanding on the probability of receiving a wet week (≥10 mm) is very useful in planning cultural operations. It was observed that in all the areas the probability lines indicating the change with standard weeks for the period; 1971-2006 lies below the 1941-1970 lines for most of the occasions. This indicates that there was a decrease in probability of receiving a wet week during the period 1971-2006 when compared to the period 1941-1970.

The date of onset of the two rainy seasons is another important consideration for timely operations in the rubber sector. There was no indication of any significant shift in onset and end dates throughout the period of observation in most of the sites except for Avissawella and Ambanpitiya in the low country wet zone. In mid country areas any kind of shift was not identified due to the difficulty in detecting the onset and the end of rains especially after 2000. In general, detecting the exact dates for onset and cease of rainy seasons was difficult in most rubber growing areas due to uncertain rainfall patterns. Extremely high rainfall events were also identified in some of the rubber growing areas in comparatively drier areas and erratic rainfall patterns were also observed in some areas (Wijesuriya and Herath, 2001). Further it was pointed out by the smallholder farmers in participatory studies that rain interfere with the peak yielding period of the rubber tree, viz. November to January (Wijesuriya *et al.,* 2006).

Analysis of minimum, maximum and mean temperatures indicated no limitations as per climatic requirements for rubber (Yogaratnam, 2001) in regions of low country wet and intermediate zones. In mid country intermediate zone areas, limitations are found with little magnitude at Badulla.

It was possible to confirm changes in climatic behavior of rubber growing areas through analysis of historic time series of climatic data. Some of these changes are; erratic rainfall patterns characterized by inability to detect onset and end of rainy seasons, decreased chance of receiving wet weeks, and incidence of extreme rainfall events. Although these changes are of little magnitude, it is important to note these deviations from the natural trend to develop suitable adaptation measures for different areas to minimize adverse impacts on the rubber sector.

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7. SUPPLY INSTABILITY IN NATURAL RUBBER OWING TO EXTREME AND UNUSUAL WEATHER EVENTS AND ITS IMPACT ON PRICE FORMATION

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The major physical dimensions of climate change viz., global warming, weather instability and occurrence of extreme and unusual climatic events have short-term and long-term impact on supply of agricultural crops and their price formation. The magnitude of the impact of weather factors on price formation of a crop would depend on the characteristics of the crop, nature and pattern of weather factors in the major crop growing regions and market situation. This paper provides a detailed account of the potential role of weather factors on NR price formation through supply instability and an account of weather events impacting on NR prices during the period from 2000 till date.

The latex yield of rubber trees is mainly determined by physiological factors and harvesting intensity. Both these factors are influenced by clonal characteristics, agronomic practices and environment. Given the physiological factors and agronomic practices, the major yield-limiting factor is harvesting intensity, which in turn is mainly determined by weather and price factors. Extreme weather in terms of long and intense dry spells and heavy rains can substantially reduce harvesting intensity through reduced tapping days. The response of growers to the prevailing rubber prices is also reflected in harvesting intensity. The interplay of weather and price factors in determining NR production makes it difficult to measure the influence of weather factors on price formation.

The share of Asia in world NR production remained above 90 per cent ever since the dominance of plantation rubber. But the relative shares of Asian countries in world NR production changed considerably during the recent decades. However, Southeast and South Asian regions accounted for 77.1 and 10.1 per cent of world NR production respectively in 2009. The tropical regions of Southeast Asia are most vulnerable to climate change and these regions face frequent storms and other extreme weather events. The major expressions of climate change in Southeast Asia are decrease in the number of cool days and nights, increase in the number of hot days and warm nights and decrease in the number of rainy days per year. Intermittent heavy showers and prolonged dry spells have marked the weather in the recent years in Southeast Asia with an accompanying increase in average temperature. The major rubber growing South Asian regions also report similar changes as described above. The frequency of occurrence of natural disasters related to extreme weather events also has risen globally and in South and Southeast Asia. All these point to increased inter and intra year variability in weather leading to instability in supply, which will have a direct bearing on the NR market, mainly depending upon the demand from the consuming industry.

The impact of NR supply instability on price formation as a result of climatic variations depends on market situations such as demand-supply balance, marketing framework and lead factors influencing NR prices. The major factors on the supply side are level of inventories and relative production in relation to normal production. The normal production of NR is determined by planted area, age of the trees and yield profile. However, actual production would depend on weather and price factors; the former directly affects tapping and the latter indirectly influences tapping through grower behaviour. Relatively high levels of inventories and actual production of NR being substantially below normal production would lessen the impact of weather factors on NR price formation. NR is mainly used globally in the transportation sector as tyres and other auto components. The transportation sector is highly sensitive to the trends in the world economy. The balance between NR demand and supply is a crucial factor determining the impact of weather factors on price formation particularly when the economy is on a strong footing.

The marketing framework includes institutions and systems setting the context of markets. The increasing process of market integration has led to more harmonisation of commodity price trends around the world. Another important aspect is the emergence of TOCOM price as an international trendsetter in NR market. The sentiments of market players in TOCOM are easily influenced by weather events occurring in major rubber growing areas of Southeast Asia and these sentiments get reflected in TOCOM rubber prices, almost instantly. The trends in TOCOM rubber prices percolate into the South and Southeast Asian rubber markets with immediate effect.

There are several factors apart from demand-supply balance and marketing framework that can profoundly influence the price formation of NR and these include price and supply of substitutes, oil prices, currency exchange rates etc. If one or more of these factors tend to be the lead factors that overwhelmingly determine NR prices, weather induced supply disruptions will have only a supplementary role in NR price formation.

During the current decade, world NR production was adversely affected by extreme and unusual weather conditions especially in 2005, 2007 and 2009. The same period also witnessed very low rubber prices, recovery and boom. The paper discusses how weather factors influenced NR supply and thus the price formation during the three phases.

8. GLOBAL SCENARIO ON NATURAL RUBBER SUPPLY

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The global production of natural rubber (NR) mostly comes from Asian region. There was a structural shift in NR prices from the late 1970s. The prices of NR reached a peak until the end of 1970s. In response to the booming prices, in the beginning of 1980s, a large scale new-planting/replanting of rubber happened in all major producing countries. These new-planted/replanted rubber trees were expected to attain the replanting age from 2010 onwards, assuming a productive life span of rubber is 30 years.

To push the existing yielding area into a gestation phase, in 2003-09 there were a large-scale replanting in non-traditional regions, concerning the new-planting undertaken in the beginning of 1980s would enter the declining phase in 2010 because of ageing. The output from new-planting from 2003 to 2009 were expected to start in 2010 onwards, 6-7 years of after the gestation phase. These new-planted/replanted areas in 2003 and 2004 would marginally add the global supply from 2010 to 2011. From 2012 to 2016 a substantial addition of supply is expected according to the new-planting/replanting which was undertaken from 2005 to 2009.

On the other hand, the new-planting/replanting undertaken during 2003-09 were mostly in non-traditional regions. These areas are agro-climatically marginal to grow rubber. This happened due to the limitation of areas. These areas have used the best available clones. However, the cultivation skill of the entrepreneurs should be improved to enhance the yield.

The other limitations to improve the yielding areas are i) the existing areas are still occupied by low-yielding clones, ii) shortage of skilled tappers, iii) unscientific harvesting practices and iv) climate change. Spiraling wages, cost of input materials and lack of mechanical harvester cause shortage of skilled tappers and scientific harvesting worker. Hence, the existing marginal farmers to be skilled in tree improvement, vegetation propagation, latex harvesting, processing technology and so on. Climate change affects the harvesting days due to the excess of rainy days, relatively higher temperature, less of cold days, extended wintering season and new diseases.

On the farm level, large extent of existing trees were replanted during 1980s and these tress are now at the declining yield phase. Moreover, smallholders realize the low farm-gate prices because of the inability of smallholders to stock raw rubber due to price movements. Non-rubber income from rubber holding will enhance net-farming income of the farmers and encourage them to process harvested crops from intercropping and co-cropping. Lack of other sources of income can cause postponed replanting of the aged trees especially when the rubber prices are high. In addition, the existing gap between prices of NR and SR give a threat to the NR supply.

Climate change would have a negative bearing on future yield. Rain and drought affect tapping days and disrupts harvesting. The higher temperature especially in the morning will affect latex flow and as a result, the yield of rubber will be low. Furthermore, climate change may cause new diseases which are detrimental to rubber trees. The existing clones that have tolerance to climate change is limited. Therefore, it is necessary to develop clones which are tolerant to an extreme climate.

In summary, to accommodate the issues and challenges in global supply of NR some adjustments to improve the yield of rubber are needed. Mechanization for harvesting and processing is preferable to improve the quality of cup lumps and slabs. Dissemination of market information can be used to strengthen the existing system. Government incentives for replanting can minimize the ageing issues and attract farmers from rubber holding. Besides, export must orient to finished rubber-based products than raw rubber, improving net farm income and value added from rubber. Rain guarding method should be popularized to maintain the existing yielding areas from negative effect of climate change together with other scientific practices.

GLOBAL CLIMATE CHANGE: ADAPTATION STRATEGIES FOR STRESSFUL ENVIRONMENTS WITH FOCUS ON HIGH TEMPERATURE AND DROUGHT

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Emission of greenhouse gases particularly CO_2 by anthropogenic activities is the most significant factor responsible for global climate change. It is estimated that during the 1980's out of the total CO_2 emission of 7.1± 1.1Pg C/year, about 3.3± 0.42 Pg C per year remained in the atmosphere contributing to 1.6 ppm rise in the atmospheric CO_2 (Jacob, 2006). Increased CO_2 content in the atmosphere affects global climate through its greenhouse radiative effect and also through its effects on plant physiology (referred to as CO_2-physiological forcing) as detected in both field experiments and the studies on climate modeling (Hungate et al., 2002, Long et al., 2006; Cao et al., 2010). It is predicted that doubling of CO_2 in the atmosphere may cause significant land surface warming (Cao et al., 2010). Global warming has several deleterious effects on plant physiological processes since temperature regulates growth and development throughout the life cycle of plants. For example, temperature-dependent growth abnormalities have been reported in different natural accessions of model plant *Arabidopsis*. Reduced activity of leucine biosynthetic genes was noticed in *Bur-o* accession at elevated temperature (30° C) resulting in developmental abnormalities (Sureshkumar *et al.*, 2009). Temperature induced regulation of plant architecture involves integration of multiple hormones (such as gibberellins, salicycic acid, cytokinin and auxin) signaling (Patel and Franklin, 2009). In many crops, phenological events such as bud burst, reproductive growth and senescence have received increased interest in the light of global warming.

The climate change associated problems like the incidence and severity of drought and other abiotic stresses are of serious concern which will have direct effect on productivity of rainfed annual field crops as well as perennial crops like *Hevea brasiliensis*. Plants' adaptive responses to drought and elevated temperature are complex and controlled by multiple genes. Since elevated CO_2 is known to have beneficial effect on photosynthesis, minimum C-loss by photorespiration and dark respiratory processes under elevated temperature would be desirable. Plant water relation-associated traits such as water use efficiency, water mining, water conservation and intrinsic cellular tolerance are a few important factors essential for better adaptations. In *Hevea*, it is likely that latex production might be adversely affected by drought coupled with high temperature. In *Parthenium argentatum* cooler temperature is favorable for rubber production (Benedict and Foster, 1993). Studies on the effect of temperature and/or desiccation stress on cambium differentiation to produce laticferous cells and/latex production are essential. Plant hormones such as auxins and cytokinins have a role in differentiation events. Fluctuations in endogenous auxin levels have been reported at elevated temperature. Expression of auxin biosynthesis genes was repressed by increasing temperature (Sakata et al., 2010). Temperature induced hormonal imbalance may lead to early senescence and affect biomass production and latex yield.

Discovery and characterization of specific adaptive traits in *Hevea* are vital for crop improvement. Exploitation of natural variations in relevant traits may be rewarding to mitigate climate change. The use of modern genomic tools and technologies may assist in understanding the complex adaptive traits, identifying regulatory loci, genes and interacting networks. The modern "*Omics*" technologies might help in the large scale analysis of genes (*genomics*), proteins (*proteomics*) and metabolites (*metabolomics*) that are unsurpassed compared with traditional targeted approaches. There are a number of examples indicating that profiling approaches can be used to expose significant sources of variation in the composition of crop plants. These modern technologies aid in quick identification of adaptive pathways, stable genes and desirable alleles (allele mining) which are essential for future genetic engineering approach. Since understanding the adaptive responses in *Hevea* is rather difficult due to its perennial nature, it is worthwhile to borrow the information from other related model systems for certain traits.

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9. REDUCING GHG EMISSIONS FROM N FERTILISER: A NUTRIENT BALANCE APPROACH

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Nitrogen (N) is an essential nutrient for *Hevea* as well as other crops. It is required in substantial amount in order to support growth and must be adequate to produce economically sufficient rubber yield. N constitutes 3-4 per cent of leaf dry matter. In both young and mature *Hevea*, N deficiency tends to produce small and yellowish leaves resulting in stunted growth. When the amount of soil N is deficient for satisfactory rubber yields, N fertiliser is added to supplement the soil N. If N is supplied in excess it leads to environmental problems. When applied into the field, N fertiliser is largely converted to nitrate and this form is soluble and readily moves with the soil solution. This surplus N may be available to leach to groundwater. Alternately, N can also contribute in the nitrate, ammonium or organic form to surface water contamination by means of surface water runoff. The other problem encountered from using N fertilizer is Green House Gas (GHG) emissions, as nitrate can be transformed into NH_3, NO_3, N_2O, N_2 etc. through mineralization process.

As part of an effort to reduce environmental pollutants along with the emissions of GHG from using N fertiliser in *Hevea* plantation, the nutrient balance approach is suggested. A nutrient balance approach (NBA) has been suggested as a simple decision-support tool to monitor the effects of changing land use and suggest interventions that could improve the nutrient balance. As input and output determinants cannot all be quantified equally well, the tool recognizes primary data, estimates and assumptions. The NBA determinants are mostly scale-neutral and can therefore be used to monitor nutrient balance at holdings either at regional or national level.

NBA is fed by a number of basic data, and by nutrient input and output data. Basic data include the hectarage of the holdings, land use systems (LUS), combining of current soils and climate data. Nutrient input and output data are reflections of the processes IN 1-5 and OUT 1-5. Each process has a certain value, and the nutrient balance is given by Ó IN – Ó OUT. The result of Ó IN – Ó OUT is called nutrient balance. From the Ó OUT values, the estimation of GHG emission such as N_2O and methane can be made and the sources of pollutions could be determined.

The combination of using NBA and other best management practices for N fertiliser such as matching fertiliser type to environmental conditions, the use of slow release or controlled release fertilizers and nitrification inhibitors contribute to reducing GHG emissions from N fertiliser. The other practices such as better timing and placement of N, application of the minimum amount of N to achieve satisfactory rubber yield, optimization of soil physical conditions, particularly avoidance of excessive wetness and compaction, would be expected to reduce the emission of GHG.

10. YIELD OF MODERN *HEVEA* CLONES AND THEIR RESPONSE TO WEATHER PARAMETERS ACROSS DIVERSE ENVIRONMENTS

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Genotype-Environment–Interaction (GEI) is exploited extensively by plant breeders for phenotypic selection while testing varieties across a range of environments. The concept assumes greater significance in breeding perennial tree crops like *Hevea*, particularly because rubber yield is a polygenic trait influenced by a multitude of genotypic and environmental factors. The performance of clones is subjected to variation over long periods of exploitation in different locations, depending on the magnitude of GEI. The evaluation of promising clones in multi environment trials (METs) with an aim of investigating the genotype - environment - interaction, facilitates selection of potential genotypes with stable performance in a wide range of environments. Several attempts to exploit GEI in *Hevea* have been reported from all major rubber growing countries viz. Sri Lanka (Jayasekera *et al.*, 1977, 1984; Jayasekera 1983,) Indonesia (Daslin *et al.*, 1986), Nigeria (Onokpise *et al.,* 1986), Malaysia (Tan, 1995), India (Meenattoor *et al.*, 1991, 2000) and Brazil (Goncalves *et al.*, 1998a &b).

The first MET for investigations on GEI was laid out in India during 1996 in five locations across traditional and non-traditional rubber growing tracts. A total of 12 promising clones including the newly released RRII 400 series clones were evaluated in the five diverse locations viz., Kanyakumari (08° 26'N; 77° 36'E) in Tamil Nadu and Padiyoor (11°58'N; 75°36'E) in North Kerala in the traditional region and Agartala (23° 53'N; 91° 15'E) in Tripura, Nagrakata (28° 54'N; 88° 25'E) in W. Bengal and Bhubaneswar (21° 15'N; 85°

15'E) in Orissa in the non-traditional regions. Among these, tapping could be initiated simultaneously in three locations viz., Kanyakumari, Agartala and Nagrakata in 2003. In Padiyoor tapping was delayed until 2006 due to poor growth of all the clones in general. In Bhubaneswar, the trial was badly affected in the early phase by a super cyclone and tapping could be initiated only in 2009. The present paper reports the yield performance of a set of *Hevea* clones for the 4^{th}, 5^{th} and 6^{th} year of tapping (2006-2008 period) across the above three locations with a view to identifying clones with wide adaptability as well as stable clones within a location. The response of clones to changes in meteorological variables in different locations in the same period is also examined.

Several methods are available to quantify the GEI, of which the AMMI model (Additive Main Effects and Multiplicative Interaction) is an effective and useful tool to diagnose the interaction patterns graphically. AMMI analysis of yield was tested in nine environments (3 Locations x 3 Years). The analysis revealed that, 36.6 % of the total variation was contributed by the environment (E) and 36.4 % was contributed by Genotype Environment Interaction (GEI), indicating large differences in environmental means as well as GEI means contributing to a major proportion of the variations in rubber yield. Twenty seven percent of the total variation was attributed to genotypes.

An analysis of main effects of genotypes (AMMI -1) revealed that genotype means ranged from 35.31 to 56.24 g/t/t. Clones RRII 429, RRII 422, RRII 417, RRII 430 and RRII 105 were the high yielding ones across environments. Among these RRII 105 and RRII 430 had almost similar means but their interaction pattern was different. RRIM 600 which showed the least interaction was found to be the clone with wide general adaptability. The largest absolute IPCA (Interaction Principle Component Axis) score observed for the high yielding clone RRII 429 makes it the least stable clone.

An analysis of main effects of environment (AMMI-1) revealed that Kanyakumari and Nagrakata were the sites with the top yielding environments. Agartala was in general a low yielding environment. The interaction pattern of Nagrakata was almost similar during the three years of study indicating less variation in environment between years. The other two locations showed greater environmental variation between years. Analysis of GEI from AMMI-2 biplot showed that among the high yielders, RRII 105 and RRII 430 were best suited for Kanyakumari region whereas RRII 429, RRII 422 and RRII 417 were more suited to the non traditional areas.

Weather parameters viz., maximum and minimum temperatures, RH, sunshine hours and rainfall were studied in relation to rubber yield in the three locations. Stepwise multiple regression analysis for rubber yield and six meteorological variables for the same period were done to determine the most significant meteorological variable influencing yield in each location during the specific period. The yielding period was split into low and high yielding regimes in each location and regressed. In the low yielding regime (May – Sept.) no consistent response was observed in any of the locations which may be due to the fact that meteorological variables were not limiting in this period. However, in the high yielding regime (Oct- Jan) which coincides with wintering in the traditional region and low winter temperatures in the non-traditional region the effect of temperature was observed to be significant in all locations. Maximum temperature was negatively correlated with yield in Kanyakumari, irrespective of clones. In Agartala and Nagrakata the results were however inconclusive. Increase in maximum/ minimum temperature was positively correlated with yield in certain clones. The clone RRII 429 which showed maximum interaction pattern was significantly influenced by temperature in all locations. The response of clone RRIM 600 to climatic factors was least significant indicating greater stability and wide adaptability of this clone whereas the strength in the response of other clones showed variation.

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

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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. Rain fed crops are more vulnerable to the variations in climate such as changes in precipitation regimes, temperature, sunshine hours and relative humidity. The current agronomic practices followed in rubber cultivation may be inappropriate and 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 dry spells and bright sunny days with warm temperature during the monsoon season increases casualty. In a field study it was observed that casualty of young plants (two months 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 showing wilting symptoms. Planting was done during the first week of July which is the middle of monsoon season in both years. Although soil moisture status was sufficient in both the years, atmospheric drought due to bright sunshine hours and high temperature during the first week of July 2008 might have resulted in higher casualty. In a survey conducted also, the casualty after planting increased over the years and high casualty percentage was observed in certain years with dry spell in the monsoon season. The occurrence of dry spell with bright sunshine and warm temperature during monsoon season may or may not be related to climate change. However, new management strategies to mitigate the resulting adverse effects should be developed. 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.

Increasing temperature and deficient soil moisture during summer are major concerns for survival of young rubber plants. In a survey conducted in Kerala, it was observed that in addition to the recommended management practices like mulching and shading, life saving irrigation is increasingly being practiced. During the summer of 2010, in almost 18 per cent of the holdings where planting was taken up in 2009, rubber plants were irrigated. Life saving irrigation was hitherto an unusual practice in the traditional rubber growing regions to tide over drought. Chlorophyll bleaching and leaf scorching were observed in the unirrigated plants whereas growth was much better in irrigated plants as expected.

To find out whether additional moisture conservation measures will have beneficial effect during drought, a field experiment was conducted in a comparatively drought prone area of Kerala. The experiment was initiated during 2008 at Puthukkad estate 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 was tilled to a depth of 10 cm. Hundred plants were given life saving irrigation twice weekly from December 2008 onwards and hundred plants were retained as control without irrigation or tillage. The base of the plants in all the three treatments was mulched as per the standard practice and stems of the rubber plants were protected from sun scorch by contact shading with dried grass. Soil moisture was recorded periodically during summer and diameter was recorded at the end of summer (April 2009). The extent of casualty at the end of the summer was also recorded in all the treatments. The experiment area did not receive rains during December to February 2009. Tillage enhanced soil moisture content significantly during January and February and the growth of plants was significantly superior to that of control and was on par with that of plants with life saving irrigation. The extent of casualty was 4 per cent in the control whereas there were no vacancies in the other two treatments as of April 2009. 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 more economic and feasible management practice.

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

12. ADAPTING RUBBER CULTIVATION TO CLIMATE CHANGE

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Natural rubber (NR) is a prominent plantation crop of considerable significance to Indian economy and its share in NR production and consumption globally is 8.9 and 8.7 per cent respectively. In India rubber is cultivated mainly as a rain-fed crop. Climate change has many facets including long-term trends in temperature and rainfall regimes as well as unexpected breaks in monsoon, severe and prolonged droughts and unseasonal rains *etc*. Like other agricultural crops, the growth and productivity of natural rubber are also adversely affected by climate change. Climate change aggravates abiotic stresses like heat, drought *etc*. Drought being one of the most important manifestations of climate change, the strategies should be aimed at mitigating drought impact through development of stress tolerant clones and adoption of improved agronomic practices.

The effect of type of planting material and water conserving techniques like tillage, mulching and *in situ* water harvesting, on growth of immature rubber and soil moisture storage in two ongoing experiments is discussed. Root system plays an important role in capturing the below ground resources. Root signals are known to reflect soil water, nutrient, and mechanical attributes, as sensed by roots. Among the different planting materials, polybag plants got wide acceptance among rubber growers compared to budded stumps or field budding because of easy establishment, uniformity and better performance in the main field. Polybag plants are prepared by two different methods; one involving raising seedling nursery and then bud-graftng on that with high yielding clone followed by raising the budded stump in polybag. Alternatively, germinated seeds are planted in polybags and bud-grafted *in situ*. Growth parameters of planting materials produced through direct-seeding and budded stumps were compared in a nursery experiment. 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 was significantly superior in diameter, height, number of whorls, fibrous root production and dry matter over the budded stump plants. The *in situ* preparation of polybag plants does not place any restriction on the development of root system and a well- developed root system was always associated with the direct - seeded plants.

