WATER USE BY NATURAL RUBBER TREES IN THREE DIFFERENT AGRO-CLIMATIC REGIONS OF INDIA

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Water mining by mature rubber trees grown under three different agro-climatic conditions, *viz.* traditional rubber growing region in Kerala, and two non-traditional regions, namely the hot and dry North Konkan region in Maharastra and cold Sub-Himalayan region in West Bengal was measured using thermal dissipation probes (TDP). In Kerala and West Bengal, rubber trees were grown under rain fed conditions whereas in the drought prone Maharastra, they were grown either as rain fed or irrigated (during rain-free summer months). The mean water mining rate was 22 L $tree^{-1}$ day^{-1} in Kerala, around 23 L $tree^{-1}$ day^{-1} in West Bengal and around 25 and 19 L $tree^{-1}day^{-1}$ for irrigated and rain fed trees, respectively in Maharastra. Water use efficiency (WUE) of mature rubber trees estimated as dry rubber production or tree biomass for a unit amount of water consumed varied between the three regions. In Kerala this worked out to be $8.0x10^{-4}$ kg rubber kg^{-1} water and $3.8x10^{-3}$ kg biomass kg^{-1} water whereas in the drought-prone Maharastra WUE was very less ($3.7x10^{-4}$ kg rubber kg^{-1} water and $2.0x10^{-3}$ kg biomass kg^{-1} water in rain fed and $4.8x10^{-4}$ kg rubber kg^{-1} water and $2.3x10^{-3}$ kg biomass kg^{-1} water in irrigated trees). In the case of cold prone West Bengal, WUE was $6.7x10^{-4}$ kg rubber kg^{-1} water and $3.4x10^{-3}$ kg biomass kg^{-1} water. Our results showed that the higher the rubber yield or biomass production, the higher the WUE and therefore, WUE of rubber trees is determined predominantly by rubber yield or biomass production rather than by the amount of water consumed.

Key words: Agro-climatic regions, Rubber tree, Thermal dissipation probes, Water use efficiency

INTRODUCTION

There is a public perception that natural rubber (NR) cultivation results in depletion of ground water even as there is no scientific evidence to support this general contention. Natural rubber plantations occupy large areas of land which account for almost 21 per cent of the total cultivated area and 14 per cent of the total geographical extent of Kerala (MoE & F, Govt. of India, 2018). It is reported that ground water level has gone down in the state in recent decades (Shaji *et al*., 2008). It is generally believed that when mature rubber trees are felled, water levels in the nearby wells go up. These empirical observations are often taken as

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anecdotal evidence to conclude that rubber cultivation is responsible for this. What is not considered by the proponents of this notion is that ground water depletion happens in areas where NR cultivation is not present (Chindarkar and Grafton, 2019). Naturally there must be other more compelling explanations for depletion of ground water than mere cultivation of NR. Published literature indicated that water mining rate of rubber tree is modest compared to several forest and cultivated tree species. Water mining rate in kg water tree^{-1} day^{-1} ranged from 10-12 in Quercus,13-44 in *Pinus*, 45-51 in *Populus*, 45-59 in *Acacia*, 90-123 in Eucalyptus (Wullschleger *et al.*, 1998); 30-120 in coconut (Jayasekara and Jayasekara 1993); 20-25 in rubber (Annamalainathan *et al.*, 2013) and 40-45 in mango (Cotrim *et al.*, 2019).

Water is fast becoming a scarce natural resource as its domestic, agricultural and industrial consumptions are on the rise (World Water Assessment Programme, 2018). Global warming has caused significant deviations in the distribution of annual rainfall in many parts of the world (Pendergrass *et al.*, 2017) including NR growing regions of India. Occurrence of heavy intensity rainfall has been on the rise leading to flash floods and landslides in the different Western Ghats states where NR is a major crop. Atmospheric temperature has been steadily going up in almost the entire rubber belt along these states (Shammiraj *et al.*, 2011; Satheesh and Jacob, 2011). Evaporative demand of the atmosphere has increased and water holding capacity of the soil has decreased over the years (Scheff and Frierson, 2014). These micro and macro-climatic and pedological changes may have an overwhelming impact on ground water recharge than a particular vegetation type present in a region. In the present study, we measured water mining by mature rubber trees grown in three distinct agro-climatic regions using a dual-probe sap-flow measurement system based on the principle of thermal dissipation (Granier, 1985). These three agro-climatic regions represent locations where NR is a major existing crop (traditional region) or where this is being extended as a new cash crop (non-traditional regions). Rate of water mining showed wide variability in the different agro-climatic regions depending on the season (ambient weather conditions), available soil moisture and phenological phase of the rubber trees. In an earlier study (Annamalainathan *et al.*, 2013) using the thermal dissipation probe technique, it was shown that the mean transpiration rate of mature rubber tree was 20-25 L water tree^{-1} day^{-1} or in the range of 1.5 - 2mm day^{-1}.

