CHAPTER 9

CLIMATIC REQUIREMENTS

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Hevea brasiliensis is indigenous to the rain forests of the Amazon basin, situated generally within 5° latitudes of the equator and at altitudes below 200 m. The climate of this region is wet equatorial type (Strahler, 1969), characterized by a mean monthly temperature of 25 to 28°C, ample rainfall with no marked dry period, and mild breezes round the year (Bradshaw, 1977). The species, evolved in this environment, has developed an ecological preference for warm, breezy, humid weather and fertile soil (Polhamus, 1962; Opeke, 1982). Under commercial cultivation, Hevea performs best in climates closely resembling that in its centre of origin. But with the increase in global demand for natural rubber, plantations have been extended to less suitable regions beyond the traditional latitudes, in India, China, Burma and Brazil (Dijkman, 1951; Omont, 1982; de Barros et al., 1983; Pushparajah, 1983; Zongdao and Xueqin, 1983; Sethuraj, 1985; Sethuraj et al., 1989).

The optimum climatic requirements of Hevea are:

A rainfall of 2000 mm or more, evenly distributed without any marked dry season and with 125-150 rainy days per annum,

A maximum temperature of about 29-34°C, minimum of about 20°C or more with a monthly mean of 25-28°C,

High atmospheric humidity of the order of 80 per cent with moderate wind, and

Bright sunshine amounting to about 2000 hours, at the rate of six hours per day in all months.

Only a few rubber growing regions in the world quality to fall within such a climatic profile (Yew, 1982; Domroes, 1984; Chan et al., 1984). The substantial differences in productivity observed among different regions can be ascribed to the variations in the climatic composition (Table 1 and Fig. 1).

Table 1. Climatic characteristics of certain major rubber growing regions in the world.

Region	Location	Air Temperature (°C)		Rainfall		R.H. (%)	Mean wind speed $m\ s^{-1}$	Sunshine duration (h)
		Annual Mean	Range	Total (mm)	Days			
Agartala (NE India)	25°53'N,91°15'E,21M	24.9	10.1	1932	119	77	1.9	2049
Jinghong (China)	21°52'N,101°04'E,553M	21.7	9.9	1209	--	83	1.6	2153
Danxian (China)	19°30'N,109°35'E,169M	24.1	11.4	1826	164	83	2.4	2020
Qiong Hai (China)	19°14'N,110°28'E,24M	24.1	12.1	2006	168	86	2.8	2116
Chum Phon (Thailand	10°30'N,99°11'E,10M	27.4	5.1	1888	188	73	13.3	--
Kottayam (South India)	09°32'N,76°36'E,73M	26.6	3.1	3171	139	76	1.0	2546
Phuket (Thailand)	07°53'n,98°24'E,3M	28.0	1.7	2150	170	72	8.5	2163
Dartonfield (Sri Lanka)	06°32'N,80°09'E,66M	27.3	1.7	4129	219	79	0.6	1773
Kepala Batas (Malaysia)	06°12'N,100°25'E,4M	27.7	1.6	1977	163	79	1.6	2586
Anguededou (Ivory Coast)	06°N, - -	27.4	2.6	1867	129	83	--	1649
Kuala Lumpur (Malaysia)	03°07'N,101°42'E,39M	27.1	1.1	2499	195	77	--	2230
Senai (Malaysia)	03°08'S,104°18'E,10M	27.2	1.1	2361	191	88	2.4	2049
Manaus (Brazil)	03°08'S,60°01'E,48M	27.4	1.9	2101	171	81	1.6	2097

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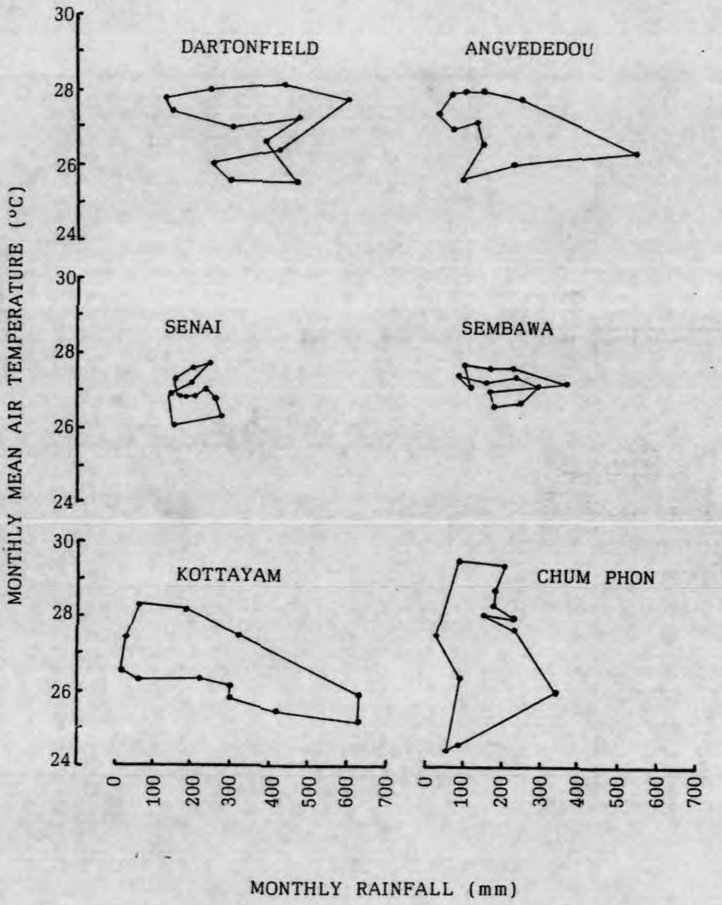

Fig. 1. Climatograms showing the distribution of mean monthly rainfall and temperature at certain rubber growing regions.

In the traditional rubber growing areas, the total rainfall ranges between 2000 and 4000 mm, spread over 140-220 days. It is evenly distributed throughout the year, with not more than one to four dry months. The mean annual temperature is 27±1°C, and the difference between the highest and the lowest monthly temperature is within 3°C. The mean annual maximum and minimum temperatures are 30-33°C and 22-23°C, respectively. The diurnal temperature range is in between 7-10°C. Correlation of mean monthly temperature with rainfall distribution (Fig. 1) indicates that the seasonal changes are minimum at Senai (South Malaysia) and Sembawa (South Sumatara, Indonesia). In these regions conventional planting techniques give satisfactory establishment of rubber.

In non-traditional rubber growing regions (above 10°N latitude), even where annual rainfall is sufficient, there can be periods of severe moisture deficits for four to six months. The mean annual temperature is less than 25°C (around 20°N latitude) and the difference between the highest and the lowest monthly temperatures is 10-12°C. The mean annual maximum and minimum temperatures are 30-37°C and 11-24°C, respectively. Thus, away from the equator, most of the regions in North-East India, China, Bangladesh and Vietnam experience severe cold and dry conditions. In these areas the diurnal temperature differences are high and are in the range of 15-31°C during winter months. Further, in some areas in eastern and western India as well as northern parts of Thailand there is a marked dry season of 6-7 months, with severe moisture deficit. The temperatures may range between 14 and 38°C, with a rainfall of 1500-2500 mm per annum. All these conditions will also demand appropriate location specific planting practices as well as harvesting techniques.

EFFECT OF CLIMATIC COMPONENTS ON GROWTH AND YIELD

Rainfall and water balance

Rubber plantations are traditionally raised under rainfed conditions except in nurseries where essential irrigation is given. Ideally, the monthly rainfall should be sufficient to meet the water requirement of the plantation. In the tropical monsoonal climate, the potential evapotranspiration rate is around 4 mm day^{-1} (Montieth, 1977). Therefore, a rainfall of 125 mm per month with equal distribution is considered essential to maintain optimum gaseous exchange. The amount and distribution of rainfall in the rubber growing regions show considerable variation (Table 2).

Rain interception by the Hevea canopy causes direct evaporation from the leaves and this amount of water is lost. Rain water reaching the ground is the net rainfall (stem-flow and throughfall). This is not fully absorbed by the soil. Depending on the terrain and permeability of the soil, a certain amount of water reaching the ground is lost as surface run-off. This occurs when the net rainfall is in excess of the infiltration capacity of the soil. Part of the water entering the soil is lost through deep percolation and seepage. Measurements by Toeh (1971) showed that in an eight year old plantation, about 83% of the rain reaches the ground as throughfall and 2% as stem-flow. Between 0.5 and 1.6% of the gross rainfall is lost as

Table 2. Rainfall distribution at different rubber growing regions (millimeters)

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Manaus (Brazil)	276	277	301	287	193	98	61	41	62	112	165	228
Senai (Malaysia)	151	142	192	236	200	149	166	159	204	229	257	275
Kepala batas (Malaysia	14	41	105	204	236	150	200	199	279	280	203	67
Sembawa (Indonesia)	180	163	366	227	167	100	122	85	164	241	301	245
Phuket (Thailand)	10	20	47	139	279	261	338	250	352	260	130	64
Surat thani (Thailand)	75	30	27	91	194	159	137	155	150	258	455	180
Chumphon (Thailand)	62	95	28	89	209	181	177	228	155	235	341	88
Tombokro (Ivory Coast)	23	54	99	119	187	180	101	95	214	130	35	16
Abidjan (Ivory Coast)	39	71	101	145	232	561	239	60	94	154	137	73
Anguededou (Ivory Coast)	35	69	100	144	247	545	225	62	91	151	128	69
Dartonfield (Sri Lanka)	137	125	246	432	601	416	251	295	466	391	472	297
Kottayam (India)	18	32	62	180	320	629	631	417	304	305	221	54
Punalur (India)	14	42	74	228	294	460	434	295	242	355	217	37
Mudigere (India)	3	14	42	81	111	501	619	496	236	162	66	35
Dapchari (India)	0	0	0	0	9	597	936	544	426	94	9	0
Agartala (India)	4	19	62	185	307	348	232	303	270	150	41	11
Xaun Loc (Vietnam)	10	15	22	96	241	294	355	362	376	286	95	36
Cox's Bazar (Bangladesh)	92	98	125	135	140	107	107	97	95	91	82	93
Qiong Hai (China)	38	40	69	126	185	240	190	289	331	286	135	76
Danxian (China)	*22*	*24*	*40*	*93*	*211*	*217*	*229*	*306*	*352*	*208*	*87*	*37*

surface run-off. A canopy of 15 year old LCB 1320 trees intercepts about 18-24% of the rainfall (Haridas and Subramaniam, 1985). The percentage of throughfall is bound to decrease with increasing density of planting.

Positive correlations between rainfall deficit and cumulative production loss during a season have been established (Ninane, 1970; Cretin, 1978). At low soil moisture levels, the rate and duration of latex flow as well as yield are reduced (Buttery and Boatman, 1976; Sethuraj and Raghavendra, 1984; Devakumar et al., 1988; Gururaja Rao et al., 1988, 1990; Vijayakumar et al., 1988). Clonal variation in tolerance to moisture stress also has been observed (Saraswathyamma and Sethuraj, 1975).

Soil moisture stress has significant effect on the yield components such as initial flow rate, plugging index and dry rubber content. Besides the direct effect on turgor pressure, water deficit also triggers a series of biochemical changes in latex (Premakumari et al., 1980). The turgor pressure of the laticiferous system is influenced by the evapotranspiration demand, soil moisture availability and root resistance. Under prolonged dry conditions, however, fall in turgor pressure is countered to a great extent by osmotic regulation by the plant (Chandrashekar et al., 1990). High rainfall for a prolonged period, however, can also have a negative effect on yield. Shorter sunshine duration, associated with high rainfall, results in low photosynthetic efficiency. Higher moisture status in soil may also lead to dilution of latex.

Soil moisture never becomes a limiting factor for growth during wet season. In heavy soils, however, excess rainfall may lead to problems associated with water logging. Heavy rainfall also causes nutrient loss by erosion and leaching. In a study conducted in Sri Lanka (Yogarathnam, 1985) about 62 t ha^{-1} of top soil was found to be lost during the initial three years, when the land was clean weeded and kept bare. However, it was possible to reduce this loss to 1.3 t ha^{-1} by mulching or by growing leguminous cover crop.

Rate of evapotranspiration (ET) is determined by the availability of soil moisture in the root zone, plant water status, stomatal conductance and atmospheric demand (Devakumar et al., 1988). Atmospheric demand is regulated by radiation, temperature, vapour pressure deficit and wind speed. The relation between soil moisture content and transpiration rate in the available moisture range is complex. The root characteristics such as density and distribution also affect transpiration rates, primarily as they influence water uptake by the plant.

In Malaysia, the daily ET rate of the clone RRIM 600 grown under glass house was found to vary from 2.1 to 6.9 mm d^{-1} (Haridas, 1980) and under field conditions this was found to be 4.4 mm d^{-1} when averaged over 21 months. While measuring stream-flow in a small watershed, Haridas (1985) found close agreement between annual ET and pan evaporation, and the daily ET fell between 2 to 8 mm d^{-1}. In Ivory Coast, while measuring the energy balance components of a homogenous plot of 25 ha with 18 year old rubber trees, Monteny et al. (1984, 1985) observed that rubber plantations give out 4 to 6 mm of water vapour daily into the atmosphere when the soil moisture availability is adequate and only 2 to 4 mm when it is inadequate.

Measurement of transpiration rates in mature trees of different Hevea clones (RRII 105, RRII 118,Tjir 1 and Gl 1) under South Indian conditions by Devakumar et al. (1988) and Gururaja Rao et al. (1990) indicated that the relative transpiration rate varies from 0.11 during dry period to 1.13 during the peak production period. Assuming the crop coefficient to be 1.0, Vijayakumar et al. (1988) estimated the water requirement of Hevea at different ages under South Indian conditions. The estimated mean water requirement of rubber tree was found to vary from 10 l per plant per day for the plant in the first year to 100 l per plant per day for the mature plant.

The concept of water balance model is useful in assessing the suitability of areas for planting rubber and for analysing the causes of yield fluctuations in already established regions. Application of the Thornthwaite's climatic water balance model (Thornthwaite and Mather, 1955) to the established rubber growing regions indicates that some of the regions are free from water deficit (Table 3). However, annual water deficits of the order of 200 to 350 mm are found in marginal areas brought under plantations, indicating the adaptability of the plant to dry conditions (Moraes, 1977). In such regions, however, there could be water surplus during rainy season.

At present, cultivation of rubber is being extended even to regions with well defined and prolonged dry season (five to seven months) in many countries. With a marked dry season of six months in Thailand, around 15% growth inhibition was recorded (Saengruksowong et al., 1983). In Ivory Coast, growth of clone GT 1 under dry conditions was found to be reduced significantly (Omont, 1982). The extent of growth retardation was, however, smaller with increase in age of the tree. It is probable that under severe moisture deficit conditions, moisture absorption by the tap root occurs at 2-3 m depth. Under such conditions water stored in the trunk of the plant also might be utilised (Monteny et al., 1985).

In certain dry regions in India, where seven to eight rainless months

Table 3. Components of climatic water balance from various rubber growing regions of the world (millimeters).

Region	Rainfall	Evapotranspiration		Water deficiency	Water excess
		Potential	Actual		
Dartonfield	4129	1066	1066	0	3063
Siantar*	2705	1665	1665	0	1040
Singapore*	2282	1716	1715	1	567
Kuala Lumpur*	2499	1709	1705	4	794
Yangamki*	1840	1333	1329	4	511
Malaca*	2190	1665	1655	10	535
Medan*	1931	1579	1560	19	371
Kotatingi	2828	1669	1639	30	1189
Sembawa	2361	1437	1407	30	924
Chumphon	1889	1334	1229	105	660
Djakarta*	1797	1540	1308	232	489
Anguededou	1866	1658	1405	253	461
Kottayam	3170	1411	1147	264	2023
Cox's Bazar	2923	1262	974	288	1949
Phuket	2150	1807	1480	327	670
Altor Star	1770	1575	1229	346	541

*Adapted from Moraes (1977).

Table 4. Girth (cm) of <u>Hevea</u> clones in the fifth year after planting under different agroclimatic conditions in India.

Clone	Chethackal (9°N,50M)	Poonoor (11°N, 75M)	Mudigere (13°N,950M)	Dapchari (20°N, 58M)
RRII 105	30.9	27.8	20.0	18.7
RRIM 612	32.2	27.5	21.9	25.3
RRIM 501	24.3	26.4	20.1	26.1
Gl 1	26.1	21.3	16.7	24.4
PR 107	23.1	20.2	17.3	28.7
GT 1	27.8	28.3	21.8	26.4
RRIM 600	31.6	25.5	23.1	28.5
Tjir 1	33.1	20.9	21.1	26.0
RRII 118	32.2	33.0	20.1	26.4
Mean	29.0±3.6	25.7±4.0	20.2±2.0	25.6±2.9

Source: Rubber Research Institute of India, Annual Reports 1986-87 & 1987-88.

(Latitude and altitude of the locations are given in parenthesis.)

are common (Dapchari, Konkan region of Maharashtra) the overall growth inhibition recorded by rubber plants, maintained with life saving irrigation during summer, was in the range of 14-20% by the fifth year of planting (Table 4). Clones PR 107 and RRIM 600 were found to perform better under these conditions. In addition to loss of leaf area, severe reduction in photosynthetic rate achieved was only 50% of that recorded during the wet season. However, Chandrashekar et al. (1990) reported reasonably good yield in the first year of tapping from clones RRIM 600 and GT 1 under rainfed conditions in this region. Tapping rest for 3-4 months has been suggested considering the low latex vessel turgor pressure observed during summer months.

Pushparajah and Haridas (1977) showed that moisture deficit of about 180-220 mm in two consecutive years severely affected growth of young rubber in a well drained clay soil. However, the effect was not so severe even in an alluvial soil where the water table was high. Haridas (1984) showed that irrigation can increase yield of GT 1, RRIM 612 and RRIM 703.

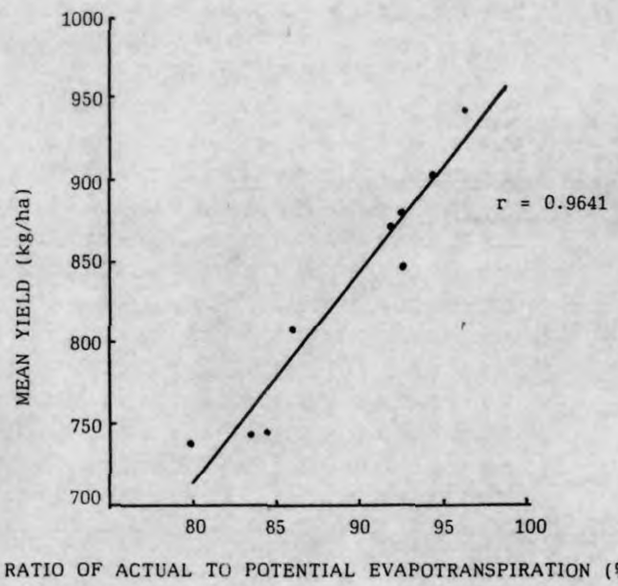

Fig. 2. Estimated soil moisture availability from meteorological data and its relationship with yield under South Indian conditions. (Source: Sanjeeva Rao et al., 1990).

In Ivory Coast, irrigation at the rate of 0.9 times pan evaporation could reduce the immaturity period by 18 months (Omont, 1982). By the fifth year of tapping, even with irrigation, a yield of only 1650 kg ha^{-1} could be obtained compared to that of 1900 kg ha^{-1} expected under favourable rainfed conditions.

In South India, regional yield fluctuations were found to be related to the moisture availability in soil (Sanjeeva Rao et al., 1990) and is shown in Fig. 2. By increasing the availability of moisture to the plant by way of irrigation, or by adopting moisture conservation techniques like silt *pits, biological bund and mulch, problems of initial establishment, retarded* growth and low yield can be avoided to some extent (Haridas et al., 1987; Vijayakumar et al., 1988). However, more data have to be generated to evaluate the effectiveness and economics of irrigation during pre and post tapping phases. Another approach is to select drought tolerant clones for predominantly dry regions.

RAINFALL AND TAPPING

Rainfall exceeding 9-11 mm per day is not congenial to high yield owing to difficulties in harvesting and other operations (Liyanage et al., 1984; Haridas and Subramaniam, 1985). A larger than optimum number of rainy days in a year decreases the total yield expected for that year. It is difficult to operate a plantation economically with more than 150 rainy days due to loss of tapping days, unless tapping is done with the help of rain guard and panel protectants. Rainfall higher than 34 mm in 24 h may make tapping operation difficult. Such conditions may also promote soil erosion.

The diurnal pattern of rain also has a marked influence on crop harvesting. Rainfall in the early hours of the day or just before the normal time of tapping, makes the bark wet and untappable. Such a condition may necessitate late tapping and will be reflected in a pronounced decrease in the total volume of latex, but may result in increased dry rubber content (d.r.c.) due to increased rate of evaporation caused by high radiation *and vapour pressure deficit (v.p.d.). Rain during tapping interferes in* the operation and causes spillage and washout. Heavy rainfall before latex collection leads to washout even with the skirt type of rain guard. When rain occurs after latex collection, an increase is generally noticed in the volume of latex obtained on the next day. However, d.r.c. will be below normal indicating dilution of latex due to increased moisture availability and higher plant moisture status.

In Malaysia, of the total rainfall, 21% occurs between midnight and 0600 h, 16% in the normal tapping period of 0600-1200 h, 35% during 1200-1800 h and 28% during the remainder of the day (Wycherley, 1963; Watson, 1989; Daud et al., 1989).

The response of trees to chemical yield stimulation also depends on climate and soil moisture. A highly significant positive correlation has been demonstrated between response to stimulation and cumulative rainfall during the months preceeding stimulation (Abraham and Tayler, 1967). During the dry season, stimulation may not only be ineffective but may also be harmful to the tree.

TEMPERATURE

Temperature is one of the key environmental factors influencing plant growth. Hevea, being a species adapted to moderate temperatures, naturally gets affected by extreme temperatures. Mean monthly temperatures of 25 to 28°C has been found to be the optimum. The mean monthly maximum and minimum temperatures prevailing in the established rubber growing regions of the world are presented in Table 5. The temperature records from Indonesia and Brazil indicate a range from 29.9 to 33.1°C as mean maximum temperature and 22.7 to 24.1°C as mean minimum temperature. In the tropics, the mean annual air temperatures are in the range of 27 to 28°C with a diurnal variation of 4 to 10°C. In the drier parts of Malaysia, the maximum temperature is more than 34°C for two months but the minimum is always above 20°C. In Thailand, the mean maximum temperature is more than 34°C for about four months and the minimum less than 20°C for about five months. In South India, temperature range is 20 to 34°C, whereas in the Konkan region (North West India) the maximum is 34°C and above for three months and the minimum 20°C or below for five months. Occasionally, temperature rises above 40°C in this region.

High temperature conditions result in higher rates of evapotranspiration, leading to severe soil moisture stress in the absence of rainfall. High temperatures above 37°C, coupled with soil moisture stress, result in injury to leaf and killing of leaf margins (Chandrashekar et al., 1990). During planting, thermal injury results in increased casualty. Clonal variation in susceptibility to thermal injury has been reported (Rajagopal et al., 1988). However, drying of leaf margins due to the combined effect of drought and high temperature could be prevented by adequate irrigation in the North Konkan region of India (Mohankrishna et al., 1991). Contact shading of leaves by spraying a suspension of China clay was also found to be effective in mitigating thermal injury (Rubber Research Institute of India, 1991).

Table 5. Temperature at different regions of rubber cultivation.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Mean Maximum (°C)							
Manaus	30.0	29.9	30.0	29.9	30.7	31.1	31.6	32.7	33.1	32.7	32.0	31.7
Sembawa	30.0	30.8	31.1	31.7	31.6	31.8	31.5	32.0	31.7	31.9	31.4	30.5
Senai	30.7	32.0	32.3	32.6	32.3	31.9	31.2	31.4	31.3	31.6	31.2	30.3
Kepala batas	32.8	34.4	34.5	33.6	32.4	31.9	31.5	31.6	31.2	31.5	31.4	31.5
Anguededou	*31.9*	*32.9*	*32.5*	*33.0*	*32.4*	*29.8*	*29.0*	*27.9*	*28.2*	*30.3*	*31.5*	*31.2*
Dartonfield	32.7	33.6	33.8	33.0	31.8	30.5	30.3	30.4	30.5	31.2	31.6	32.2
Phuket	33.4	34.9	35.3	35.6	34.3	33.5	33.3	33.8	33.1	33.3	32.9	33.1
Chum phon	31.8	33.8	35.6	36.7	35.8	34.5	33.9	33.4	33.7	33.4	32.4	31.7
Kottayam	31.9	32.7	33.4	32.8	31.4	29.2	28.4	28.6	29.3	29.9	30.4	31.1
Dapchari	30.5	32.3	35.3	36.1	35.9	32.3	29.3	28.5	31.8	33.5	33.0	30.8
Agartala	25.7	27.8	32.0	33.5	32.2	31.6	31.4	31.5	31.1	31.4	29.6	26.2
Qiong Hai	30.6	32.6	34.8	35.2	38.9	37.1	39.0	37.1	36.0	33.5	31.3	30.4
Danxian	34.3	36.5	37.8	38.6	38.1	38.9	37.7	36.1	36.0	34.3	34.5	32.3
					Mean Minimum (°C)							
Manaus	23.3	23.2	23.3	23.3	23.6	23.4	23.2	23.5	23.9	24.1	24.0	23.5
Sembawa	23.1	23.1	23.2	23.4	23.6	23.5	22.7	22.9	22.7	22.8	23.0	22.8
Senai	21.4	21.7	22.1	22.7	22.9	22.6	22.3	22.2	22.2	22.4	22.4	22.2
Kepala batas	21.6	22.2	23.0	23.8	24.3	24.0	23.4	23.5	23.4	23.5	23.2	22.6
Anguededou	22.9	23.5	23.4	23.3	23.5	23.0	22.9	23.3	23.1	22.8	23.1	22.9
Dartonfield	21.6	21.7	22.4	23.4	23.7	23.6	23.3	23.1	22.9	22.5	22.1	22.1
Phuket	21.1	21.6	21.9	22.4	22.6	22.7	22.4	22.4	22.3	22.2	22.1	21.5
Chum phon	17.0	19.0	19.3	22.3	22.9	22.9	22.4	22.7	22.5	21.9	19.5	17.4
Kottayam	21.1	22.1	23.2	23.6	23.5	22.6	22.1	22.2	22.4	22.3	22.2	21.5
Dapchari	14.0	15.8	19.7	22.9	26.0	26.0	24.7	24.6	23.8	21.6	17.4	14.9
Agartala	10.4	12.6	19.0	21.8	22.6	24.7	24.6	24.6	23.8	21.3	16.1	11.6
Qiong Hai	5.9	7.2	9.2	10.6	18.8	20.8	21.0	21.2	16.6	14.8	9.7	5.3
Danxian	2.9	5.8	8.6	9.2	17.0	19.6	20.4	20.6	16.1	11.7	7.2	3.4

In Malaysia, even under marginal management, rubber plantations can be brought into production in about six years, while in Bangladesh (23°N) the immaturity period could be seven years or more (Pushparajah, 1983). In the traditional rubber growing regions in India, the gestation period is normally about six to seven years and in the non-traditional regions it could be eight years or more (Sethuraj et al., 1989). Notwithstanding this general trend, growth of certain clones in the non-traditional region is comparable to that in the traditional region (Table 4).

The rubber growing regions in China are exposed to extreme temperature variations, maximum temperatures of 36 to 39°C and minimum temperatures of 2.9 to 14.8°C are experienced. The mean minimum temperature drops below 20°C for about nine to ten months and the mean maximum temperature rises above 34°C for about seven to eleven months.

In North East India, the minimum temperature recorded is less than 20°C for five months and the maximum temperature throughout the year is less than 34°C. During periods of low temperature, growth retardation has been observed both in North East India and in China. At Agartala (North East India) during winter months clones RRII 118, RRII 300 and RRIM 600 performed better than the other clones tested (Sethuraj et al., 1989). In China, growth of rubber is retarded drastically during winter, the growing period being limited to between June and October (Zongdao and Xueqin, 1983). The higher the temperature the higher the growth rate and the threshold temperature for growth is believed to be in the range of 20°C (Jiang, 1988). Clonal variation in susceptibility to occasional low temperature had been reported (Polhamus, 1962).

It has been demonstrated in China that a ten day mean temperature of over 22°C at 6 a.m. during July-September was donducive to latex regeneration but unfavourable for latex flow. A temperature of 18-21°C at 6 a.m., on the other hand, favoured latex flow (Tropical Crops Research Institute, 1986). According to Shangpu (1986), optimum temperature condition for latex production is 27-28°C, while an ambient temperature of 18-22°C is most ideal for latex flow. High temperature was found to retard latex flow and reduce yield (Lee and Tan, 1979). A significant positive correlation, between the temperature at 8 a.m. and plugging index, was reported (Tropical Crops Research Institute, 1986).

At altitudes higher than 200 m, for every 100 m increase in altitude, a six month delay in reaching tappable trunk size has been reported (Dijkman, 1951; Moraes, 1977). This corresponds to approximately a 0.6°C decrease for every 100 m increase in altitude. About 26% growth inhibition has been recorded by different clones under tropical high elevation conditions (Table 4). RRII 105 was found to perform worse than RRIM 600 and GT 1. In China, GT 1, Haiken 1, PR 107 and RRIM 600 were found to be better performers in the cold-ridden high altitude sub-tropical monsoon regions.

In the tropical low elevation regions such as Kottayam a monthly mean temperature of 26-28°C with adequate soil moisture and sunshine are associated with high production. During the peak production period of November, the daily temperature varies from 22-31°C with a mean of 26.3°C. *During this period adequate soil moisture is available from 200-250 mm* rainfall received during 11 days. The average duration of sunshine during this period is 6.5 h d^{-1}. In July, on the other hand, heavy rainfall of the order of 600 mm is received during 24 days. In this month the mean minimum and maximum temperatures are 22°C and 29°C respectively. Average daily sunshine duration is only 2.3 h. These conditions are not congenial for good productivity and the latex yield is lower during this period. Temperatures of 23-34°C during March with 9.4 h of sunshine and low rainfall of around 60 mm also result in low yields. This may be due to the combined effect of high temperature and soil moisture stress in addition to the effects of annual defoliation.

RELATIVE HUMIDITY

Transpiration rate is influenced by temperature and relative humidity (R.H.) of the surrounding atmosphere. The moisture exchange capacity of the atmosphere is indicated by the R.H. Conditions of high and low R.H. occur during rainy and dry seasons, respectively. In the rainy season irradiation is low and duration of leaf wetness is high. Relative humidity is an indirect measurement of v.p.d. at ambient temperature. High to moderate R.H. prevails in most of the rubber growing regions (Table 6).

Monteny et al. (1985) observed that with low soil moisture availability and a weak surface to air water vapour gradient, ET rate is reduced progressively by the activity of stomata. Variations in v.p.d., wind and radiation results in differences in the water requirements of plantations in different locations.

It was demonstrated that diurnal variation in latex yield is inversely related to saturation deficit of the air (Paardekooper and Sookmark, 1969; Ninane, 1970). Conducting tapping at different hours of the day, it was found that latex yield was maximum and constant between 8 p.m. and 7 a.m., and decreased gradually to a minimum of 70% of the maximum at around 1 p.m. The decrease in yield during the course of the day is related to increased loss of water due to transpiration and the resultant drop in

Table 6. Mean relative humidity (per cent) at different rubber growing regions.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Manaus	88	88	88	88	86	83	80	77	78	79	82	85
Senai	81	79	80	81	82	82	82	82	82	82	83	84
Kuala Lumpur	83	81	82	85	84	84	83	83	84	85	87	85
Kepala batas	72	70	73	78	82	83	83	83	83	83	82	77
Sembawa	90	90	90	90	90	88	87	85	87	87	89	90
Dartonfield	77	75	75	80	81	82	82	80	80	80	81	78
Anguededou	80	78	83	80	82	85	86	90	89	84	82	79
Surat thani	86	85	81	82	84	79	86	87	86	87	88	86
Phuket	67	67	66	70	74	75	76	73	76	75	73	70
Chumphon	72	71	67	70	73	74	75	75	76	76	75	73
Kottayam	64	66	68	73	77	83	85	83	80	79	77	70
Agartala	71	68	66	72	79	83	85	85	86	82	75	73
Danxian	84	84	82	79	80	81	81	85	87	85	85	84
Qiong Hai	86	88	87	86	83	84	83	86	87	86	85	86

pressure potential in the latex vessels (Buttery and Boatman, 1976; Devakumar et al., 1988). The recovery of yield in the late afternoon is correlated to reduction in v.p.d. A sharp decline in yield was also found whenever v.p.d. reached 8 mm and restoration of yield in the afternoon lagged behind the decrease in v.p.d. (Ninane, 1970).

SUNSHINE

Though photosynthetic light conversion efficiencies of agricultural crops with closed canopy are in the range of only 7.4-10.2%, positive correlation exists between radiation and biomass production. Effect of sunshine hours on crop growth and productivity is often mediated through its effects on photosynthesis and crop water requirements. Under limited soil moisture availability, sunshine duration will have a negative effect on photosynthesis and growth. Any condition contributing to good supply of water to tissues or limiting loss of water by ET are favourable for prolonged flow of latex. Seasonal variation in the availability of water and sunlight cause a change in d.r.c.

