Ind J Plant Physiol. (July–September 2013) 18(3):231–239
DOI 10.1007/s40502-013-0033-z

ORIGINAL ARTICLE

Adaptation of *Hevea brasiliensis* clones in three widely different cold prone areas of northeastern India

G. Das · M. J. Reju · G. C. Mondal · R. P. Singh · A. P. Thapliyal · D. Chaudhuri

Received: 23 July 2012 / Accepted: 25 June 2013 / Published online: 3 October 2013

Abstract Growth and yield of clones cultivated in three climatologically widely different areas viz. Ganolgre (Tura, Meghalaya), Nagrakata (Jalpaiguri, West Bengal) and Sarutari (Kamrup, Assam) were compared to understand the behavioral difference of the clones under the native climate. Clone trails were initiated at the three locations with 14 clones along with a check clone. The growth period over years was separated as non-winter (NW—April to September) and winter (W—October to March) periods. A clear indication of adverse effect of low winter temperature on girth increment was observed. Girth of *Hevea* clones at 20th year of growth with high biomass was found to be better in the climatic condition of Ganolgre than Nagrakata followed by Sarutari. It seems that the optimum rainfall and marginally suitable slope along with proper range of low winter temperature favoured better growth in Ganolgre compared to that in Nagrakata though altitude of Ganolgre was more than Nagrakata. Yield of all the clones were at par with or lower than the check clone. Yield in Nagrakata was the best among the three locations followed by Sarutari; and it was lowest in Ganolgre. The study explored the scope of cultivating *Hevea brasiliensis* in "severe cold prone areas", which in future may be come partially cold prone areas due to gradual but steady change in climate.

Keywords Adaptation · Agroclimate · Biomass · Growth rate · Rubber · Yield

G. Das (✉) · G. C. Mondal · D. Chaudhuri
Rubber Research Institute of India, Regional Research Station, Dispur, Guwahati, India
e-mail: gitalidas@rubberboard.org.in

M. J. Reju · R. P. Singh · A. P. Thapliyal
Rubber Research Institute of India, RRS, Tura, India

Present Address:
M. J. Reju
Rubber Research Institute of India, Kottayam, Kerala, India

Introduction

The deviating climate, consisting of sets of weather attributes along with gaseous distribution (ozone, CO_2 etc.) and biotic potential over years, brings about erratic/unpredictable environment that imposes stress on the growth and productivity of plants. In forest trees, the adaptation strategy of tree species and varieties needs to be studied extensively, because due to long life span it gets acclimatized slowly but steadily (Lindner et al. 2010). Whereas, in annual or biennial crop, where the lifespan is short, the phenotypic expression is faster (Anderson et al. 2011). In perennial trees such expression comes from the cumulative effect over the years.

The fact that acclimatization of *Hevea* to non-indigenous climate, especially stress prone areas (like low temperature, higher altitude, high windspeed) of China resulted in profitable returns (Guohua and Haiping 2005), attracted the attention for cultivating rubber in the or near to the Sub-Himalayan range of northeastern India viz. Tripura (Priyadarshan et al. 1998), Assam (Mondal et al. 2007a), Meghalaya (Reju et al. 2002, 2007) and Northern parts of West Bengal (Das et al. 2010). Moreover, due to the climate change some of the today's severe cold prone areas may come under partially cold prone areas in the future where rubber cultivation would be recommendable. For such future scope, suitable cultivation package needs to be available for these partially cold prone areas. Hence the growth and yield of clones cultivated in three widely different areas of sub-Himalayan northeastern India were compared to understand the behavioural differences of the clones under the native climate, to screen clone(s) performing better in low winter temperature of northeastern India and to understand, which weather parameter(s) would be the utmost constraint in these three regions.

Materials and methods

Clone trials were undertaken in three different locations of sub-Himalayan northeastern India viz. Ganolgre, (Tura, Meghalaya), Nagrakata (Jalpaiguri, West Bengal) and Sarutari (Kamrup, Assam). The experimental site at Ganolgre is situated at the highest elevation (600 m MSL) among the three stations (Table 1) followed by Sarutari (hilly terrain of 50–105 m MSL); Nagrakata (69 m MSL) is a flat area compared to the other two sites. Weather data of all the stations were collected from the meteorological station established near to the experimental sites in 1990, 1989 and 1991 in Ganolgre, Sarutari and Nagrakata, respectively. Mean of successive 10 years of weather data collected from different stations was used to calculate moving average over years to understand the weather change, if any, within the experimental period.

Clone trail at Ganolgre and Sarutari was started in 1985 and 1986 in complete randomized design and at Nagrakata in 1990 and 1991 in randomized block design. Fourteen clones viz. GL 1, GT 1, PB 235, PB 260, PB 310, PB 311, PB 5/51, PB 86, RRIC 102, RRII 105, RRII 118, RRII 203, RRII 208 and RRIM 605 were selected for study and RRIM 600 was considered as the check clone for all the stations. Plants were tapped (cutting of bark) under half spiral alternate day (S2d2) system of tapping with Sunday rest and winter tapping rest (no tapping during winter period approximately from January to March) with around 104–108 tapping days in an year for all the stations, provided rain guarding were fixed to the plants for saving loss of tapping days due to rain. Girth data was taken at 125 cm height on monthly basis from 3rd year of planting till 12rd year and annually there after. Tappable girth of 50 cm was attained in 70 % of the plants in the experimental block by 8rd year of planting in all the stations, however, regular monthly yield data (g dry rubber tree^{-1} tapping^{-1}) recording was initiated from 9rd year onwards on fresh weight basis, which was transformed to dry weight using the formula $Y = 0.4355x + 1.1428$ (Das et al. 2010). Biomass calculation was done following the equation girth$^{2.783}$ $\times$ 0.0026 (Shorrocks et al. 1965). Efficiency of the clones was calculated by dividing mean projected yield (kg dry rubber ha^{-1}) with mean biomass (kg tree^{-1}) after tapping at 20th year of growth. Girth increment rate (GI) at juvenile phase was calculated from 3rd to 5rd year, followed by immature phase from 6rd to 8rd year and mature phase from 9rd to 11rd year. The crop harvested from May to December every year and over the yielding period was separated into non-winter (NW—May to September) and winter (W—October to December) periods. All the data were subjected to analysis of variance.

Severity of powdery mildew disease was recorded by random sampling of ten representative trees of each clone. The incidence of powdery mildew disease was assessed from immature top whorl of leaves on five twigs selected randomly from each experimental tree. For estimation of severity, the sum of infection grade of each sample was divided by the total observation number, which included both infected and non-infected leaflets (Samaradeewa et al. 1985).

Results and discussion

Distribution of weather attributes during non-winter (NW) and winter (W) periods revealed that climate of Sarutari was warmer during NW period (Table 1) with a range of T_{max} 31.6–33.4 °C followed by Nagrakata (30.0–32.2 °C) and Ganolgre (29.0–31.9 °C). The mean NW T_{max} was higher in Sarutari, whereas T_{min} was lowest in Ganolgre. The W T_{max} was similar in all the stations and T_{min} was similar in Ganolgre and Nagrakata. Mean temperature in Ganolgre was lower than Sarutari followed by Nagrakata. Duration of bright sunshine hour (SSH) during NW period was similar at all the sites. During W period, the range of T_{max}, T_{min} and mean temperature in Nagrakata was wider than Ganolgre and Sarutari. The total rainfall in Nagrakata during NW period was the highest followed by Ganolgre and Sarutari; this trend was followed during W period also. The statistically analyzed data with mean, SE, range and SD on different weather attributes at these three locations showed that the influence of experimental period (weather) over the locations was negligible. The successful establishment of *Hevea* in North Konkan (drought) as well as in NE (cold prone) region in India confirms the wide adaptability of the rubber plants (Jacob et al. 1999). Average of weather parameters for successive 10 years and also during non-winter (NW) and winter (W) period was calculated (termed as moving average) and graphically represented (Fig. 1) in order to understand the successive changes within the short time span. Over the years T_{max} showed increasing trend (Fig. 1A) at all the sites, T_{min} showed significant decreasing trend at Ganolgre. Bright SSH showed decreasing trend in Ganolgre and Nagrakata but in Sarutari the trend was not promising. Total precipitation

Table 1 Distribution of climatological parameters in three different Sub-Himalayan range during non-winter and winter periods (yearly mean over 19–21 years)

Place	Position	Mean climatological parameters over years				
		T_{max} (°C)	T_{min} (°C)	Mean temp. (°C)	SS (h)	Total RF (mm)
Non-winter (May–September)						
Ganolgre, Tura, Meghalaya (1990–2009)	Latitude 25°26′N	30.5 ± 0.17	20.7 ± 0.22	25.6 ± 0.13	4.8 ± 0.11	2122 ± 119.35
	Longitude 90°91′E					
	Altitude 600 m MSL					
	Range	29.0–31.9	18.0–22.4	24.1–26.5	4.0–5.9	1303–3176
	SD	0.78	0.97	0.60	0.50	533.76
Nagrakata, West Bengal (1991–2009)	Latitude 26°43′N	31.5 ± 0.12	22.5 ± 0.32	30.0 ± 0.32	4.5 ± 0.13	3425 ± 142.36
	Longitude 88°26′E					
	Altitude 69 m MSL					
	Range	30.0–32.2	19.3–5.2	25.7–28.1	3.8–5.9	2189–5145
	SD	0.51	1.41	0.70	0.59	620.53
Sarutari, Kamrup, Assam (1989–2009)	Latitude 26°35′N	32.2 ± 0.11	22.5 ± 0.21	27.4 ± 0.11	4.6 ± 0.16	1389 ± 105.57
	Longitude 90°52′E					
	Altitude 50–105 m MSL					
	Range	31.6–33.4	19.9–23.5	26.2–28.2	2.9–5.6	662–2923
	SD	0.51	0.95	0.52	0.72	483.80
Winter (October–December)						
Ganolgre, Tura, Meghalaya (1990–2009)	Latitude 25°26′N	27.1 ± 0.22	12.3 ± 0.16	19.7 ± 0.15	7.0 ± 0.16	296 ± 50.59
	Longitude 90°91′E					
	Altitude 600 m MSL					
	Range	25.8–29.2	11.3–13.9	18.8–21.6	5.4–8.1	73–901
	SD	0.99	0.71	0.66	0.72	226.23
Nagrakata, West Bengal (1991–2009)	Latitude 26°43′N	27.2 ± 0.28	12.3 ± 0.38	19.8 ± 0.27	6.5 ± 0.17	332 ± 46.85
	Longitude 88°26′E					
	Altitude 69 m MSL					
	Range	23.8–29.3	8.0–16.2	16.7–21.1	5.4–7.7	104–760
	SD	1.23	1.67	1.16	0.75	204.22
Sarutari, Kamrup, Assam (1989–2009)	Latitude 26°35′N	27.4 ± 0.14	14.5 ± 0.23	20.9 ± 0.17	6.2 ± 0.16	207 ± 17.76
	Longitude 90°52′E					
	Altitude 50–105 m MSL					
	Range	26.5–28.7	11.7–15.8	19.1–22.2	4.3–7.4	23–332
	SD	0.68	1.06	0.78	0.73	81.37

T_{max} Maximum temperature, T_{min} minimum temperature, *SS* sunshine duration, *P* precipitation

showed increasing trend at all the sites, especially in Ganolgre.

During NW period (Fig. 1B), the increasing trend in T_{max} was prominent in Nagrakata and Ganolgre and the decrease in T_{min} was significant in Ganolgre only. Bright SSH in Nagrakata and Ganolgre decreased, whereas rainfall in Sarutari and Ganolgre showed increasing trend. During W period (Fig. 1C), T_{max} and T_{min} showed increasing trend and bright SSH showed decreasing trend at all the sites. Increasing trend in precipitation (rainfall) was observed in Nagrakata and Ganolgre, whereas in Sarutari, it did not change. The data revealed that the trend of change in meteorological parameters in Ganolgre and Nagrakata was similar, however, the decreasing trend in sunshine duration in NW period could be due to gradual increase in number of day-time-rain and that during W period, it could be due to more humid (foggy) days during day time. From the study on changes in weather attributes within the experimental period viz. the rise in T_{min} and T_{max} over the years and during winter period, it seems that there would be a chance of shifting the climatic condition in Nagrakata and Ganolgre towards a better suited region for rubber cultivation in future compared to the present day condition.

The growth characteristics of clones in these three climatically widely different regions were studied (Table 2).

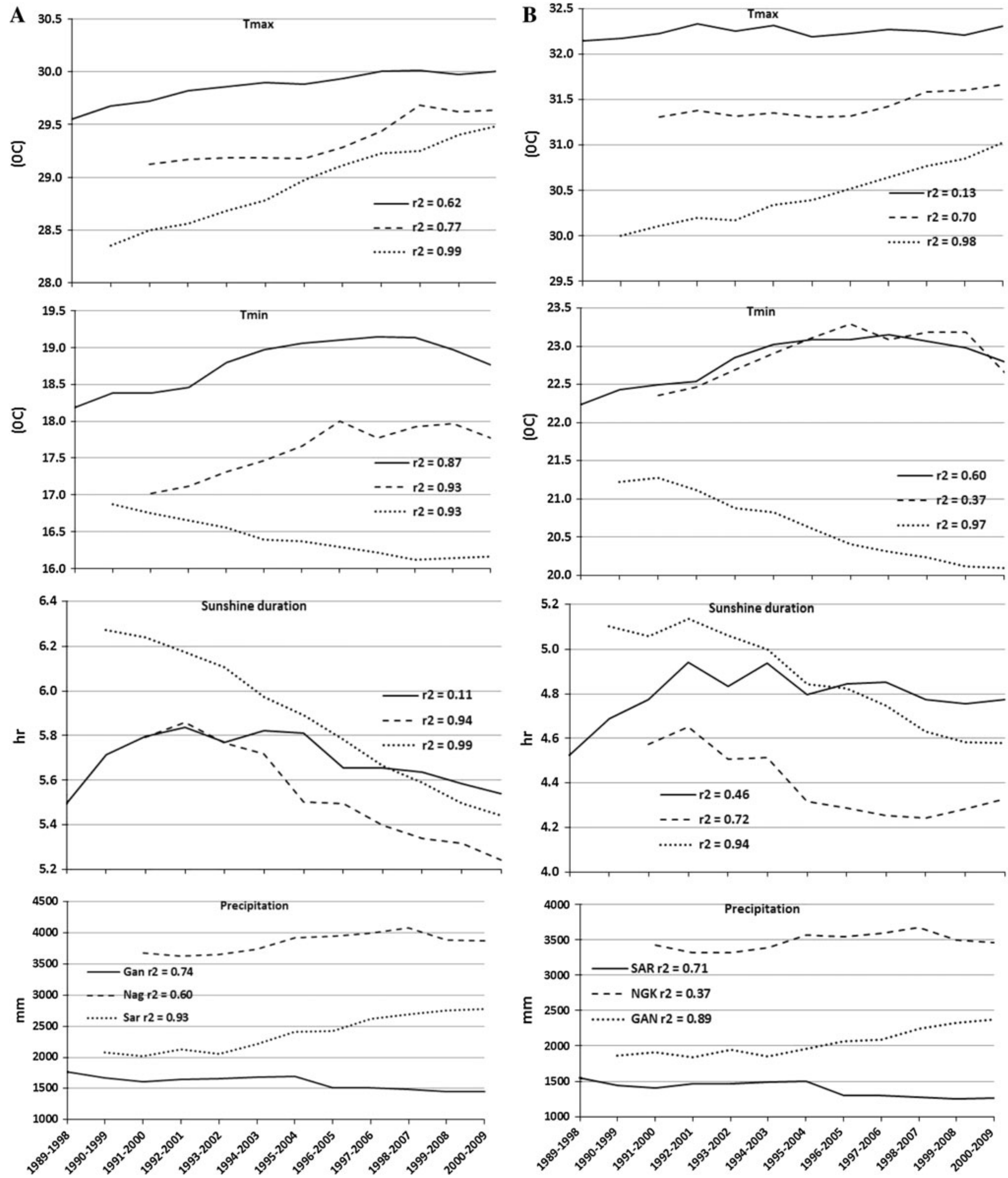

Fig. 1 Moving average of weather parameters in successive 10 years from 1989–2009. **A** Whole year, **B** non-winter period, **C** winter period

In general, girth increment (GI) during NW period was more than the W period. At Ganolgre GI in NW period were 5 times greater than that in W period during juvenile phase though SSH was more during W period (Table 1) at the higher altitude of 600 m MSL. At Nagrakata the GI in NW period was 3.1 times more than the W period during juvenile phase, which declined to 2.8 times in mature phase. At Sarutari the GI during NW in juvenile phase was

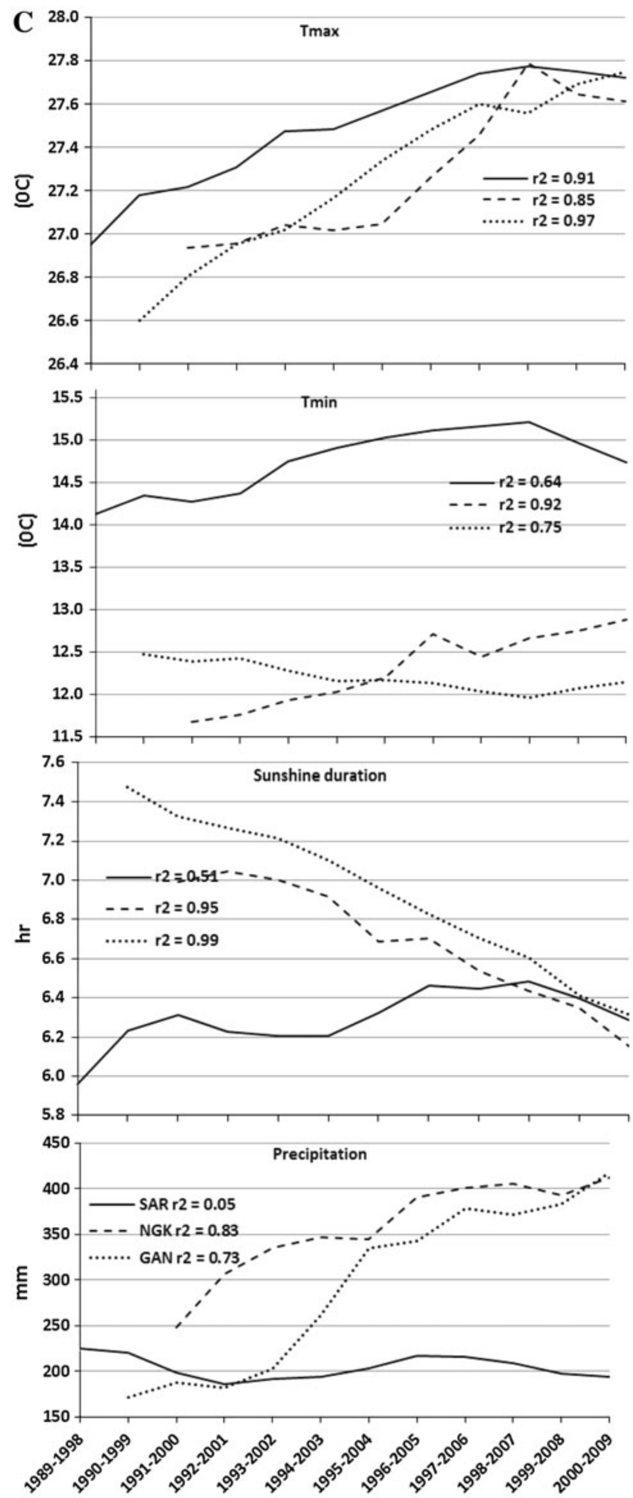

Fig. 1 continued

2.3 times more than W period which declined to 1.8 times during mature phase. The adverse effect of bright sunshine with low temperature (Jacob et al. 1999) could be the reason of lower growth of the plants during winter which was more deleterious during juvenile phase and evaded gradually through immature phase to the mature phase. The number of clones showing better growth was more at Sarutari during NW period and it was more during W period in juvenile phase at Nagrakata. During immature phase, it was more in Ganolgre during NW period and during W period it was in Sarutari. During mature phase, number of clones showing better growth during NW period was more at Ganolgre while during W period it was more at Sarutari. A clear indication of adverse effect of low winter temperature on GI was observed. Minimum girth increment has also been reported during winter period in Tripura (Meenatoor et al. 1991; Priyadarshan et al. 1998).