In the present study we measured water consumption and rubber production and estimated the water use efficiency of NR trees grown in three different agro-climatic regions of India where this crop is cultivated. It was found that mean water consumption was 23.5 L tree^{-1} day^{-1} in rubber growing regions of India. However, WUE was the highest in Kottayam, Kerala followed by West Bengal and the lowest in North Konkan. This closely followed rubber yield and biomass production in the three study regions, indicating that WUE was largely determined by variations in rubber yield and biomass production rather than water consumption by the trees.

MATERIALS AND METHODS

Experimental sites

The study was carried out in three distinct agro-climatic regions of India *viz.* a traditional rubber growing area in Kerala (Kottayam), a drought prone semi-arid

Table 1. **Geographical locations and other experimental details of the three agro-climatic regions of the study**

Experimental station	Geographical location	Climatic zone	Clone	Age of the plants	Rainfed/ irrigation
RRII, Kottayam, Kerala	Longitude 76° 34′ E, latitude 9° 32′ N and altitude 72 MSL	Central Kerala: traditional rubber growing region	RRII 5 and PR 255	18-20 years old	Rainfed trees
RRS, Dapchari, Maharastra	Longitude 72° 04′ E, latitude 20° 04′ N and altitude 48 MSL	North Konkan, Semi-arid drought prone region	RRIM 600	22-24 years old	Rainfed and irrigated trees
RES, Nagrakata, West Bengal	Longitude 88° 57′ E, latitude 26° 51′ N and altitude 69 MSL	North Bengal, Sub-Himalayan cold stress prone region	RRII 417 and RRII 429	18-20 years old	Rainfed trees

station located in North Konkan region of Maharastra (Dapchari) and a cold stress prone Sub-Himalayan region of West Bengal (Nagrakata). The age of the trees during experimental period was 18-20, 22-24 and 18-20 years in Kerala, Maharashtra and West Bengal, respectively (Table 1). The traditional region, Kottayam experiences moderate climate conditions (well distributed annual rainfall of around 2800mm; T_{max} 29 - 34°C; T_{min} 22-24°C and RH 60-100%) conducive for successful rubber cultivation compared to the other two extreme climatic zones. Dapchari in the North Konkan region of Maharastra experiences prolonged soil and atmospheric drought with concomitant occurrence of high light and high temperature conditions during post monsoon and summer seasons (December-June). The average rainfall is around 2400mm received from June-November (narrow distribution) and rest of the year goes without any rain. This region experiences high solar light load in the range of 1800-2000 μmol m^{-2} s^{-1}, high T_{max} (> 37°C) and low RH (30-45%) during summer months. Nagrakata located in the Sub-Himalayan region of northern West Bengal experiences cold winter during November-February. T_{min} can be as low as 5°C for a few days during winter. The annual rainfall in this region is around 2000mm which is comparatively well distributed. Details of geographical locations of the study, rubber clones used, age of the trees, irrigation *etc.* are given in Table 1.

Measurement of xylem sap flow rate using TDP probes

Sap flow rate was measured continuously round the clock for whole year using Granier's type TDP probes (Granier, 1985). The probes with 50 mm length were inserted in main trunk of rubber trees (three trees/ clone and three trees each for irrigated and un-irrigated treatments) at breast height and the probes were connected to a programmable data logger (DL 2, Delta T Devices, UK). Sap flow rate is calculated based on computation of speed of thermal dissipation between two probes (Allen and Grime, 1995). The upper probe is heated and its temperature is compared to a lower ambient temperature needle. Sap flow is a function of temperature difference: it reaches the maximum (dTM) when sap flow is close or near to zero and it decreases as water comes up. Empirically the sap flow velocity (V) is estimated as

$V = 0.0119 * K^{1.231}$ cm s^{-1}...........................(1)

where K = (dTM-dT)/dT, dT is the measured difference in temperature between that of the upper heated needle referenced to the lower non-heated needle and dTM is the value when there is no sap flow or the lowest flow in a day.

Sap flow velocity can be converted to sap flow rate Fs(mL hr^{-1}) as below

Fs = As * V* 3600 mL hr^{-1} ....(2)

Where 'As' is the cross-sectional area of sap conducting wood (cm^2).

The average active xylem area in rubber wood (a diffuse porous wood) was estimated to be 30 per cent of cross sectional area (Reghu *et al*., 2006). Fs is a direct measurement of transpirational water loss at a given time.

Soil moisture content

Soil moisture content (%) was determined at 0-30 cm and 30-60 cm soil depth by gravimetric method (Reynolds, 1970).

Shoot biomass estimation

For accounting the annual shoot biomass increment, girth of trunks of all trees under each treatment was measured at a height of 150 cm from bud union every year during the month of March. The shoot dry biomass (W) of trees was calculated using the Shorrocks regression model (Shorrocks *et al*., 1965), $W=0.002604\ G^{2.7826}$, where G is the mean trunk girth at 150 cm from bud union. From the shoot biomass of consecutive years the annual biomass increment was calculated.

Dry rubber yield

Latex volume (ml) and dry rubber content of latex (%) were recorded from the tapped plots on all tapping days to estimate average annual dry rubber yield of trees (kg $tree^{-1}$ $year^{-1}$).

Meteorological observations

The daily meteorological parameters *viz.* minimum and maximum temperatures, rainfall and potential evaporation were recorded at a meteorological observatory in the respective experimental sites. These parameters were used for establishing environmental relationships with the sap flow rate.

RESULTS AND DISCUSSION

Pattern of daily water mining of rubber trees round the year in Kerala, Maharashtra and West Bengal is given in Figure 1, 2 and 3, respectively. As expected, with the onset of wintering, rate of water mining declined and reached a lowest rate when leaf fall was complete in Kerala and West Bengal. On the contrary the lowest rate of water mining was observed during peak summer season in Maharastra when soil moisture content was the lowest in this region. The lowest rate occurred during February in Kerala and West Bengal and May/June in Maharastra. The rate of water mining at the peak of leaf fall was 11.0 L day^{-1} in Kerala 9.6 L day^{-1} (rainfed) and 16 L day^{-1} (irrigated) in Maharashtra and 10.5 L day^{-1} in West Bengal (Fig. 1, 2, 3 and Tables 2, 3). Drop in water mining with the onset of leaf fall was the sharpest in Kerala (February) and Maharashtra (February and May/June) compared to West Bengal where this started to decline early (November/December) in a gradual and steady manner as the winter temperature started to drop and well before leaf fall

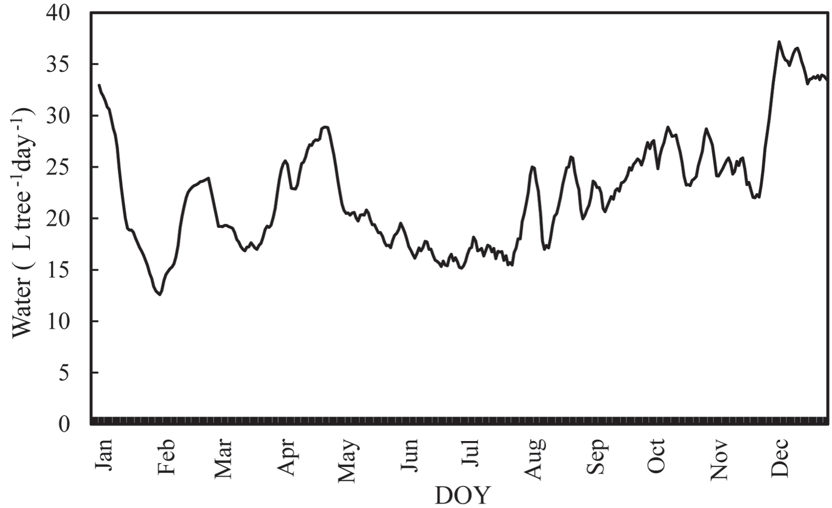

Fig. 1. Annual water mining pattern in a mature stand of rubber plantation at RRII, Kottayam, a traditional rubber plantation area

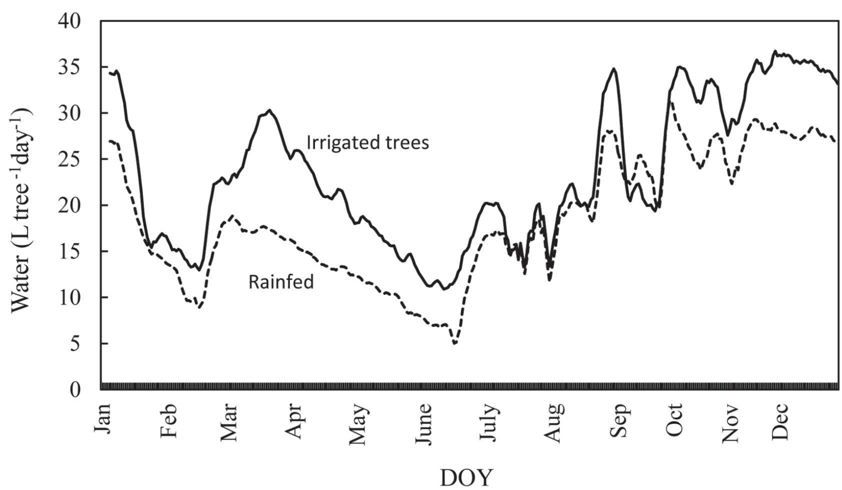

Fig. 2. Annual water mining trend in rainfed (red line) and irrigated trees (Green line) at RRS, Dapchari, Maharashtra

began. The rate of flow of transpiration water in different seasons and various environmental factors which regulate the water flow in mature rubber trees in Kerala was already reported (Annamalainathan *et al.*, 2013). From the rate of decline in water consumption, it can be deduced that leaf fall was more an abrupt phenomenon in Kerala and Maharashtra compared to West Bengal where it was more gradual and late as winter season advanced. Atmospheric temperature prevailing in West Bengal is much lower than that of Kerala and Maharashtra during the months preceding leaf fall (Das *et al.*, 2011) which may be a reason for the delayed onset of leaf fall there.

As expected, when refoliation picked up rate of water mining showed a concomitant increase at all the three study sites (Fig. 1, 2 and 3). This increase was early by a couple of weeks in Kerala, followed by Maharashtra and the last (March) in West Bengal roughly in line with the leaf fall/refoliation pattern in these states. There was a second drop in water mining in Kerala and Maharashtra that coincided with the peak summer period characterized by high temperature and receding soil moisture (Fig. 1, 2). Compared to the rainfed trees, water mining rate in Maharashtra was higher in the irrigated trees during summer (Fig. 2) due to more availability of soil moisture to the trees which led to luxury water consumption. There was no appreciable drop in water mining by rubber trees during summer in West Bengal where the seasonal temperature was much less than in Maharashtra and Kerala. Summer drop in water mining was the sharpest in Maharashtra where the seasonal temperature remained the highest and RH was the lowest and therefore, the evaporative demand of the atmosphere was also the highest. Even in the irrigated trees in Maharashtra, water mining decreased sharply during summer (Fig. 2) which indicates that stomata were forced to remain closed for the better part of the day due to the high temperature and sunlight and very low RH (Jacob *et al.*, 1999; Tuzet *et al.*, 2003). It is well known that a high atmospheric temperature will normally increase the evaporative demand of the air leading to more transpiration (Schoppach and Walid, 2013) and thus more mining of water from the soil, provided soil moisture is not a limiting factor. However, if the VPD is very high, hydraulic conductivity of the tree may not be high enough to maintain a steady stream of water flow to the canopy leading to closure of stomata and drop in water mining by the tree.

Table 2. **Sap flow rate in mature rubber trees of RRIM 600 at RRS, Dapchari, Maharashtra**

Month	Monthly mean sap flow rate (L tree^{-1} day^{-1})		Soil moisture (%)			
			Rainfed		Irrigation (0.5ETc)	
	Rainfed	Summer irrigation	0-30 cm	30-60cm	0-30 cm	30-60cm
January	19.5 ± 1.0	25 ± 1.3	19.5	23.5	22.0	24.0
February	13 ± 0.7	17.2 ± 0.6	16.8	19.0	20.5	22.0
March	17 ± 0.3	27 ± 0.6	16.0	20.0	21.0	23.5
April	13.6 ± 0.3	22 ± 0.5	15.5	19.0	18.5	21.0
May	9.9 ± 0.4	16.0 ± 0.7	14.0	17.2	17.5	20.0
June	9.6 ± 0.6	16.5 ± 0.9	31.4	34.5	32.5	34.0
July	16.5 ± 0.3	17 ± 0.6	saturated soil moisture			
August	22 ± 0.6	24 ± 0.4	- do -			
September	23.5 ± 0.8	23 ± 0.9	- do -			
October	28.5 ± 0.5	33 ± 1.1	- do -			
November	29 ± 0.6	36 ± 1.2	26.0	27.5	26.5	28.5
December	27.6 ± 0.6	36.5 ± 0.5	22.4	26.0	23.0	26.5

Around 0.5 ETc level of irrigation was provided from January onwards till the onset of monsoon in the case of 'irrigation' treatment

Table 3. **Monthly mean sap flow rate in rainfed rubber trees at RRII, Kottayam, Kerala and RES Nagrakata, West Bengal**

Month	Monthly mean sap flow rate (L tree^{-1}day^{-1})	
	Kottayam, Kerala	Nagrakata, West Bengal
January	29 ± 1.0	13.0 ± 0.8
February	11.0 ± 0.6	10.5 ± 0.3
March	14.0 ± 0.7	24.5 ± 1.1
April	21.0 ± 0.6	21.5 ± 1.2
May	16.5 ± 0.7	25.0 ± 1.5
June	14.5 ± 0.6	25.5 ± 1.1
July	19.5 ± 0.7	23.5 ± 1.0
August	21.5 ± 0.8	23.0 ± 0.9
September	22.5 ± 1.1	26.0 ± 1.0
October	33.0 ± 1.0	25.5 ± 1.8
November	28.0 ± 1.5	30.0 ± 1.7
December	36.0 ± 1.4	24.5 ± 1.4

Trees were grown as rain fed crop through the year

With the onset of monsoon (June, July), there was a perceptible increase in water mining in Kerala as well as in Maharashtra. In West Bengal this remained more or less constant during monsoon, although day-to-day variations were the highest here which may be related to more weather disturbances in West Bengal than in Kerala and Maharashtra.

The lowest rate of water mining was noticed in Maharashtra which was due to the small canopy size of the trees and deficit soil moisture during summer months (April-June) in the rainfed trees (Table 2). Rainfed rubber trees of Kerala and West Bengal and irrigated trees of Maharashtra had more or less similar water consumption (Table 2&3). However, rubber yield and biomass increment/year were the smallest in the latter. Compared to West Bengal, rubber yield was slightly more in Kerala, but shoot biomass increment year^{-1} was comparable (Table 4).

Climatic factors and water mining rate

The major environmental factors that regulate the sap flow rate are solar radiation, sunshine hours, temperature variance, atmospheric vapour pressure deficit (VPD) and soil moisture conditions. Sunlight intensity has a direct role in regulating the sap flow rate as reported earlier in the case of traditional region in Kerala (Annamalainathan *et al*., 2013).

Relationship between water mining rate and weather parameters like temperature,

Table 4. **Water use efficiency (WUE) of rubber plants as a function of rubber productivity and biomass increment in different agro-climatic regions**

Station	Irrigation condition	Water consumption (L tree^{-1}day^{-1})	Rubber yield (kg rubber tree^{-1} year^{-1})	Shoot biomass increment (kg tree^{-1} year^{-1})	Water use efficiency (WUE)	
					(kg biomass kg water^{-1})	(kg rubber kg water^{-1})
Kottayam, Kerala	Rainfed	22 ± 0.35	6.4	30.5	8.0×10^{-4}	3.8×10^{-3}
Dapchari, Maharastra	Rainfed	19 ± 0.4	2.5	13.4	3.7×10^{-4}	2.0×10^{-3}
	Irrigated	25 ± 0.45	4.4	21	4.8×10^{-4}	2.3×10^{-3}
Nagrakata, West Bengal	Rainfed	23 ± 0.36	5.5	29	6.7×10^{-4}	3.4×10^{-3}

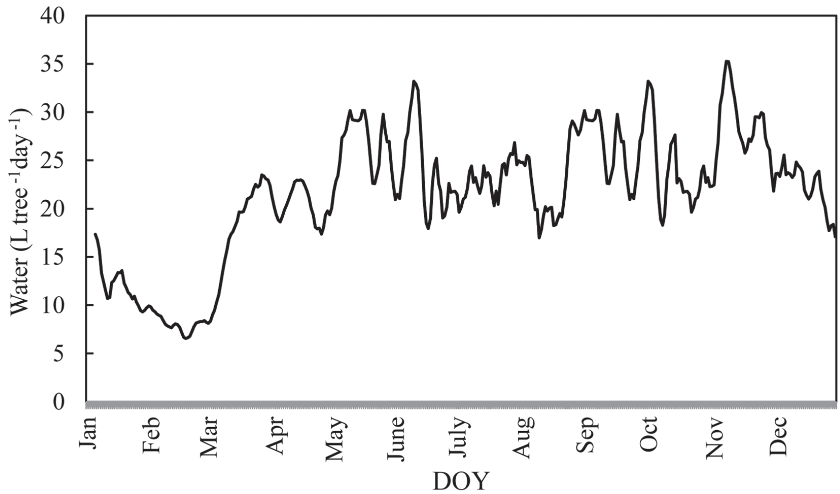

Fig. 3. Annual water mining pattern of mature rubber plantation at RES, Nagrakata, West Bengal

sunshine hours and evapotranspiration were analyzed in different seasons of the year by simple linear regression. Relationships between weather parameters and xylem sap flow rate in mature rubber trees grown in traditional region were already reported. In that study the seasonal changes in the water consumption rate in Kerala was well explained which responded to prevailing weather conditions like sunlight intensity, sunshine hours, temperature and rainfall (Annamalainathan *et al*., 2013). In general, it was observed that sunlight intensity strictly controlled water mining by rubber trees in Kerala. During monsoon season on intensive rainy days a remarkable decline in rate of water mining was observed in Kerala most probably due to cloudy days causing closure of stomata and low transpiration pull. T_{max} and potential evapotranspiration (PET) rate had negative effects on water mining rate in North Konkan region (Fig. 4c). High temperature coupled with low soil moisture condition favoured a low rate of water mining rate in rainfed plantation. Prevailing soil moisture deficit was aggravated by concomitant occurrence of high atmospheric temperature and high rate of evaporation (Fig. 4a and 4c) during summer. However, in irrigated plots the prevailing adverse climatic conditions did not significantly influence water consumption rate (4b and 4d). Similar pattern of decline in water consumption of rubber tree was observed in North East Thailand as the dry season progressed (Isarangkool Na Ayutthaya *et al*., 2009). Interestingly there was no significant effect of temperature (T_{max} and T_{min}) on the water consumption rate of rubber trees during monsoon season, possibly because soil moisture was abundant. Sunshine hours did not strictly influence the water mining rate in this region indicating overwhelming effects of other weather parameters especially temperature.

In Sub-Himalayan region water consumption was very low during the onset of winter season, apparently when canopy was good suggesting profound effects of low temperature on water mining.

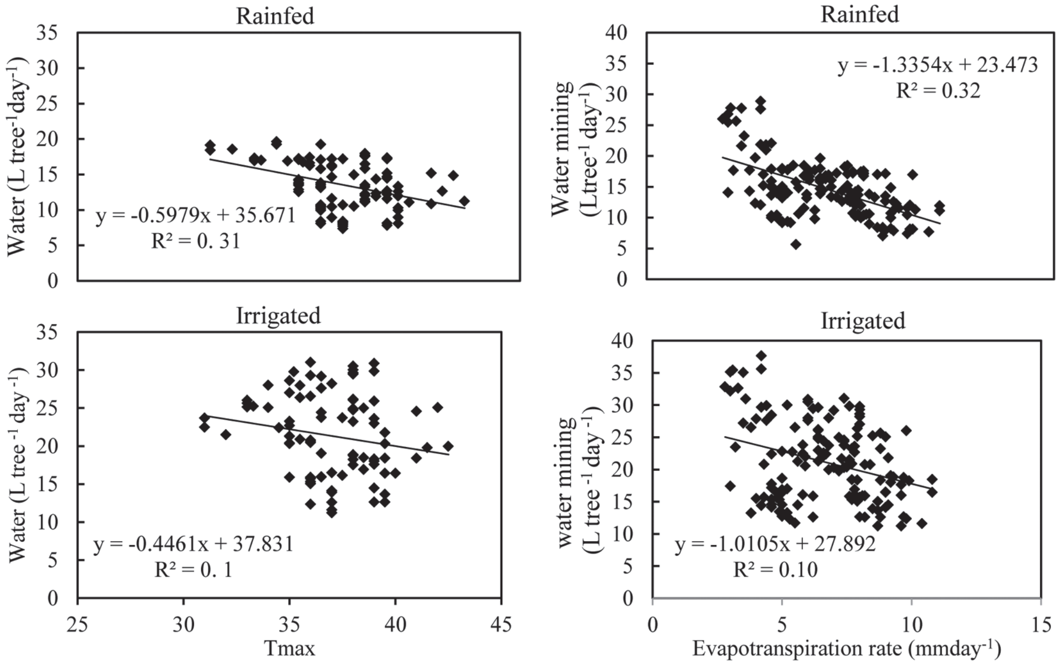

Fig. 4. Relationship between T_{max} (^{o}C), Evapotranspiration rate ($mmday^{-1}$) and same time xylem sap flow rate ($mL\ h^{-1}$) in mature rubber trees during summer season at RRS, Dapchari, Maharashtra

Regression analysis indicated positive regulation of water mining rate under warmer temperatures in this region especially during November-February (Fig. 5). Water mining increased as the temperature (T_{max} and T_{min}) increased. In other seasons mostly temperature did not have any significant influence on water consumption rate in this region nor did other weather parameters like sunshine hours and relative humidity.

Water use efficiency of rubber plants

The water use efficiency (WUE) of mature rubber trees as a function of dry rubber production was worked out in the different

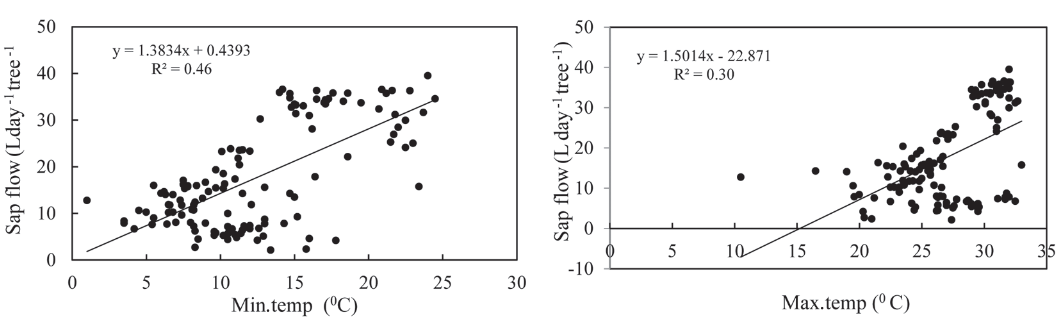

Fig. 5. Relationship between T_{min} (^{o}C) and T_{max} (^{o}C) with xylem sap flow rate ($mL\ h^{-1}$) during winter months at Nagrakata, West Bengal