In the field experiment integrating the use of direct –seeded green- budded plants, conservation practices like tillage, mulching and conservation pits and enhanced fertilizer application along with the use of organic manures, it was observed that soil moisture storage during summer significantly increased compared to the plots where budded stumps were planted following 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 which was also reflected in the better growth of the plants. The growth of the direct-seeded green- budded plants under integrated management was significantly superior to others. Introduction of planting materials with a good root system could play an important role in adapting to future extremes of climate change. The use of crop residues as mulch helps in lowering the soil temperature in the tropics where supra-optimal temperature adversely affects crop growth, preventing wind and water erosion, improving water infiltration in soils, increasing soil water storage in the root zone and managing weeds. All these along with the *in situ* water harvesting through the conservation pits could have contributed towards the increased growth and soil moisture storage observed in the direct-seeded plants.

One of the most significant impacts of 'greenhouse effect' is anticipated to be on water resources affecting ground and surface water supply. With the increasing scarcity of water resources, irrigation may not be a practical option for alleviating drought in most of the rain-fed areas. Therefore, along with the use of drought tolerant clones, the use of good quality planting material and good agricultural practices which can reduce the drought impacts through enhanced water conservation, retention and absorption should be a center-piece of climate change adaptation in rubber.

13. PROPOGATION TECHNIQUE OF RUBBER FOR A WARMER AND DRIER CLIMATE

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Climate is supposed to get warmer and drier in the coming years in most of the traditional rubber growing tracts of the world and cultivation of natural rubber (NR) under these climatic extremes seems to be one of the most important challenges before the rubber plantation industry in the immediate future. High ambient temperature, low humidity, extended soil moisture stress and low ground water table are supposed to be the majour climatic constraints under the influence of global warming. Being a highly heterozygous crop, NR is cultivated commercially by vegetative multiplication of improved cultivars on rootstocks raised with assorted seeds. Since there is little scope for the improvement of rootstocks, a better root system is the only way to fight against soil moisture stress and depleting ground water level.

Vegetative multiplication of improved cultivars by bud grafting was a breakthrough in enhancing productivity of rubber cultivation. The successful bud grafts could either be planted directly in the field or could be raised in polybags and transplanted at an advanced stage. Rubber Board started promoting polybag plants during the 1980s and at present more than 90% of rubber planting is being done with polybag plants. Despite various advantages, polybag plants were noticed to have certain drawbacks like coiled taproot, spiral growth of lateral roots etc. Naturally, taproot of rubber is capable to grow up to a couple of meters deep in the soil, but due to the limited space available in the bag the taproot undergoes coiling at the bottom of the polybag. A coiled taproot can never attain its normal growth even several years after transplanting and has been reported to adversely affect wind fastness and drought tolerance of plants in several crop species. Further, depending on the extent of aeration of the nursery soil, rubber seedlings were noticed to possess an average of 30 to 60 lateral roots, but these laterals are pruned before planting in polybags. Out of these an average of 5.6 lateral roots only were noticed to regenerate in polybags, others remained dormant. A propagation technique, which will promote deep growth of taproot and well-developed lateral roots, is very important under an agro-climate influenced by global warming. Polybag plants with coiled taproot and under developed lateral roots may not withstand the stresses characteristic of warmer and drier climate in future.

In due consideration of these serious drawbacks of polybag plants, the Agricultural Division of the World Bank has recommended (Josiah and Jones, 1992) root trainer planting technique as an alternative to polybag plants for tree crops. In root trainers the taproot coiling was avoided by natural air pruning and the naturally air pruned taproot was noticed to grow deep in to the soil, just like the taproot of a seedling tree. The lateral roots, which remained dormant, were induced to sprout by giving an artificial stress during the hardening process. The lateral roots were also subjected to air pruning and these naturally air pruned roots were found to resume growth immediately on transplanting to the field. This quick growth of roots was found to be very helpful to attain 100 per cent establishment success of plants transplanted to the field. The root trainer plants possessed an average of 18.9 lateral roots as against 5.61 lateral roots observed in polybag plants.

Polycross planting materials are derived from specially designed polyclonal seed gardens. Plants derived from polycross seeds are supposed to possess a strong root system with sturdy shoot. There are several documented evidences for better performance of polycross plants under stressful agro-climate. Seed at stake planting has the advantage that roots are not lost at any stage and the entire set of roots will ramify in all direction. So, polycross seeds raised by seed at stake planting seem to perform well under dry agro-climate. Plants derived from polycross seeds may exhibit high variability with respect to growth and yield. So, the plants raised out of polycross seeds should be test tapped at the age of one year. A stringent selection based on test tap yield followed by field budding of poor yielders may improve yield potential of the stand significantly. Under conditions of extreme agro-climatic stress the entire polycross plants could be used as rootstocks and field budding could be done with high yielding clones, which have proven track record of drought tolerance. However, seed at stake planting and field budding are a laborious process, which make the technique practically impossible for large planters. The cultural operations in the field have to be initiated one year in advance, which may not be practical in many cases.

Young budding in root trainers is a modification of root trainer planting technique standardized for rubber. In this modified technique stock seedlings were raised by direct seeding in root trainers. Bud grafting was done at the age of 28 days with budwood of age 20 days. The successful bud grafts were cut back on attaining the age of five months and the scion was grown till they attained two whorls of growth. In this technique the plants were retained in stand, off the ground, during the entire period in the nursery. Roots were not lost at any stage and the entire root system had undergone natural air pruning on growing out through the drainage hole at the bottom of the container. Natural air pruning of roots provided a stress to the plant and plant responded to the stress by producing large number of additional lateral roots into the well-aerated potting medium. The air-pruned taproot was noticed to grow deep into the soil, which may help the plant to avail the much-needed ground water during the extreme soil moisture stress. The well formed and naturally air pruned lateral roots would resume growth very quickly on transplanting and this quick growth of roots would be helpful to the plant to attain 100 per cent establishment success on transplanting to the field. Lateral roots of rubber will be confined to the topsoil up to a depth of one foot. The full set of lateral roots, supplemented by additional number due to air pruning, would spread in all directions and help the plant to acquire more absorption area. This additional absorption area may help the plant to absorb more water and nutrients under conditions of severe soil moisture stress.

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14. INFLUENCE OF CLIMATE CHANGE ON RUBBER HONEY PRODUCTION

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Apiculture and commercial honey production in Kerala totally depend on the rubber plantations. Rubber *(Hevea brasiliensis Muell)* is a tree which yields both 'milk' (latex) and honey (nectar). The latex is produced by the latex cells in the bark and nectar exuded from the extra-floral nectaries at the junction of the trifoliate leaf petiole. The leaves of rubber tree shed during December - February. Generally the shedding of older leaves commences in the Northern parts of Kerala during December and extends up to February in the Southern parts. After this, refoliation starts almost within one or two weeks depending on the weather conditions. The occurrence of rainfall during this period results in fungal infection of tender leaves causing leaf shedding seriously affecting nectar production. The young leaves at half maturity (light green colour) start secreting nectar. There are three extra-floral nectaries at the junction of the petiole. The honey flow begins in Northern districts of Kerala during January – February months and it extends upto March- April in Southern districts. A study was conducted by AICRP on Honey bees and Pollinators, to correlate the influence of untimely rainfall with honey yield in rubber in different districts of Kerala.

Weather conditions influenced exudation of nectar from the extra floral nectaries. Untimely rainfall adversely affected production of honey resulting in severe economic loss to the beekeepers. Rains washed away or diluted the nectar from the leaves. The increased relative humidity during the commencement of new flushes due to untimely rainfall paved the way for the incidence of powdery mildew (*Oidium heveae* Steinm) on tender leaves. The leaves showed powdery/ ashy coating, curling, crinkling and edges of leaves rolled inwards resulting in leaf fall within a period of one week. The average honey yield and data on summer rains for the last five years showed that untimely rainfall influenced the secretion of nectar from the extra floral nectaries which was more reflected in the 2008 honey flow season causing total failure with very little yield of honey. The secretion of extra floral nectaries and in turn the production of honey from the rubber plant is directly related to the weather changes during the nector season.

15. GLOBAL WARMING? TAP EARLY MORNING FOR BETTER YIELD

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With 7400 ha under natural rubber, Harrisons Malayalam Limited (HML) is the single largest rubber holding in India. The HML rubber plantations have long history of successful existence since 1905. Over the years climate has undergone major changes in the areas where its rubber estates are located. Both the early morning (minimum) temperature and afternoon (maximum) temperature have gone up in recent years. It is felt that this has substantially affected the growth rate and productivity of its estates. Similar results have been obtained by RRII as well.

Generally, tapping starts in HML rubber estates by 6.00 AM and latex collection would start at 10.00 AM and it will be over by 12.00 noon. Considering that the morning temperatures have gone up in the recent years and knowing that cooler temperatures will favour better yield, the company took a strategic decision to pre-pone the commencement of tapping to 3.00 AM since 2009 in its Kumbazha estate. Results so far have been spectacular. There was 20-30 per cent increase in productivity with substantial reduction in the percentage of field coagulum. It is suggested that likely higher turgor pressure prevailing in the cooler hours of early morning was responsible for the better yield. Since the latex was collected only after sunrise there was adequate time for dripping to stop and therefore the percentage of field coagulum was less. Early morning collection of latex ensured better preservation of latex due to the congenial temperature during this time. In order to carry out effective tapping, the tappers were provided with superior quality headlights and better tapper productivity led to 20 per cent more earnings for the tapper. The increase in production and productivity ensured that the investment in these equipments was paid back within a period of less than a week in most cases.

The new approach has been christened as “fireflies” by HML. This is a practical way of managing the adverse impact of rise in temperature on yield. HML feels that unless proper studies are made and effective strategy devised and implemented to mitigate the adverse effects of climate change, cultivation of natural rubber may become difficult in future. Seeing its initial success, HML has decided to extend “fireflies” to all its rubber estates this year.

16. IMPRINTS OF CLIMATE ON THE PROPERTIES OF THE SOILS IN THE TRADITIONAL RUBBER GROWING TRACT IN SOUTH INDIA

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The traditional rubber growing tract in India lies between 75° 10’ E and 77° 30’ E longitudes and 8° 15’ and 12° 35’ N latitudes. The rubber plantations occur in a belt with an elevation of 30 m to 450 m MSL mostly in the midlands and, to a small extent, in the lower parts of the highlands. Details on the soil properties and the data on rainfall (normal for 35-50 years), temperature and potential evapotranspiration were reported in NBSS and LUP (1999). The major soil forming factor in this tract is climate. Humid tropical climate with a pronounced dry season has resulted in intense leaching of silica and bases down the profile or out of it with accumulation of clay and hydroxides of iron and aluminium. Kaolinite is the most dominant mineral in the clay-size fraction of the soils. The higher content of clay in the subsoil than in the surface soil in most of the area indicates that a major process operative in profile development is lessivage (clay leaching), a process of mechanical entrainment by percolating water of dispersed fine particles.

Exchange properties of the soils from the five locations with distinct variation in average annual rainfall were compared. The average annual rainfall of the selected locations representing south, central and northern regions ranged from 2000 mm to 4500 mm. The mean annual temperature is almost uniform in the entire belt. The potential evapotranspiration ranged from 1688.3 mm in the south to 1729.5 mm in the north. In general, PET exceeds rainfall from December to April in the southern part and from November to April in the northern part. The soil water balance studies indicated that the soil moisture deficit is indicated from December to April in the southern region and from middle of November to April in the northern region. The number of dry months (less than 50 mm rain), which is three or less in the southern portion and greater than three in the northern portion.

Wide variation in the exchange properties of the soils from these five location was recorded. The base saturation for the Ap horizon ranged from 14 to 78 per cent between soils receiving high rainfall and low rainfall. The cation exchange capacity for the Ap horizon ranged from 3.6 to 9.3 cmol (+)/kg between the locations. Though wide variation in the base saturation values was noticed between low rainfall and high rainfall receiving soils, no such variation could be noted for cation exchange capacity. The exchangeable calcium content for the Ap horizon ranged from 0.23 to 1.77 cmol (+)/kg soil. Similarly, the exchangeable magnesium for the Ap horizon ranged from 0.16 to 1.00 cmol (+)/kg soil with soils of the low rainfall regions recording high values and soils of the high rainfall area recording low values. The exchangeable potassium for the Ap horizon ranged from 0.08 to 0.50 cmol (+)/kg soil. Exchangeable sodium also showed wide variation and the values ranged from 0.01 to 0.20 cmol (+)/kg soil for the Ap horizon. The pH of the soil was in the strongly acidic to extremely acidic range but was not related with the intensity of rainfall.

The base saturation and exchangeable bases showed wide variation between soils with variation in rainfall pattern. Soils of the heavy rainfall areas were showing very low base saturation with poor status of K, Ca and Mg. Low base saturation and low amount of weatherable minerals in these soils reflect the advanced stage of weathering of the soils. The low base saturation indicates correspondingly higher content of $Al^{3+}$and H^{+} ions in the exchange complex with potential to turn the soil more acidic. Soils in the heavy rainfall region are continuously subjected to intense leaching and the chances of further decline in the base status of the soil cannot be ruled out which may adversely affect the growth and yield of natural rubber. Though natural rubber is adapted to low base environment, studies are required to assess the growth and yield performance of natural rubber in soils with extremely low base status.

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17. ENVIRONMENTAL STRESS MEDIATED TPD INCIDENCE IN *HEVEA* – THE EXTENSION PERSPECTIVE

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Tapping Panel Dryness (TPD) is a serious threat to high yielding clones of rubber that are commonly cultivated by rubber growers. The incidence of TPD in plants growing in stressful environments of non-traditional areas was more compared to traditional rubber growing tracts. The study is relevant in the present scenario where rubber cultivation is being extended to marginally suitable non-traditional areas/pockets where climate change impacts may contribute more severely to environmental stress. The agro-climatic factors in such pockets vary significantly from the optimum level for the growth and productivity of NR and even it may go beyond the tolerance limits in certain situations. Response to 'stress' in many occasions may reflect in the rate of growth and vigour of plants and in the incidence of TPD as well.

The rate of TPD incidence in rubber plantations in different locations in India was studied in response to the different environmental stress factors such as (i) high altitude (between 500 - 700 m. msl) and cold stress (ii) low altitude (0- 3 m. msl) areas where there was water logging (iii) high temperature stress (above 40^{o}C) and (iv) low temperature (winter) stress -below 20^{o}C- for more than two months in a year. The tapping system adopted in the plantations covered under this study was S/2 d2, with very few exceptions of S/2 d3.

Survey data was collected from each plantation in pre-designed questionnaire furnishing information on various parameters such as the year of planting, name of the clone, planted area, no. of trees planted and trees opened for tapping, girth at the time of opening, tapping panel (A, B, C or D) at the time of visit, tapping system followed, time of tapping, duration of dripping, standard of tapping (Poor, Average or Good), number of trees affected with TPD and the status of TPD incidence viz., late dripping, tapping panel dried or burr developed etc. Preliminary analysis of the impact of low temperature was based on observations on 141126 trees spread over 22 block plantations in Tripura State, Noth Eastern (NE) region of India. The data from observations on 26415 trees spread over two block plantations, one each in Orissa and Andhra Pradesh formed the baseline information for the inference on to TPD in response to exposure of plants to high temperature (above 40 degree C for over two months). Primary data based on observations on 2615 trees and secondary data from a study covering over 50000 trees (Michael. S, 2009) in Udumbanchola taluk of Idukki District, Kerala were used for analyzing the rate of TPD incidence at high altitude. Moreover, information was collected on the influence of stress prevailing in high altitude and TPD incidence, in rubber plantations following ½ S d2 and ½ S d3 system separately, through personal visits in selected units in Idukki District.

Information was collected on water logging and TPD incidence through direct visits to almost all the rubber plantations under tapping (3046 trees) in Kuttanad taluk of Alappuzha district. Units were selected based on stratified random sampling and the significance of variations of TPD incidence with regard to altitude and temperature was statistically analyzed.

The highest recorded incidence of TPD of above 30 per cent was in the plantations in low altitude (0-3 m msl) Kuttanad taluk of Alappuzha district, which is a marginal zone within the traditional rubber growing tract. The soil remains moisture rich almost round the year and hence the root system is subjected to water logging (high moisture) stress, especially during monsoon. Soil moisture status (not measured) as well as TPD incidence were relatively low in high ranges and in areas experiencing prolonged drought. The logical conclusion therefore is that TPD incidence and soil moisture status are related.

Analysis of incidence of TPD in relation to temperature revealed that the TPD incidence ranged from 7–11 per cent in trees exposed to cold stress (due to low winter temperature continuously for over two months) in NE region. The plantations in high altitude (high ranges of Idukki) where also the temperature is quite cool during December-January recorded almost similar range of TPD (6-10%). NE region is colder than high ranges; but there was proof of higher TPD incidence in NE region than the high ranges of Idukki.

Rubber plantations in Eastern India, where the rate of TPD incidence was observed to be between 2-3 per cent only, are subjected to stress due to high temperature above 40°C for 2-3 months. Metabolism retards at high temperature. Low metabolism stress, the ultimate result of which is low productivity, may be the reason for low TPD incidence in this region.

Temperature and soil moisture status are the two stresses inducing environmental factors which may lead to incidence of TPD in *Hevea*, especially in NT areas. Providing proper drainage for surplus water and adoption of Low Frequency Tapping (S/2 d3) are the two precautionary measures recommended. Incidence of TPD in low temperature is controllable by adoption of LFT and regulating the dose of manure for the intercrops. The advantage, if any, of low TPD incidence at high temperature or an increase in temperature due to climate change is only by compromising the high productivity and hence is of concern to rubber growers.

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18. CARBON AND NUTRIENT CYCLING THROUGH FINE ROOTS IN RUBBER PLANTATIONS AS A FUNCTION OF SOIL MOISTURE AVAILABILITY

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One of the widely predicted and observed effects of climate change, which has direct impact on agricultural productivity, is the changes in precipitation regimes with more precipitation deficits during summer season. Though the impact of environmental variables on above ground processes and productivity is well documented in literature, only limited information is available on below ground fluxes of carbon and nutrients mainly due to the difficulty in quantification due to high spatial and temporal variability. Fine roots account for a significant proportion of carbon and nutrient fluxes in soil and to some extent, the carbon cycle of forest ecosystems are regulated by fine root biomass and production (Vogt *et al.*, 1996). The present investigation was taken up to study the fine root production of rubber trees and to quantify the carbon and nutrient cycling through fine roots as influenced by soil moisture availability.

Fine root (defined as roots with less than or equal to 2 mm diameter) dynamics was studied in a 17 year old rubber plantation during 2005-2007 by sequential coring. Eight sites in the inter-row area with representative tree height and girth were selected at random for root sampling. Root samples were collected with a sharp corer 50 mm in diameter. At each sampling site, six samples were collected at a time (48 samples in total at a time). Fine root decomposition was determined by litter bag technique. Fine root production was estimated using minimum-maximum and mass balance approaches (Hertel and Leuschner, 2002). Fine root production was also quantified by in growth core method (Steingrobe *et al.*, 2001). Mesh bags (length 30 cm, diameter 6 cm and mesh size 3 mm) were pulled over a plastic tube of the same size and inserted in to the soil. 64 mesh bags each was inserted (2 cores x 8 sites x 4 sampling periods) during November 2005 and 2006. For filling the mesh bags, soil collected from the same plots was used after removing the roots through sieving. The plastic tubes were pulled out after filling the mesh bags with soil. The mesh bags were extracted 3, 6, 9 and 12 months after installation. Fine root turnover rate was estimated from the quotient of annual production and annual mean fine root biomass. Seasonal root carbon and nutrient contents were determined and carbon and nutrient turn over through fine roots was computed.

Fine root biomass quantified through both sequential coring and in growth core methods showed significant seasonal variation and the fluctuations were particularly wide during the transition period from summer season to rainy season. Soil moisture stress was significantly higher during the summer season of 2007 than in 2006. The fine root biomass after the onset of rains was significantly high during 2007 compared to 2006 and the fine root production estimated by minimum-maximum and mass balance approaches was also higher during 2006-07. Fine root production quantified by in growth core method after the onset of rains was also significantly high during 2006-07 (561.79 g/ m^{-2}) compared to 2005-06 (411.06 g/m^{-2}). Fine root turn over ranged from 1.15 per year during the low soil moisture stress year (2005-06) to 2.28 per year during the high stress year (2006-07). Significant temporal variability was observed with respect to carbon and nutrient content of fine roots, significantly lower C, N, P and Ca contents were observed during rainy season (June) whereas K and Mg contents were significantly low during October. The annual recycling of C, N, P, K, Ca and Mg through fine roots (0-7.5 cm soil layer) was 1010.72, 49.02, 6.84, 17.78, 19.84 and 7.52 kg per ha during the low soil moisture stress year (2005-06) and 1758.26, 85.27, 11.90, 30.94, 34.51 and 13.09 kg per ha during the high soil moisture stress year (2006-07).

The results indicated that the below ground fluxes of carbon and nutrients in rubber plantations are influenced by soil moisture availability and when soil moisture stress is more severe, fine root production and turnover and consequently carbon and nutrient cycling through fine roots will be more.

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19. COLD-INDUCED GENE EXPRESSION PROFILING IN RUBBER (*HEVEA BRASILIENSIS*)

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Plants have the ability to respond to environmental changes by altering the expression of complex gene networks through sensing environmental cues. These transcriptional changes can result in successful adaptations to adverse conditions. To understand stress adaptation processes, transcript profiling of both tolerant and sensitive responses under different abiotic stresses have been initiated. This will provide a comprehensive understanding of stress adaptation and clues for identification of genes, which are useful for improvement of abiotic stress tolerance essential for extending rubber cultivation in non-traditional areas.

The goal of this research was to identify genes that are differentially expressed during cold acclimation in rubber. Transcript profiling in two relatively stress tolerant *Hevea* clones PR 261 and RRII 208 in relation to cold stress was performed. Sequencing of 131 cDNA sequences (59 down-regulated and 72 up-regulated cDNAs) revealed 110 unique sequences comprised of 13 clusters/contigs and 97 singletons. Most of them had no match with the GenBank sequences. However, several differentially expressed genes *i.e.*, catalase, phosphatidylinositol/ phosphatidylcholine transfer protein, NADH dehydrogenase, Myb transcription factor, downward leaf curling protein, epimerase/ dehydratase, Na^+/H^+ antiporter, chloroplast Ycf2 and chloroplast FtsH protease involved in cold adaptation process were also identified along with the unique transcripts.

A directional cDNA library was constructed from cold stressed leaf samples of rubber for the expressed sequence tag (EST) generation. The objective of our EST sequencing project is to establish and provide a well-characterized, non-redundant EST resource for genetic enhancement of this important crop. To identify cold responsive genes, around 873 clones were isolated from the library and checked for their insert size. *In-vivo* excision of the recombinant lambda clones for sequencing is in progress.

A subtracted cDNA library was also constructed from the cold stressed leaf sample. A total of 213 clones were generated from the forward subtraction of differentially expressed transcripts. High quality sequences of 156 subtracted cDNA clones (ScDNA) were subjected to 'contig analysis' to assemble similar sequences in groups. Thirty-one contigs containing 90 clones (2 to 8 clones per contig) and 66 singletons (single sequences) were identified. All sequences were subjected to BLASTX search to know about the homology with the gene sequences existing in GenBank from rubber or other plant species. Transcripts/clones were assigned to the category based on the shared structural elements and (or) inferred functions. All these ESTs, except a few with unknown functions, are relevant to cold responsiveness mainly grouped into following categories for which interesting functions in relevance to stress response could be inferred. These groups are (1) osmoprotection / detoxification, (2) oxidoreductases, (3) cell wall and polysaccharide metabolism, (4) protein /aminoacid metabolism (5) transport and secretion and (6) transcription factors. 96 stress responsive cDNA clones (31 contigs + 65 singletons) were subjected to reverse northern dot-blot analysis to screen for truly differentially expressed cDNA fragments. Duplicate blots of the 96 stress responsive cDNA clones (subtracted) were hybridized with labeled cDNA probes from cold treated and control RNA samples to screen for truly differentially expressed cDNA fragments. Out of 96 clones, 56 gave quantitatively more signals with the cDNA probe from cold treated PR261 plants indicating over-expression of the respective genes under cold stress. Among these genes, carbonic anhydrase, glutathione peroxidase, metallothionein, chloroplastic Cu/Zn SOD, serine/threonine protein kinase, transcription factor, DNA binding protein etc. showed significant increase in expression levels.