Number of clones showing girth below 50 cm (tappable girth) was only two at Ganolgre and Sarutari, whereas at Nagrakata it was eight. Clones with superior girth and biomass than the check clone, after 20th year of planting were not observed at Ganolgre. Two clones in Nagrakata showed significantly higher girth and biomass compared to RRIM 600. In Sarutari only one clone showed higher girth and biomass than the check clone. In general, the girth and biomass of trees in Ganolgre was higher, though the low winter temperature was severe than at Nagrakata and Sarutari. Jiang (1988) reported that growth in *Hevea* is severely inhibited when monthly mean temperature goes below 20 °C. In the present experimental sites, it might be the range of temperature coupled with adequate rainfall and optimum sunshine duration that could be one of the important weather attributes along with the mean T_{max} or T_{min} rather than any one attribute alone. The better growth of plants in Ganolgre could be due to adequate sunlight coupled with optimum rainfall compared to Nagrakata; moreover, during W period, the range of temperature was 11.3–13.9 °C at Ganolgre, whereas in Nagrakata it was 8.0–16.2 °C which might be reflected on growth also.

In general, yield of all the clones was either on par with or lower than that of RRIM 600 because among the selected clones, the yield of RRIM 600 (check). The yield of clones during NW period was lower than the W period at all the sites (Fig. 2).

The projected yield over 11–13 years in hectare is presented in Fig. 3. At all the three widely different climatic conditions of northeastern India, yield of RRIM 600 was the best. At Ganolgre yield of PB 311 and RRII 105 were on par with RRIM 600, while at Nagrakata RRII 208, PB 310 and PB 235 and at Sarutari RRII 208, PB 235, RRII 203, PB 310, RRII 118 and RRII 105 were on par with RRIM 600. It was observed that the number of clones showing yield at par with check were more at Sarutari as the climate was more suitable for rubber growth than the other two stations where severe low winter temperature was one of the constraints. Compared to the yield potential of clones at the northeastern regions, mean estimated yield of RRIM 600, PB 235, PB 310, PB 311 and RRII 105 have

Table 2 Girth increment rate (cm year^{-1}) during (a) non-winter period, (b) winter period in some clones of *Hevea*

Clones	Juvenile			Immature			Mature		
	Ganolgre	Nagrakata	Sarutari	Ganolgre	Nagrakata	Sarutari	Ganolgre	Nagrakata	Sarutari
(a)									
GL 1	1.11	0.96	0.58	0.37	0.63	0.33	0.29	0.15	0.16
GT 1	1.23	1.00	0.58	0.45	0.42	0.48	0.36	0.35	0.22
PB 235	1.24	0.91	0.58	0.44	0.66	0.36	0.32	0.41	0.19
PB 260	0.93	0.98	0.94[a]	0.73[a]	0.51	0.37	0.51[a]	0.40	0.30[b]
PB 310	1.02	0.96	0.77	0.78[a]	0.47	0.42	0.71[a]	0.32	0.25
PB 311	1.07	1.13	0.83[b]	0.86[a]	0.52	0.45	0.80[a]	0.14	0.17
PB 5/51	1.04	0.95	0.50	0.26	0.52	0.21	0.31	0.14	0.11
PB 86	1.11	0.99	0.60	0.31	0.61	0.48	0.31	0.26	0.24
RRIC 102	0.84	1.03	0.84[b]	0.82[a]	0.63	0.48	0.71[a]	0.33	0.22
RRII105	0.98	1.04	0.67	0.61[a]	0.65	0.43	0.47[b]	0.19	0.13
RRII 118	1.19	1.08	0.67	0.45	0.37	0.47	0.37	0.18	0.22
RRII 203	1.13	1.04	0.32	0.51	0.58	0.42	0.45[b]	0.19	0.24
RRII 208	0.96	0.94	0.88[b]	0.71[b]	0.60	0.38	0.75[a]	0.30	0.22
RRIM 605	1.27	1.12	0.68	0.39	0.60	0.40	0.29	0.17	0.13
RRIM 600	1.30	1.08	0.67	0.37	0.64	0.54	0.30	0.38	0.23
Global mean	1.09	1.01	0.67	0.54	0.56	0.41	0.46	0.26	0.20
CD($P \leq 0.05$)	NS	NS	0.13	0.16	NS	NS	0.15	NS	0.04
Good growth[b]	0	0	4	6	0	0	7	0	1
Low growth[a]	10	9	2	0	6	11	0	8	5
(b)									
GL 1	0.23	0.42[a]	0.27	0.32	0.10	0.12	0.22	0.06	0.13[b]
GT 1	0.29	0.25	0.25	0.27	0.13	0.16	0.35	0.08	0.10
PB 235	0.29	0.44[a]	0.35	0.44	0.17	0.13	0.40	0.10	0.03
PB 260	0.08	0.20	0.25	0.13	0.12	0.18	0.15	0.09	0.08
PB 310	0.10	0.35[b]	0.47	0.15	0.14	0.27[a]	0.25	0.03	0.18[a]
PB 311	0.07	0.19	0.31	0.12	0.13	0.26[a]	0.15	0.04	0.12[b]
PB 5/51	0.31	0.36[b]	0.16	0.33	0.16	0.10	0.29	0.10	0.07
PB 86	0.30	0.36[b]	0.25	0.51	0.16	0.23[b]	0.38	0.11	0.09
RRIC 102	0.12	0.34	0.37	0.17	0.27[a]	0.24[b]	0.25	0.15[b]	0.23[a]
RRII105	0.21	0.35	0.25	0.25	0.16	0.16	0.25	0.08	0.05
RRII 118	0.33	0.27	0.29	0.29	0.16	0.10	0.39	0.13[b]	0.07
RRII 203	0.22	0.35	0.18	0.31	0.13	0.13	0.32	0.11	0.19[a]
RRII 208	0.06	0.39[b]	0.38	0.18	0.17	0.18	0.21	0.06	0.18[a]
RRIM 605	0.39	0.40[b]	0.21	0.30	0.14	0.19[b]	0.25	0.05	0.12[b]
RRIM 600	0.46	0.29	0.44	0.44	0.19	0.14	0.39	0.09	0.07
Global mean	0.23	0.33	0.29	0.28	0.16	0.17	0.28	0.09	0.11
CD($P \leq 0.05$)	NS	0.06	NS	NS	0.03	0.05	NS	0.03	0.05
Good growth[b]	0	7	0	0	1	5	0	2	7
Low growth[a]	13	2	11	12	7	0	9	3	0

