Rubber Science, **31**(2): 152-163, 2018 *RESEARCH ARTICLE*

IDENTIFICATION OF AGRO-CLIMATICALLY SUITABLE AREAS FOR NATURAL RUBBER CULTIVATION IN LEFT WING EXTREMISM AFFECTED STATES

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The present study was undertaken to assess the agro-climatic suitability of left wing extremism (LWE) affected states of India for cultivating natural rubber (NR). Monthly means of maximum temperature, amount of rainfall, number of rainy days, potential evapotranspiration, hot degree days, vapour pressure deficit and aridity index were used in the present analyses. Variations in these parameters in the LWE affected districts of Odisha from Kottayam and Kanyakumari districts which have more congenial conditions for NR cultivation were first estimated. No district fell within a variability of up to 20 per cent from Kottayam and Kanyakumari districts when all the above parameters were taken together. When aridity index (A_I), which is a function of air temperature, wind speed, vapor pressure deficit, solar radiation and rainfall alone was considered, Ratnagiri district in Maharashtra was at par and four districts in West Bengal were within 20 per cent variability of Kanyakumari district. It was also found that between periods 1901-1955 and 1956-2002, there was no significant variation in A_I in the study areas. Earlier studies have shown that favorable limits of climate parameters for NR cultivation are: annual rainfall ≥1500 mm, rainy months ≥6, monthly maximum temperature ≥36^{0}C, monthly minimum temperature ≥10^{0}C and A_I ≥0.50. Considering these parameters as the normal climate tolerance limit (CTL), we found that 10 districts in LWE affected regions fall within these normal limits. By relaxing the CTL favourability by 10 and 20 per cent from the normal, a total of 29 and 76 districts, respectively could be identified. Maximum number of districts were from Odisha and West Bengal. Identification of suitable districts for growing NR using the A_I and CTL approach should be taken with abundant caution even as it is not known how stressful it would be to grow NR commercially in a district where the A_I or CTL is 10 or 20 per cent different from the normal range. Moreover, the east coast states, particularly Odisha are prone to frequent cyclonic storms almost every year. Therefore, results from the present study could be used only as a general indication. Ecological Niche Modelling and Geo-spatial approaches could be used in conjunction with the present analyses for identifying suitable areas for cultivating NR with greater confidence.

Key words: Agro-climatic suitability, Area-under-curve, Climate tolerance limits, Natural rubber

INTRODUCTION

Natural rubber (*Hevea brasiliensis*) being a native of the Amazon basin, grows well in areas where there is good distribution of annual rainfall (2000 mm per year) and the climate is warm (21 to 35^{0}C) and humid

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(Bradshaw, 1977; Rao and Vijayakumar, 1992). Climate suitability for any crop mainly depends on rainfall, temperature, relative humidity, sunshine duration and wind speed (Webster and Baulkwill, 1989; Rao and Vijayakumar, 1992). As natural rubber (NR) is mainly a rain-fed crop, the quantum and pattern (distribution) of rainfall can affect the crop. Temperature is one of the main factors that has a direct bearing on latex yield on a daily basis. Today NR is grown in areas where annual rainfall is as low as 1500 mm or summer maximum temperatures are above 40^0C and winter temperatures are below 10^0C (Jacob *et al*., 1999; Lemmens *et al*., 1995). Cultivation of NR is extended to non-traditional areas to meet the increasing demand for this industrial raw material in India. Parts of north eastern states and the Konkan regions are two major non-traditional areas where NR cultivation is expanding fast in India.

Natural rubber can tolerate a dry season of four to five months, provided at least 100 mm of rain is received during this period (Compagnon, 1987). High temperature coupled with low RH can increase the evaporative demand of the atmosphere and cause higher rate of transpiration which in turn leads to moisture deficit stress (Sethuraj, 1986; Ouseph, 1987; Sethuraj *et al*., 1989; Chandrashekar *et al*., 1990; Bhaskar *et al*., 1991; Mohankrishna *et al*., 1991; Rao *et al*., 1998). The situation becomes all the more extreme if rainfall is scanty. Effects of rainfall and temperature on the photosynthetic rate (Nataraja and Jacob, 1999; Sangsing, 2004), and growth and latex yield (Jiang, 1988; Rao *et al*., 1990) of rubber trees have been studied.

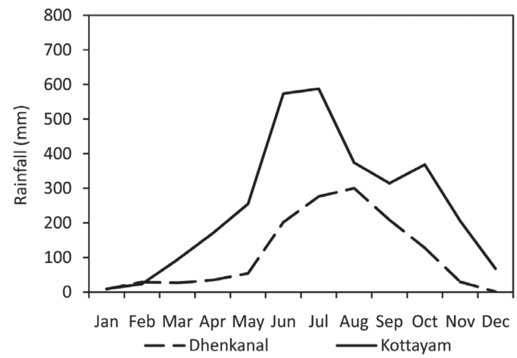
The agro-climatic suitability of a new region needs to be assessed first before scarce resources are spent on expanding NR cultivation. Therefore, the present study was undertaken with an objective of assessing the agro-climatic suitability of all districts in the ten left wing extremism (LWE) affected states of India for cultivating this crop. The LWE affected states considered for the study were Andhra Pradesh, Bihar, Chattisgarh, Jharkand, Maharashtra, Madhya Pradesh, Odisha, Telengana, Uttar Pradesh and West Bengal comprising a total of 288 districts. Out of this, a total of 106 districts are listed by the government of India as LWE affected districts. The objective of the study was to assess the climatically suitable districts in the LWE affected states for NR cultivation by analysing long term climatic data.

MATERIALS AND METHODS

Mean monthly data of maximum temperature (T_x), minimum temperature amount of rainfall (R_n), number of rainy days (R_d), and potential evapotranspiration (P_{ET}) (Allen *et al*., 1998) for a period of 102 years (1901 to 2002) were obtained from the India Water Portal website (www. indiawater portal.org) for all the 10 LWE affected states in India. Data obtained for this period from the website pertains to the undivided districts of the Indian states as of the year 2002. This published dataset consists of interpolated (on a 0.5 degree latitude-longitude grid) global monthly rainfall, temperature, humidity and cloud cover data, from 1901 to 2002 (Mitchell and Jones, 2005). The original datasets were utilised to extract the mean monthly values of rainfall, maximum, minimum and average temperatures, vapour pressure and P_{ET} from 1901 to 2002. Vapour pressure deficit (e_d) is calculated from the difference between ambient vapour pressure (e_a) and the saturation vapour pressure (e_s) at mean temperature (T) (Abtew and Melesse, 2012). Monthly A_I is defined as the ratio of annual rainfall and P_{ET} (UNESCO, 1979). It is conceptually and operationally a simple index based solely on the two main parameters. Warm arid regions have low R_n and high P_{ET} rates and thus very low A_I values. In general, higher values of A_I ³ 1 indicate less aridity and better climate suitability for crop growth.

The mean monthly values of these parameters over all 30 districts of Odisha were individually plotted and these graphs were scanned and digitized with the help of Plot Digitizer 2.6.3 software to obtain the area-under-curve (AUC) based on the standard trapezoidal method. AUC is denoted by the total area under a curve in graph units. The agro-climatic conditions prevailing in Kottayam district in the traditional NR growing region (which also has the largest area of NR grown in any district in the country) is generally considered as the most optimum. Considering Kottayam as the benchmark, the extent of deviation in the climatic parameters of the LWE affected districts from Kottayam were determined. The percentage AUC variation was calculated (Fig. 1) by estimating the percent area of each plot with respect to Kottayam (considering Kottayam AUC as 100%). In this manner the percentage variation in AUC for each LWE district from the respective standard AUC of Kottayam was calculated for all climate parameters mentioned above.

The AUC for T_x can confound the real situation if there is large seasonal variation in temperature. For example, if there are a few months with very high temperature (which can cause serious damages to rubber plants), the AUC will be large. But this effect is negated if there are a few months with relatively low temperature. Therefore AUC alone will not reflect the real situation in such cases. This was overcome by calculating hot degree days (D_d) which is defined as the sum total of the product of mean monthly temperatures exceeding that of Kottayam and the total number of days for the month.



$$\text{AUC percentage variation for Dhenkanal} = \frac{\text{Area}}{\text{Area}} \times 100$$

Fig. 1. Rainfall curves of Dhenkanal and Kottayam showing the calculation of Area-Under-Curve (AUC)

As an example, consider the maximum temperature AUCs of Kottayam and Baleswar (Fig. 2). It can be seen from November through March, the monthly maximum temperature was constantly below that of Kottayam, while this was consistently above for the rest of the months. This can result in similar AUC values which may not represent the true picture. By comparing the D_d values with Kottayam for the same period when the temperature for a district is higher than that of Kottayam, we get a better representation of the exact measure of heating at a place.

RESULTS AND DISCUSSION

Crop growth requirements are defined by the FAO in terms of impact on the growth and production and specific values

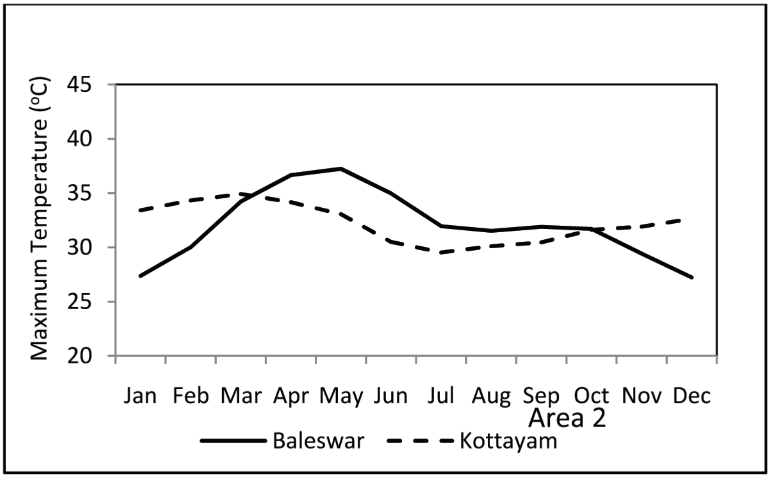


Fig. 2. Monthly maximum temperature of Baleswar and Kottayam

corresponding to optimal (no constraint) and progressively more marginal condition and severe constraints (Bhakar *et al*., 2016). For making a comparison between the climatic parameters in the districts of the Odisha state with that of Kottayam, as a thumb rule, we assumed that any deviation within up to 20 per cent of the climatic conditions prevailing in Kottayam district is within tolerable limits for cultivating NR. The adoption of such arbitrary deviation from the optimum required, will give an idea of the degree with which agro-management practices are to be adopted for the sustenance of NR in areas less suitable for NR cultivation. In the present analysis, we first examined the districts in Odisha that fell within 20 per cent variability for the respective climatic parameters compared to that of Kottayam district (assessed from the AUC for each weather parameter in every LWE district and Kottayam district). A district is not considered suitable if any one out of the seven climate parameters falls beyond the 20 per cent deviation limit (*i.e.* tolerance limit defined for the purpose of our comparison). Analysis based on this assumption shows that no district in Odisha could be classified as favourable (Table 1) for NR cultivation (*i.e.* falling within the prescribed 20% variability compared to that of Kottayam).

It was evident that when a state like Odisha, where some NR plantations already exist in a few districts did not show any suitability from the above analysis, further analyses in the same lines will not give reliable results within the 20 per cent tolerance limit in the other LWE states where NR plantations exist only nominally. This prompted us to use A_I instead of taking individual parameters assigning the same weightage to each of them. As the A_I is a function of P_{ET} and R_n, this variable was selected as a single parameter which could represent the suitability of a place. But the AUC difference (%) of A_I also varied beyond 20 per cent of Kottayam for all districts in Odisha (Table 1). The same result was obtained when the analysis was carried out for the rest of the states as none of the 288 districts showed any variability within 20 per

Table 1. **AUC difference (%) between Kottayam and each of the 30 districts of Odisha for seven selected parameters**

Districts	T_x	R_n	R_d	P_{ET}	V_d	A_I	D_d
Anugul	102	40	38	146	156	30	105
Balangir	104	47	41	159	219	31	106
Baleswar	107	49	43	143	144	36	109
Barghar	106	44	40	152	236	30	113
Baudh	102	40	38	135	170	29	109
Bhadrak	108	50	41	141	139	35	108
Cuttack	101	44	35	137	115	31	106
Debaghar	107	46	37	150	195	31	113
Dhenkanal	104	41	46	116	146	31	109
Gajapati	103	33	31	138	119	26	106
Ganjam	97	39	35	135	105	27	105
Jagatsinghapur	100	43	36	125	90	35	105
Jajapur	106	46	40	140	143	33	108
Jharsuguda	111	45	39	152	243	32	116
Kalahandi	102	45	39	142	193	31	109
Kandhamal	99	38	38	144	148	28	107
Kendrapara	104	49	40	133	124	37	107
Khendujjar	108	42	38	151	182	30	114
Khorda	101	41	36	133	105	30	105
Koraput	100	45	41	151	166	30	107
Malkangiri	105	39	40	149	193	26	110
Mayurbhanj	105	48	42	147	160	31	109
Nabarangapur	103	48	44	152	222	33	112
Nayagarh	121	43	35	139	114	28	105
Nuapada	104	45	40	152	243	32	113
Puri	88	37	31	113	126	33	84
Rayagada	99	41	37	143	142	30	105
Sambalpur	108	45	37	153	242	30	114
Sonapur	104	38	35	151	203	30	111
Sundargarh	109	48	40	154	222	33	116

cent when compared with that of Kottayam. The climate of Kanyakumari district was also considered for comparison with all districts of the ten states. Kanyakumari has a more distributed rainfall with a lower annual rainfall (48%) than Kottayam. Generally the rainfall is distributed throughout the four seasons of south-west monsoon (37%), north-

Table 2. **Suitability of districts based on AUC differences with Kanyakumari up to the 20 per cent deviation limit**

Districts	% AUC difference
Suitable	
Maharashtra	
Ratnagiri	121
at ≤10% deviation	
West Bengal	
Jalpaiguri	99
Darjeeling	90
Cooch Behar	91
at ≤ 20% deviation	
Bardhaman	89

east monsoon (38%), hot weather summer season (22%) and winter season (3%). In Kanyakumari, the growth and yield of NR is comparable to or better than that of Kottayam. The analysis (Table 2) showed that only undivided Ratnagiri (Maharashtra) was suitable at 121 per cent of the AUC of the Kottayam A_I. The four districts in West Bengal *viz*., Jalpaiguri, Darjeeling and Cooch Behar (^{3} 10%) and Bardhaman (^{3} 20%) varied within the chosen limits.

The analysis was further carried out with the climatic datasets classified into two long periods of time series data. Period I (1901 to 1955) and Period II (1956 to 2002) were analysed for detecting whether any changes had occurred in the long term AUC differences with Kottayam between the two periods in the context of climate change. Percentage AUC deviation of A_I with respect to Kottayam was calculated for each district for the two periods separately for all the 10 states. Independent T-tests showed that A_I did not show any significant difference between the two periods in any of the districts, even up to the 20 per cent variability level as shown for two states *viz.* West Bengal and Jharkand (Table 3).