sites where this study was conducted. In traditional region (Kottayam, Kerala) the WUE (rubber yield/unit water consumption) was $8.0x10^{-4}$ kg rubber kg^{-1} water whereas in the drought prone region (RRS, Dapchari, Maharashtra) it was very less ($3.7x10^{-4}$ (rainfed trees) and $4.8x10^{-4}$ (summer irrigated trees). In the case of the cold stress prone region (Nagrakata, West Bengal) the WUE was $6.7x10^{-4}$ kg rubber kg^{-1} water (Table 4). Similarly WUE as a function of shoot biomass increment was also worked out in these regions as a ratio of biomass increment for unit water consumption in one year. This was the highest in traditional rubber growing region ($3.8x10^{-3}$ kg biomass kg $water^{-1}$) followed by Nagrakata in the Sub-Himalayan region ($3.4x10^{-3}$ kg biomass kg $water^{-1}$). Irrespective of irrigation provided during summer months in the North Konkan region, WUE was very less ($2.0x10^{-3}$ kg biomass kg $water^{-1}$ in rainfed and $2.3x10^{-3}$ kg biomass kg $water^{-1}$ in irrigated trees) in Maharashtra. WUE in mature rubber trees was the highest in the traditional region followed by cold stress prone Sub-Himalayan region (Table 5). From the above results it is clear that water requirement is very high in North Konkan region for the production of a unit dry rubber as well as plant biomass when compared to traditional region in Kerala and non-traditional Sub-Himalayan region. WUE in the different regions indicated that this parameter was mainly determined by rubber yield or biomass increment rather than by the amount of water consumed by the trees. In the Konkan region WUE was only around 50 per cent under rainfed condition when compared to the traditional region. The prevailing climatic factors are limiting both plant growth and rubber yield substantially. This region experiences acute summer climate distinguished by very hot and dry conditions for several months. Here the summer season is very lengthy (with no rainfall for more than six months) and experiencing soil moisture deficit coupled with atmospheric drought also (Jacob *et al*., 1999). Practically it is very challenging to establish rubber plantation in Konkan region without irrigation at least for the first couple of years after planting. Even for the grown up trees with fully closed canopy a minimum level of irrigation (0.25 ETc) is required for a reasonable yield (Jacob *et al.*, 1999; Singh *et al.*, 2010). It is also pertinent to note that photosynthetic rate of leaves was seriously affected by the severe drought and high temperature prevailing for several months and this resulted in poor growth and prolonged immaturity period in Dapchari (Jacob *et al*., 1999). In the cold stress prone regions too, there was inhibition in photosynthetic rate, but this was confined to a much shorter period than in Dapchari. Moreover, in the cold stress prone regions, the time of annual leaf fall also coincided with inhibition in photosynthesis and by the time new flushes emerged, temperature became warm. This was unlike in Dapchari where photosynthesis during the entire summer season was affected.

Water use efficiency estimated based on rubber yield was the highest in Kerala followed by West Bengal, Maharashtra (irrigated) and Maharashtra (rainfed) reflecting the trend of deceasing rubber yield in the same order. Interestingly, WUE estimated based on biomass increment also followed the same trend with Kerala showing the highest WUE followed by West Bengal, Maharashtra (irrigated) and Maharashtra (rainfed) in the same decreasing order of shoot biomass. These results indicate that it was productivity (either rubber yield or biomass) that had predominant role in determining the WUE rather than the amount of water consumed by the trees. The present findings hold important ecological implication for expanding rubber cultivation in different agro-climatic regions of the country. The extent of difference in water use efficiency noticed between the regions was more striking in the case of water use efficiency calculated based on rubber yield compared to biomass.

CONCLUSION

The water mining rate of rubber tree is mainly controlled by available soil moisture and prevailing climatic conditions. Overall water mining by mature rubber trees was almost the same in the different regions except in rainfed plots of Kongan region. It was very low here under rain fed conditions due to severe soil moisture deficit during summer season. However, if adequate level of irrigation was provided, the water consumption increased and there was a similar increase in plant growth and yield in this region. Rate of water consumption declined with the onset of wintering. Water use efficiency in terms of water consumption for a unit amount of rubber production or plant biomass increment was higher in cold stress prone North Bengal region than the drought prone Konkan region. WUE is determined mostly by rubber yield or biomass production and not by variations in the amount of water consumed. Studies on water consumption by rubber plantations in different agro-climatic conditions have significant ecological implications on policy decisions about extension of NR plantation to climatically constraint regions like North Konkan and North East regions of India. Further studies may be required to analyze the potential available water resources and climatic suitability in these regions before implementing any major NR expansion plans in the nontraditional regions.

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