Most of the agrometeorological observatories in the rubber growing regions have only sunshine recorders and the data are presented in Table 7.

Table 7. Mean sunshine duration at different rubber growing regions (hours per day).

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Danxian	4.3	4.5	4.9	6.0	7.1	6.7	7.3	6.3	5.7	5.2	4.4	4.1
Qiong Hai	4.2	3.5	4.7	6.3	7.7	7.2	8.2	6.9	6.2	5.5	4.5	3.9
Senai	5.7	6.4	6.0	5.7	5.8	5.7	5.4	5.4	4.5	4.7	4.2	4.5
Kuala Lumpur	6.2	7.4	6.5	6.3	6.3	6.6	6.5	6.3	5.6	5.3	4.9	5.4
Kepala batas	8.8	8.4	8.4	8.3	7.1	6.6	6.6	6.3	5.7	6.0	5.9	7.0
Sembawa	4.1	5.0	5.1	6.1	6.5	6.7	6.6	7.0	5.6	5.2	5.1	4.3
Dartonfield	5.5	7.0	6.6	5.1	4.2	3.2	3.8	4.5	3.7	5.0	4.8	5.0
Anguededou	6.0	5.5	5.5	6.9	5.1	3.1	2.6	2.0	2.4	4.0	5.6	5.6
Kottayam	9.4	9.4	9.3	8.6	7.0	4.5	3.9	4.9	6.2	6.2	6.5	8.0
Agartala	7.8	8.3	8.5	7.8	6.3	5.4	5.8	5.6	4.8	7.5	8.5	8.3

Detailed radiation data are available from only a few stations. The duration and intensity of sunshine should have a significant influence on latex sucrose levels (Tupy, 1989). An increase in sunshine duration towards the end of the rainy season is often associated with an increase in latex production. Also, lower latex production during rainy season can be attributed to reduced sunshine hours.

High radiation and its long duration from December to April cause scorching of bark in young rubber plants. To protect the bark, contact shading of stem with reflectants is adopted in South India. Contact shading of leaves of young plants of rubber was found beneficial in the Konkan region (North West India). Monthly variation in yield performance may be influenced by differences in hours of sunshine, but the exact requirement for optimum yield is yet to be quantified.

WIND

Wind is another important climatic factor having a tremendous influence on the performance of rubber plantations. High frequency of gale can cause considerable damage to plantations by promoting branch snap, trunk snap, uprooting etc. Morphological and anatomical deformations are reported to be usually associated with high wind velocities. In addition to the mechanical effects, advective cold and dry winds affect physiological processes. One of the notable features of trees in windy places is the deformation of their canopies to produce an asymmetric structure in which the branches appear to be swept to the leeward side (Grace, 1977). In valleys where the wind direction is often upslope in the day and downslope in the night due to cold air drainage, flagging is in the direction of night winds.

Windiness, whether indicated by mean wind velocity or the incidence of gale has a tendency to increase near the coast and at higher elevations. In general, the mean wind speeds in the rubber growing areas are in the range of 1-3 m s^{-1} and at times 4 m s^{-1} (Oldeman and Frere, 1982). Wind damages, mechanical and physiological, often lead to low productivity (Yee et al., 1969).

In general, young plantings with heavy canopy may show stem bending and require corrective pruning and roping. Susceptibility to wind damage is the greatest at the time of maximum girthing and canopy development. Trees with narrow crotches are more prone to wind damage (Dijkman, 1951). Tracks of strong wind should be avoided for cultivation of rubber.

In China, an annual mean wind velocity below 1 m s^{-1} has a favourable effect on the growth of rubber trees. At a velocity of 1.0-1.9 m s^{-1} no retardation in growth was observed and at 2.0-2.9 m s^{-1} both growth and latex flow are affected. At a velocity of above 3 m s^{-1}, however, growth and latex flow are severely inhibited (Zongdao and Xueqin, 1983). Strong wind of 8-14 m s^{-1} causes crinkling or laceration of young leaves. A cold wave with strong wind will aggrevate the damage. When wind velocity is beyond 17 m s^{-1}, wind susceptible clones are subjected to branch break and trunk snap. At wind speeds of over 24.5 m s^{-1}, most of the rubber trees are uprooted. Clonal variation in susceptibility to wind damage is generally observed.

Shelter belts are widely used in China to protect rubber trees in highly wind prone areas. In such areas, shelter belts of 20-25 m width are made, consisting of main, secondary and undergrowth trees forming dense mixed forest belts. Main trees shall be fast growing and wind resistant species such as Eucalyptus with Accacia confusa, Homalium hainanesis and Michelia macclurei as secondary trees and Camellia oleifera as under growth trees (Zongdao and Xueqin, 1983). High density planting with wind resistant clones will provide mutual shelter and will tend to limit crown size leading to reduced chances of wind damage.

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