Identification of metallothionein gene (Hev-MT) in subtracted cDNA library derived from cold stressed leaf samples of rubber, prompted us to clone and characterize the same, as it codes for a low molecular weight, cysteine-rich protein that acts as a reactive oxygen species (ROS) scavenger in the cells to protect plants from oxidative stress. Expression of Hev-MT gene under the control of T7 promoter in a bacterial system was also studied. A fusion protein band (~14 kD) was noticed on SDS-PAGE within an hour of induction of the transformed *E. coli* cells with 1 mM IPTG. To further elucidate the role of Hev-MT genes in stress tolerance we are experimenting with it in yeast system.

However, our ultimate objective is to identify cold responsive genes with consistent pattern of expression in selected rubber seedlings showing better performance in cold-prone areas for developing region-specific rubber clones.

20. EFFECT OF LOW WINTER TEMPERATURE ON GROWTH AND YIELD OF *HEVEA* CLONES

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Acclimatization of *Hevea* to a non-traditional region and extracting profitable returns in terms of rubber yield as well as timber has gained the attention of the rubber plantation industry and policy makers to meet the increasing demand for natural rubber. In this context, evolving planting material for cultivating rubber in cold prone areas is one of the mandates of research. Sustainable cultivation of *Hevea* in cold (frost) areas of China encouraged extension of rubber cultivation in India to the Sub-Himalayan ranges of Northeastern India viz. Tripura, Assam, Meghalaya and Northern part of West Bengal. Moreover, due to the global warming some of today's severe cold prone areas may come under partly-suitable (hydrothermally suitable) rubber cultivating zones for which a readymade cultivation package needs to be available. With this objective, a few clones of *Hevea* were evaluated in the northern part of West Bengal to test their performance in the cold climate. The performance of the clones in non-winter (NW) period (April to September) was compared to that in winter (W) period to identify clones adapted to low winter temperature.

The weather parameters of the experimental site i.e., Regional Experiment Station, RRII, Nagrakata, Jalpaiguri, West Bengal, showed that the weekly mean T_{max} and T_{min} during NW was 31.4^0 C and 23.2^0 C respectively and during W it was 27.1^0 C and 12.3^0 C respectively. The fluctuation in minimum temperature between NW and W was more than the maximum temperature. Similarly in terms of RH at evening the difference between the mean of NW and W was more than the RH at morning. The duration of sunshine during NW was less than W; however, wind speed in both the seasons was similar. Total yearly rainfall was more during NW than W because the NW period included all the rainy months. The climatological data showed that variation in weather parameters during winter was more than the non-winter period.

The trial was initiated in 1991 with 10 clones along with a check clone RRIM 600 in an RBD with three replications. Girth at opening (in 8^{th} year) was significantly higher in Haiken 1 and PB 235 than in the check clone RRIM 600. Clones RRIC 102, SCATC 93/114 and PB 235 showed a significantly higher percentage of trees that attained tappability compared to the check. Highest girth was recorded in PB 310 in the 10^{th} year after tapping with the highest timber volume. The girth increment in NW during juvenile phase (3^{rd} to 5^{th} year) and immature phase (6^{th} to 8^{th} year) was more than the W period; however during mature phase (9 to 11 year) it was the reverse.

Data on the dry rubber yield showed that none of the clones were superior than the check clone. Highest yield was recorded in RRII 208 with lowest CV value across nine years indicating stability of performance compared to RRIM 600 which showed high yield but high CV value. Yield efficiency of all the clones was similar. Winter yield contribution was significantly higher in few clones viz., SCATC 93/114, RRIM 612, PR 107, PB 86, PB 235, PB 260 and PB 310, indicating that these clones were better adapted to the low winter temperature than the others. Of these PB 235 recorded a high yield of 55.96 g/tree/tap with a low CV over nine years The mean yield in BO_2 panel was lower than BO_1 panel except in SCATC 93/114 where it was higher.

The results indicated that yield of the recommended clone i.e., RRIM 600 along with RRII 208, PB 235, Haiken 1 and PB 310 was promising with appreciable crop efficiency. Winter yield contribution of these clones was above 55 per cent indicating that they were acclimatized to the low winter temperature condition of the region. Girth after nine years of tapping of these clones was above 60 cm with a clear bole volume above 0.06 m^3. Girth increment during juvenile phase in non-winter period of these clones was significantly higher than the check clone. Clone PB 235 with a winter yield contribution of 60.61% coupled with high and stable yield over nine years of tapping is noteworthy. Further evaluation of selected clones on a larger scale is under progress.

21. CLONAL VARIATIONS IN LEAF FATTY ACID COMPOSITION: POSSIBLE ROLE IN COLD TOLERANCE IN *HEVEA*

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Plants respond to environmental stresses through a wide variety of biochemical and physiological changes, such as synthesis of many regulatory proteins and accumulation of compatible solutes etc. Tolerance to low temperature is required for plants grown in many subtropical areas and in high altitudes in the tropics. Cold injury in plants induced by low temperature can occur at any stage of their growth and development. Over the past one decade, a number of reports in many crop plants have shown physiological effects on cell membrane properties due to low temperature stress.

Cell membrane undergoes both qualitative and quantitative modifications during low temperature stress and these modifications increase the membrane fluidity. The lipid composition, level of fatty acids and its level of saturation/ unsaturation regulate the cell membrane fluidity. Saturated fatty acids solidify much faster at lower temperatures than unsaturated fatty acids and tissues with high quantities of unsaturated fatty acids would have a low freezing point. In an earlier study, the fatty acid composition of leaf polar lipids of cold tolerant and susceptible rice genotypes suggested that double bond index of lipid unsaturation is significantly high in the cold tolerant genotypes (Majumder *et al.*, 1989). Gustavo *et al.* (1990) Another study on the fatty acid composition of leaf phospholipids of barley seedlings subjected to cold stress observed that the content of linolenic acid increased significantly in cold stressed plants compared to the control plants. Regardless of the species, the common mechanism adopted by plants to deal with cold stress is by changing the membrane stability and integrity in tissues. This study was conducted to find out the fatty acid composition of polar lipids in the leaf samples from different Hevea clones and to develop this as a screening tool for cold tolerance. Development of this screening technique would help to identify rubber clones suitable for cultivation in the areas affected with low temperature stress.

Fully expanded and physiologically mature sun leaves were collected from three year old plants belonging to 12 Hevea clones viz. SCATC 88-113, SCATC 93-114, RRII 105, RRII 5, RRII 118, RRII 208, Haiken 1, PR 255, PR 261, RRIM 600 and RRII 308. Three plants were selected at random from a complete random planting of the various clones. Total lipids were extracted and fractionated to polar lipids using silicic acid chromatography. Polar lipids were hydrolysed to free fatty acids and uv-absorbing phenacyl derivatives were prepared. Fatty acid phenacyl esters were analysed using high pressure liquid chromatography (HPLC). Fatty acid esters were identified by comparing their retention times with known standards. The double bond index (DBI) of polar lipids was computed.

The main unsaturated fatty acids identified in the leaf polar lipids of Hevea are palimitoleic acid (65.0%), linolenic acid (5.3%), linoleic acid (3.4%) and oleic acid (0.7%). The main saturated fatty acids are palmitic acid (15.7%) and stearic acid (9.7%). Clonal variations were observed in the double bond index of the polar lipids in the leaves of different Hevea clones. Among the clones, maximum double bond index was noticed in RRIM 703 followed by Haiken 1, RRII 118, and RRIM 600 in order and the least in RRII 105.

Investigations by earlier workers have shown that the membrane lipids become more unsaturated during cold acclimation in several plant species (Tasseva et al., 2004; De Palma et al., 2008; Badea and Basu, 2009). As increased unsaturartion of membrane lipid is considered as a necessary adaptation to cold stress, the high double bond index in RRIM 703 suggests it was the most cold tolerant clone and RRII 105, the least tolerant one.

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22. GENES ASSOCIATED WITH COLD TOLERANCE IN *HEVEA* AND THEIR RELEVANCE TO CLIMATE CHANGE

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The demand for natural rubber, both domestically and globally has been on the rise and to meet the demand, cultivation of *Hevea brasiliensis* in India has to be extended to non-traditional regions. The regions identified for such purpose are only marginally suitable areas like Konkan and Orissa regions where high temperature, concomitant with high light intensity during summer season and scarce water availability are the constraints for optimum growth and productivity. In North-Eastern region of India, the temperature during winter is too low and to obtain optimum productivity, it is necessary to identify or evolve suitable clones that can tolerate low temperature in such regions. Investigations in this line are also gaining much importance in the context of climate change. Hence, in this study, attempts were made to investigate the molecular basis of cold tolerance in *Hevea* with special reference to identification of genes/regulatory factors associated with cold tolerance which can be employed for the selection of genotypes suitable for low temperature regions of India.

Six months old polybag plants of RRII 105 (cold susceptible) and RRIM 600 (cold tolerant) were acclimatized in a growth chamber for three days with a minimum temperature of 15° C during night (for 3 hours) and a gradual rise to maximum temperature up to 25° C during day time. Fourth day onwards, cold treatment was imposed: 8° C for 3 hours between 2 and 5 am followed by a gradual increase of maximum temperature up to 16° C in the day time for five consecutive days mimicking natural conditions in winter. The control plants were allowed to grow at stress free and ambient weather conditions of RRII. Cold induced inhibition of photosynthesis in the low temperature treated plants when compared to the control plants was confirmed by analyzing the CO_2 exchange rate using a portable photosynthesis system.

Leaf sample collection, mRNA isolation, cDNA synthesis and quantitative PCR (qPCR) were performed as per standard protocols. After standardization of primers for their specificity and amplification efficiency and optimizing the template concentration, qPCR was performed with selected stress associated genes such as WRKY transcription factor (WRKY tf), ABC transporter protein (ABCT), transcription factor MBF (TfMBF), LEA 5 protein, CRT/DRE binding factor (CRT/DRE bf), glutathione peroxidase (GPX), a hypothetical protein (33HP), Dna J protein and peroxidase. Suitable endogenous control genes were selected (ADP ribosylation factor and polyubiquitin gene) from four primers after performing qPCR and calculating their gene stability (*M* value) using GeNorm software. One set of quantitative expression analysis was performed with control plants of RRII 105 as calibrator and the other set with control plants of each clone as calibrator.

Out of the nine genes analyzed, only two genes showed remarkable fold change (over control) under cold conditions in both the clones. When relative gene expression analysis was performed using control plants of each clone as calibrator, both LEA5 protein as well as peroxidase were found to be up-regulated by 8.14 and 5.8 fold in the low temperature treated plants of RRII 105 and RRIM 600 respectively. Though the expression of TfMBF and 33HP were 2.66 and 3.26 fold higher in low temperature treated plants of RRII 105, their expression was lesser than control plants of RRIM 600. In contrast, ABCT protein was 3.67 fold higher in cold treated plants of RRIM 600 and was lesser than control in the case of RRII 105. These results indicate that both peroxidase and LEA5 protein were up-regulated in both the clones. However, ABCT expression was found higher only in RRIM 600 indicating the possibility of it playing a role in cold tolerance.

When the data was analyzed by keeping RRII 105 control plants as calibrator, about 6.3 and 36.5 fold increase in peroxidase expression was found in control and cold treated plants of RRIM 600 compared to RRII 105 control plants. This high magnitude of expression in RRIM 600 may be attributed to its known cold tolerance in the field conditions of NE regions. Similarly, expression level of LEA5 was also found to be several fold higher in RRIM 600 (2.15 and 12.57 fold in control and cold treated, respectively) than the RRII 105 control. Again, expression of TfMBF and 33HP were higher only in RRII 105 cold treated plants (2.65 and 3.25 fold, respectively). The expression level of ABCT protein was about four fold higher in RRIM 600 than the RRII 105 control plants.

The results indicate the relevance of LEA5 and peroxidase in contributing for the enhanced cold tolerance in RRIM 600 as evidenced from its field performance. Expression of ABCT protein needs to be ascertained further in other cold tolerant clones also. Expression of ABCT was found significantly higher only in RRIM 600 while it was repressed in RRII 105. Thus, identification of such genes associated with cold tolerance gains importance in the context of evolving clones that are suitable for regions which are under low temperature stress. Quantification of selected genes has to be extended to other cold tolerant clones and wild accessions identified from the field trials as a measure of further confirmation to use them as markers for cold tolerance. Further, it is also essential to employ more genes in such quantitative studies to ascertain their association with cold tolerance.

23. DEVELOPMENT OF STRESS TOLERANCE IN *HEVEA BRASILIENSIS* THROUGH TRANSGENIC APPROACHES

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Plants are often exposed to a variety of abiotic stresses such as drought, temperature extremes, intense sunlight *etc.* causing severe oxidative stress leading to heavy crop loss. The direct cause of oxidative stress is an increase in the production of reactive oxygen species (ROS) that damage the tissue and cell organelles. Plant cells contain a number of ROS detoxifying agents that are distributed in most cellular compartments. The role of superoxide dismutase (SOD) in the protection of plants against oxidative stress is well documented. SOD is the first enzyme involved in the detoxifying process of the reactive oxygen species. Being a family of metallo enzymes, SOD accelerate the spontaneous dismutation of superoxide radicals to hydrogen peroxide and molecular oxygen. The hydrogen peroxide generated is eliminated by catalase and peroxidase enzymes. In addition to SOD, low molecular weight antioxidants like ascorbate, glutathione, and antioxidant enzymes like ascorbate peroxidase (APX), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR) and glutathione reductase (GR) are also involved in the ROS detoxifying process.

Over-expression of SOD in plants would facilitate tolerance against oxidative stress induced by several stress factors. Many crop plants were transformed with genes coding for mitochondrial MnSOD, chloroplastic/ cytosolic Cu/ZnSOD or FeSOD and the over expression of these genes were observed. The increased tolerance to abiotic stresses by the over expression of SOD gene has already been achieved in transgenic crop plants like tobacco, potato, alfalfa, tomato, rice, canola, poplar etc. Increased level of other antioxidant enzymes like catalase, peroxidase, ascorbate peroxidase were also observed in plants transformed with SOD gene. Development of plants with increased abiotic stress tolerance is of high priority in *Hevea* for crop improvement programme, considering the changes in climate and extending rubber cultivation to the marginal non-traditional areas where the rubber plants are exposed to a variety of environmental stresses.

Transgenic plants integrated with a gene coding for mitochondrial targeting MnSOD were developed in *H. brasiliensis* (clone RRII 105). *Agrobacterium mediated* gene transfer was carried out using immature anther derived calli as the target material. The transformed cell lines were selected over MS medium containing 500 mg/l cefotaxime and 300 mg/l kanamycin. Plantlets were developed from two transformed cell lines (L1 & L2) through somatic embryogenesis and the gene integration was confirmed by GUS assay, PCR and southern hybridization. The transgenic plants were multiplied by bud grafting and maintained in glasshouse.

Experiments were performed to assess the MnSOD transcript abundance and drought tolerance traits of the plants at the nursery stage. Six month old bud grafted plants of clone RRII 105 (control), non-transgenic somatic plants (control) and transgenic plants (L1 & L2) were grown in poly bags filled with garden soil in a protected area under ambient conditions. In summer the plants were grouped into two sets and one set was irrigated daily and the other set was kept un-irrigated for two weeks for inducing drought stress. At the end of the drought treatment leaf samples were collected for physiological, biochemical and molecular analysis. Physiological parameters such as leaf water potential, photosynthetic O_2 evolution, respiratory O_2 uptake, PS II activity etc. were carried out. Leaf water potential was measured by using psycro water potential system (Wescor, USA). The rate of photosynthetic O_2 evolution and respiratory O_2 uptake in the leaf discs were measured by using Hansatech Oxygen Electrode (LD2/2, King's Lynn, UK). PS II activity was measured in the intact leaf by using PAM Fluorometer 2000 (Walz, Germany). Activity of antioxidant enzymes such as superoxide dismutase, ascorbate peroxidase, catalase and peroxidase were also studied. The transcript abundance of SOD gene was studied through northern analysis.

Physiological studies indicated that the transgenic plant L1 showed significant improvement in PS II activity upon exposure to drought compared to the transgenic plant L2, bud grafted plantsplants and the somatic plants of RRII 105. Though, the maximum potential photochemical efficiency of PS II was not altered under drought stress, the effective PS II quantum yield and mid –day leaf water potential were less inhibited in the transgenic L1 plants than all other plants. The drought mediated reduction in photosynthetic oxygen evolution rate was smaller in SOD transgenic plants L1 than in the plants of other category. The SOD activity was 35 per cent higher under normal condition and 31 per cent higher under drought condition in the transgenic plant L1 than the bud grafted wild plants of clone RRII 105. Though there was an increase in SOD activity and H_2O_2 content in L1 plants, corresponding changes were not observed in the case of peroxidase activity. Northern analysis indicated a higher MnSOD transcript level in the stressed transgenic plants. The level was higher in the transgenic plant L1 than in L2, whereas the expression was very less in the bud grafted control plants of clone RRII 105 and the non-transgenic somatic plants of the same clone.

The results showed that in the MnSOD transgenic plants over expressing the SOD enzyme, there appears to be a significant reduction in oxidative stress. The efficient ROS scavenging activities in L1 plants led to better protection of photosynthetic activities against drought induced photo-oxidative damage. Developing transgenic plants for abiotic stress tolerance is an important approach towards crop improvement in *Hevea*. In the scenario of climate change, generation of location specific new clones with sustainable yield potential and adaptation to environmental stresses could be achieved through transgenic approaches.

24. TECHNIQUES FOR IDENTIFYING POTENTIAL DROUGHT TOLERANT ACCESSIONS FROM WILD *HEVEA* GERMPLASM COLLECTION

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As global demand for natural rubber increases a major challenge for cultivation of rubber plants is their capacity to withstand unfavourable environmental conditions in the context of global climate change. Drought remains one of the most biologically damaging and ecologically limiting factors among all environmental constraints. Drought stress can occur at any stage of the growing process, and can cause complete loss of crops or serious damage to yield. In India natural rubber production comes mostly from a single popular clone RRII 105 and it occupies most of the area under rubber cultivation. Although it is the highest yielding clone in India it does not exhibit good drought tolerance capacity. This clone was found more susceptible to extreme climatic conditions especially in non-traditional rubber growing regions.

Experiments were conducted in the laboratory to identify intrinsic drought tolerance traits in *Hevea* using leaf discs subjected to different environmental stresses like drought, high temperature and light. Combination of stresses was found more deleterious to *Hevea* than single stress. An increase in cell membrane injury, enhanced chlorophyll bleaching and reduction in PS II activity were observed. The popular clone RRII 105 was found more susceptible than RRIM 600. The leaf samples of clone RRII 105 upon incubation with PEG (60% Polyethylene glycol solution) and light (350 µmols/m^2/s) exhibited 45 per cent membrane injury compared to 38 per cent in clone RRIM 600. *In-vitro* drought combined with light also decreased the chlorophyll content and enhanced chlorophyll bleaching more in clone RRII 105 (33%) than RRIM 600 (11%). Similarly the photochemical efficiency of photosystem II was drastically reduced in clone RRII 105 when exposed to drought and light. Thus compared to clone RRIM 600, the clone RRII 105 was found more susceptible to drought and any addition of stresses like temperature, light etc. caused more damage. Though the prevailing climatic conditions in traditional rubber growing regions are suitable for cultivation of clone RRII 105, the laboratory studies confirmed that the adverse climatic constraints, further augmented by a global climate change, might exhibit a reciprocal effect on growth of this clone even in traditional area in the coming years.

Under acute drought stress in field condition the young nursery grown plants of RRII 105 produced leaves with reduced leaf area and low chlorophyll content, possibly due to enhanced photo-oxidative damage leading to pigment bleaching. Three weeks of drought reduced the leaf chlorophyll content by 24 per cent and the mid-day water potential of leaf by 25 per cent in clone RRII 105 and 8 per cent and 15 per cent, respectively in clone RRIM 600. Under similar stress condition the PS II quantum yield declined by 41 per cent in clone RRII 105 whereas in clone RRIM 600 there was only 17 per cent reduction. As a result of drought intensity of green colour of leaves diminished and became yellowish due to photo-bleaching with their margins often dried. The effect was more pronounced in clone RRII 105. Burning of lamina, drying and senescence were also observed causing considerable reduction in total functional leaf area of plant RRII 105. Clone RRIM 600 performed better in similar stress condition. Total leaf area of young RRII 105 plants grown in field was reduced by 35 per cent as compared to 21 per cent in clone RRIM 600.

RRII has acquired nearly 4500 wild germplasm accessions that are excellent repository of various useful traits including tolerance to adverse environmental stresses. Attempts were made to identify accessions that have intrinsic drought tolerance traits. Symptoms of drought on the leaves were visually scored in one year old plants in the field. The percentage of leaf yellowing and leaf senescence was recorded in these plants by empirical scoring. Accessions were then sorted numerically and ranked for leaf senescence and leaf yellowing. About 3772 germplasm accessions were screened for visual drought tolerance traits and analyzed. Accessions that were exhibiting less senescence and yellowing in field were ranked in top as the most drought tolerant ones. Similarly, accessions exhibiting high rate of senescence and severe leaf yellowing were ranked as the most drought susceptible ones. A total of 168 wild accessions were selected as drought tolerant and 125 wild accessions as drought susceptible ones. The short listed accessions were subjected to *in-vitro* water deficit stress with PEG and changes in the effective quantum yield of PS ll were estimated. A significant relationship was obtained between the visual drought tolerance scoring and PS II activity. The selected accessions with intrinsic drought tolerance qualities would be included in future breeding programmes for evolving clones that can better tolerate adverse environmental conditions.

25. SEASONAL VARIATIONS IN YIELD AND ASSOCIATED BIOCHEMICAL CHANGES IN RRII 400 SERIES CLONES OF *HEVEA BRASILIENSIS*

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Latex production in rubber tree varies round the year depending upon the environmental conditions. Yield depression during stress period is of particular importance as it limits productivity of the crop. Latex harvesting is done throughout the year in the traditional rubber growing areas and the peak crop yielding period is from September – November and low yielding (stress) period is from February- April which is often considered as a stressful summer period. During stress situations, different factors contribute to yield reduction. Lower rubber yield during stress period is a combined effect of defoliation (wintering), refoliation during January/ February and the subsequent summer stress during March-April months. Several physiological and biochemical factors vary and they influence the yield potential of the tree during different seasons in a year. In the present study, seasonal variations in yield and biochemical parameters associated with latex flow and regeneration were analyzed and related with yield depression during summer period in different clones of RRII 400 series.

The study was carried out in five new clones viz. RRII 414, RRII 417, RRII 422, RRII 429, RRII 430 along with the popular check clone RRII 105 planted in 1993 at CES, Chethackal. Nine trees each of uniform girth and yield were selected for biochemical studies. The trees were under S/2 d3 6d/7 system of tapping. Parameters related to rubber biosynthesis such as sucrose content, ATP and C-serum invertase, and antioxidant enzymes SOD and peroxidase and other biochemical components such as thiols and proteins were measured during peak yielding season (Sep-Nov) and low yielding summer season (Feb-April) for two consecutive years (2008 and 2009). Mean peak season yield (Sep-Nov), summer yield (Feb-April) and yield depression during stress periods were also calculated for all the clones. The data was statistically analyzed to observe the seasonal variations in biochemical parameters and their interaction with different seasons.

The statistical analysis of the data showed that mean yield depression during the stress period compared to the peak season over two years (2008 and 2009) of these clones was 45.29 (RRII 414), 63.35 (RRII 417), 50.03 (RRII 422), 57.0 (RRII 429), 58.7 (RRII 430) and 64.5 (RRII 105) per cent. Among the biochemical parameters studied, latex sucrose content increased in clones RRII 417, RRII 429 and RRII 105 during stress season compared to peak yielding season and invertase activity was low in these clones. All the clones showed an increased peroxidase activity in C-serum during the stress period compared to peak yielding season. A general decrease in protein content in the latex was also observed in all the clones during summer compared to peak season.

Significant clonal variations were observed in the case of C-serum thiols, SOD and peroxidase during the stress season and clone x season interaction was also observed. RRII 422, RRII 430 and RRII 414 showed higher thiols, invertase and SOD in the C-serum during stress season. Clones RRII 429, RRII 417 and RRII 105 showed very low SOD and invertase during this period.

It was earlier reported that in clone RRII 105, even though thiol metabolism is activated during stress, decrease in cytosolic enzymes such as invertase and SOD leads to lower yield during stress period. The present study indicates that among the clones studied for yield attributes such as thiols, SOD and invertase, RRII 422 followed by RRII 430 and RRII 414 may be more tolerant to stress situation than the other clones.

Under the changing scenario of climate, environmental stresses are becoming more important in the traditional rubber growing areas in India. Identifying clones with stress tolerance and yield sustainability would therefore be important to enhance the crop productivity. Such clones are expected to perform well in non-traditional areas also where drought is a limiting factor for crop production.

26. MECHANISM OF DROUGHT TOLERANCE IN *HEVEA BRASILIENSIS*- POSSIBLE BIOCHEMICAL INDICATORS

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Drought is one of the most important environmental stress factors which adversely affect plant growth and productivity. Global climate change may make this situation more serious in the years ahead. To improve crop productivity and reduce the yield gap between optimal and stress conditions, it is necessary to understand the mechanism of plant responses to various environmental stresses. Plants under stress develop many physiological and biochemical mechanisms to protect themselves against the harmful effects. Evidences suggest that many environmental stresses have their effects directly or indirectly through the production of reactive oxygen species (ROS) such as superoxide, hydroxyl radical and hydrogen peroxide. Excessive ROS production can cause oxidative stress to the photosynthetic apparatus and impair the normal functioning of cells. ROS can damage lipids, carbohydrates, proteins and nucleic acids. To keep the levels of ROS under control, plants have evolved a series of anti oxidative systems which are composed of low molecular weight antioxidants such as ascorbate, glutathione, a-tocopherol *etc*, and ROS scavenging enzymes such as superoxide dismutase, peroxidase, ascorbate peroxidase, glutathione reductase and catalase. Many studies have indicated that antioxidant defense mechanisms provide protection against oxidative damage in cellular membranes and organelles in plants grown under unfavorable conditions.

The present paper is a general overview of the results of earlier studies on oxidative stress and antioxidant defense mechanisms in *Hevea*. Several studies relating to the constraints for cultivation of *Hevea* in agro-climatically stressful regions and physiology of drought tolerance have been conducted in traditional and non-traditional regions such as the North Konkan where severe drought is common. This study was conducted at the Regional Research Station of Rubber Research Institute of India, Dapchari, located in a highly drought prone area in the North Konkan region of the country. The climate in Dapchari is characterized by severe drought concomitant with high temperature and solar radiation and low atmospheric humidity for six to seven months in a year (December-June). The experimental trees were selected from a 12 year old rainfed polyclonal plantation. Drought tolerant and susceptible trees were identified on the basis of girth and yield data for two years. The trees were classified into high/low yield and high/low girth types. Ten trees per type were selected for the study.

The dry rubber yield, girth of the trees, biochemical composition (phenols, aminoacids, sugars, proteins and glutathione) and the activities of antioxidant enzymes superoxide dismutase (SOD), peroxidase (PER), ascorbate peroxidase (ASPX) and polyphenol oxidase in the leaf and bark tissues were determined during summer (peak drought) and post monsoon (drought free) seasons. The mean dry rubber yield of low yielding category (drought susceptible) ranged from 14.4 to 34.9 g/t/t whereas for high yield category (drought tolerant) it was 32.3 to 107.7 g/t/t. The mean girth ranged from 27.5 to 30.2 cm in the low girth (drought susceptible) and 76.5 to 82.9 cm in the high girth (drought tolerant) category trees. The biochemical composition and enzyme activities in the leaf and bark tissues of the four tree types showed wide variations. The glutathione content in the bark was higher in the high yielding than the low yielding trees irrespective of the seasons. The high yielding trees showed greater peroxidase and ascorbate peroxidase activities in the leaves and low polyphenol oxidase activity in the bark than the low yielding trees. High girth trees consistently showed increased leaf peroxidase activity compared to low girth trees during both the seasons, indicating their efficient ROS scavenging and thereby drought tolerance capacity. Peroxidases and catalases are involved in hydrogen peroxide scavenging and they have different affinities for hydrogen peroxide. Peroxidase may be responsible for the modulation of ROS production during stress and catalase may remove the excess ROS generated. Catalase activity did not show any significant variation between drought tolerant and susceptible trees, probably catalase may be less important during stress when peroxidase is active.

In a heterogenous seedling population like a polyclonal rubber plantation, it is difficult to identify reliable markers because of large tree to tree genotypic variations.

Although our results have been reproducible with a fair degree of accuracy, some of the trees belonging to high girth or high yield categories could have been having deep root system and thus they were able to obtain moisture from the deeper layers of soil during summer. We measured the soil moisture availability in deeper layers (1.5 m) during summer and found that out of the seven trees with high girth monitored, four received very low soil moisture, similar to low girth trees. These high girth trees showed a higher peroxidase activity in their leaves than the low girth trees, which had been exposed to similar drought stress.

The results of the study suggest that high peroxidase and ascorbate peroxidase in the leaf and low polyphenol oxidase activity in the bark could be used as possible biochemical indicators/ markers for drought tolerance in terms of yield and biomass production. The findings reported in this paper are useful for future breeding programme and screening germplasm accessions for selecting drought tolerant clones with sustainable yield which will be suitable for the non-traditional areas where drought is a major factor limiting rubber productivity.

27. PERFORMANCE OF RUBBER PLANTATION RAISED FROM BUD GRAFTED CLONES AND POLYCROSS SEEDS UNDER DIFFERENT MOISTURE REGIMES IN NORTH KONKAN REGION OF MAHARASHTRA

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Rubber cultivation is being extended to agro-climatically less congenial but potential areas in view of limited scope for further expansion of cultivation in traditional regions and to bridge the widening gap between production and consumption of natural rubber. The North Konkan region along the western coastline of India was identified as one of the potential non- traditional areas for rubber expansion. The present study was conducted at Regional Research Station (RRS), RRII, Dapchari that lies at 20.04° N latitude and 72.04 ° E longitude at an altitude of 48 m above MSL. The region characterized as sub humid climate with annual precipitation ranging from 2300-2800 mm. The annual drought due to continuous absence of rainfall for nearly 7 months coupled with high evaporation pressure deficit, high temperature, high intensity of solar radiation, low atmospheric humidity and dry winds during summer months inhibits the growth and productivity of rubber plantation. During dry period, the available water for irrigation in this region is scarce. It is important to manage the available water resources to the optimum utilization by employing judicious methods and dose of application if the plants need irrigation. There is also a need to identify drought tolerant clones suitable for this agro-climatic condition. if the plants need irrigation. The present paper is aimed at evaluation of growth and yield performance of clonal bud grafted trees (RRII 5, RRII 6, RRII 208, RRII 308, RRIM 605, PB 310, PB 311, RRIC 52, RRIC 100, RRIC 102, RRIC 105, PR 255, PB 260, PB 261, RRII 105) and polycross seedling population under two contrasting water regimes (different levels of irrigation and rainfed un-irrigated conditions) for identification and recommendation of suitable drought tolerant clones with optimization of irrigation schedule for higher and sustainable rubber yield.

A very good response of irrigation during summer months was noticed in clonal bud grafted trees to various levels of irrigation provided by different methods (drip and basin methods). The trunk girth increment was negligible or very low during dry season under rainfed condition indicating the severity of stress condition. Significant clonal variation in survival and growth of young bud grafted trees was seen under severe soil moisture stress whereas polyclonal seedling maintained better plant moisture status under drought condition leading to better plant growth. Among the irrigation treatment 0.50 ETc basin irrigation during summer was found sufficient to reduce the immaturity period to 6 years whereas rainfed bud grafted plants attained tappable girth only after 10-11 years after planting. With adequate irrigation 80 per cent tappability was achieved in clonal bud grafted plants 6-7 years after planting. Under rainfed condition, a few polyclone seedling population had attained tappable girth in the seventh year of planting, the number of tappable trees increased gradually and attained 100 per cent tappability within a maximum period of 10 years. Results revealed that polyclonal seedlings exhibited early tappability, good girth increment upon tapping in comparison to rainfed clonal bud grafted trees in North Konkan region. With adequate irrigation, yield was significantly increased in clones RRII 105 and RRII 118. The yield was increased with high level of irrigation and thereafter yield seems to be stabilized and no further increase was noticed with high level of irrigation in mature bud grafted trees. Reducing the irrigation level from 0.75 ET_C basin to 0.25 ETc and 0.50 ET_C drip to 0.25 ET_C did not show any adverse effect on the growth and yield of mature plants. From the evaluation of 15 bud grafted clones under rainfed condition, it was revealed that the clone RRII 208 performed with better vigour and yield than RRII 105, RRII 6, PR 255, and RRIC 100. While the annual yield obtained from clonal bud grafted plants was in the range of 700-1500 kg per ha per yr, it was approximately 1000-1200 kg per ha per yr from polyclonal plantation both were grown as rainfed crops except for life saving irrigation in the first couple of years. Significant level of summer yield depression was recorded in clonal bud grafted trees. Conversely, the analysis of seasonal variation in yield data of polyclonal seedling population showed a stable yield even in summer months which indicated the ability of the polyclones to withstand severe drought condition in North Konkan region. Previous studies revealed that higher level of water use efficiency, increased activities of SOD, peroxidase and ascorbate peroxidase in leaves, lower polyphenol oxidase activity in bark tissues etc are associated with drought tolerance traits of polyclonal seedling trees.

A clonal bud grafted tree grown under irrigated condition was shown to be more vulnerable to sudden onset of drought if irrigation failed while no much causality and yield reductions were observed in plants raised from polycross seeds grown under rainfed condition. Interestingly, the incidence of TPD also appeared to be less in the case of polyclonal seedling trees.

Though the yield of rainfed polyclonal populations was lesser than that of irrigated bud grafted trees, the yield reduction in polyclone could be compensated for by the high requirement of irrigation cost. The cost incurred towards irrigation can be avoided substantially by growing polyclonal seedlings in agro-climatically marginal regions of North Konkan region.

28. PHYSIOLOGICAL EVALUATION OF MODERN *HEVEA* CLONES FOR DROUGHT TOLERANCE USING GAS EXCHANGE AND CHLOROPHYLL FLUORESCENCE TECHNIQUES

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Water is becoming increasingly limiting in many areas and water deficit stress will be one of the most important environmental factors that limits crop productivity in the changing climate scenario. Drought stress in plants is aggravated by both high solar radiation and increased atmospheric temperature, thereby increasing the magnitude of damage even under a short period of drought. Natural rubber (*Hevea brasiliensis*) is generally grown as a rainfed crop in the traditional as well as non-traditional areas in India where drought is increasingly becoming a common occurrence and this may become more serious in the years ahead if the current warming trend continues. The effect of any abiotic stress is usually perceived as decrease in photosynthesis followed by growth reduction. Chlorophyll fluorescence has been used as a rapid and accurate technique to detect and quantify plant tolerance to stress.

Five modern *Hevea* clones viz., RRII 414, RRII 417, RRII 422, RRII 429 and RRII 430 and three check clones (RRII 105, RRIM 600 and Tjir 1) were included in the present study. Seven month old polybag plants grown in open and glasshouse conditions were subjected to drought by withholding irrigation continuously for twenty days, while irrigated plants served as control. Photosynthetic CO_2 assimilation (A) and chlorophyll fluorescence measurements in mature leaves were carried out using a portable photosynthesis system (Li-6400 LI-COR) with a leaf chamber fluorometer (LI-6400-40). The measurements in both drought and control plants grown in open condition were taken on the tenth and fifteenth day of drought imposition and on the tenth day in the case of plants grown in glasshouse. In another experiment water deficit condition was induced *in vitro* by incubating the leaf discs in 40 per cent PEG for four hours under a PPFD of 400 $\mu mol/m^2/s$ and PS I and PS II activities in leaf discs were measured using Dual-PAM-100 (Walz).

The results showed that the clone RRIM 600 grown in open condition recorded the least decline in CO_2 assimilation rate (46%) followed by RRII 430 (73%) 15 days after drought imposition. The clone RRII 414 was found to be severely affected (100% inhibition in A) by drought. RRII 430 maintained relatively higher stomatal conductance (g_s) followed by RRIM 600 after 15 days of withholding irrigation. All the remaining clones showed more than 90 per cent decline in g_s during this period. Total chlorophyll content remained almost the same in RRII 105 while all other clones showed 20-25 per cent decline with drought stress. Similar trend was noticed in the glasshouse grown plants 10 days after drought treatment. The rate of decline in A was lower in RRIM 600 (14%) followed by RRII 430 (20%) and RRII 429 (20%); while maximum reduction in A was observed in RRII 105. Stomatal conductance in water stressed glasshouse grown plants was maintained better in RRII 422, RRII 429 and RRII 430 than in clones like RRII 105, RRII 414 and RRII 417. The effective quantum yield of PS II (ö PS II) was better in RRIM 600 (0.41) and RRII 430 (0.35) than clones RRII 417, RRII 105 and RRII 422 which showed drastic decline in PS II activity after 20 days of drought imposition. Under glasshouse conditions RRII 430 and RRII 422 showed stable ö PS II activity both under control and drought conditions. PS I activity was higher in water stressed plants of clones RRII 429, RRII 430 and RRII 105 under glasshouse conditions. RRII 430 and RRIM 600 showed a small reduction in PS II activity (29 and 28% respectively) under PEG treatment while RRII 414 recorded maximum decline (57%). Among the modern clones, RRII 422, RRII 429 and RRII 430 showed high PS I activity under drought stress probably indicating an increased rate of cyclic electron flow around PS I when the PS II function is impaired.

Gas exchange and fluorescence data revealed that the clone RRII 430 is more likely to endure drought stress than the other RRII 400 series clones and it stands almost on par with RRIM 600 which is a known drought tolerant clone. PS I activity remained higher in drought imposed plants than control plants in most of the clones studied, indicating more photon utilization by PS I than PS II under stress condition. Among the RRII 400 series clones studied, RRII 414 and RRII 417 were found inferior in terms of drought tolerance capacity. Gen-Next clones for future cultivation should have better tolerance to changing climatic conditions and the results of the present study help in this direction.

29. AN ANALYSIS OF INTRINSIC WATER USE EFFICIENCY (WUE) IN RRII 400 SERIES CLONES OF *HEVEA*

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Limiting water availability is one of the major factors that affect the productivity in crop plants. Generally plants manage to survive water deficit to a certain extent either by morphological or physiological modifications that enable them to avoid or postpone desiccation stress. In India, 85 per cent of the natural rubber cultivated area is in the traditional rubber growing region where rain fall and other agro-climatic conditions are better suited for rubber cultivation than in the non-traditional areas. Rubber cultivation is being extended to marginal areas of western and eastern parts of India with varied climatic constraints like moisture stress, high and low temperatures, drought and cold stresses which are major factors that limit growth and productivity of rubber in these regions. Among the various growth/productivity limiting factors, the negative impact of drought on yield has been well established in different *Hevea* clones.

The intrinsic water use efficiency of plants is known to be related to the efficiency of plants to grow with limited availability of water (Majken *et al.*, 2005). The drought tolerance capacity of the modern *Hevea* clones (RRII 400 series) is largely unknown. The present study was aimed at establishing the relationship between leaf water status and CO_2 assimilation rate (*A*) and stomatal conductance (*gs*). The intrinsic water use efficiency (WUEi) of the modern clones in relation to drought tolerance mechanisms was also studied.

The experiment was conducted in polybag plants of seven month old *Hevea* clones belonging to RRII 400 series (RRII 430, RRII 414, RRII 429, RRII 417, RRII 422) with three check clones namely RRIM 600, RRII 105 and Tjir 1. Polybag plants were maintained under open ambient conditions. Irrigation and other routine cultural operations were provided to all plants. Water stress was imposed by withholding water to a set of plants (n=6) during February 2010. Another set of six plants in each clone was used as control, where irrigation was continued. Leaf water status and leaf gas exchange were measured before subjecting to drought (pre- stress) and on 10^{th} and 15^{th} day of drought imposition. Three replications per clone were taken for physiological measurements and observations. Net CO_2 exchange rate *(A)* and stomatal conductance (*gs*) were measured using a portable IRGA (Infrared gas analyzer, Li 6400, LI – COR Inc.). The leaf water potential (Y_L) was measured at noon using Psypro Water Potential System (Wescor). The data were analyzed statistically by ANOVA and correlation was worked out from the mean values.

Water stressed plants showed significantly smaller values of CO_2 assimilation (*A*), stomatal conductance (*gs*) and reduced leaf water potential than control plants. Drought reduced *A* and *gs* drastically. A significant inter-clonal difference was observed for *A* and *gs*. After drought imposition for 15 days RRIM 600 recorded more stable *A* (5.6 µmol/m^2/s) and *gs* (0.06 mol/m^2/s) than other clones studied followed by RRII 430 (*A*= 4 µmol/m^2/s, gs= 0.03 mol/m^2/s^1). A significant relationship was established between assimilation rate and leaf water potential (n = 36, r = 0.66, P d" 0.001). Reduced leaf water potential (Y_L) had pronounced effect on assimilation rate. The Y_L values decreased on 10th and 15th day of withholding irrigation in all the clones. It was observed that the degree of reduction in Y_L was lower in RRIM 600 compared to other clones. During water stress period *gs* started to decline and remained lower than the control plants throughout the experiment. A strong relationship existed between leaf water potential (Y_L) and *gs* (n = 36, r = 0.61, P d" 0.001).

Reduction in *gs* was more pronounced than *A* with increasing water stress. An estimate of intrinsic water use efficiency was obtained from *A/gs* ratio. The initial responses to declining leaf water content were reduced stomatal conductance (*gs*) and low transpirational water loss. Drought tolerant clones that maintained better leaf water potential followed by better carboxylation rate during water deficit condition. Although there was a significant reduction in *A* (46%) and *gs* (75%) in RRIM 600, it was lesser than other clones. Among the RRII 400 series clones maximum reduction (100% for both *A & gs*) was observed in RRII 414 and hence the most drought susceptible. The check clone RRIM 600, a known drought tolerant clone maintained a stable rate of *A* but considerable decline in *gs* resulting in an increase in intrinsic water use efficiency with limited water availability. The increase in intrinsic water use efficiency (*A/gs*) could be due to an efficient assimilation of CO_2 by the mesophyll under water stress. In spite of low gs, the efficient CO_2 utilization indicates the well functioning of mesophyll metabolism. In earlier studies the role of mesophyll has been well established in regulating net photosynthesis in *Hevea*. Among the RRII 400 series clones, RRII 430 was shown to have better intrinsic WUE in terms of better *A/gs*. The clones RRIM 600 and RRII 430 recorded relatively high CO_2 assimilation per unit *gs a*nd they were able to withstand water stress for a relatively longer period of time. This study concludes that RRIM 600 and RRII 430 are physiologically better adapted to drought conditions. Screening of clones for better WUE is an important tool to identify clones with intrinsic drought tolerance potential which may become increasingly relevant in a future climate when water becomes highly scarce.

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30. POTASSIUM AND SILICON HELP YOUNG RUBBER PLANTS TIDE OVER TRANSIENT DROUGHT

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Variations in annual monsoon pattern and increasing frequency of occurrence of dry spells adversely affect early establishment and initial growth of rubber plants even in traditional rubber growing regions. Scarcity of irrigation water and agricultural laborers limit the large-scale adoption of irrigation in young rubber plantations, even if one were to go for life saving irrigation for young plants.

Status of mineral nutrients in plants plays a critical role in increasing plant resistance to drought stress (Marschner, 1995). It is known that potassium has a specific role in alleviating the adverse effects of soil water stress, by decreasing the loss of water from leaves by reducing transpiration and increasing the retention of water in the plant (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). 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 also plays an important role in enhancing tolerance of plants to environmental stresses like drought and cold. Silicon improved water use efficiency and maintained high rates of photosynthesis under water stress (Ma, J.F, 2004).

To study the effect of silicon and potassium application on drought tolerance of young rubber plants, a glass house experiment was conducted with polybag plants of clone RRII 105. The soil used for filling the polybags had the following characteristics : pH-8.6, organic carbon (%)-1.02, available P- 0.5 mg/100g and available K- 4.5mg/100g. The experiment consisted of two main treatments, viz, irrigated and un-irrigated. Under each main treatment, there were four sub-treatments viz, control (standard practice), silicon (Si), potassium (K), Si+K. Silicon, @ 1g /kg soil was supplied as rice husk ash containing 47 per cent Si. In treatments of potassium, 2.5 times the recommended dose of K was added so that N:K = 1:1, and applied as muriate of potash. The treatments were imposed 15 days prior to withdrawing irrigation. There were 40 plants under each treatment, out of which 20 were kept un-irrigated, while the rest were irrigated on alternate days. Chlorophyll content was measured after 10, 20 and 30 days of withdrawing irrigation using a chlorophyll content meter (CCM 200, Opti-science, USA). Leaf water potential was recorded after 10 and 20 days with a Psypro water potential meter (Wescor Inc.) Leaf area was recorded 20 days after withdrawing irrigation using a LiCOR leaf area meter. After 35 days of withholding irrigation, plant girth was recorded. Plants were uprooted and dry weight of root and stem were recorded, and sub-samples were analyzed for nutrient status. The data was subjected to analysis by two factor CRD.

Chlorophyll content index (CCI) recorded 10, 20 and 30 days after imposing water stress showed significant reduction in stressed plants compared to irrigated plants. Among un-irrigated treatments, CCI was significantly higher for treatments of Si, K and Si+K compared to stressed control. After imposing water stress for 30 days, there was 54 per cent reduction in CCI in the stressed control compared to the irrigated control. This reduction in CCI compared to irrigated control was only 25 per centfor K, 34 per cent for Si and 33 per cent for Si+K treated plants, indicating a positive effect of potassium and silicon in retaining chlorophyll under moisture stress condition.

Leaf water potential (-MPa) recorded after 10 and 20 days of imposing water stress showed a significant decrease in un-irrigated plants compared to irrigated plants. LWP recorded after 10 days did not show significant difference among sub-treatments. After 20 days, among the un-irrigated treatments, significantly higher LWP was observed for Si, K and Si+K treated plants compared to control. LWP data indicate that application of K and Si is helpful in maintaining a better plant water status under soil moisture stress condition.

Significant decrease in plant diameter was observed in plants subjected to water stress for 35 days. Leaf area recorded after 20 days showed a significant reduction in un-irrigated plants, compared to irrigated plants. Among the un-irrigated treatments, leaf K content was significantly higher in K supplemented plants.

After imposing water stress for 35 days, all the plants were irrigated uniformly, and it was observed that K supplemented plants recouped at a faster rate and showed better survival percentage.

Results of this study show that supplementing silicon and potassium help the plants to retain chlorophyll content and to maintain leaf water potential under moisture stress regime. 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. Similar experiments have to be conducted in the main field to further ascertain the beneficial effect of potassium and silicon in drought prone areas.

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31. MOLECULAR BASIS OF TOLERANCE TO DROUGHT STRESS IN *HEVEA* AND ITS RELEVANCE TO CLIMATE CHANGE

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Cultivation of *Hevea brasiliensis* is being extended to regions where drought and warmer temperature limit its growth and productivity. This warrants identification of drought tolerant clones for such regions. Recent reports indicated an increase in the number of hot days and warm nights per year in the recent past. A shift in the pattern of rainfall also has been noticed. Under this scenario, it is likely that the summer season would be getting warmer every year and it is necessary to identify clones/genotypes that can survive severe drought conditions. Hence, attempts were made to identify the molecular basis of drought tolerance in *Hevea* with special reference to genes/regulatory factors that can be used for the selection of genotypes suitable for drought prone and warmer regions.

Initially, attempts were made to identify drought responsive genes from *Hevea* using differential display reverse transcript PCR (DDRT-PCR). For this purpose, cDNA from one year old polybag grown plants of RRII 105 (drought sensitive) and RRIM 600 (relatively drought tolerant) experiencing drought stress for four weeks were subjected to DD-RT PCR analyses using 24 primer combinations. A total of 77 (44 up and 33 down) and 109 (76 up and 33 down) transcripts were identified as differentially expressed transcripts from clones RRII 105 and RRIM 600, respectively. Thirty nine drought responsive transcripts were common to both the clones. When a total of 111 differentially expressed bands were gel eluted, cloned and sequenced, 37 transcripts showed significant homology with reported genes and 74 transcripts were novel or specific to *Hevea*. NAC transcription factor, Ferredoxin III, uvr ABC system protein A, zinc finger protein, yrdc family protein, general secretary pathway protein, cation channel family protein, peroxisomal biogenesis factor 3-1, peroxin 3 family proteins, etc. were some of the known drought responsive transcripts identified from this study.

