Songklanakarin J. Sci. Technol.
30 (5), 565-570, Sep. - Oct. 2008

Songklanakarin Journal of Science and Technology
http://www.sjst.psu.ac.th

Original Article

Monitoring of sap flow, leaf water potential, stomatal conductance, and latex yield of rubber trees under irrigation management

Prapaporn Tongsawang and Sayan Sdoodee*

Department of Plant Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songkhla, 90112 Thailand.

Received 5 April 2007; Accepted 8 August 2008

Abstract

To investigate the physiological responses and latex yield of rubber trees under irrigation management, an experiment was established at Songkhla Province, southern Thailand. The sap flow of rubber trees was measured by heat-pulse technique. First, the anatomy of sapwood and the optimum depth for implanting the sap flow sensor probe were determined. Then, the diurnal changes of the physiological responses (sap flow, leaf water potential, and stomatal conductance) and latex yield under three regimes of irrigation (T1: no irrigation, T2: irrigation at 1.0 crop evapotranspiration (ETc) and T3: irrigation at 0.5 ETc) were determined. The results showed that xylem vessels in sapwood were homogeneous and the optimum depth for implanting the sap flow sensor probes was 10 mm beneath the cambium. In the measurements of diurnal changes of the physiological responses, it was found that stomatal conductance and sap flow rates were related to radiation. Sap flow and stomatal conductance increased from the morning to the midday. Then they decreased slowly during the afternoon. However, leaf water potential changes showed an opposite effect. Among the three treatments, the results showed that sap flow, leaf water potential and stomatal conductance in T2 were highest. The trees in T2 also exhibited the highest latex yield from April to July 2006, which was significantly different from those of T3 and T1. This implied that latex yield increased with an increase of sap flow.

Keywords: sap flow, heat-pulse technique, rubber trees, latex yield, irrigation

1. Introduction

Climatic changes induce significant manifestations in the phenology of plants with defoliation, refoliation, and the seasonal emergence of new leaves. In rubber (*Hevea brasilliensis*), Priyadarshan and Sasikumar (2001) reported that the fluctuation of rainfall and temperature has an influence on the latex yield and growth of rubber. Chandrashekar *et al.* (1998) also found that during the dry season the growth rates of the rubber clones declined substantially. Heavy leaf injuries and shedding are experienced in summer months; therefore, irrigation requirement of rubber trees have been investigated. Vijayakumar *et al.* (1998) suggested that a sufficient irrigation led to eliminate foliar injuries and resulted in a higher photosynthetic rate.

Several techniques are currently available to measure sap flow in plants (Dragoni *et al.*, 2005). The heat-pulse technique has been applied in studies of forest hydrology, plantation water use, horticulture, and tree physiology. The heat-pulse velocity (HPV) methodology was first developed in 1937 by Huber and Schmidt (Luangjame, 2005). The heat-pulse method seems to be an appropriate technique to infer the rate of water movement up the trunk of a tree by the use temperature sensing probes inserted into the tree, at locations above and below the heating probe. (Luangjame, 2005; Nicolas *et al.*, 2005). The compensation heat-pulse method is a reliable technique for making non-destructive continuous measurements of sap flow in plants (Ortuno *et al.*, 2005). The heat-pulse sap flow sensors can be used for

*Corresponding author.
Email address: sayan.s@psu.ac.th

a continuous record over three weeks (Sdoodee *et al.*, 2002; Luangjame and Lertsirivorakul, 2005). Lu (2002) and Ormsubsin (2000) measured the sap flow of some tropical and subtropical trees. They found that it is suitable for implanting the probe 1-2 cm beneath the cambium. It has been also used on either roots to study the hydraulic behavior or on trunks to estimate the whole-tree water consumption and its relationships with physiological and environmental variables (Giorio and Giorio, 2003; Chang *et al.*, 2006)

Da Conceicao (1985) suggested that leaf water potential and stomatal conductance are good indices for the estimation of rubber clones subjected to water deficits. Sangsing *et al.* (2003) found that the maximum potentials of stomatal conductance of three rubber clones (RRIM 600, RRII 105 and RRIT 251) were exhibited between 09:30 and 11:30 h due to the changes of the vapour pressure deficit.

The objectives of this study were : 1) to study the xylem vessel anatomy in the sapwood of rubber trees to optimize the implanting depth of the sap flow sensors 2) to measure the physiological responses (sap flow by heat-pulse technique, leaf water potential, and stomatal conductance) and the latex yield of rubber trees under irrigation management.

2. Materials and Methods

The experiment was carried out at Thepa Rubber Research Station, Songkhla Province (6^o 17'N, 100^o 07'E). The soil texture in the experimental plot was sandy loam, (soil moisture at F.C. = 19% and W.P. = 11%). Fourteen year-old rubber trees (RRIM 600) in the experimental plot were used. There were two main parts in this research: 1) An anatomical study of the xylem vessels in the portion of sapwood. Then investigation of the optimum depth for inserting the sensor probe. 2) The measurement of certain physiological responses and determination of the latex yield of the rubber trees under irrigation treatments compared with control or rainfed condition.

Sapwood of the rubber trees was sampled by using an increment borer (Suunto, Finland) at 1.30 m height from the ground level. The depths of the boring were 0-50 mm beneath the cambium. Then the sapwood samples were fixed in formalin/acetic acid/alcohol (FAA) and taken to the Scientific Equipment Center, Prince of Songkla University. The samples were divided into 5 parts and each part was 10 mm length. Scanning electron micrographs of the transverse section of the sapwood were taken using a Scanning Electron Microscope (Model JSM-5008 LV, JEOL, Japan). Then, xylem density and vessel size in each portion of sapwood (0-10, 10-20, 20-30, and 40-50 mm beneath the cambium) were determined. The assessment was done in three replicates.

In the measurement of the sap flow of the rubber trees, the optimum depths has been investigated. Therefore, three depths of sensor installation were carried out, 10 mm, 20 mm, and 30 mm beneath the cambium. At each depth, one set of heat-pulse sap flow sensors (Model PSU-NRC), comprising one datalogger with two sensor probes, was installed on the trunk around 1.30 m from the ground level. Diurnal changes of sap flow at three depths of installation were recorded, then the data were compared among the three depths. The measurements were done in three replications. However, in the calculation of the sap flow, the volume fraction of water (Vh) and wood (Vw) are needed. They were done by the method of Edward and Warwick (1984) reported by Sdoodee *et al.* (2002) as follows:

$$Vh = (Wf - Wd)/Wi$$

$$Vw = Wd/(1.53 \times Wi)$$

Wf = weight fresh, Wi = immerse sample and weight, Wd = oven-dry the sample at 80-90^{o}C for at least 48 hours, then weight (Note: the factor 1.53 comes from the specific gravity of wood)

These investigations were carried out on five trees. Additionally the stem diameter, the bark thickness, and the sapwood radii were also recorded. In the experimental plot of rubber trees under irrigation management, it was arranged in a randomized complete block design with three treatments, 1. control or no irrigation, 2. irrigation at 1.0 crop evapotranspiration (ETc), and 3. irrigation at 0.5 ETc, and three replications (12 trees per replicate). The irrigation in the treatments 2 and 3 were applied at a 2-day interval. A sprinkle irrigation system was established along the rows of the rubber trees. A sap flow sensor set was installed at one tree in each treatment at 1.30 m above ground level (Figure 1). It was wrapped in a plastic sheet to prevent it from rainfall or water leaking. The measurements were done between January and July 2006. Diurnal changes of leaf water potential and stomatal conductance were determined using a pressure chamber (PMS, USA), and a AP4 porometer (Delta-T Device, UK), respectively. