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Phenological Changes in *Hevea brasiliensis* under Differential Geo-climates

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Climatic changes induce significant manifestations in the phenology of plants viz. *defoliation and refoliation, flowering and fruiting, seasonal emergence of new whorls of leaves* etc. *The relegation of* Hevea brasiliensis *towards north and south of the equator is seen to influence the phenology. The expressions of phenological attributes and yielding pattern are in tune with the seasons/climate in the north and south of the equator. Rainfall and its distribution pattern, sunshine hours, mean temperature, wind velocity and evaporation are found to be crucial factors governing establishment, growth and yield of* Hevea. *Information gathered on phenology and yielding pattern from the non-traditional regions of China, Brazil, Cote d'Ivoire, French Guiana and Indonesia are compared in relation to differential geo-climates. While north of the equator has the lean yielding period during March-April, the south of the equator experiences lean period during September-February, which perhaps ensures stabilised supply of rubber in the international market.*

Keywords: *Phenology, equator, geo-climate,* Hevea, *latitude, non-traditional areas, biotic stress, yielding pattern.*

Plants are excellent indicators of climate changes. In their original habitat or otherwise, plant species express their sensitivity to environmental changes through phenological manifestations. This has become evident in studies on International Phenological Gardens (IPG) (Menzel, 2000; Menzel & Fabian, 1999). These manifestations are in the form of defoliation and refoliation, flowering and fruit set and seed dispersal. In a perennial crop species, where yield can be retrieved throughout the year, the fluctuations in yield in accordance with the seasonal changes are also vital while detecting and measuring these manifestations.

Para rubber (*Hevea brasiliensis*), though has a history spanned over more than 450 years, attained prominence only during later half of the nineteenth century. Introduced from the Amazon basin to Southeast Asia, it staked almost 40 per cent of the export revenue of Brazil until 1940 (Dean, 1987). While Indonesia and Malaysia started commercial ventures during early 1900, India and Thailand began cultivation during 1920's and 1930's respectively. China came to the scene in early 1960's (Barlow, 1997). The current rubber statistics keeps Thailand as the top rubber producer followed by Indonesia, Malaysia, India, China, Sri Lanka, Nigeria, Vietnam, Cote d'Ivoire, Philippines, Liberia, Brazil and Zaire in the descending order of hierarchy. The Southeast Asian countries continue to enjoy dominance in rubber production and trade

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through manoeuvering more than 60 per cent of the 5.7 million metric tonnes of annually produced rubber worldwide with India sharing maximum productivity.

The natural habitat of *Hevea* is the rain forests of the Amazon basin situated within 5° latitudes at altitudes below 200 m. The climate is equatorial monsoon type characterised by mean monthly temperature of 27-32° C, with high humid atmosphere, well-distributed rainfall (2 000 mm) with no marked dry period. In general, trees perform best in climates, which closely resembles its original habitat. The center of origin and geographical distribution of crop plants reveal that latitudinal changes affect the expression of characters more than altitude. Since the genus evolved in the tropical rain forests, the prime climatic factors that influence its cultivation are rainfall and its distribution, temperature, sunlight hours, relative humidity and wind speed. Among these, total rainfall and its distribution as well as mean minimum and maximum temperature have to be considered vital while selecting regions for successful rubber cultivation.

The traditional rubber growing tracts extend to 10° north and south of equator and these areas offer ideal environment with a mean annual temperature of 28±2° C, in addition to well spread annual rainfall of 2 000-4 000 mm extending from 100 to 150 days (Pushparajah, 1983). The ideal altitude shall be below 400 m though rubber is seen even at 1000 m in Annamallai Hills in South India, Colombia and Uganda (Wright, 1998). Towards the end of the twentieth century, many Asian countries took up rubber cultivation in marginal conditions due to multitude of reasons. A few would be: expansion of civilisation in traditional areas, the awareness created about quality improvement of agricultural products and competitiveness among the people of non-traditional environments and the implementation of policy decisions to upgrade the living standards of people in non-traditional areas. China, Vietnam and the northeastern states of India fall under non-traditional zones that experience one or more physical stresses *viz.*, drought, low temperature, high altitude and strong winds. Similarly, Thailand and Brazil also have non-traditional zones delineated based on latitudinal and altitude changes.