Another attempt was made to analyze the suitability of LWE districts based on the "crop criteria" for tolerance limits in terms of climate favourability for NR as prescribed in the literature (Vijayakumar *et al*., 2000). Climatic tolerance limits (CTL) is defined as the extreme tolerance limits of important climatic parameters beyond which detrimental effects are seen in terms of growth and yield of NR trees. Suitability is determined only if all the CTL parameters come within the tolerance limits. Natural rubber could be cultivated in regions with an annual rainfall limit of 1500 mm with at least four to seven months rainfall period. In the present study, the minimum required annual rainfall has been considered as ^{3}1500 mm with ^{3} six months rainfall period. Monthly maximum temperature could be considered up to 35^0C with higher temperatures up to two months in summer and minimum temperature as $^3 10^0$C (Vijayakumar *et al*., 2000). An earlier study indicated that high temperatures above 37^0C coupled with soil moisture deficit resulted in injury and drying of leaf margins in North Konkan (Chandrashekar *et al*., 1990). Here the monthly maximum temperature of $^3 36^0$C and minimum temperature of $^3 10^0$C have been chosen as the extreme temperature tolerance limits. Based on the UNESCO method, areas recorded with aridity index higher than 0.5 are classified as sub-humid, humid and ultra-humid zones, capable of being used in normal agriculture (Ghasemi *et al*., 2008). This limit of ^{3}0.5 for A_I was chosen for the present study.

The five chosen limits under normal CTL based on favourability for NR are given in Table 4. It also gives the CTL values based on the ^{3}10 and ^{3}20 per cent levels of

Table 3. **Differences in AUC of aridity index between Kottayam and districts for West Bengal and Jharkand in two different periods**

State	West Bengal		State	Jharkand	
Districts	1901-55	1955-02	Districts	1901-55	1955-02
Bankura	33	32	Bokaro	28	28
Bardhaman	51	48	Chatra	22	24
Birbhum	43	29	Deogarh	27	26
Dakshin Dinajpur	35	33	Dhanbad	27	29
Darjeeling	52	47	Dhumka	27	42
Howrah	37	43	Garhwa	26	24
Hooghly	36	36	Giridih	27	26
Jalpaiguri	57	54	Godda	28	25
Cooch Behar	53	52	Gumla	28	28
Kolkata	38	42	Hazaribag	27	26
Malda	32	29	Kodarma	26	25
Mednipur	37	38	Lohardaga	27	27
Murshidabad	31	30	Pakaur	28	26
Nasdia	34	34	Palamu	26	25
North 24 Parganas	42	45	Pas. Singhbum	27	25
Purulia	29	28	Pu. Singhbum	27	26
South 24 Parganas	44	51	Ranchi	27	26
Uttar Dinajpur	36	32	Sahibganj	27	25
$(T_{.05} = 0.8624^{NS})$			$(T_{.05} = -0.0571^{NS})$		

favourability. Favourability in terms of CTL is considered in such a manner that ^{3}10 per cent indicates that CTL is increased from the normal by 10 per cent for maximum temperature, while it is decreased by 10 per cent for the other four parameters thereby relaxing the yardstick for selection of districts based on CTL favourability. A total of 10 districts could be selected (Table 5) which falls within the normal CTL. Undivided Ratnagiri and Kolhapur districts in Maharashtra, Baleswar district in Odisha and seven districts of West Bengal could be classified as favourable, based on the normal CTL for rain-fed rubber cultivation. Tables 6 and 7 show the selected districts based on favourability of CTL up to 10 and 20 per cent deviation from the normal CTL respectively. By relaxing the yardstick of climate favourability by 10 per cent from the normal, we could identify a total of 26 districts within

Table 4. **Values for CTLs based on normal, ≤ 10 and ≤ 20 per cent favorability from the normal CTLs for NR cultivation**

Parameters	Normal	≤10%	≤20%
Maximum temperature (°C)	≤36.0	≤39.6	≤43.2
Minimum temperature (°C)	≥10.0	≥9.9	≥8.2
Rainfall (mm)	≥1500	≥1350	≥1200
Annual rainy months	≥6	≥5	≥5
Aridity index	≥0.50	≥0.45	≥0.40

Table 5. **States with districts coming under the normal CTL**

State	Maharashtra	Odisha	West Bengal
Districts	Ratnagiri	Baleswar	Cooch Behar
	Kolhapur		Hoogly
			Howrah
			Jalpaiguri
			Kolkata
			Medinipur*
			North 24 Parganas

*LWE affected districts

the states of Maharashtra, Odisha and West Bengal where NR could be grown. Further relaxing the favourability to 20 per cent, a total of 76 districts within eight LWE states emerged as suitable for growing NR. By relaxing the favourability from 10 to 20 per cent, the climate constraints for growing NR decrease with respect to the normal CTL used in the present study. The maximum number of districts below the 10 and 20 per cent tolerance levels were found situated in the states of Odisha and West Bengal. In Telengana, only Adilabad district qualified for suitability below the 20 per cent level. No districts in Andhra Pradesh and Uttar Pradesh were found suitable even at the 20 per cent level. Tables 5 to 7 also show that the total number of LWE affected districts coming under the normal, 10 and 20 per cent suitability were found to be 10, 29 and 76, respectively. A majority of the suitable districts identified mainly comes under the eastern states of West Bengal and Odisha.

With respect to the suitability proposed at various levels, caution will have to be exercised for the weather calamities that

Table 6. **States with districts coming under the ≤ 10 per cent level from the normal CTL**

State	Maharashtra	Odisha	West Bengal
Districts	Ratnagiri	Baleswar	Bankura
	Kolhapur	Bhadrak	Bardhaman
	Pune	Debaghar	Cooch Behar
	Sangli	Jagatsinghapur	Dakshin Dinajpur
	Satara	Jajapur	Hooghly
		Kendrapara	Howrah
		Mayurbhanj*	Jalpaiguri
		Nabarangapur*	Chattisgarh
		Sundargarh*	Kolkata
			Medinipur*
			Murshidabad
			Nadia
			North 24 Parganas
			South 24 Parganas
			Uttar Dinajpur

*LWE affected districts

Table 7. **States with districts coming under the ≥ 20 per cent level from the normal CTL**

State	Bihar	Chattisgarh	Jharkand	Maharashtra	Madhya Pradesh	Odisha	Telengana	West Bengal
Districts	Araria	Bastar*	Bokaro*	Ratnagiri	Balaghat*	Anugul	Adilabad*	Bankura
	Kaithar	Dhamtari*	Dhanbad*	Kolhapur	Seoni	Balangir*		Bardhaman
	Kishanganj	Jashpur*	Dhumka*	Pune		Baleswar		Birbhum*
	Pa. Champaran*	Korba	Giridih*	Sangli		Barghar*		Cooch Behar
	Purnia	Mahasamund*	Godda	Nashik		Baudh		Cuttack
		Raipur	Gumla*	Gondia*		Bhadrak		Dakshin Dinajpur
		Rajnandgaon*	Kodarma*	Satara		Debaghar*		Hooghly
		Surguja*	Lohardaga*			Dhenkanal*		Howrah
			Pakaur*			Jagatsinghapur		Jalpaiguri
			Pa.Singhbum*			Jajapur		Kolkata
			Pu. Singhbum			Kalahandi*		Maldah
			Ranchi*			Kendrapara		Medinipur*
			Sahibganj			Khendujjar*		Murshidabad
						Khorda		Nadia
						Koraput*		North 24 Parganas
						Mayurbhanj*		Purulia*
						Nabarangapur*		South 24 Parganas
						Nuapada*		Uttar Dinajpur
						Rayagada*		
						Sambalpur*		
						Sonapur		
						Sundergarh*		

*LWE affected districts

occur in the districts mentioned in the study. Hazards associated with tropical cyclones are long-duration rotatory high velocity winds, very heavy rain and storm tides. Although the north Indian Ocean extending to (the Bay of Bengal and Arabian Sea) generates only about seven per cent of the world's cyclones (5 to 6 cyclones per year), their impact is comparatively high and devastating. Details of landfall cyclones which caused devastating damage to land and vegetation on the east and west coasts are reported by Mohapatra *et al.,* (2012). The east coast of India is highly affected by cyclones with varying frequency and intensity. In general, the coastal districts of West Bengal, Odisha, Andhra Pradesh and Tamil Nadu are more prone to cyclones and the damages due to wind are classified as high to very high category in a four point scale (low, moderate, high and very high) ratings. Cyclone probabilities are very high for the districts of South 24 Parganas, and Medinipur in West Bengal; Balasore, Bhadrak, Kendrapara, Jagatsinghapur in Odhisa; Nellore, East Godavari, Srikakulam and Krishna in Andhra Pradesh (Mohapatra *et al*., 2012). No districts were reported to be cyclone affected in Karnataka. Traditional rubber growing belts comprising of Kerala, Kanyakumari district of south Tamil Nadu and Maharashtra in the west coast are less prone to the hazards of tropical cyclones.

CONCLUSION

Two different methods were followed to assess the climatic suitability for rubber cultivation in ten LWE affected states in India. In the first method, undivided Ratnagiri district in Maharashtra showed suitability comparable to that of Kanyakumari district and a few districts in West Bengal qualified up to the 20 per cent variability. However, the study based on CTL values in the second method could identify 10 districts falling within the normal climate range. By lowering the CTL up to 20 per cent, a total of 76 districts became suitable for growing NR. This does not merely reflect on the possibility of growing NR without any hurdles in these districts. Other vital aspects like topography, altitude, soil health *etc.* have not been considered in the present study. The present results can only be considered as a thumb rule for locating suitable districts for growing NR. Combining the present analysis with Ecological Niche Modelling and Geo-spatial techniques can substantially improve the accuracy and reliability of the present findings. Pilot scale planting should be taken up on a trial basis before expanding NR cultivation in these districts.

REFERENCES

Abtew, W. and Assefa, M. (2012). Vapor pressure calculation methods, Chapter 3. In: *Evaporation and Evapotranspiration*. DOI 10.1007/978-94-007-4737-1-5, pp. 53-62.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. *FAO Irrigation and drainage paper 56*, Rome, Italy.

Bhakar, S.R., Jat, M.L., Anil, K.K. and Sharma, S.K. (2016). Alternative land use planning, Chapter 21 In: *Dryland Technology (2nd edition)*. Scientific Publishers (India). ISBN: 978-81-7233-998-2(HB), 641 p.

Bhaskar, C.V.S., Mohankrishna, T., Chandrashekar, T.R., Rao, P.S., Vijayakumar, K.R. and Sethuraj, M.R. (1991). Effect of irrigation on growth and other physiological parameters of *Hevea brasiliensis* in the Konkan region of India.

Physisology and Exploitation of Hevea brasiliensis. Proceedings of IRRDB Symposium, 1990, Kunming, China, pp.130-135.

Bradshaw, M.J. (1977). *Earth: The Living Planet*. Hodder and Stoughton, London, 302 p.

Chandrashekar, T.R., Jana, M.K., Thomas, J., Vijayakumar, K.R. and Sethuraj, M.R. (1990). Seasonal changes in physiological characteristics and yield in newly opened trees of *Hevea brasiliensis* in North Konkan. *Indian Journal of Natural Rubber Research*, **3**(2): 88-97.

Compagnon, P. (1987). Le Caoutchouc Naturel-Biologie, Culture, Production. Techniques Agricoles et Productions Tropicales. G.-P. Maisonneuve & Larose, Paris. ISBN 2-7068-0910-8, 595 p.

Ghasemi, V.R., Mahmoudi, S., Ghafari, A.A.A. and De Pauw, E. (2008). Agro-climate zoning (ACZ) through UNESCO approach and modified aridity index in some parts of East Azerbaijan and Ardabil provinces. *Iranian Journal of Agricultural Sciences (Journal of Agriculture)*, **39**(2): 281-289.

Jacob, J., Annamalainathan, K., Alam, B., Sathik, M.B.M., Thapliyal, A.P. and 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&2): 1-16.

Jiang, A. (1988). Climate and natural production of rubber (*Hevea brasiliensis*) in Xishuangbanna, southern part of Yunnan province, China. *International Journal of Biometeorology*, **32**(4): 280-282.

Lemmens, R.H.M.J., Soerianegora, I. and Wong, W.C. (1995). PROSEA Plant Resources of South-East Asia 5(2), *Timber Trees: Minor Commercial Timbers*. Backhuys, Leiden. ISBN 90-73348-44-7, 655 p.

Mohankrishna, T., Bhaskar, C.V.S., Rao, P.S., Chandrashekar, T.R., Sethuraj, M.R. and Vijayakumar, K.R. (1991). Effect of irrigation on physiological performance of immature plants of *Hevea brasiliensis* in North Konkan. *Indian Journal of Natural Rubber Research*, **4**(1): 36-45.

Mohapatra, M., Mandal, G.S., Bandyopadhyay, B.K., Ajit, T. and Mohanty, U.C. (2012). Classification of cyclone hazard prone districts of India. *Natural Hazards*, **63**: 1601-1620. Springer. DOI 10.1007/s11069-011-9891-8.

Mitchell, T.D. and Jone, P.D. (2005). An improved method of constructing a database of monthly climate observations and associated high resolution grids. *International Journal of Climatology*, **25**: 693-712.

Nataraja, K.N. and Jacob, J. (1999). Clonal differences in photosynthesis in *Hevea brasiliensis* Muell. Arg. *Photosynthetica*, **36**(12): 89-98.

Ouseph, T. (1987). Drought and rubber planting, *Rubber Board Bulletin*, **22**(4): 24-26.

Rao, G., Rao, P., Rajagopal, R., Devakumar, A.S., Vijayakumar, K.R. and Sethuraj, M.R. (1990). Influence of soil, plant and meteorological factors on water relations and yield in *Hevea brasiliensis*. *International Journal of Biometeorology*, **34**(3): 175-180.

Rao, P. and Vijayakumar, K.R. (1992). Climatic Requirements. In: *Natural Rubber: Biology, Cultivation and Technology*. Developments in Crop Science (Eds. Sethuraj, M. R. and Mathew, N. M.) Elsevier, Netherlands. ISBN 0-444-88329-0, pp. 200-220.

Rao, P., Saraswathyamma, C.K. and Sethuraj, M.R. (1998). Studies on the relationship between yield and meteorological parameters of para rubber tree (*Hevea brasiliensis*). *Agricultural and Forest Meteorology*, **90**: 235-245.

Sangsing, K. (2004). Carbon acquisition and plant water status in response to water stress of rubber (*Hevea brasiliensis*). *Ph.D thesis*. Kasetsart University. ISBN 974-274-410-6,130 p.

Sethuraj, M.R. (1986). Physiology of growth and yield in *Hevea brasiliensis*. *Proceedings of International Rubber Conference, 1986*, Kuala Lumpur, Malaysia, pp. 3-19.

Sethuraj, M.R., Potty, S.N., Vijayakumar, K.R., Krishnakumar, A.K., Rao, P.S., Thaspliyal, A.P., Mohankrishna, T., Rao, G.G., Chaudhuri, D., George, M.J., Soman, T.A. and Meenattoor, J.R. (1989). Growth performance of *Hevea* in the non-traditional regions of India. *Proceedings of the Rubber Research Institute of Malaysia, Rubber Growers' Conference, 1989*, Malacca, Malaysia, pp. 212-227.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (1979). *Map of the world distribution of arid regions: Map at scale 1:25,000,000 with explanatory note.* MAB Technical Notes 7, UNESCO, Paris.

Vijayakumar, K.R., Chandrashekar, T.R. and Philip, V. (2000). Agroclimate. In: *Natural Rubber: Agromanagement and Crop Processing*. (Eds. P. J. George and C. Kuruvilla Jacob). Rubber Research Institute of India, Kottayam, pp. 97-116.

Webster, C.C. and Baulkwill, W.J. (1989). *Rubber*. Longman Scientific and Technical, Essex, 614 p.