[a] No of clones showing lower growth compared to RRIM 600

[b] No of clones showing better growth compared to RRIM 600

been reported to be higher with traditional area of India (Marattukalam et al. 2006). The yield of RRIM 600 at Nagrakata was higher over 11 years compared to that in Kerala (Table 3).

The data on severity of powdery mildew disease (Table 4) showed that the pattern of disease invasion was similar at all the three regions. The average of disease incidence showed that the Nagrakata area was more

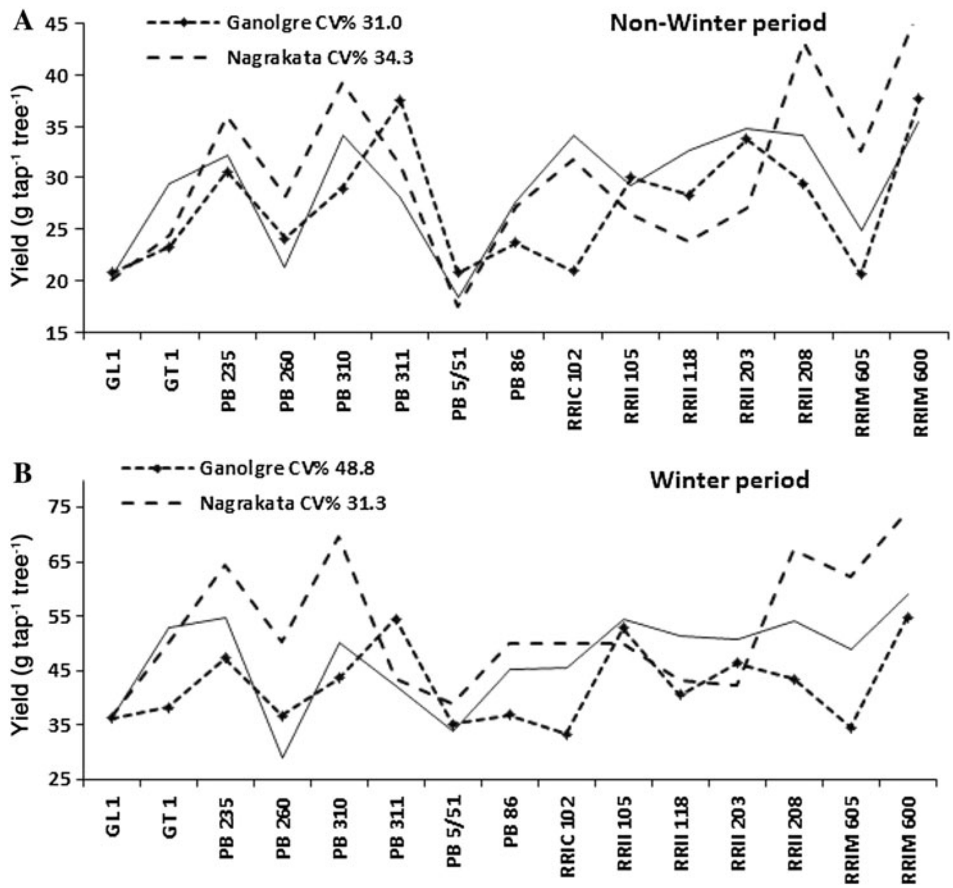

Fig. 2 Pattern of yield in non-winter (**A**) and winter (**B**) periods in some clones of *Hevea*