The mean annual temperatures decreases and dry period increases when moved away from the equator with more prominent winter conditions during November-January. Northeastern states of India and rubber growing areas of China lying between 18° and 24° N are regions well recognised as inhospitable for the crop, exhibiting stress situations like low temperatures and typhoons (Priyadarshan *et al.*, 1998a; Zongdao & Yanqing, 1992). It may also be worthwhile to note that climatic conditions in vivid pockets of China shall vary since China's tropical and sub-tropical regions are undulating and diversified (Priyadarshan *et al.*, 1998a). An attempt is made here to assess phenological changes in *Hevea* when grown under different geo-climatic situations. The non-traditional areas *viz.*, Tripura and Sao Paulo (Brazil) are considered to derive conclusions on phenological changes and yielding pattern.

CLIMATIC AND BIOTIC ATTRIBUTES INFLUENCING *HEVEA BRASILIENSIS* IN TRIPURA (NORTH EAST INDIA) AND CHINA

Tripura in India offers suitable non-traditional environment for rubber, in spite of its prevailing abiotic stresses like low winter temperature and high-speed wind. It is the smallest state of Northeast India with an area of 10491.69 sq.

km, situated between 22° 56' and 24° 32' N ; 91° 10' and 92° 21' E. The climate is sub tropical (Mediocre) with moderate temperature (summer: 36.6°-17.9°C; winter: 28.9°-7.17°C) and a high humid atmosphere. It is worth mentioning that rubber-growing areas of Northeast India and China fall under the same latitudinal range. In Northeast India, the minimum temperature seldom falls below 7° C during extreme winter, while in China, two types of cold regimes have been identified *viz.*, radiative and advective (Zongdao & Xueqin, 1983). In radiative type, the night temperature falls sharply to 5° C and the day temperature ranges between 15 to 20° C or above; while in advective type, the daily mean temperature remains below 8 to 10°C, with a daily minimum of 5° C. In both these types, under extreme circumstances, complete death of the plant is the ultimate outcome. Zongdao and Xueqin (1983) further enumerated the spectrum of damages caused by various levels of ambient temperatures (*Table 1*). Reports from China indicate that clones GT 1 and Haiken 1 can withstand temperature of upto 0° C for a short span, while SCATC 93-114 can endure temperature of even -1° C. The cold wave conditions in Tripura State (Northeast India) can be conveniently classified as radiative type. A geo-climatic comparison of environments of Tripura, China, Brazil, Thailand, Cote d'Ivoire and French Guiana would amply reveal a spectrum of climatic conditions over which rubber is being grown (*Table 2*). This wide range in geo-climatic attributes are noteworthy and deserve special attention while deriving adaptive clones, evolving agro-management strategies and rescheduling exploitation systems.

Wind is yet another abiotic stress influencing establishment and growth of rubber. It is argued that wind speeds of 2.0-2.9 m per second retards rubber growth and latex flow and that of 3.0 m per second and above severely inhibit normal growth. Wind over Beaufort force of 10-play havoc with branch breaks,

TABLE 1
SPECTRUM OF DAMAGES CAUSED BY VARIOUS LEVELS OF AMBIENT TEMPERATURES

Ambient temperature (° C)	*Manifestations*
40	Respiration exceeds photosynthesis; retardation of growth and scorching of young leaves
27-30	Optimum range of temperature for photosynthesis
22-28	Favourable for latex flow
less than 18 more than 28	Yield decreases with late dripping in the former case
18	Plant cells divide normally just for survival
10	Mitosis occurs but photosynthesis discontinues
less than 5	Cold damage
less than 0	Severe cold damage

after Zongdao & Xueqin (1983)

TABLE 2

SPECTRUM OF WEATHER VARIABLES UNDER DIFFERENT GEO-CLIMATES

Attributes	*Bogor (Indonesia)*	*Pindorama (Brazil)*	*Kourou (French Guiana)*	*Abengourou (Cote d'Ivoire)*	*Nong Khai (Thailand)*	*Hainan (China)*	*Agartala (India)*
Temperature (° C) (annual mean)	27.4	22.9	26.3	26.8	26.8	22.6	25.4
Relative humidity (%)	79	67	81.5	74.5	74	79.9	76.8
Sunshine (% h)	61	55.1	49.9	47	58.1	46.8	50.8
Wind speed (m/s)	2.4	1.6	1.35	1.2	1.2	2.7	1.38
Rainfall (mm/annum)	1791.5	1117.6	2573.53	1029.7	1455.96	1431.29	1960.1
No. of rainy days	159	117	193	111	128	151	93
Moisture availability index	0.78	0.49	1.4	0.51	0.7	0.6	1.1
Penman ET_o (mm/day)	4.4	3.87	3.78	3.8	3.97	3.48	3.39
Latitude	**5 ° 9' S**	**20 ° 25' S**	**5 ° 7' N**	**7 ° 10' N**	**17 ° 51' N**	**19 ° 2' N**	**23 ° 49' N**
Longitude	**106 ° 58' E**	**49 ° 59' W**	**52 ° 56'W**	**3 ° 58' W**	**102 ° 44' E**	**109 °30'E**	**91 ° 16' E**
Altitude (m)	**16**	**505**	**48**	**227**	**164**	**671**	**31**