To identify the candidate genes for drought tolerance in *Hevea*, a cDNA array comprising of 84 gene transcripts was prepared with drought and non-drought responsive transcripts obtained through DDRT-PCR analyses. The cDNA probes made from three *Hevea* clones with varying levels of drought response viz. Dap 35 and RRII 208 (relatively drought tolerant) and RRII 105 (relatively drought sensitive) were allowed to hybridize on these arrays. The results after analysis indicated the de-regulation of gene transcripts related to transcription factors, psaA-psbB fragment as well as hypothetical proteins.

Out of the 84 gene transcripts spotted in the array, two genes were up regulated and five genes were down regulated in the drought susceptible clone RRII 105. In the case of drought tolerant clone Dap 35, two genes were up regulated and six genes were down regulated. In clone RRII 208 (relatively drought tolerant), two genes were up regulated and only one gene was down regulated. The gene transcripts HbDRT 50, HbNRG 6 and HbNRG 7 were specifically repressed in drought sensitive clone, whereas HbDRT 73 and HbTPD 29 were induced. In contrast, HbNRG 33 was down regulated only in both the drought tolerant *Hevea* clones, where HbNRG 18 showed a tendency of enhanced transcription. Results of this study demonstrated the existence of differential gene responses under drought stress among various *Hevea* clones that exhibited varying levels of drought sensitivity. From this study, a few genes like HbNRG 18, HbNRG 21, HbDRT 5b and HbDRT 50 were identified to be associated with drought tolerance.

To further validate the above results, an attempt was made to quantify the expression of these genes by quantitative PCR (qPCR). One year old polybag plants of clones RRII 105 (susceptible), RRIM 600 (tolerant) and RRII 208 (tolerant) were raised in RRS, Dapchari. They were subjected to drought for fifteen days in ambient condition during the summer period of 2009. After confirming the magnitude of stress effect by measuring gas exchange parameters in these plants, leaf samples were collected. cDNA prepared from these samples were used for the quantitative expression study. GAPDH gene was used as endogenous control for normalization and quantitative expression of each gene had been analyzed with reference to irrigated plants of RRII 105. The quantitative expression analysis indicated up-regulation of HbNRG 18 and HbDRT 5b in both irrigated and drought imposed samples of RRIM 600 and RRII 208. This confirms the association of HbDRT 5b and HbNRG 18 with drought tolerance as both RRIM 600 and RRII 208 are drought tolerant clones.

Our preliminary attempt with DD-RT PCR method yielded 145 transcripts as differentially expressed under drought conditions. Further, when spotted on microarray and analyzed with various stress treated cDNA samples, we could narrow down to four genes such as HbNRG 18, HbNRG 21, HbDRT 5b and HbDRT 50 as most closely associated with drought tolerance. Attempts were further made to validate their association with drought by quantitative PCR. The results showed strong association of genes such as HbDRT 5b and HbNRG 18 with drought tolerance as evidenced by its up-regulation only in drought tolerant clones (RRIM 600 and RRII 208) while their expression level was smaller in the drought susceptible clone (RRII 105). Having narrowed down to HbDRT 5b and HbNRG 18, it is imperative to extend validation of these genes using various field proven clones and to link the expression of these genes with drought tolerance. If further proven, these two genes can be employed for screening of germplasm lines or could be used as potential marker gene for drought tolerance. This approach deserves special attention in the light of rise in atmospheric temperature as well as drought as a result of climate change and associated problems.

32. GOOD AGRICULTURAL PRACTICES FOR NON-TRADITIONAL NATURAL RUBBER GROWING AREAS EXPERIENCING EXTREME AGRO CLIMATIC CONDITIONS

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The term Good Agricultural Practices (GAP) can refer to any collection of specific methods which when practiced in the field will help to promote sustainable agriculture. GAP related to soil include maintaining or improving soil organic matter through soil carbon buildup by appropriate crop rotation, manure application and land use practices like conservation tillage and maintenance of soil cover to minimize erosion losses by wind or water. GAP related to water includes those that maximize water infiltration and minimize unproductive efflux of surface water from water sheds and managing ground and soil water by proper use, adopting techniques to monitor crop and soil water status and accurately scheduling irrigation.

The North Eastern region of India which is outside the traditional rubber growing region has been identified as potential area where rubber can be grown successfully. In this region the unique agro-climatic condition like low minimum temperature during cold season (up to 5°C) makes winter stress a problem for the rubber plants. A combination of low temperature and high sunlight occurs during winter which affects photosynthesis and thereby growth of young rubber plants.

Studies have shown that low temperature reduces photosynthesis and the high light intensity prevailing during winter is harmful as it causes photoinhibition. Harmful photoinhibition effects could be reduced by decreasing the light intensity by partial shading of young plants during winter.

Rubber seedlings in North East experience low temperature stress during its early growth period. The growth of the plants slows down as winter approaches. Any strategy that enables new growth in nursery plants during winter is useful to produce maximum number of seedlings for budding within a short span of time. Sprouting percentage of budded stumps kept inside poly house and outside the poly house in open air during winter season (November to February period) was studied. It was observed that sprouting percentage inside the poly house during the winter months ranged from 50 – 70 per cent whereas in the control plants kept outside the polyhouse it was 6-20 per cent. In poly house the air temperature was about 10°C higher than outside which led to the higher percentage of sprouting during winter season.

Mulching the seedling nursery could enhance the mean soil temperature by 1.9°C than the control during winter. Seedlings under mulching (FYM + paddy straw) with polythene overhead recorded better growth. The same treatment (FYM + paddy straw) in one year old plants showed a significant girth increment over control plants grown in the open.

The North Konkan region of Western India (5° – 20° North) also comes under the non- traditional area. In this region prolonged and severe soil moisture deficit and high summer temperature are the major environmental constraints affecting growth and productivity of rubber. Dry period extends from November to middle of June. During April and May the maximum temperature is higher than 36°C and about 14 per cent growth depression was observed in various clones during this period. Water deficit during the summer month in the north Konkan region was estimated to be around 1070 mm while it was around 350 mm in traditional belt of Kerala.

Irrigation along with shading improves growth of rubber seedlings in the nursery. Irrigation twice in a week is effective for the poly bag plants. Contact shading of polybag plants using China clay spray (10%) can effectively replace conventional shading with coconut leaf basket and this is three times cost effective. Wherever irrigation facility is available, basin irrigation @ 0.5 ETc at earlier stage contributed substantially to better growth. Drip irrigation @ 0.5 ETc is better than basin irrigation. Reducing the irrigation level in mature trees did not show any adverse effect in growth and yield provided in the soil was deep. Expected maturity period was achieved in seven years by providing adequate irrigation whereas it took 10-11 years without irrigation. The commercial production (t/ha/year) with irrigation was 1.5 whereas without irrigation it was 1 t/ha/year.

Soil moisture retention at 30-60 cm depth and growth during post monsoon period was enhanced by digging silt pits @ 150 pits per ha. 10 kg saw dust should be added in every pit to hold water. To arrest the evaporation of stored soil moisture the tree basins should be covered with heavy organic mulch (4 t /ha).

Hence, to tackle the suboptimal and stressful conditions prevailing in non-traditional regions like North East India and North Konkan, rubber cultivation in those region demands for specialized good agricultural practice for its better performance and sustainability.

33. STUDIES ON DROUGHT TOLERANCE OF CERTAIN MODERN CLONES IN NORTH KONKAN REGION OF MAHARASHTRA

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In India, rubber is traditionally cultivated in the zone between 8°15' N and 12°52' N latitudes covering the states of Tamil Nadu, Kerala and Karnataka. Most of the area lies towards the west of Western Ghats, where the total rainfall, its distribution and ambient temperatures are suitable for the crop. In view of the limited scope for the expansion of area in the traditional zone, cultivation of the crop was extended to less congenial but potential areas. The North Konkan region along the western coastline of India is one of the potential areas for rubber cultivation. This region experiences severe moisture deficit coupled with very high temperatures, high intensity of solar radiation and low atmospheric humidity for about five to six months every year. Though the Konkan region receives about 2500 mm of annual rainfall from south west monsoon (June to October), the evaporation rate from November to May is in the order of 4 to 9 mm per day. These are the major climatic constraints which inhibit growth and productivity of rubber plantation in North Konkan region. However, these can be overcome by identifying suitable clones and following appropriate agromanagement practices. Recent observations in traditional and non-traditional areas indicated that yield of certain popular clones is in a declining trend. More over many clones do not cope with adverse climatic conditions in the non-traditional regions.

Very limited information is available on the extent of moisture deficit that can be tolerated by the modern clones. The present study was conducted at Regional Research Station (RRS), Dapchari that lies at 20.04° N latitude and 72.04 ° E longitude at an altitude of 48 m above MSL. Polybag plants of three modern clones belonging to RRII 400 series and a few existing clones of RRS, Dapchari were subjected to drought stress by withholding irrigation under open sun light condition. Plants with uniform height belonging to clones such as RRII 208, RRII 414, RRII 429, RRII 430, RRIM 600 and RRII 105 (n=10) were selected for the study. The maximum temperature during the study period (summer months) ranged between 35.5 to 43.0°C. The symptoms of drought *viz.,* leaf yellowing, chlorophyll bleaching, drying, leaf fall and leaf fall pattern were observed at different intervals (twice in a week). The result revealed that RRII 429 was more prone to drought as indicated by early chlorophyll bleaching due to drought. It showed chlorophyll bleaching symptoms earlier than the other clones viz., RRII 430 and RRIM 600. Leaf yellowing was first noticed in RRII 429 followed by RRII 430. On 15th day of withholding irrigation the RRII 400 series clones recorded 5-10 per cent leaf yellowing. RRIM 600 recorded the least percentage of yellowing compared to the other susceptible clones. The clonal variation to drought was due to maintenance of better leaf water potential and higher stomatal conductance in tolerant clones.

Drying of plants due to drought was also recorded in polybag plants. Among the different clones studied, severe drying was noticed in clone RRII 208 (80%) and RRII 429 (70%) on 26th day of drought. Maximum leaf fall was noticed in RRII 208 (50%) followed by RRII 429 (50%). Leaf fall pattern also was recorded during the study period. In RRII 429 and RRII 105 leaf fall started from top whorl to bottom but in RRII 414 it was from bottom to top.

Similar observations and scoring were made in main field for the same clones. In the field RRII 414 was found to be more susceptible to drought than the other clones. Clones such as RRIM 600 and RRII 430 showed the least yellowing and chlorophyll bleaching in the field. While RRIM 600 and RRII 430 were found to be drought tolerant in the field, RRIM 600 was the only clone tolerant to drought in polybag stage. Life saving irrigation may become an essential farm practice for the survival of modern clones in nursery as well as in the field in a sub humid climatic zone like the North Konkan.

34. ADAPTABILITY OF POPULAR *HEVEA* CLONES AND WILD GERMPLASM TO THE DROUGHT PRONE REGION OF CENTRAL EASTERN INDIA

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Natural rubber, with its center of origin in the Amazon rain forests of Brazil, is a strategic industrial crop cultivated mainly in the southeast Asian countries. To broaden the narrow genetic base of cultivated rubber in this region, a huge collection of wild germplasm was made from three states in Brazil viz., Acre (AC), Rondonia (RO) and Mato Grosso (MT) by IRRDB in 1981, and distributed to member countries including India. Around 4500 accessions are now being conserved in nurseries in India, and are under different stages of evaluation. Preliminary nursery studies in some of these accessions showed indications of promising growth and other secondary traits such as drought, cold, disease resistance etc. which can be used in crop improvement programmes after confirmation of their potential, for which these selected accessions are subjected to further detailed field evaluation.

In the present study, a set of 30 potential wild accessions and six modern clones viz., RRII 105, RRII 118, RRII 208, PB 260, GT 1 and Gl 1 were evaluated in detail in a replicated trial planted in 1996 in the non-traditional rubber growing region of Chhattisgarh state, India. The design adopted was simple lattice with two replications at the standard spacing of 4.9 m x 4.9 m and plot size of 10. The trial was located on plain land with uniform stand and soil status at Regional Research Sation at Sukma (19^0 5'N, 82^0 02'E, 202 m MSL). The soil was acidic in nature (pH 5.3) and low in organic carbon content (0.53%). The soil exhibited considerable shrinkage and cracking on drying. The region received a total annual rainfall of 1530 mm maximum in four months (June-September) with only 65 rainy days and more than seven months was dry period. In summer months, ambient temperature during day time crossed 38^0 C.

Girth was recorded annually from the 4^{th} year onwards. A study was carried out in the eighth year of growth and measurements including traits such as girth, branching height, bark thickness and number of laticifer rows (NLVR) were recorded. Yield was recorded (½ S d2) for a period of two months from November-December (peak season) and again from February-March (summer season) in the 10^{th} year of growth, and the average yield of two seasons estimated, the results were published elsewhere (Rao *et. al.*, 2006). Performance of these genotypes in terms of girth (9^{th} - 13^{th} year), girth increment (GI) per year over five years, bole volume, NLVR and yield (peak, summer, average of two seasons) are presented here.

Highly significant clonal variability was observed for all the characters studied. In the ninth year after planting, among the six modern clones, RRII 208 had the highest girth (60.75 cm) followed by RRII 118 (56.78 cm), while RRII 105 had a girth of 51.11 cm. Among the thirty wild accessions RO 5430 (58.67 cm) and RO 2635 (58.55 cm) recorded the highest values and were on par with the popular clone RRII 208. In the 13^{th} year of growth, AC 619 (79.33 cm) followed by RO 5554 (78.60 cm), RO 5430 (77.84 cm) and RO 2635 (75.71 cm) had the highest girth, while the popular clone PB 260 had a girth of 80.46 cm followed by RRII 208 (77.82 cm). Highest mean girth increment per year over five years was recorded in AC 619 (7.01 cm) followed by AC 685 (6.94 cm), RO 5463 (6.44 cm) and AC 763 (6.27 cm) while the popular clones recorded 6.73 cm (PB 260) and 6.04 cm (Gl 1) respectively.

Highest bole volume was observed in RO 5430 (0.133 m^3), RO 5554 (0.118 m^3), MT 44 (0.112 m^3), AC 619 (0.111 m^3) and MT 196 (0.109 m^3) while the modern clones showed a range of 0.089 m^3 (RRII 105) to 0.117 m^3 (PB 260).

Number of laticefer rows ranged from 5.88 (RO 5554) to 13.30 (RRII 208) and highest NLVR were recorded in the modern clones RRII 208 (13.30), RRII 105 (11.40) and PB 260 (9.83). Among the wild accessions, highest number was recorded in MT 2229 (11.20), MT 2594 (10.12), RO 2629 (10.03) and RO 5408 (9.96) respectively.

Peak season yield was the highest in RRII 208 (31.90 g/t/t) followed by RRII 118 (29.16 g/t/t). The wild accession RO 5363 (20.79 g/t/t) was on par with RRII 105 (19.58 g/t/t). The remaining clones GT 1, PB 260 and Gl 1 recorded yield ranging from 19.42 g/t/t to 14.62 g/t/t. RO 5430 and MT 196 recorded relatively high yield among the remaining wild accessions (11.86 g/t/t and 10.08 g/t/t respectively). In the second round of summer season tapping (February-March) in the 10th year of growth, RRII 118 (26.56g/t/t) followed by RRII 208 (20.19 g/t/t) recorded the highest yield. Again the wild accession RO 5363 (10.85 g/t/t) was on par with RRII 105 (8.41 g/t/t). Correlations between the yield in the two seasons, with girth in the respective years, girth increment during this period and NLVR were worked out and found to be significant.

Based on this study, the wild accessions RO 5363 and RO 5430 were found to be superior for yield and growth in the drought stress region. These clones are also superior in the cold prone area of North East India and may be very stable. Since it comes from genetically diverse wild source, transgressive segregation and heterosis can be expected on crossing these accessions with elite Wickham cultivars, which could be of use in future crop improvement programmes, particularly for stress prone regions.

35. JUVENILE GROWTH RESPONSE OF SELECTED WILD AMAZONIAN ACCESSIONS AND HYBRID *HEVEA* CLONES OF WICKHAM ORIGIN IN A DROUGHT STRESSED ENVIRONMENT

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Present day rubber cultivation faces various climatic constraints even in traditional areas and these constraints are expected to become more serious in future. Soil and atmospheric drought and high temperature are major environmental factors limiting growth and yield in *Hevea* necessitating the development of drought tolerant clones suitable for such areas. A wide genetic variability within the base material is the primary requirement in breeding programmes aimed at selection for any specific trait. The narrow genetic base of the cultivated *Hevea* species developed from a minuscule of a genetic stock (Wickham base) and the unidirectional selection for yield over the years further narrowed down the genetic base. The wild *Hevea* germplasm collected through the IRRDB expedition in 1981 from the primary center of origin of the crop is a likely reservoir of genes conferring tolerance to various biotic and abiotic stresses. By conducting systematic screening using various drought related parameters, potential wild Amazonian accessions with drought tolerance can be identified at an early stage. These selected accessions when used for a detailed field study for yield potential under drought stress environment could lead to the development of drought tolerant clones. Evaluation of hybrid clones, resultant of gene introgression from popular parent clones from the Wikham base enhances the scope for selection which would contribute to development of clones for stressful environments.

With this objective, during the year 2007, a field evaluation of 33 *Hevea* clones comprising Amazonian accessions and Wickham clones was initiated at Regional Research Station (RRS), Dapchari located in the North Konkan region of Maharashtra state in India. The experimental material comprised 22 wild accessions, five hybrid and six check clones. The clones were planted in a Rectangular Lattice Design with a plot size of four plants in three replications at a spacing of 4.9 m. x 4.9 m. This Station is located in a drought prone region experiencing high temperature (exceeding 40° C in April- May), high light intensity and very low soil moisture during the summer months with a rainfall pattern confined mainly to four months in a year, the average annual rain fall being 7.5 mm per day with an average of 90 rainy days in a year. The check clones in the experiment were RRII 105, RRII 430, RRII 414, RRII 208, RRIM 600 and Tjir 1. Growth parameters such as plant height after 18 months of planting, girth at 30 cm. height from collar region at every six months interval and number of leaves six months after planting were recorded and annual and summer girth increment were worked out. The period from first week of February to last week of May was considered as the summer period. Based on the growth data, the growth response of wild Amazonian clones and hybrid Wickham clones were assessed and was compared with that of the check clones. Leaf yellowing and leaf drying were also used as criteria to assess drought susceptibility.

At the end of two and half years, the wild accession MT 4788 recorded the highest girth and it showed consistent performance throughout the period under observation. The foliage production at the age of six months was also highest in this accession. After experiencing the two summer periods of 2008 and 2009, four wild accessions out of 23 and one among the hybrid clones recorded higher girth than the proven drought tolerant clones RRIM 600 and RRII 208. Among the five hybrid clones, 93/53, 93/270 and 93/105 were superior to the check clones for annual girth increment and one of which clone 93/270 was superior in girth in the third year after planting. Girth increment in summer was high in accessions MT 67, MT 1619, RO 1769 and MT 1627. Visual scoring on leaf yellowing at weekly intervals was done during the summer of 2009. There was differential response among the clones for these two characters which ranged from 0- 10 per cent for leaf yellowing and 3 – 23 per cent for leaf drying in the year 2009.

The growth performance of the clones RRII 430 and RRII 414 was assessed for the first time under Dapchari conditions and it was found that the annual girth increment in these two clones was higher than the rest of the four check clones with RRII 430 being superior in terms of absolute girth in the third year after planting. Clone RRII 430 also showed higher annual girth increment whereas the clone RRII 414 showed a higher summer period girth increment than RRII 430, but while assessing the overall growth response, clone RRII 430 appeared more suitable than RRII 414 in the drought prone area. Compared to RRII 414, leaf yellowing was less in clone RRII 430 indicating the better suitability of RRII 430 for establishment in a drought prone region.

36. STUDIES ON CLIMATIC FACTORS INFLUENCING YIELD IN CERTAIN CLONES OF *HEVEA BRASILIENSIS*

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Hevea brasiliensis Muell. Arg. is the most important source of natural rubber (NR). Rubber yield in para rubber tree is a quantitative trait, thereby climate dependency is well pronounced. Important agronomic characters such as growth, yield, disease susceptibility, wintering etc. are directly related with climatic factors. Breeding of improved clonal cultivars revolutionized rubber production; however, development of clones suited for a range of climates is very important in the era of climate change and clones with wide adaptability are highly preferred to extend rubber cultivation to areas in North-East India and other non-traditional areas. Studies relating rubber yield of clone and climate are rare, only few attempts have so far been conducted to study the implications of weather parameters on yield of NR (Rao *et al.,* 1998; Raj *et al.,* 2005). The present study reports the relationship of long term yield (g/t/t) with corresponding climatic factors such as minimum temperature, maximum temperature, mean temperature, sun shine hours, rain fall and relative humidity.

The study was performed at the Central Experiment Station of Rubber Research Institute of India at Chethackal, Kerala State, South India (Latitude 9 °22' N, Longitude 76 °5' E; altitude 100m). The study materials consisted of seven clones (RRII 105, RRII 118, RRII 203, RRII 208, GT 1, Gl 1 and RRIM 600) planted in a large scale trial. These clones are from diverse origin as they belong to different genetic background. Trial plantation was raised from six month-old two-whorl, brown-budded plants and field planted in July 1984 in a randomized block design. Plot size was 25 trees at a spacing of 4.9 m x 4.9 m. The field had slightly undulating topography. Recommended crop management practices were adopted throughout the experiment.

All trees were opened for tapping in 1991 (in the seventh year after planting). The tapping system followed was S/2 d3 6d/7. Dry rubber yield was measured in grams per tree per tapping (g/t/t) by coagulating the latex in collection cups. Dry rubber yield of 24 samples per tree per year (fortnightly interval) was recorded and the dry weight was determined. ANOVA and DMRT were carried out to determine the clone-wise differences in yield and to classify the clones based on yield. Clone-wise yield from 1993 to 2003 was analyzed with corresponding mean monthly meteorological parameters, which were collected in the same spot about 100 m away from the experimental trial in Chethackal. Climatic parameters considered were minimum temperature (T_{min}), maximum temperature (T_{max}), sunshine hours (s), rainfall (R) and relative humidity (Rh1: Morning and Rh 2: afternoon). The analysis was carried out by considering yield as the dependent variable and the meteorological parameters as independent variables. Stepwise regression was carried out (using SPPS 10.0 software) for yield of all the clones and final regression equations were computed.

Results were discussed on the basis of regression equations obtained and clone-wise yield stability with time. Grouping clearly indicated distinction of RRII 105 with respect to very high yield (68.0 g/t/t), compared to Gl 1 (40.5 g/t/t) and RRIM 600 (43.8 g/t/t) which registered low yield. The stepwise regression of yield showed that, among the climatic parameters considered, maximum temperature was most important in determining the dry rubber yield. In the case of RRII 208 and GT 1 the Rh 1 and Rh 2 also were the determining factors of yield. It appears that all other factors including rain fall do not have any direct role in determining the yield of clones. Seasonal yield stability of clones over the 11 years was plotted and yield of individual clones was analyzed using mean values.

From the results of the analysis considering relationship between yield and T_{max}, significant R^2 values indicate trends of yield with temperature. Relationship was found to be strong as the slopes of the clones ranged from -7.299 to -3.353, which showed negative relationship of T_{max} with yield. T_{max} over the period imparted less monthly variability compared to Rh in the corresponding period. Rh was seen to be low during the winter and pre-monsoon seasons in Chethackal. During the study period, it has been observed that even with clones having stability over the years, T_{max} was found to be a function of yield (R^2= 0.21) i.e., 21 per cent of the variation in the yield can be explained by T_{max} fluctuations. Most of the clones showed an increase with time mainly during the monsoon season. The slopes varied from 4.94 to 2.55 per year. The R^2 ranged from 0.30 (RRII 105) to 0.76 (RRII 203) during the monsoon season. The clone RRII 208 did not show any increase in yield during the study period, while RRIM 600 showed a varied response of yield with time over different season. Highest increase in annual yield was shown by GT 1 (R^2= 0.51). The lowest increase was found to be in RRIM 600 (1.87 g/t/t per year).

The study indicated the moderate level of decrease in yield with increasing T_{max}. However, in the context of the rising temperature in the long term climate change scenario, the yield decline will have to be further evaluated on a large scale. From the trend analysis of the T_{max} in Chethackal farm from 1992 to 2009, T_{max} showed an increasing trend during winter and monsoon season.

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37. INVESTIGATION OF TAPPING PANEL DRYNESS ON RUBBER CLONES IN RELATION TO LATEX PHYSIOLOGICAL PARAMETERS

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An investigation of tapping panel dryness (TPD) was conducted on four large-scale clonal trials including a total of ten rubber clones. Dryness incidence, yield per tree and latex physiological parameters were recorded over four consecutive tapping years on panel BO-1. RRIV 2, RRIC 121, RRIC 100 and GT 1 showed lower percentage of total dry tree than the other clones. On the other hand, RRIV 4, PB 260, PB 235 and RRIV 5 showed higher percentage of total dry tree. Percentage of dry tree at the end of dry season in June was highest then it was lower in September and the lowest percentage was recorded in December when concided with the peak yield. This variation of TPD was accounted for the reversible case which resulted from seasonal effect.

Based on the recorded data, ten trees of each class of TPD from three clones were selected for determining tree-by-tree latex physiological parameters in order to screen the onset of dryness. The results showed that low content of thiols and inorganic phsophorus might be the first indicator of dryness.

38. CLIMATE CHANGE AND CO_2 ASSIMILATION IN RUBBER TREE: AN ECOPHYSIOLOGICAL APPRAISAL

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Photosynthetic response of rubber tree is a reliable index for quantifying any change in its optimal growth environment. It has been well established that despite very narrow genetic base of rubber tree, remarkable variability in photosynthetic traits does exist. Appreciable and notable changes in the photosynthetic rates at varying environmental factors have been reported. The effects of environmental factors which ranged from optimum humid plain in Kottayam, dry hot sub-humid climate in Dapchari in the Konkan coast and cold climate in high altitude of about 1700 m MSL in Mattupetty on photosynthesis were tested. As in the case of extremely hot and dry environment of Dapchari, there was remarkable reduction in photosynthetic CO_2 assimilation rate (P_N) in all the different clones studied. However, the magnitude of reduction in P_N in few clones namely RRIM 600 and the clones selected from polyclonal field trial in Dapchari namely DAP-34 was less. Similarly, it was also noted that the clone RRIM 600 also sustained comparatively better P_N in cold climate. This is a clear indication of climate resilience of the clone RRIM 600. There must be some unique traits in this clone which could be made use to develop strategies for further crop improvement for growing rubber in stressful environments. It has also been observed that the clone RRIM 600 maintained relatively better stomatal conductance (Gs), even in dry climate which is noteworthy. In this direction, it has been observed that Gs of rubber clones is unambiguously moderated by the diverse agroclimatic situations. Low temperature at a high altitude of 1700 m MSL in the Western Ghats of Kerala had comparatively more drastic effects than the dry hot summer of Dapchari. This fact was clearly understood when the Gs of rubber clones from the diverse agroclimatic situations was compared.

39. SEASONAL VARIATION IN CO_2 EXCHANGE AND ENERGY FLUXES IN *CENCHRUS CILIARIS* L. GRASSLAND ECOSYSTEM IN SEMI-ARID REGION

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Cenchrus ciliaris L. (Buffel grass) also known as Anjan grass is one of the most important forage crops of India and other tropical and semi-tropical regions of the world due to its low water demand, high nutrition content and ability to recover from grazing. Grasslands in semi-arid regions of the southern part of India experience hot and dry summer which adversely affects the physiology of the plants. The semi-arid tropics are likely to undergo changes in future due to the critical environmental conditions of changing temperature and precipitation pattern. Since arid and semi-arid ecosystems occupy two fifths of the earth's terrestrial surface, an understanding of the temporal variations in ecosystem CO_2 exchange in these regions will give better insight on the estimation of global carbon budgets. The Eddy Covariance (EC) technique is a micro-meteorological technique which is commonly used for non-destructive and direct measurement of CO_2, water vapor and energy exchange between the atmosphere and terrestrial ecosystems in diurnal, seasonal, inter-annual and decadal time scales, and to elucidate physical and biological controlling factors; and in estimation of energy budget and net carbon gain or loss by ecosystems such as forests, grasslands and crop lands.

EC measurement on *Cenchrus ciliaris* grassland ecosystem was conducted during July, 2008 to June, 2009. The daily *NEE* and soil moisture content showed similar seasonal variations. The early part of July showed positive *NEE* which indicated that CO_2 was released by the grassland ecosystem. Ecosystem CO_2 uptake was observed soon after the rainfall during late July that indicated the starting of the growing season which lasted till the mid of January. The high CO_2 uptake during September to December corresponded with the rainy season during which high soil moisture content was observed. Maximum average CO_2 uptake of 18.73 $g/m^2/d$ was observed in November. Soil moisture content showed a minimum of 0.022 m^3/m^3 in July and maximum value of 0.275 m^3/m^{-3} in October. The gradual decrease in soil moisture from late December corresponded with the gradual decrease in CO_2 uptake and eventually the release of CO_2 by the ecosystem. Positive *NEE* from late January to June, except few days after summer rains in April and May, indicated that the ecosystem was a source of CO_2 in the dry season during which soil moisture was below 0.08 m^3m^{-3}. Positive pulses in the *NEE* were observed in the first rainfall events (evident from the soil moisture content) after prolonged drought. The pulse or sharp increased in

CO_2 release occurred was caused by the rewetting of soil and dropped down to stable value after one or two days. The light summer rains during March and May caused pulses in CO_2 bursts. Short duration of CO_2 uptake was observed after the rewetting during April and May.

The variation in diurnal *NEE* was strongly regulated by seasonal changes during the study period. During the wet season although there was high nocturnal CO_2 efflux from the ecosystem, the daytime uptake of CO_2 was comparatively much higher; so the ecosystem was a net sink of CO_2. Maximum average uptake of 1.809 $g/m^2/30$ min was observed during December at 12:30 hrs. During the dry season from February to June, there was a significant reduction in daytime and nighttime CO_2 fluxes and in February, March and June, the average CO_2 fluxes were close to zero. In March, the ecosystem respiration rate exceeded the assimilation rate due to the drying up of the aerial parts of the plant.

Ecosystem respiration (*Reco*) showed similar pattern of seasonal variation with soil moisture. The *Reco* ranged from 0.0309 CO_2 mg $/m^2/s$ in July to 0.365 CO_2 $mg/m^2/s$ in October which was in correspond to the minimum soil moisture of 0.018 m^3/m^3 in July and maximum soil moisture of 0.324 m^3/m^3 in October. Unlike the pattern of CO_2 uptake where there was a lag between the maximum soil moisture content and the time of high CO_2 uptake, the maximum *Reco* occurred when the soil moisture content was maximum and decreased gradually with the gradual depletion of soil moisture. *Reco* and volumetric soil water content showed strong positive correlation of coefficient of determination, R^2=0.768. The energy balance closure derived from the regression between Latent Heat (LE) + Sensible Heat (H) and Net Radiation (Rn) – Soil Heat Flux (G) showed r^2=0.914. Soil heat flux (G) was comparatively higher during the dry season than the G in the wet season. This implies that lesser solar radiation reached the soil due to the dense leaf and shoot produced by the active growth in the wet season. In the dry season as the grassland remained dormant due to depletion of soil water content, the soil was more exposed to solar radiation with maximum G of 114.15 W/m^2 in February, 2009 which coincided with the maximum Rn of 694.23 W/m^2 in this month. This result, suggested that the water vapor flux in the wet season was mainly contributed by transpiration from plants where as in the dry season, evaporation from soil was more pronounced.

From this preliminary study, it is evident that grassland ecosystems in semi-arid tropics are highly sensitive to changes in environmental factors. The immediate response (in carbon uptake) to the increase in soil water content by rainfall and the high carbon uptake in the wet season proved that grasslands have high carbon sequestration capacity. The grassland being a carbon source during the dry season implies that grasslands in semi-arid regions are in a critical state under global climate change where prolonged drought has been predicted in arid and semi-arid regions.

40. RUBBER PLANTATION AS A POTENTIAL SINK FOR ATMOSPHERIC CARBON DIOXIDE: AN ECOSYSTEM FLUX APPROACH

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Tyres, whether they are made of natural or synthetic rubbers are indispensable to the automobile sector which emits 14 per cent of the global greenhouse gases. 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 and therefore results in emission of CO_2. Secondly, natural rubber plantations have the capacity to sequester significant quantities of CO_2 from the atmosphere.

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. Eddy covariance (EC) method is a more sophisticated micro-metereological method in which the fluxes of CO_2 and water vapour and the three-dimensional wind velocities are measured. Employing statistical tools, these primary data are used to calculate net ecosystem level fluxes of CO_2 and water vapour in real time. The present study describes ecosystem level net CO_2 sequestration rates (photosynthesis and respiration including litter decomposition) and evapotranspiration for a continuous one year period in a four year old rubber plantation.

The experimental site was situated at Central Experimental Station (CES) of Rubber Research Institute of India (RRII), Chethackal, Pathanamthitta District, Kerala. The observation site, an immature (four - five year old) plantation, with different *Hevea* clones namely, RRII 105, PB 260, RRII 430 and ten selected ortet clones (Konny and Mundakayam selections) was spread over more than five hectare area with 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. Carbon dioxide and water vapour fluxes of the plantation were continuously measured by Eddy covariance (EC) technique. The EC method of flux observation is a micro-meteorological technique which continuously measures the water vapour and CO_2 concentrations on real time basis. From the EC data the net ecosystem exchange (NEE) of CO_2 and water was calculated. The net CO_2 exchange obtained from the system is the difference between photosynthetic assimilation by the canopy and the total respiratory efflux from the foliage, roots and soil.

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 and temperature and relative humidity (RH) sensors. Other weather parameters namely rainfall, maximum and minimum temperatures, sunshine hours, etc. were collected from a nearby weather station. The EC equipments were commissioned in a flux tower of 18 m height and the sensors were fixed on the tower at 4 m above the canopy.

Raw data were collected and corrected by Edi Re software and processed into half-hourly values. The CO_2 flux (Fc) and the water vapour flux (LE) data were corrected for density effects. Daily diurnal NEE and day and night flux rates were also calculated. The latent heat of vapourization (LE) was converted in to evapo transpiration (ET) on per day basis. The rates of ecosystem photosynthesis, respiration and decomposition may 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. Attempts were also made to correlate the CO_2 flux values with prevailing environmental parameters.

The flux values were continuously measured throughout the year (April 2009 to March 2010). The daily pattern of CO_2 exchange showed positive and negative values. Positive values measured during the night indicated net efflux of CO_2 from the ecosystem to the atmosphere, i.e, net ecosystem respiration (Reco). The flux values during daytime were mostly negative indicating net CO_2 assimilation by the ecosystem, i.e, net photosynthesis. NEE increases (i.e, by default the values become more negative) when the photosynthetically active radiation increases in the morning. NEE decreases in late afternoon due to the lesser light intensity and stomatal closure.

The daily NEE by the rubber ecosystem ranged from 1-25g per m^2 per day during the study period. Most of the days recorded CO_2 influx in to the plantation; however, a few days (around 20 days) recorded net carbon efflux from the plantation to atmosphere. On those days, around 1-7g CO_2 per m^2 per day was released to atmosphere and during these days there was rain and relatively less sunshine hours. Heavy rainy days witnessed a net efflux of CO_2 to atmosphere, most probably, due to a low rate of canopy photosynthesis and possible sudden spurt in release of locked up CO_2 from the soil. Sunny days (when soil moisture level was not deficient) were more favourable for the influx of carbon to the ecosystem. On an average, the NEE was 11g $CO_2/m^2/day$ which is equivalent to 33.5 tons CO_2/ha/year. Relationship could not be established between canopy photosynthesis and sunshine hours except for a few months of the year. The ET values calculated from the latent heat of vapourization (LE) indicated a 3-4 mm net evaporative water loss from the rubber plantation per day.

The amount of carbon sequestered by the rubber trees was estimated during the same period by estimating the annual shoot biomass increment during this period. According to this method, the CO_2 sequestration was 13.5 ton CO_2 per ha per yr (which does not include root biomass, soil respiration, litter decomposition and sequestration by weeds and cover crops). Our studies showed that natural rubber plants are a good sink for atmospheric CO_2.

41. CARBON SEQUESTRATION POTENTIAL OF NEW CLONES OF NATURAL RUBBER (*HEVEA BRASILIENSIS*) IN INDIA.

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Land use systems differ in their ability to sequester carbon depending on the type of vegetation and management practices followed. Perennial tree crops have a greater carbon sequestration potential than annual crops since they function as carbon sinks for a longer period of time. Trees, like natural rubber (*Hevea brasiliensis)* can stock large amount of carbon in their standing biomass and the wood and latex used for diverse long term products constitute an additional carbon sink for decades. Sequestering atmospheric CO_2 through tree cultivation is an environmentally acceptable option and rubber plantations have more potential because they add lot of carbon to the soil stock through annual litter recycling also. The growth habit of the clone/variety cultivated will influence the capacity of the tree crop to accumulate carbon; those with vigorous growing habits having greater sequestration potential. Jacob (2003) estimated the carbon sequestration potential of the most popular clone RRII 105. Recently the Rubber Research Institute of India released new high yielding clones of *Hevea* (RRII 400 series clones) and the present study was taken up to determine the carbon sequestration potential of these clones.

The trees planted in a clone evaluation trial at Rubber Research Institute of India, Kottayam were used for the study. The clones selected were RRII 414, RRII 417, RRII 422, RRII 429, RRII 430 and RRII 105 The experiment area was under uniform manuring and other management practices. When the trees were 23 years old, 5 trees each of all the clones were uprooted. Carbon sequestration potential was determined from biomass accumulation by two different approaches i.e., conventional destructive methods of biomass quantification and the biomass calculation from the growth curve using allometric equation. For the conventional destructive method, fresh weight of each plant part *viz.*, trunk, branches, leaf and roots was determined using field balance and sub samples were collected and dried in the oven at 70 ^{o} c to determine the moisture content and dry weight of each plant part was estimated. Carbon content of plant parts were quantified based on the carbon content in each plant part (Jacob, 2003.) and from this the total carbon accumulation per tree was computed. The carbon sequestration potential of clones at the plantation level was estimated assuming 350 trees / ha. In the second approach, the biomass accumulation at different growth stages was estimated using allometric equation based on girth of the tree as the basic parameter and the carbon accumulated at each growth stage was estimated assuming an average carbon content as 42 per cent of the biomass.

Results of the study showed that the clones varied in growth pattern, biomass accumulation and carbon sequestration potential. Biomass distribution pattern into various plant parts showed wide variation in different clones. 23 years after planting, RRII 429 recorded the highest girth (99 cm) among the various clones. RRII 105 recorded a girth of 73 cm and it was comparable with that of RRII 422 and RRII 430. The carbon sequestration potential of RRII 429 was 113.73t ha^{-1} in 23 years and it was significantly superior to that of all the other clones. The clones RRII 414 and RRII 417 also had a significantly higher carbon sequestration potential than RRII 105. Growth curves of the clones showed that the biomass accumulation pattern of various clones followed similar trend till 12 years and after this period, the curves diverged and RRII 414 and RRII 429 continued to accumulate more biomass. The 400 series clones have higher yield potential (Licy *et al.*, 2003; Mydin *et al.*, 2007 and Meenakumari *et al.*, 2010) and higher timber out put (Mydin *et al.*, 2007) than RRII 105 and the resulting higher carbon sequestration potential are added advantages.

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42. WHAT SHOULD BE OUR STRATEGIES TO ESTABLISH RUBBER IN STRESSFUL ENVIRONMENTS

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Attempts were made to identify the impacts of changes in rainfall pattern if any in major rubber growing areas of Sri Lanka and possible impacts on growth and yield of rubber. Subsequently, suitable adaptation measures were developed. The capacity of rubber plantations to mitigate adverse weather conditions is also discussed. Adverse impacts of soil moisture stress identified in this study were 30 per cent decrease in establishment success, 35 per cent reduction in girth at six months after planting and increase in unproductive immature period by more than two years. Planting hole application of organic material, mulching around rubber plants at the time of planting and application of high dose of K fertilizer were identified as suitable adaptation measures. Low water use, osmotic adjustments, capability of capturing more rainfall and high carbon sequestration were identified as adaptation characteristics inherent in rubber plantations. This paper emphasizes the role of rubber plantations as a self-sustaining and environmentally acceptable ecosystem, which can withstand drought while simultaneously contributing to maintenance of the global carbon balance.

Rubber is one of the main plantation crops in Sri Lanka, which significantly contributes to the national economy by earning large foreign exchange and employment generation. Rubber plantations provide a canopy, which reduces the impact of sun as well as high intensity rains. Rubber plantations are therefore to be considered as a self-sustaining environmentally acceptable eco-system, which can mitigate extreme weather conditions.

Data from existing field experiments conducted by the Soils and Plant Nutrition Department of RRISL were used to investigate the performance of rubber under different environmental conditions and as a system to mitigate climate change.

In the wet traditional rubber growing areas in the Southwest region of Sri Lanka, moisture deficits are relatively absent while in the dry marginal areas, moisture deficits are severe and prolongs for a period of 4-5 months. Data on recovery of rubber plants at the time of planting indicated that the establishment success under dry weather conditions is nearly 30 per cent lower and the girth at six months after planting is 35 per cent lower than in the wet region. Similarly, data on girthing pattern of rubber trees in the two regions indicated that the harvesting (tappable[1]) age in the dry regions is more than two years longer than in the wet region.

Extensive researches have been done and some are in progress on soil moisture conservation in rubber plantations. Some of them are application of organic manure, Potassium (K) fertilizer programme, mulching around rubber plants and effective ground cover management by growing *Mucuna*, which appears possible to eliminate or at least minimize the adverse effects of moisture stress. The higher soil moisture content may increase the water uptake by young plants thereby increasing their growth especially during dry periods.

The adaptability of rubber tree, such as water regulating latex system, presence of leaf epicuticular waxes, leaf tissue membrane thermostability, low water use, osmotic adjustment, canopy characteristics and the extensive root system, has enabled it to be established in many unfavourable environments. A monoculture of rubber has been reported to be a relatively efficient converter of solar energy into dry matter production. Data shows that the total biomass produced by a rubber tree at the age of 33 years is 1.8 tonnes which extrapolates to 903 tonnes per hectare. The amount of carbon sequestered in one hectare of 33 year old stand of rubber trees is 596 tonnes, the major portion of which is sequestered in the trunks and branches. The total amount of carbon sequestered in one hectare of rubber plantation made up of tree biomass, latex produced and cover crop biomass is computed to be 680 tonnes. Accordingly, the carbon credit revenue could play a key role in ensuring that rubber continues to be cultivated at current prevailing prices. Moreover, the grower can take comfort in the fact that they have contributed to the sustenance of an environmentally friendly, ecologically sustainable crop with dual economic potentials of both rubber (latex) and timber production for world consumption, while simultaneously contributing to maintenance of the global carbon balance in the atmosphere.

43. RESPONSE OF LOW FREQUENCY HARVESTING SYSTEMS IN DRIER CLIMATIC CONDITIONS OF SRI LANKA

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The rubber plantations in Sri Lanka lie mostly in the Wet zone (WZ) of the country and in certain regions in the Intermediate zone (IZ). Whilst the WZ is receiving an annual rainfall over 2,500 mm, rainfall in the IZ is in the range of 1,270 - 2,540 mm with considerable dry spells (Wijesekera, *et al.,* 2004) and two distinct dry periods falling from August to September and from January to March (Anon, 2009). Coinciding with the dry spells, the temperature can rise up to about 35 °C in the IZ (Anon, 2009). The IZ rubber plantations are condensed in IL1a agro ecological region (AER) where 75 per cent expectancy value of annual rainfall is above 1400 mm.

Escalating cost of production (COP) and inadequate supply of skilled harvesters are among the major issues faced by natural rubber industry. Low frequency harvesting (LFH) systems, in which trees are tapped in a lesser frequency than once in two days, are considered to be one of the solutions to overcome these issues. LFH systems are known to be profitable, if over 90 per cent of the yields given by traditional systems is achieved (Kewi and Sivakumaran, 1994; Tasi *et al.,* 1991). In LFH, the trees are generally stimulated to obtain yields comparable to that of traditional d2 (i.e. tapping a tree once in two days) frequency. Obviously, the stimulation protocol depends mostly on the clone and harvesting frequency. With the higher level of climatic variability resulted from the climate change, prolonged droughts are expected to add another factor to be considered in designing the stimulation protocol of LFH systems. Almost all regions of the island have a potential threat of drought and such possibility in the IZ is relatively high compared to the wetter parts of the island (Chithranayana and Punyawardena, 2008). As a means of simulating the drier conditions, the IZ was used. Low rainfall, prolonged dry spells and resulting low relative humidity in the IZ create an extra stress to the trees. Therefore, the present study was aimed at investigating the variability in yield in LFH systems, viz. harvesting trees once in three (d3), four (d4) and six (d6) days in drier climates.

A mature field from Notinghill Estate in Kurunegala districts with widely used Sri Lankan *Hevea* genotypes, i.e. RRIC 121, was selected, which falls in the agroclimatic zone IL1a representing the IZ of Sri Lanka. All trees were tapped on BO-1 panel. Harvesting systems were based on half spiral cut length (S/2) and three LFH systems were imposed, i.e. d3, d4 and d6, together with traditional alternate day tapping (d2). Experiment began in 2008 after an initial trial period. Yield and growth parameters were continuously monitored from April, 2008. Latex flow measurements and incidence of tapping panel dryness were also monitored. Yield and related parameters of RRIC 121 planted in Dartonfield Estate in the WZ and harvested under d2, d3, d4 and d6 frequencies were taken for comparison. Stimulation protocol of each LFH system was similar in both WZ and IZ.

As expected, yield per tree per tapping (g/t/t) increased with the decrease in harvesting frequency in both climatic zones. However, yield per tree per year (YPT) reported in the IZ deceased by 19 per cent and 36 per cent in d4 and d6 harvesting frequencies, respectively but only by 2 per cent in d3 frequency from the values given by d2. No such declines were observed in the WZ. In contrast, YPT of d3 and d4 frequencies showed 7 per cent and 6 per cent increase over d2 value, respectively and only a 2 per cent decline in d6 frequency. Percentage dry rubber content in latex (% DRC) increased with the decrease in the harvesting frequency. In general, DRC (%) in WZ was higher than that of IZ in all four harvesting frequencies.

Volume of latex per harvest increased with the reduction of the harvesting frequency. However, the volume in d3, d4 and d6 frequencies increased only by 36 per cent, 47 per cent and 76 per cent over d2 value in IZ whilst the increase in WZ was 42 per cent, 68 per cent and 160 per cent, respectively. The increase in overall flow rate over that of d2 in IZ was not up to the expected level resulting in low latex volumes. However, the increase in flow rate in d3 was comparable in both zones. Under the extended LFH systems (i.e. d4 and d6), soil moisture levels in IZ might have not been sufficient to compensate the water taken out from the tree as latex within a short period. Low rainfall, extended dry spells and low relative humidity create more stresses to the tree. This would not be the case in WZ with high rainfall. As a result, overall yield given by d4 and d6 was less than that of d2 only in IZ. Therefore, stimulation protocols are to be designed to obtain higher yields during the wet period of IZ. Obviously, extra care is to be taken in the application of LFH systems in stressful environments prevailing in the dryer climatic regions.

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44. GIS – BASED INVESTIGATION OF TPD STATUS OF NATURAL RUBBER TREE UNDER VARYING SOIL CONDITIONS

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Soil nutrient unbalances and/or soil toxicity may cause tapping panel dryness (TPD), a metabolic disorder/physiological syndrome, resulting in reduction or even complete loss of natural rubber (NR) yield and production. In the current study, GIS-based investigation was carried out in Southeast region of Vietnam on a transitional grey (acrisols)-red (ferralsols) soil area to examine TPD affected trees under varying soil conditions. The study was conducted on a 180 ha area, planted with PB 235 rubber clone at the 13th year of tapping. Based on spatial distribution, 36 sample plots were selected and examined with TPD and soil parameters, including soil texture, pH, soil organic matter (OM), total nitrogen (total N) available phosphorus (available P), exchangeable potassium, manganese, magnesium, aluminum, calcium, (exchangeable K, exchangeable Mn, exchangeable Mg, exchangeable Al and exchangeable Ca). TPD affected trees were investigated by measuring dry-cut length and tapping panel length of both downward and upward panels, which was then averaged and calculated into partial TPD (P-TPD, reversible TPD) and complete TPD (C-TPD, irreversible TPD), based on significant correlation of the TPD indexes measured from the two panels. C-TPD was higher in grey soil area than in the transitional area and red soil area, whereas P-TPD was similar in the three sub-areas. Soil fertility index (SFI) and soil evaluation factor (SEF) were lowest in grey soil area. The irreversible dryness was highly and linearly correlated with soil texture, whereas it was significantly and non-linearly correlated with OM, available P, exchangeable Ca, exchangeable Al, exchangeable Mn, SFI

and SEF. The same correlation pattems were not observed with the reversible TPD. All significantly correlated soil parameters could together explain 46 per cent of total variation of the C-TPD. Inverse relationships observed between C-TPD index and OM, available P, exchangeable Ca, SFI and SEF indicated a nutrient deficiency. While a proportional relationship between C-TPD index and exchangeable Al and Mn suggested that Al and Mn toxicity might be a co-factor contributing to higher irreversible TPD in the grey soil area. SEF seems more relevant in prediction of C-TPD index than SFI, as SEF explained for 27 per cent of total variation of C-TPD, whereas SFI accounted for 12 per cent of the dryness.

45. APPLICATION OF REMOTE SENSING AND GIS IN CLIMATE CHANGE STUDIES AND RUBBER CULTIVATION

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Global climate change impacts are larger, faster and more wide spread than expected. The Intergovernmental Panel on Climate Change (IPCC) technical Paper VI on Climate Change and Water (Bates *et al.*, 2008) has projected increased precipitation intensity and variability which increase the risks of flooding and drought in many areas. An increased runs of dry days between precipitations was also projected. There has been an increase in the frequency of heavy precipitation events during the later part of the 20th century.

Efficient management of land and water is of utmost importance to mitigate the impacts of climate change on land and agricultural productivity. Soil moisture is a part of the hydrological cycle and it acts as an interface between runoff, evaporation and infiltration into ground water. Soil parameters like depth, organic carbon (OC), available water holding capacity (AWC) and slope are important in soil water storage capacity which in turn influences the vegetation to adapt to variability in rainfall. The effect of a sudden variability in rainfall pattern due to climate change will be more adverse if these parameters are not favorable and the vegetation growing on soil with favorable conditions can better adapt to climate change. First step in mitigating the adverse effect of climate change in relation to rainfall variability is the inventory of soil and land resources so as to understand the adaptability of managed ecosystems like rubber plantation to climate change. For this purpose, an integrated analysis is necessary and remote sensing and GIS are ideal tools. In this regard, RRII has launched a project on developing rubber information system using RS and GIS.

A case study was undertaken in Kozhanchery taluk of Pathanamthitta district of Kerala, India to assess the vulnerability of rubber plantations to climate change as reflected by rainfall variability and runoff. Soil and land properties like depth, slope, AWC, OC and elevation were selected for integrated analyses and brought into GIS platform. Data on each layer of information was scaled 1 to 5 and each layer was assigned an empirical weightage (ranging from 1 to 5) considering its importance in the multi-criteria overlay analysis to identify the locations likely to be best adaptable to rainfall variability. Rubber distribution was mapped using IRS P6 satellite image for February 2005 and it was superimposed over the location identified using overlay analysis to know the distribution of rubber plantations over different locations. It was found that major portion of rubber plantation (76.9 %) was distributed in locations categorized as moderately adaptable to rainfall variability and the small extent (13 %) in low adaptable areas. About 9.1 per cent rubber was distributed in areas well adaptable to rainfall variability. Similarly soil erodibility factor estimated for rubber growing soils under different landforms (Satisha and Ulaganathan, 2008) was used along with slope map generated from 90 m resolution SRTM DEM data to assess the areas vulnerable to erosion by heavy rainfall. About 2.5 per cent of rubber area is distributed in areas highly vulnerable to soil erosion. The information so generated in the form of map can serve as a tool for the managers, administrators and researchers to identify vulnerable areas and prioritize and plan strategies to mitigate adverse effects of climate change.

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IMPACT OF CLIMATE CHANGE ON VECTOR BORNE HUMAN DISEASES

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A number of drivers of global change exert pressure on physical and social environment of the earth. Climate change is an indicator of global change and this is a dynamic but slow phenomenon. Earth has warmed by about 0.6oC and temperatures have warmed at nearly all locations worldwide with great temperature changes in very high latitudes. Climate change with warming of the planet projected to have both positive and negative consequences that will vary temporarily and spatially. Warmer, dryer or wetter in many places, rise in sea level, most frequent and more intense extremes of climate, and more acidic sea water are the effect of climate change, influencing on precipitation (erratic), food production (high variability), industries, human settlements and societies (location related - distorted) and human health (direct and indirect). The impact could be realized more in temperate region.

The IPCC foresees climate change leading to changes in infectious disease transmission by vectors such as mosquitoes and ticks, as a result of changes in their geographic range, seasons of activity and population size. The ecology, development, behavior and survival of human disease vectors and the transmission dynamics of the diseases are highly climate sensitive. There is considerable evidence that climate change has and will increasingly have, a direct influence on the distribution of vectors, either directly or indirectly through the changes in the distribution of hosts and thus parasite transmission, leading to changes in both the distribution and incidence of the diseases. Globally, it is predicted that malaria will appear in areas with a population of 360 million and will disappear in areas with a populationof 330 million. Zoonotic diseases that are newly recognized or newly evolved or those have occurred previously but show an increase in incidence or expansion in geographical, host or vector range. Most of the studies relating to the impact of climate change have been on malaria, but there is also evidence shown that other vector borne diseases such as leishmaniasis, chagas disease and human American trypanosomiasis are expanding or shifting distribution as a result of climate change. There are also views that although models (statistical or biological models) suggest that higher global temperatures will enhance transmission rate of mosquito borne diseases, to what extent thay are correct.

Climate has not been the principal determinant of the prevalence or range of three vector borne diseases - malaria, yellow fever, and dengue - but human activities and their impact on local ecology have generally been more significant in the past. It is therefore inappropriate to use climate – based model alone to predict future prevalence.

Recent WHO consultation meeting on climate change and vector borne diseases identified gaps in social and ecological changes and their impact on vectors and reservoir hosts, cost-effectiveness and evaluation of curative and preventive interventions and of early warning systems, and the disappearance of infectious diseases from specific socio-economical settings without control interventions.

Recognition of the complex relationship between the vector and the biological, ecological, epidemiological, and sociological changes remains to be the key in combating the issue of climate change and infectious diseases. A multi-faceted approach is necessary to tackle the multiple disease determinants. Improved disease specific estimates of current mortality, morbidity and burden are required to predict future climate and environmental impacts on vector borne diseases. Climate based statistical, spatial and temporal risk mapping and modeling, as well as qualitative and quantitative risk assessment of indirect effects on vector borne diseases from land use changes and other socio-economic environment are essential as cross cutting research. Enhanced surveillance capacity to recognize the spread of the vector borne diseases and documentation of the facts related to climate change along with other epidemiological and entomological data will be useful to predict the effects as well as identify appropriate methods of mitigation.

IMPACT OF CLIMATE CHANGE ON CROP DISEASES AND THEIR NATURAL ENEMIES

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Climate-variability and change are exerting additional pressure on developing countries of tropics and subtropics which are already at the threshold to cope with the increasing demand for food for increasing population pressure. Even a small increase in temperature in these areas will cause significant yield decline in major food grain crops. The changing climate not only influences the crop growth and development but also expected to alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host-pathogen interactions. It is expected that the range of many insects, diseases and weeds will expand or change and new combinations of pests and diseases may emerge when current natural ecosystems respond to altered temperature and precipitation profiles. Although, the research in establishing the impacts of pathogens and their natural enemies is at its infancy, independent studies conducted across the laboratories could be used to draw inferences. Elevated CO_2 levels are known to increase foliar density which in turn will influence the microclimate of the pathogen, altered host morphology which in turn may influence host-pathogen interaction, enhanced sporulation of anthracnose pathogen and increase dry- root rot under moisture stress conditions. For instance, an increase in temperature may lead to increased host susceptibility, a new/rapid development of the pathogen, more rapid vector development leading to faster spread of the insect-borne viruses, a variable overwintering/over summering of the pathogen/ vector; shift in spread pattern of the pathogens. Initial studies shown an increased sporulation and altered biocontrol traits in *Trichoderma,* a known biocontrol agent. Efforts are underway at CRIDA to assess climate change impacts on important pathogens and their natural enemies. The present paper reviews the interaction of different weather variables with different insects, diseases and weeds and the probable threats for food grain production, availability and quality.

46. EPIDEMIC OF RUBBER DISEASES UNDER CLIMATE CHANGE IN THAILAND

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The close relationship between the environment and diseases implies that climate change will change patterns of rubber disease distribution. Recently, unexpected diseases, i.e. die-back caused by *Botryodiplodia* sp. and *Botryosphaeria* sp., collar rot caused by *Phytophthora* sp., occurred. Some rubber diseases changed their relative importance, such as *Colletotrichum* leaf spot, powdery mildew, *Corynespora* leaf fall were estimated more severe under climate fluctuation. *Phytophthora* leaf fall occurred in new rubber planting area where this disease had not been recorded. In fact, plants will be stressed and have their defenses weakened by abiotic factors and are predisposed to infection by plant pathogens as known in term of "complex diseases".

Research on impact of climate change on the spatial and temporal distribution of rubber diseases is important. Understanding quantitative relation of a pathogen to weather may be appropriate to use a weather-based prediction system for evaluating the risk of disease epidemic. The growers should be advised to prevent the economic loss resulting from disease outbreaks.

47. PREVALENCE OF PESTS AND DISEASES OF *HEVEA BRASILIENSIS* IN INDIA – PAST AND PRESENT

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Agricultural production of the world suffers an annual loss of about 20 to 30 per cent on account of pests and diseases affecting crop plants in different crops and in different countries. Plant diseases are one of the major bottlenecks in agricultural production particularly in a monoculture cultivation like natural rubber.

For the occurrence of a disease caused by a biotic agent, there should be an interaction among a susceptible host, a virulent pathogen and a favourable environment for the development of the pathogen. Thus, weather parameters have an important role in triggering and spreading pests and diseases in natural rubber. Almost all the pests and diseases known to affect natural rubber have been existing since long back. However, of late, some of them that were minor in nature have become major and some prevailing only in nurseries are occurring in mature trees also. Changes in severity and pattern of occurrence have also been noted. In view of this an attempt has been made to analyse the pests/disease incidence in natural rubber in India for the past 30 years and the critical climatic factors favouring them are compared.

Abnormal leaf fall disease (ALF) caused by the fungus *Phytophthora* spp. occurring during monsoon season is highly influenced by the rainfall pattern. Incidence of this disease in one large estate (Malankara estate, Idukki district) was compared with the total monthly rain fall in that estate during May to August of every year from 1980. The influence of the rainfall pattern on the ALF disease incidence could be clearly observed during this period. The rainfall pattern of Kanyakumari region of Tamil Nadu, where the incidence was very less up to 1980's and later became severe was also analyzed. An increase in disease incidence corresponding to an increase in rainfall could be noted here also.

Corynespora leaf fall disease caused by the fungus *Corynespora cassiicola* has found to infect nursery plants in Central Kerala from 1958 onwards (Ramakrishnan and Pillay, 1961). But in 1996 it became severe in mature rubber plantations of southern Karnataka and neighbouring places in Kerala. Though the epidemic could be effectively managed by timely adoption of suitable control measures, the disease appeared every year in a manageable form in this region. Relative humidity (RH) and early morning temperature in the plantations are reported to be the critical parameters that determine the disease initiation (Sailajadevi *et al.*, 2005). Both these parameters prevailing in plantations of South Karnataka and nearby places in Kerala during the months from January to March were compared with the disease incidence from 1996 onwards. A significant correlation with the disease incidence and RH was established. RH during this period and also the disease showed a declining trend during this period. However, definite correlation could not be observed with the minimum temperature. Since a good correlation between Corynespora incidence and RH was observed, the pattern of RH in the traditional rubber growing areas since 1957 was analyzed. RH showed an increasing trend in traditional areas indicating a probable Corynespora attack. This is more convincing since there are already some reports of Corynespora attack in the traditional rubber growing areas during 2010.

Powdery mildew disease caused by *Oidium heveae* is the major leaf disease in the north-eastern states of India during the winter period from January to March (Mondal and Jacob, 2002; Mondal *et al.*, 2007). Disease incidence was compared with the average minimum temperature during these months. A reduction in the disease incidence corresponding to an increase in the minimum temperature was evident in the North East region of India. It may be noted that winter temperatures have been on the rise in North East India in recent years (Sailajadevi *et al.*, elsewhere in this volume).

Though pest incidence in natural rubber is comparatively less, the same is also found to be on the rise as a result of warming temperature in recent years. Both bark feeding caterpillar (*Aetherastis circulata)* and mealy bug (*Ferrisiana virgata)* are thermophilic insects attacking rubber. Incidences of these two pests showed an increasing trend as the maximum temperature during the pest attack season (December to April) also increased over the years. It is interesting to note that mealy bug which was only infesting nursery plants earlier was found to infest the mature plants during summer in 2010.

Attack of cockchafer grub (*Holotrichia serrata)* and slug *(Mariaella dussumieri)* on young rubber plants is generally seen during the rainy season from June to October. Incidences of these two pests were compared with the rainfall pattern from 1957 and both showed a decreasing trend (although there was increased Cockchafer grub attack in the past two years). Another interesting finding in the study was the decreasing trend in the overall pest incidence in North East states of India. In general, a change in the disease and pest incidence in natural rubber in India corresponding to the changes in climatic parameters could be observed. Therefore, in the current scenario of climate change, shift in the pattern of these pests/disease attacks in natural rubber should be anticipated and their evolution should be closely watched. A proper and effective mechanism of forewarning of various diseases and pests has to be developed based on the changes in the climatic parameters. Monitoring the possible changes in pests and pathogen, as a result of climate changes is highly required.

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48. FISHING FOR *PHYTOPHTHORA* FROM RUBBER PLANTATIONS IN TRIPURA (NORTH EAST INDIA) – IS CLIMATE INIMICAL TO THE DEVELOPMENT OF *PHYTOPHTHORA* IN NE INDIA?

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Abnormal leaf fall (ALF) disease caused by *Phytophthora* spp. is one of the most destructive diseases of rubber (*Hevea brasiliensis*) in India. Crop loss due to *Phytophthora* was estimated to be 7 to 32 per cent in the traditional rubber growing regions of India (Jacob *et al.*, 2006). However, ALF has not been observed in rubber plantations of North East India, where a *Phytophthora*-susceptible clone RRIM 600 is widely cultivated. Mild to moderate incidence of diseases caused by *Phytophthora* on crops like potato, taro, coconut, arecanut, citrus and black pepper have been reported from Tripura. Late blight of potato caused by *Phytophthora infestans* was observed in Tripura during mid-December to mid-February and reached an epiphytotic form when the relative Humidity (RH) was above 80 per cent, day temperature was 10-24^{0}C, night temperature was below dew point for 4 days along with continuous cloudy days and light showers for 3-4 days (Bhat *et al.*, 2008). Dutta *et al* (2009) observed heavy infection (> 60%) in potato during 2008, when the temperature was 10-20^{0}C and RH 88 per cent. Singh (1998) earlier reported that spread of the disease takes place at 90 per cent RH and 16-22^0 C and when the mean temperature was over 25^0 C, the disease was rare and unknown as was observed in 2009. Late blight of potato occurs regularly in the north western hills of Himachal Pradesh and Uttaranchal, north eastern hills in Meghalaya and Darjeeling districts of West Bengal and Nilgiris in southern hills, and in the Indo Gangetic plains of Punjab, UP, Bihar and West Bengal. However, the disease is more frequent and serious in the north eastern hills where the weather is favourable to the pathogen. It was observed that races 0 and 1 were present in north western hills, while race '0' was present in North Eastern hills during 1958. Racial pattern among *Phytophthora* was simple until 1966 and later complex races were recorded during 1970s. A total of 29 races possessing 7 to 11 genes were recorded in 2005-06 (Singh and Singh, 2007) indicating increase in the pathogen complexity as years proceeded. Similarly, taro blight caused by *P. colocassiae* was observed in Tripura in 2005 when the disease incidence was 46 per cent.

Pod rot and ALF disease on rubber trees caused by *P. botryosa* was observed in 1988 and 1989 in three regions of Tripura (Pathalia, Taticheri and Warrangberi) and the disease incidence was high (Mondal *et al.*, 1994). However, the disease was not observed during subsequent years. So, a possible threat of *Phytophthora* exists in the form of a sudden and serious outbreak of ALF disease in North East India, where a monoculture with a susceptible clone RRIM 600 exists. In this context, a study was undertaken to detect likely presence of *Phytophthora* inoculum in rubber growing regions of Tripura (NE India). This study was initiated during the rainy season (June to August) of 2008. Soil, litter and dried pod samples were collected from nine different rubber plantations of clone RRIM 600 in Tripura (Taranagar, Rangamala, Santarampara, Bagma, Kariamura, Warangbari, Paticheri, Takmachera and Bogafa) and they were monitored by placing rubber leaves in water submerged with the samples to fish for *Phytophthora. Phytophthora* are semi-acquatic; while they can exist in a vegetative or resting stage in moist or even fairly dry substrates, they require free moisture for the production, liberation and dispersal of their free swimming zoospores, though not for subsequent development of the pathogen in host tissues. Rubber leaves acted as baits to attract the swimming phase of *Phytophthora* in water. *Phytophthora* was observed at a lesser frequency as the baits picked up infection at a very slow pace (9-10 days) in Tripura samples compared with the samples collected from Kottayam, Kerala (4-5 days). Virulence tests performed *in vitro* (Goth and Keane, 1997) with the isolates obtained from Tripura revealed that the isolates were less virulent than those isolates obtained from Kerala. Thus, it was observed that *Phytophtora* is present in rubber soil and litter of Tripura, but the inoculum density is very low and they were less virulent than in Kerala.

Weather plays an important role in development and spread of a disease. It was observed that rainfall is the most important climatic factor governing the onset and severity of ALF disease in traditional region. It has been reported that a continuous spell of 250 to 350 mm rain for 7 to 10 days without intermittent hot sunshine, with minimum and maximum temperatures within the range of 22-25^0 C and 26-30^0 C respectively and relative humidity (RH) above 90 per cent are most congenial for the outbreak of the disease (Edathil *et al*., 2000). Few important weather parameters like maximum and minimum temperature, RH, number of rainy days and rain spells at Agartala, Tripura were examined during May to August 1988 to 2009 and compared with that of Kottayam, Kerala. During rainy season (May to August 1988 to 2009), the mean maximum and minimum temperatures at Agartala was observed to be 31.2^0 C and 24.9^0 C respectively, which was higher than that observed in Kottayam during the same period (30.4^0 C and 23.2^0 C respectively). Thus, Agartala weather was observed to be hot during the rainy season (>30^0 C), which may be one of the factors inimical to the development of *Phytophthora*. During the same period, RH was found to be higher in Kottayam (85%) than in Agartala (82.6%), yet another factor possibly associated with inoculum establishment. Rainfall plays a very important role in the survival of zoospores. Comparison of continuous spells of rainfall for 7 or more days between the two regions indicated that Kottayam received more continuous spells of rainfall (334 days) coupled with high RH and temperatures within the limits (26-30^0 C maximum temperature and 22-25^0 C minimum temperature) for *Phytophthora* survival, whereas in Agartala the number of such days was markedly less (57 days). Optimum RH and favourable temperatures coupled with consecutive rainfall for 3, 4, 6 and 9 days were observed for 17, 9, 3 and 2 times in Kottayam, whereas Agartala experienced the same conditions for 3 and 4 days for 4 and 3 times respectively. Therefore, hot weather with lower RH coupled with less number of rain spells may be some of the important factors preventing inoculum build up for initiating *Phytophthora* infection in rubber plantations of Tripura. Low virulence of *Phytophthora* in the north east India also would have contributed to near complete absence of ALF in the region. It remains to be examined if the low virlulence of *Phytophthora* is related to the prevailing climatic conditions in north east India.

Physico-chemical properties of Tripura soil did not hinder the growth of *Phytophthora*. However, build up of primary inoculum of the virulent strain, inoculum potential along with favourable weather parameters like congenial maximum and minimum temperatures, RH, frequent spells of wet days without intermittent hot sunshine hours may be some important factors determining absence of ALF in Tripura. Although *Phytophthora* causing pod rot and ALF on rubber trees was observed in 1988 and 1989 in Tripura, the disease was not detected during the subsequent years. This is interesting as there was more number and longer spells of rainy days during 1988 (6 days). From 1989 to 2003, only three days of continuous rain along with high RH and optimum temperatures were observed. After 2004, this condition has been increasing from 4 to 6 days, suggesting a possible shift in the rainfall pattern which is not a desirable trend as far as likely incidence of ALF is concerned. Hence, in the changing climatic scenario, occurrence of ALF in rubber plantations of Tripura can not be summarily ruled out and more study is required to predict if an outbreak of this disease in north east Indian rubber plantations is likely in future day.

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49. CRITICAL CLIMATIC FACTORS INFLUENCING THE INCIDENCE AND SEVERITY OF CORYNESPORA LEAF DISEASE IN RUBBER (*HEVEA BRASILIENSIS)*

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Corynespora Leaf Disease (CLD) caused by the fungus *Corynespora Cassiicola* in India, has become one of the most serious diseases in the rubber plantation sector. Incidences had been repeatedly seen in certain locations in north Kerala and south Karnataka after its epidemic manifestation since 1996. This study attempts to identify critical factors of weather influencing incidence and severity of the disease. Hot spot areas were identified for repeated attacks of the disease every year in north Kerala and south Karnataka. Field meteorological units were established in four farmers' fields. Jadkal in Kundapura district (13^{0}48'N, 74^{0}47'E, 35 m above MSL) and Guthighar in Sullya district (12^{0}38'N 75^{0}32'E 162 m above MSL) of south Karnataka were identified. Adhur in Kasaragode district (10^{0}40'N 76^{0}08'E 162 m above MSL) and Pinavoorkudi in Ernakulam district (10^{0}09'N 76^{0}43'E 46m above MSL) of Kerala were chosen for the study. The experiment commenced from December, 2008. Daily recordings of maximum temperature, minimum temperature and rainfall with twice-daily recordings of relative humidity (morning and afternoon) were made from the field units. Daily leaf collection was carried out through three leaf baskets (1 m^2 area) in half a hectare, placed in a randomized block design with four replications under the clone RRII 105 for all locations. In another experiment, spore traps with slides coated with petroleum jelly fixed to a rope at four levels of 1 m height from the top canopy, were exposed in Pinavoorkudi, Ernakulam. The spore trap was replicated thrice and the experiment was conducted from December, 2008 onwards. The amount of daily leaf fall due to disease was studied with the different daily weather parameters.

The observed daily weather parameters did not show a direct relation with leaf fall in any of the locations. The Humidity Thermal Index (HTI) which is known to influence plant diseases (Johrar *et al*, 1992, Allen *et al.*, 2009) has been calculated by taking the ratio of relative humidity and temperature. In this study, the HTI ratio between morning relative humidity and minimum temperature were highly related to daily leaf fall. The HTI was also compared with that of the Percent Disease Intensity (PDI), which was recorded periodically in different plots. It was found that during the periods of 2009 and 2010, HTI could be related with the triggering of incidence after three to four days of HTI e” 4.0 and leaf fall after seven to eight consecutive days of HTI e” 5.5.

Leaf fall intensity (at seven days lag) increased with the duration of days e” 5.5 HTI. This was mostly detected in Jadkal during 2009 when the disease severity (PDI) was 100 per cent. Increase in the intensity of leaf fall showed a positive correlation of 0.40 with the increase in HTI values above 5.5 after seven days. Similar results were obtained in 2010 also. However, 100 per cent disease was observed only in trees which had leaves at the most vulnerable stage (light-green). In Guthighar, during 2009 the PDI was noted to be 50 per cent with severe leaf fall. Here also, the leaf fall started exactly after the HTI value crossed 5.5 for seven consecutive days. Decrease in the peak leaf fall occurred only after the HTI went below 5.5. The declining trend was also noted after seven days when the HTI went consecutively below 5.5. In 2010 the HTI was below 5.5 on all days during the refoliation period, which resulted in low disease intensity and leaf fall. Increase in the intensity of leaf fall and consecutive HTI e” 5.5 after seven days showed a positive correlation of 0.74. In Adhur, there were seldom days with above 5.5 HTI during the refoliation period during 2009 and 2010. Hence, disease intensity was low with 20 and 30 per cent PDI during 2009 and 2010 respectively, without severe leaf fall.

Phenology of the leaf is an important parameter influencing the incidence and severity of this disease. Leaves during the transition stage from copper-brown to light-green stage are more susceptible to infection. Three days consecutive HTI e” 4.0 was observed to initially trigger the disease with the appearance of leaf spots in the locations studied. In Adur, during 2009, even though the disease commenced with appearance of numerous circular spots on young light green leaves, it did not develop into a severe form, as most of the days had less than 5.5 HTI during the refoliation period. In Jadkal and Guthighar continuous occurrence of HTI e” 4.0 throughout the refoliation period favoured the incidence and intensity of the disease though severe leaf fall was observed with HTI e” 5.5 for seven consecutive days.

In Pinavoorkudi, the maximum spore count was observed after a period of 6 to 8 days with HTI e” 5.5 for seven consecutive days. This could also be related to the development and severity of the disease as was observed in Guthighar and Jadkal. The correlation worked out between the 7-day lag period HTI and maximum spore count was 0.85. The maximum spore concentration was noted at 1 m below the top of the canopy. Severity of the disease is mainly concentrated on the exposed top canopy. Leaf counting and disease scoring could not be carried out, because of the simultaneous occurrence of *Oidium* and *Corynespora* in both the years.

The study indicated that HTI e" 4.0 consecutively for three to four days triggered the disease and a minimum duration of seven days HTI e" 5.5 can favour the development and severity of the disease resulting in leaf fall. It also revealed that incidence and intensity of the disease is greatly influenced by the microclimate over a particular location especially with the HTI. However, the critical values will have to be tested with the microclimate of a number of other locations where the disease is being prevalent. The critical values observed for the initiation of the disease can be utilised for forewarning and timely adoption of control measures during the refoliation period to prevent the development and spread of the disease. Based on the above findings, the critical values can further be utilised to analyse the possible occurrence of the disease in different locations within the changing climatic scenario.

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50. ROLE OF ENDOPHYTIC BACTERIA IN THE MANAGEMENT OF ABIOTIC AND BIOTIC STRESSES IN PLANTS

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Agriculture has a critical role to play in addressing climate change as it is directly or indirectly responsible for contributing to global warming and simultaneously suffering from its effects. The impact of climate adversely affected many agriculturally important crops (Rodriguez *et al.,* 2008). The factors such as elevated CO_2, drought, increased temperature and development of virulent races of pathogens affected the beneficial plant microbe interaction in the rhizophere (Stephane Compant 2010). One of the possible ways to address the impact of various stresses on plant is the efficient use of naturally available resources and internal regulations of biological processes with minimum dependence on external input. Endophytic microorganisms occurring naturally within the plant system can be manipulated for the control of various stresses. The use of these organisms to manage both biotic and abiotic stress is gaining more attention in many important agricultural crops. This paper reviews the properties of endophytes and possibilities of exploiting these to thrive various abiotic and biotic stresses in plants arises due to changing climatic conditions.

There are various mechanisms by which endophytes help the plants thrive in abiotic stress condition. During drought period, the plant hormone ethylene endogenously regulates plant homeostasis and results in reduced shoot and root growth. Ethylene is formed from methionine *via* S –adenosyl-L-methionine, which is converted into 1-aminocyclopropane -1-carboxylicacid (ACC). This cyclic nonprotein aminoacid is converted to ethylene, catalyzed by the enzyme ACC oxidase and thus modulate ethylene levels, which may cause plant stress (Blecker and Kende 2000, Meyak *et al.*, 2004). However, degradation of ethylene precursor 1-aminocyclopropane-1-carboxylicacid (ACC) by bacterial ACC deaminase releases plant stress and resumes normal growth. Many plant associated bacteria produce this enzyme. This enzyme has no function in bacteria but cleaves ACC, the precursor of ethylene in plants, produced in the host cell. Drought stress alters plant hormone balance by increase in abscisic acid (ABA) content in the leaves. The endophytic microbes produce large amount of cytokinins and control the endogenous levels of ABA to thrive stress. Drought, heat, and salt stresses affect plant water relations triggering complex plant responses, which include increased production of osmolytes (Wang *et al.*, 2003). Osmotic potential is determined primerly by two components: solute potential and matrix potential and it is likely that endophytes contribute to matrix potential, which is particularly important in helping plants to retain water and there by enhance drought tolerance (Marquez *et al.*, 2007).

Various abiotic stresses also weaken plant defence against plant pathogens. Use of endophytic micoorganisms for disease control (biotic stresses) has gained attention recently. Different groups of endophytic microorganisms occurring within the plant system can be manipulated for protection against various pathogens. Endophytes produce pathogen suppressive metabolites and stimulate defence mechanism of host through enhanced activity of the enzymes and PR proteins that induce systemic resistance to the host plant. Phloroglucinol and phenolic compounds produced by the endophytic *Pseudomonas* have antifungal, antiviral and anti helminthic effects (DeSuza *et al.*, 2003). 2-4DAPG has shown to play a key role in biological control of various plant pathogens (Thomasshow and Weller,1996). Application of purified DAPG inhibited *Pythium* infection in sugar beet (Vincent *et al.*, 1999) and damping off in tomato caused by *P.ultimum* (Rajamoorthy *et al.*, 2001).Volatile compounds such as HCN, benzothiazole, cyclohexanol and dimethyl trisulphide produced by the bacteria play an important role in the biocontrol of many soil borne pathogens (Fernado *et al.*, 2005). Salicylic acid, a natural phenolic compound present in many plants is an important component in signal transduction pathway and involved in local and systemic resistance to pathogens. The salicylic acid produced by the endophytic microorganism triggered the SA pathway in plants and enhanced Induced Systemic Resistance (ISR). Endophytic fungus treated perennial rye grass showed enhanced tolerance to 'Argentine Stem Weevil'. The peramine, produced by the endophytes were toxic to the above insect (Barker 1984 b).

Many of the endophytic bacteria isolated from leaf, stem and root of rubber (*Hevea brasiliensis*) were found to be antagonistic to the major *Hevea* pathogens viz, *Phytophthora, Colletotrichum, Corynespora* (leaf pathogens), *Corticium* (stem pathogen) and *Phelinus* (Root pathogen) in dual culture studies. They produce antifungal metabolites like volatile and nonvolatile organic compounds, HCN, siderophores and salicylic acid under *in vitro* conditions. Application of endophytes treated seedlings in glass house showed enhanced enzyme levels that are related to disease tolerance (Philip *et al.*, 2009). The colonization of antagonists was confirmed by ERIC-PCR and *gfp* tagging.

Endophytes bacteria from rubber belonged to different genera viz, *Bacillus, Pseudomonas, Burkholdaria etc*. These groups are reported to manage various biotic and abiotc stresses in plants. The feasibility of using these microorganisms in the management of biotic and abiotic stresses in rubber is to be studied under the changing climatic conditions.

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FUTURE TYRES TO ADDRESS ENVIRONMENTAL ISSUES AND INTERNATIONAL LEGISLATIONS

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The whole world is now focusing on environmental issues because of climate change and highlighted the areas of highest concern. In this respect, the major concerns in tyre industries are the usage of nitrosamine (TRGS- 522) and PAH free containing materials in rubber compounds. REACH, Tyre labelling and Tyre odour places greater responsibility on industry to manage the risks that chemicals may pose to the health and environment. Distilled aromatic extracts (DAE) are currently used as aromatic process oils for the manufacture of oil extended natural or synthetic rubbers and also in tyre compounds. Highly aromatic oils are added to the rubber compound in the factory during the manufacturing process to improve the processability of the compounds. These oils contain high levels of poly aromatic hydrocarbons (PAH) and are identified to cause tumours in various mice skin painting tests. Therefore, EU with directive 2005/69/EC prohibits the placing of poly aromatic hydrocarbon-rich tyre extender oils or tyres containing these oils on the EU market from January 1, 2010.

The directive defines that the extender oils allowed after the directive steps in force will have to meet two criteria. The content of total ECHA defined poly aromatic hydrocarbons (PAH) cannot exceed 10 ppm, which is assumed to be met if the DMSO extractable amount in the oil is below 3 per cent by method IP346. Tyres will be checked with method ISO 21461, which utilizes NMR and measures bay area protons in polycyclic aromatic compounds (PCA). It analyzes an extract from the tyre compound. The result correlates to the amount of PCA in the extender oil. A maximum limit of 0.35 per cent has to be met for the tyre to be approved for marketing in the EU.

The Petroleum oil companies have developed different extender oils which have very low PCA (poly cyclic aromatic) content to replace high PCA content aromatic oils. These oils are TDAE (treated distilled aromatic extract), RAE (residual aromatic extract) and Heavy naphthenic oil (HNO), MES (mild extracted solvent), PPO (paraffinic process oil). Tyre industries have developed formulations with alternate materials free from nitrosamine and PAH free oil which is safe for environment and not harmful to human health. EU has published list of materials that are from Nitrosamine and could not be used in tyre (TRGS-522). The rubber additive which contains nitrosamine or produce nitrosamine is to be replaced by safe material because nitrosamine is carcinogenic. Some rubber additives like MBS, DTDM, TMTD which produce nitrosamine is banned to use in rubber compound. The tyre industries are now changing all compound formulations into PAH, which is Nitrosamine and Carcinogenic free in accordance with European Union directive 2005/69/E C and TRGS - 522.

Important tyre performance properties viz., rolling resistance, wet grip and wear characteristics are interrelated through a 'triangular relationship', which tyre designers call 'Magic Triangle'. It means that achieving any one of these will be, normally at the cost of other benefits. However, in tyre compounding, low rolling resistance can be achieved without compromising traction in many ways. Tyre labelling, which will allow customers to quickly determine these performance optimisation, will be driving the market in Europe and the US from 2012 onwards. Basically, tyre development will be driven by the consumer who will want more fuel-efficient, higher-performance and environment-friendly tyres. Tyre labelling will determine his purchase decision. As we know labelling has shown positive impacts in other industries and this is coming to the tyre sector as well. Another important factor is tyre odour which is also gaining its foothold in the industry. The demand is growing fast for environmental friendly tyres and tyre industry is also switching over to green compounds and manufacturing process.

51. ESTIMATING GLOBAL WARMING POTENTIAL OF BLOCK RUBBER PROCESSING IN MALAYSIA USING LIFE CYCLE ASSESSMENT METHODOLOGY: MRB PILOT PLANT CASE STUDY

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Block Rubber processing in Malaysia is one of the major sources of organic pollution which discharge around 55 million liters of effluent daily. Life Cycle Assessment methodology was used to study the impact of the block rubber processing towards the environment specifically global warming potential using the Malaysian Rubber Board Pilot Plant SMR line as a case study. Using 1.2 tonnes of SMR 10 as the defined functional unit and gate to gate approach, results indicate that drying stage contribute the most CO_2 due to the usage of diesel as the fuel for drying rubber.

52. REDUCING EMISSION OF CO_2 THROUGH INNOVATIONS IN RUBBER COMPOUNDING

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Carbon black is well accepted as the best reinforcing material in rubber compounds. Around 80 per cent of the total carbon black produced in the world is consumed by tyre industry. Presently about nine million MT of carbon black are manufactured annually worldwide, resulting in the consumption of 20 million MT of carbon black-oil as raw material. However, along with the manufacturing process of carbon black, carbon dioxide, one of the gases responsible for global warming, is also emitted. The production of carbon black using fuel oil generates around 2.18 MT of CO_2 per one tone carbon black produced.

Today, some 800 million automobiles are in use worldwide. These automobiles are estimated to emit five billion MT of carbon dioxide every year in the lifetime of automobile, accounting for 22 per cent of all carbon dioxide emissions. Eighty-six per cent of the automobile-derived carbon dioxide is emitted during driving. Therefore, reducing carbon dioxide emissions by reducing fuel consumption is critical. The tyre industry has developed improved tyres which can reduce fuel consumption by various means, such as reduced tyre weight and reduced rolling resistance using comparatively expensive silica/ silane filler systems or carbon black /silica mixed filler system in tyres.

In this study, a new polymeric filler system was introduced to replace carbon black fully or partially from the existing rubber compounding system. The concentration of polymeric filler used for the reinforcement of rubber was very low (10 phr in comparison with 40 – 50 phr carbon black) compared to the conventional carbon black system. A tread compound was prepared by replacing the carbon black from the formulation with the new polymeric filler and compared the cure characteristics, technological properties and dynamic properties with a conventional tread compound. The new system showed almost equivalent technological properties to that of the control compound containing carbon black, in terms of tensile strength, tear strength, modulus and abrasion resistance. The added advantage of the new system was very low heat build-up and high resilience properties compared to the control compound. The DMA analysis of these compounds showed that the new system has the potential to reduce the rolling resistance up to 33 per cent compared to the carbon black based conventional tyre tread formulation. It may be noted that this is lower or at par with the rolling resistance of the so called "Green tyre" used in passenger cars manufactured by sSBR/silica/silane system. The field evaluation of the new polymeric filler reinforced NR based tread formulation is currently in progress.

53. USE OF EPOXIDISED NATURAL RUBBER AS AN ENERGY EFFICIENT ECO-FRIENDLY MATERIAL IN TYRE APPLICATIONS

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Rubber products industry could be classified into tyre and non-tyre sectors. Natural and synthetic rubbers (NR and SR) are being consumed by these industries and the extent of use of these rubbers in each product is dependent on the ultimate property requirements demanded by each product. Globally tyre industry consumes about 50 % of the total rubber being produced annually. About 9.5 million tonnes of natural rubber and 12.5 million tonnes of synthetic rubbers are produced annually. Major general purpose synthetic rubbers consumed by the tyre industry are Styrene butadiene rubber (SBR) and Poly butadiene rubber(BR), and its annual production is about 5.2 and 3.1 million tonnes respectively. Every industry is under pressure from environmental regulations for lowering greenhouse gas (GHG) emission. While natural rubber is obtained from a non-polluting and renewable source, its synthetic counterparts are derived from a depleting and non renewable petroleum based source. About 57 per cent of the world elastomer demand is met by various forms of synthetic rubber that are made from petroleum sources. About 60 % of NR and 70% of SBR produced go into tyre production. SBR is predominantly used in car tyres, while NR is used for the production of truck tyres and aero tyres.

Synthetic rubbers are produced from a non-renewable source and the technology involved is energy intensive and causes green house gas (GHG) emission. NR is produced from a renewable and environment friendly source that removes CO_2 from the atmosphere and the energy for production is also less as its main source of energy is sunlight. Modified natural rubber could be another potential raw material for the rubber industry. One of the promising rubbers of this group is the epoxidised natural rubber (ENR) which has certain advantages over natural rubber and other general purpose synthetic rubbers with regard to certain industrial applications. One of the areas where it can find application is in the tyre industry.

Technologically, tyre industry is advancing at a fast pace. In the present scenario of implementing regulatory legislations for controlling green house gas emissions, scope for ecologically and technologically superior tyre is high. It is reported that globally about 22 % of CO_2 emission are from road transport. Tyres account for 24 % of this emission. Hence tyres with low rolling resistance can lead to lesser emission of CO_2 from automobiles. Tyre, synthetic rubber and allied industries are making efforts in this line. Specially prepared synthetic rubbers such as solution SBR and end functionalized high cis-polybutadiene rubber are developments in this direction. Main raw materials that go into the tyres other than polymers are reinforcing fillers. Carbon black and silica are the reinforcing fillers used in tyres. Tyre sector consumes about 6.5 million tonnes of carbon black. Silica, a mineral filler is more preferable over carbon black due to ecological reasons. Substitution of carbon black by silica in tyres results in advantages such as CO_2 emission reduction associated with the production of carbon black, saving of petroleum feed stock for the production of carbon black and fuel saving associated with low rolling resistance. Use of silica in tyres is on the increase, especially in high performance tyres and is expected to reach about 1.5 million tonnes by 2010. However, unlike carbon black use of silica in hydrocarbon rubbers poses some technological barriers. For effective rubber- filler interaction and reinforcement of hydrocarbon rubbers with silica, silane coupling agent also has to be used, which makes the product costlier. Use of a rubber capable of interacting with silica, better than hydrocarbon rubbers is another option for the industry.

Ecologically superior tyre demands it to be manufactured predominantly using renewable materials through an energy efficient means and process and should have low rolling resistance. In this regard, natural rubber and its modified forms are more preferable than synthetic rubbers. Use of ENR in tyre compositions may be a good option that can be attempted. Logical reasons for choosing ENR is due to its origin from renewable NR and also due to its better interaction with silica even without coupling agents.

The present study is on the use of ENR in blend with SBR in sulphur vulcanized rubber compositions reinforced with silica or carbon black and silica. Up to twenty per cent by weight of SBR was replaced with ENR and the variations in properties were studied. Technological and dynamic mechanical properties were found improved on incorporation of ENR.

54. BIOMASS GASIFICATION IN BLOCK RUBBER PRODUCTION FOR REDUCING CO_2 EMISSION IN NR PROCESSING

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Technically Specified Rubber (TSR) or block rubber as it is commonly known, is the major form of processed rubber which accounts for around 6 per cent of natural rubber (NR) produced internationally although its share in India is only around 13 per cent. The production of block rubber in India started during mid 1970s and it essentially involves drying followed by size reduction. During drying, enormous quantity of energy is required to bring down the moisture content of crumbs (3- 8 mm in size) from its initial value of around 35 per cent to a final value of less than 1 per cent. Drying is traditionally carried out in tunnel type driers. Electrically heated driers were in use during the early years when electricity was cheap and was in abundant supply. The scarcity and high cost of electricity during 1990s forced the processors to switch over to Superior Kerosene (SK) and or High Speed Diesel (HSD) for their drying needs. The consumption of HSD in a fuel efficient block rubber drier is in the range of 35 – 40 litres per MT of rubber.

Opening up of Indian economy under the WTO mandated regime from April 1, 2004, posed several challenges to the rubber industry in the country. Quantitative restrictions on import of NR were lifted and free export/import of NR became possible. International competitiveness in terms of cost, quality and consistency became the key factors for survival.

The acute shortage and competition for raw material coupled with increase in cost of power, fuel and labour often prevent the processor from operating the unit profitably. Further, the power and fuel together is found to constitute around 50 per cent of direct cost of processing of block rubber. This forced the processors to explore alternative cost effective sources of heat energy and ended up with the introduction of biomass gasifiers in TSR drying.

Biomass gasifiers are now being increasingly used in the drying of TSR and majority of the units in our country utilizes this as their source of heat energy. The utilization of gasifier technology is found to reduce the drying cost of TSR by half when compared to diesel fired driers.

In a gasification system, a combustible gas mixture, often referred to as producer gas, is generated by controlled burning of agricultural residues like coconut shell, cashew shell, fire wood, briquette etc. The combustible gas mixture consisting of CO, H2, CH4, CO2 and N2 is produced in a reactor under controlled conditions.

The diesel / kerosene saved on account of change over to biomass gasifier for drying one MT of TSR works out to an emission reduction of 140 kg of carbon dioxide. Hence, the adoption of gasifier technology by the entire TSR units in the country would result in considerable reduction in emission of CO2 the atmosphere.

At present, none of the units in other rubber producing countries are reported to be using this technology. If biomass gasifier is utilized for TSR drying by at least half of the TSR units world wide, the reduction in CO2 emission would be enormous which will have a mitigating impact on global warming and erratic climate change. This will further attribute to a substantial reduction in cost of production of TSR in addition to preservation of valuable fossil fuels.

55. MITIGATING THE EMISSION OF GREEN HOUSE GASES DURING RIBBED SMOKED SHEET PROCESSING

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More than 70 per cent of total natural rubber (NR) produced in India is processed in the form of Ribbed Smoked Sheet (RSS). Environmental pollution and emission of green house gases like CO_2 and CH_4 from such processing units is a matter of serious concern. The organic constituents in the processing waste water are decomposed by microorganisms and these green house gases are emitted to the environment that causes global warming.

Earlier, most of the sheet production was under small scale sector which had very limited technical and financial capacity. Usually these units were discharging effluents directly into land or water bodies without any treatment. In order to contain the environmental pollution from these units, RRII developed a treatment method involving biomethanation technology using simple anaerobic digesters (Mathew *et al*., 1997).

Later, group processing centres (GPCs) were promoted by the Rubber Board to produce high quality RSS. Since the quantity of waste water generated from a GPC is large, an efficient anaerobic immobilized growth digester (AIGD) with attached medium for the bacteria was developed by RRII (Mathew *et al.* 2002). A medium sized GPC usually process an average of 500 kg of dry rubber per day, generating about 5000 l of waste water. It was estimated that 3 to 5 l of biogas could be generated through anaerobic digestion from one litre of RSS processing waste water in AIGD. The biogas generated during the biomethanation could effectively be used in the smoke house to dry the wet sheets, replacing about 32.4 per cent firewood.

Methane emission reduction and the CO_2 equivalent of the amount of total energy that is saved as a result of switching over to bioenergy are eligible for revenue through the Clean Development Mechanism (CDM) of the Kyoto Protocol (Mathew *et al.* 2006). The certified emission reduction (CERs) units from a GPC is the difference between the baseline emissions and the sum of project emissions and leakage, i.e.,

$ERy = BEy - (PEy + Leakage_y)$

Where,

ERy is the emission reduction of the project activity for the year "y" (t CO_2 e).

BEy is the baseline emissions in the year "y" (t CO_2 e).

PEy is the project activity emissions in the year "y" (t CO_2 e).

$Leakage_y$ is the leakage in plant in the year "y" (t CO_2 e).

The expected emission reduction by a GPC processing about 500 kg dry rubber per day works out to 30.32 CERs (or t CO_2) per year. Taking a modest price of $ 15 per CER, this can generate a potential revenue of ₹ 20466 / GPC /year.

Biomethanation of effluent and biogas utilization are environmentally benign as compared to the use of firewood which can find other uses. The biomethanation technology has been further improved by RRII and an integrated effluent treatment system consisting of a High Rate Anaerobic reactor and a diffused aeration system (Mathew *et al.* 2008) has been developed. By this system all the pollution parameters of the waste water could be brought down well within the safe limits with a lesser Hydraulic Retention Time (HRT). The treated water from this system is reused for making premium grade sheets. Attempts have already been made to further enhance the efficiency of biomethanation with a still lesser HRT as well as to reduce the cost of the treatment

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TECHNICAL SESSION I

CLIMATE CHANGE AND ITS IMPACT ON NATURAL RUBBER PRODUCTIVITY

Moderator : **Dr. Abdul Aziz Bin S.A. Kadir**
Secretary General, IRRDB

TECHNICAL SESSION II

PROJECTED CLIMATE SCENARIOS AND NATURAL RUBBER SUPPLY IN FUTURE

Moderator : Dr. Stephen V. Evans
Secretary General, IRSG

TECHNICAL SESSION III

NATURAL RUBBER CULTIVATION IN STRESSFUL ENVIRONMENTS

Moderator : Dr. M. R. Sethuraj
Former Director, RRII

TECHNICAL SESSION IV

CLIMATE CHANGE AND PREVALENCE OF DISEASES IN NATURAL RUBBER

Moderator : Dr. K. Jayarathnam
Former Project Director
World Bank Assisted Project
Rubber Board

TECHNICAL SESSION V

INNOVATIONS IN RUBBER PROCESSING AND MANUFACTURING INDUSTRY FOR MITIGATING CLIMATE CHANGE

Moderator : Dr. N. M. Mathew
Former Director, RRII