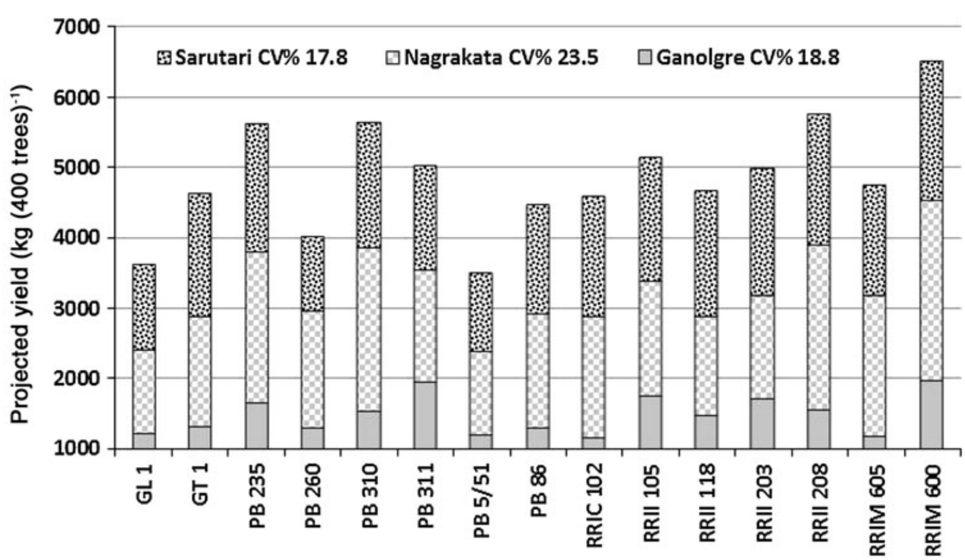

Fig. 3 Pattern of projected yield in some clones of *Hevea* in three different regions

susceptible to powdery mildew disease which might be due to congenial agroclimate for disease invasion (Mondal et al. 2007b); in Sarutari and Ganolgre the disease incidence were lower.

The study indicated that a warmer weather is developing in Nagrakata and Ganolgre (Fig. 1) compared to Sarutari, where trend of changes in T_{min} was not prominent. Yield of clones was found to be adversely affected by the climatic condition of Ganolgre compared to Nagrakata, which might be the consequence of severe low winter temperature combined with slope and altitude. Importance of slope on soil temperature and growth of *Hevea* during winter

Table 3 Growth characteristics in some clones of *Hevea*

Clones	Girth at 20th year after planting (cm)			Biomass at 20th year after planting (kg tree^{-1})		
	Ganolgre	Nagrakata	Sarutari	Ganolgre	Nagrakata	Sarutari
GL 1	72.4	63.6	61.0	390	272	242
GT 1	80.7	64.9	73.8	527	288	411
PB 235	87.0	69.6	72.7	650	349	394
PB 260	76.0	61.8	69.3	446	251	345
PB 310	93.6	89.6[a]	77.6	796	706[a]	473
PB 311	89.3	66.9	72.3	699	313	388
PB 5/51	68.4	63.4	54.9	333	270	180
PB 86	83.5	68.3	74.0	579	332	414
RRIC 102	89.0	69.5	84.3[b]	692	348	595[b]
RRII105	78.7	62.8	65.3	491	262	292
RRII 118	85.4	75.8[b]	78.8	617	443[b]	493
RRII 203	88.7	65.4	79.2	686	294	500
RRII208	85.1	66.0	72.4	611	302	390
RRIM 605	78.9	73.5[b]	70.7	495	406[b]	365
RRIM 600	91.9	68.5	77.6	757	334	473
Global mean	83.2	68.7	72.3	584	345	397
CD($P \leq 0.05$)	NS	5.67	6.08	NS	91.78	85.82
Good growth[b]	0	2	1	0	2	1
Low growth[a]	8	2	5	7	0	4

[a] No of clones showing lower growth compared to RRIM 600

[b] No of clones showing better growth compared to RRIM 600

Table 4 Severity of powdery mildew disease in some clones of *Hevea* (mean of 3 years)

Clones	Incidence of powdery mildew disease					
	Ganolgre		Nagrakata		Sarutari	
	Severity	Relative ranking	Severity	Tolerance/susceptible	Severity	Tolerance/susceptible
GL 1	3.0	S	4.0	S	3.5	S
GT 1	2.3	MT	2.5	MT	2.5	MT
PB 235	4.3	HS	5.0	HS	5.0	HS
PB 260	2.6	S	3.0	S	2.7	S
PB 310	2.4	MT	2.5	MT	2.5	MT
PB 311	2.4	MT	2.5	MT	2.5	MT
PB 5/51	4.5	HS	5.0	HS	5.0	HS
PB 86	1.4	T	1.8	T	1.5	T
RRIC 102	2.8	S	3.2	S	3.0	S
RRII 105	4.1	HS	4.5	HS	4.2	HS
RRII 118	2.6	S	2.9	S	2.7	S
RRII 203	2.5	MT	2.5	MT	2.5	MT
RRII 208	2.5	MT	2.5	MT	2.5	MT
RRIM 605	2.8	S	3.5	S	3.0	S
RRIM 600	2.0	MT	2.5	MT	2.0	MT

T tolerant (1.0–1.9), *MT* moderately tolerant (2.0–2.5), *S* susceptible (2.6–3.5), *HS* highly susceptible (>3.6)

months was explored by Saseendran et al. (1993). Performance of the thirteen clones at three different agroclimate of northeastern India also varied widely. At Sarutari RRII 208, PB 235, RRII 203, PB 310, RRII 118 and RRII 105 showed appreciable yield (Fig. 3) along with RRIM 600, while at Nagrakata RRII 208, PB 310 and PB 235 and at

Ganolgre PB 311 and RRII 105 performed better. The clones RRII 208, PB 310 and PB 235 performed better at both the agro-climate of Sarutari and Nagrakata whereas RRII 105 performed well in Sarutari and Ganolgre. Hence, the agro-climate specific recommendation of *Hevea* clones would be worth recommending. Further, a congenial weather for rubber cultivation, with increasing tendency of T_{min} and decreasing tendency of sunshine duration during winter was observed in regions like Nagrakata and Ganolgre and, such study would be of great significance for these regions in future for recommending rubber cultivation for marginally suitable areas.