Source: www.iwmi.org

trunk snaps and uprooting of trees, mainly confined in China, during June to October. In Northeast India, wind speeds of about 125 km per hour is seldom experienced. Tree loss due to heavy wind is being experienced every year in Tripura. Studies in China reveal clones PR 107 and Haiken 1 can be considered wind tolerant; and in addition to these, clone PB 5/51 is seen to be wind endurant in Tripura (Priyadarshan *et al.*, 1998a). Establishment of shelterbelts consisting of fast growing and wind resistant species is one remedial measure being followed in China to circumvent wind damages. Alternatively, adoption of judicial pruning of branches and dwarfing techniques are shown to reduce wind damage from 25.3 to 13.7 per cent in a study conducted in China (Zongdao & Xueqin, 1983). Such measures as warranted by a particular location shall be practiced in non-traditional areas of India, which is under experimental phase. For Tripura, fast growing tree species like *Pongamia glabra, Mesua ferrea, Lagerstroemia speciosa, Terminalia arjuna, Cassia nodusa, Cassia siamea* and *Acacia auriculiformis* in a multi-tier system under closer spacing is being evaluated.

Rubber trees in Tripura experience wintering during December-January and reflushing starts by February followed by flowering (Sowmyalatha *et al.*, 1997). *Hevea* normally takes 3-4 years to attain reproductive stage - a phase called ripeness to flower - similar to other tropical trees (Kramer & Kozlowski, 1979). Though the capacity to flower is retained thereafter, the periodicity of flowering varies from clone to clone as in other tropical trees (Owens, 1991). *Hevea* shows seasonal flowering in response to alteration in seasons. In Tripura, *Hevea* experiences the main flowering season during March-April and a short spell of secondary flowering season prevails during August-September (*Figure 1*).

It seems reasonable to presume that geographic location has a bearing on the trees to flower during secondary season. While it flowers in southern parts of India (6-8° N) during March-April only, Malaysia (3-6° N) experiences flowering with viable seeds during both seasons. Tripura (22-24° N) on the other hand, though experiences flowering and seed set during both seasons, the viability of seeds is largely less during secondary season. This prompts researchers to confine hand pollination experiments during March-April only when substantial number of clones undergo flowering for a short span of 10-15 days.

Yielding pattern of clones in Tripura shows a clear delineation of low and high yielding regimes. A multitude of factors may be effecting the low yielding period; mainly the utilisation of synthesised carbohydrate reserves for refoliation, flowering and fruit development during February-August. The moisture stress experienced during February-March, the after effects of foliar diseases (mainly *Oidium heveae*) and the physiological after effects of low temperature stress experienced during previous winter season (*Table 3*) together impose an ensuing low yielding period during May-September (Priyadarshan *et al.*, 2000). However, the fall in temperature during October-November stimulates yield while the daily temperature range is 8-12° C, making the atmosphere most ideal for latex flow and production, the minimum temperature experienced early in the morning is 15-18° C and after 10 am the temperature shoots to 27-28° C. While the former is congenial for latex flow, the latter is ideal for latex regeneration through accumulation (Ong *et al.*, 1998). Chinese clones like Haiken 1, SCATC 88-13 and SCATC 93-114 are being evaluated in Tripura. Initial yielding pattern shows Haiken 1 to be high yielding among Chinese clones in

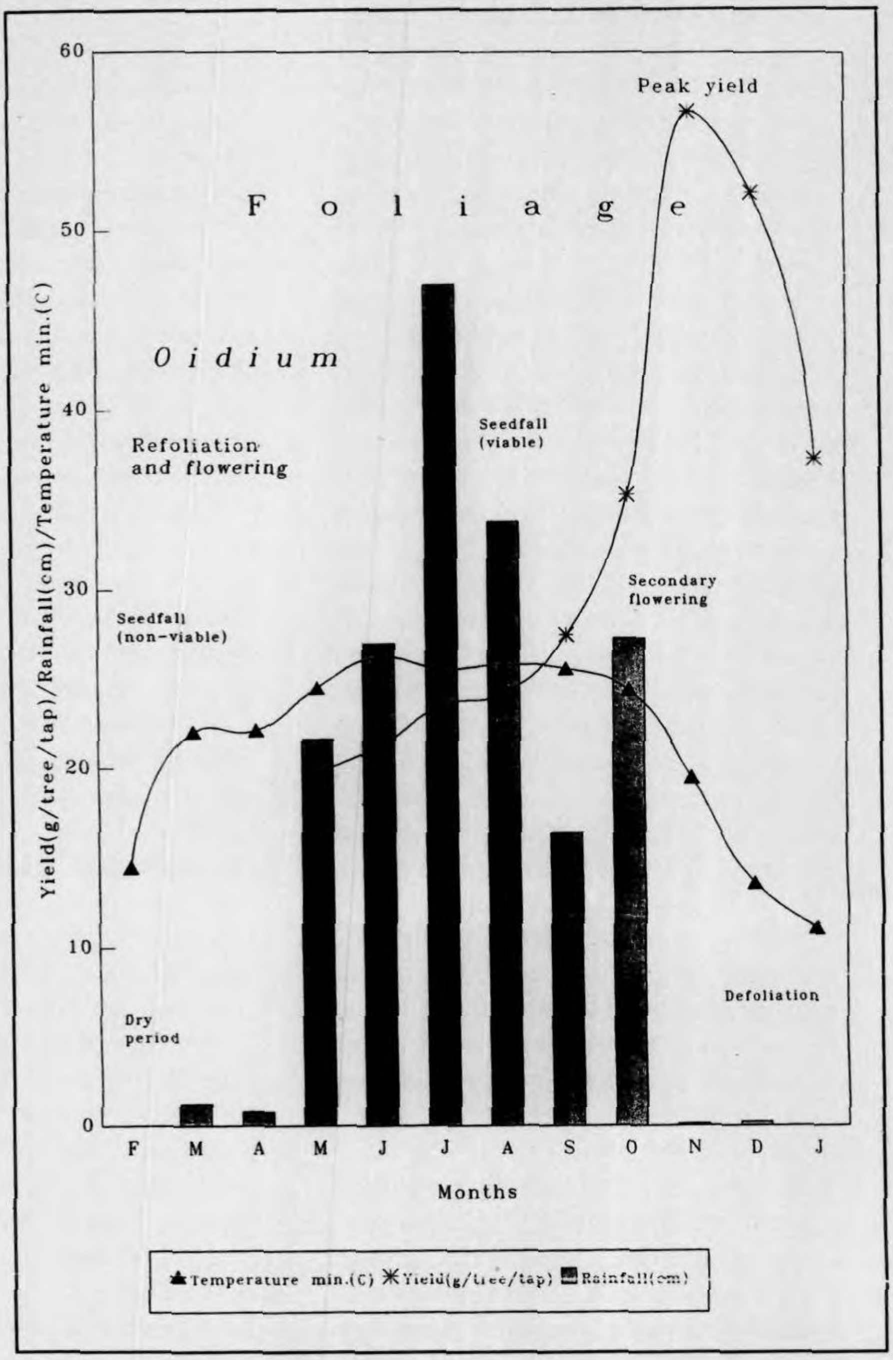

Figure 1. Phenology and yield of Hevea brasiliensis *in relation to climatic changes in Tripura*

TABLE 3
SEASONS AND PHENOLOGICAL ATTRIBUTES EXPRESSED DURING VARIOUS PERIODS IN TRIPURA AND SAO PAULO

	Location	
Phenology	*Tripura* @	*Sao Paulo* *
Defoliation	December - January	August - September
Refoliation	February - March	September- October
Flowering	March - April	October - November
Lean yield	May - September	August - January
Peak yield	October - December	February - July
Rainy season	May - August	October - March
Winter	November - January	June - August

* after Ortolani *et al*,. (1998) ; @ after Priyadarshan *et al.*, (2000)
For climatic details of Brazil see: www.brasemb.suite.dk/brief/climate.html
Tapping: Tripura = May to January; Sao Paulo = continuous (except August).

comparison to RRIM 600. Though clone SCATC 93-114 is proclaimed as cold endurant under Chinese conditions, it never shows considerable yield potential under the climate of Tripura at least in the initial yielding phase (Priyadarshan *et al.*, 1998b).