Acknowledgments The authors are grateful to Dr. James Jacob, Director (Research), RRII, for providing facilities and support in conducting the experiment. Thanks are due for Dr K. K. Mydin, Joint Director, Crop Improvement and Dr K. Krishnakumar, Joint Director, Crop Physiology for their support and encouragement in drafting the paper. The authors are thankful to Sri M Choudhury, Scientist, RRS, Guwahati for helping in interpretation of statistically analysed data. The help of all the scientists associated with the trials in the initial and mature phase is gratefully acknowledged.

References

Anderson, J. T., Wills, J. H., & Mitchell-Olds, T. (2011). Evolutionary genetics of plant adaptation. *Trends in Genetics, 27*(7), 258–266.

Das, G., Chaudhuri, D., & Varghese, Y. A. (2010). Evaluation of Hevea clones in the mature phase under the agroclimate of Sub-Himalayan West Bengal. *Journal of Plantation Crops, 38*(2), 105–110.

Guohua, F., & Haiping, X. (2005). *Empirical analysis on supply and demand of NR in China. International Natural Rubber Conference, 6–8 November Cochin* (Vol. 4, pp. 7–12). Kerala, India, Preprints.

Jacob, J., Annamalainathan, K., Alam, B., Sathik, M. B. M., Thapliyal, A. P., & Devakumar, A. S. (1999). Physiological constraints for cultivation of *Hevea brasiliensis* in certain unfavourable agroclimatic regions of India. *Indian Journal of Natural Rubber Research, 12*, 1–16.

Jiang, A. (1988). Climate and natural production of rubber (*Hevea brasiliensis*) in Xishuamg-banna, southern part of Yunan province, China. *International Journal of Biometry, 32*, 280–282.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., et al. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management, 259*, 698–709.

Marattukalam, M. A., Nazeer, M. A., Goerge, P. J., & Chandrasekhar, T. R. (2006). Long-term performance of twenty clones of *Hevea brasiliensis* under large-scale trial in India. *Natural Rubber Research, 19*(1&2), 51–57.

Meenatoor, J. R., Vinod, K. K., Sinha, R. R., & Potty, S. N. (1991). Clone x environment interaction during early growth phase of *Hevea brasiliensis*: 1. Clonal stability on girth. *Indian Journal of Natural Rubber Research, 4*(1), 51–54.

Mondal, G. C., Deka, H. K., & Chaudhuri, D. (2007a). Reaction of *Hevea brasiliensis* clones against powdery mildew disease in northeastern region of India. *Natural Rubber Research, 20*(1&2), 90–93.

Mondal, G. C., Singh, R. P., Mondal, D., Gupta, C., Gohain, T., Chaudhuri, D., et al. (2007b). Evaluation of yield potential of *Hevea brasiliensis* clones over 10 years of tapping in Assam. *Natural Rubber Research, 20*(1&2), 32–38.

Priyadarshan, P. M., Sudhasowmyalatha, M. K., Sasikumar, S., Varghese, Y. A., & Dey, S. K. (1998). Relative performance of six *Hevea brasiliensis* clones during two yielding regimes in Tripura. *Indian Journal of Natural Rubber Research, 11*, 67–72.

Reju, M. J., Thapliyal, A. P., Gopalakrishnan, J., Deka, H. K., & Soman, T. A. (2002). First panel yield of eight Hevea clones in sub-tropical Meghalaya. *Indian Journal of Natural Rubber Research, 15*(1), 190–193.

Reju, M. J., Thapliyal, A. P., Singh, R. P., Soman, T. A., Nazeer, M. A., & Varghese, Y. A. (2007). Promising *Hevea brasiliensis* clones for the sub-tropical climate of Meghalaya. *Indian Journal of Natural Rubber Research, 20*(1&2), 50–55.

Samaradeewa, P. K., Liyanage, A. S., & Wickremasinghe, W. N. (1985). Relationship between the incidence and severity of Colletotrichum gloeosporioides leaf disease in *Hevea brasiliensis*. *Journal of Rubber Research Sri Lanka, 63*, 1–8.

Saseendran, S. A., Mandal, D., Sinha, R. R., Vijayakumar, K. R., Potty, S. N., & Sethuraj, M. R. (1993). Effect of aspect on soil temperature and growth of Hevea on hills of North east India. *Journal of Natural Rubber Research Malaysia, 6*(1&2), 105–110.

Shorrocks, V. M., Templeton, J. K., & Iyer, G. C. (1965). Mineral nutrition, growth and nutrient cycle of *Hevea brasiliensis*: 3 relationship between girth and shoot dry weight. *Journal of Natural Rubber Research Malaysia, 19*, 85–92.