CLIMATIC CONDITIONS AND PHENOLOGY IN SAO PAULO

The plateau region of Sao Paulo state, an escape area of SALB disease has been referred to as the most important commercial rubber-growing region of Brazil (Costa *et al.*, 2000). While Tripura lies at 22-24° N, Sao Paulo is at 20-22° S (400-500 m MSL) making these areas non-traditional. Yield data of clone RRIM 600 over four years from Pindorama Experimental Station (21° 13' S 48° 56' W; 505 m) are used in this study. Unlike Tripura, trees are exploited for 11 months in Sao Paulo following half spiral cuts, tapped once in four days. February to June is the high yielding period and July to January is the low yielding period. Reflushing, flowering and seed fall are experienced once a year in Sao Paulo as given in *Table 3* (Ortolani *et al.*, 1998).

The winter period during June-August is dry with temperature reaching 15-20° C and may dip to 0° C rarely. The total rainfall ranges from 1 000-1 400 mm. Over the months, the average relative humidity is 70 to 80 per cent. The best environment for rubber is plateau located at 350-900 m MSL with deep, well drained podzolic and latossolic soils. A few plantations are located in volcanic red soils of high fertility. Sao Paulo experiences low leaf wetness and relatively low temperature during defoliation and this reduces South American Leaf Blight (SALB) caused by *Microcyclus ulei*. Yet, *Colletotrichum gloeosporiodes* and anthracnose disease are seen to assume epidemic proportions in many rubber areas of Sao Paulo (Goncalves *et al.*, 1999).

SITUATION IN FRENCH GUIANA, COTE D'IVOIRE AND INDONESIA

Information on the phenology of *Hevea* in French Guiana (Kourou – 5° 17' N; 52° 56'W;

altitude: 48 m) reveal that the defoliation is during February, similar to the areas north of the equator (Vincent LeGun, personal communication). This indicates that the shift in latitude towards the opposite sides of the equator has induced climatic changes stimulating phenological changes. Cote d'Ivoire experiences an analogous situation (Clement-Demange, personal communication). However, the rubber growing areas of Indonesia are spread over to both sides of the equator. Towards north it exhibits a phenology and yielding pattern similar to Tripura and in the south the attributes resemble that of Sao Paulo. Thus Indonesia offers an excellent area where in the same country both types of phenology are observed (Ridha Arizal, personal communication).

COMPARISON OF GEO-CLIMATES

A comparison of weather attributes of Agartala and Sao Paulo can reveal how the weather spectrum changes from month to month (*Tables 4 & 5*). As mentioned earlier, plants react to different environs through changes in growth response. For instance, defoliation is a phenomenon to circumvent moisture and low temperature stresses through minimising transpiration so as to ensure reproduction, seed dispersal and perpetuation of generations. Flowering and fruit formation utilise large amount of carbohydrate reserves. Hence, flowering and fruit formation is followed by low yielding phase in rubber both in Tripura and Sao Paulo (*Figures 1 & 2*). The environmental conditions inducing defoliation, flowering and low and high yielding periods are analogous. The peak yielding period in Sao Paulo is March-June followed by winter and defoliation, while in Tripura, October-December is the high yielding period. The latitudinal changes towards south and north of equator induce phenological changes in *Hevea* in *vice-versa* fashion.

The possible factors behind the low yielding period in Tripura had been explained earlier (Priyadarshan *et al.*, 2000). Sao Paulo is a disease free zone for SALB, prevalent in

TABLE 4
WEATHER VARIABLES AT AGARTALA (TRIPURA STATE – NORTHEAST INDIA)

Month	*Rainfall (mm/month)*	*Temperature (mean ⁰ C)*	*Relative humidity (%)*	*Wind run (m/s)*	*MAI@*	*Evaporation (mm/day)*
January	2.83	18.6	73	0.9	0.01	2.44
February	7.97	21.1	66	1.2	0.02	3.27
March	42.6	25.5	64	1.6	0.14	4.35
April	145.45	27.7	71	2.1	0.60	4.78
May	261.69	28.2	78	1.8	1.38	4.31
June	428.69	28.3	85	1.7	3.05	3.48
July	373.27	28.3	85	1.7	2.76	3.27
August	318.34	28.4	85	1.5	2.40	3.20
September	214.47	28.5	84	1.3	1.57	3.18
October	146.62	27.2	79	1.0	0.84	3.30
November	18.06	23.7	76	0.9	0.05	2.86
December	0.13	19.8	76	0.9	0.00	2.34

Source ; www.iwmi.org; * DTR = daily temperature range; @MAI = moisture availability index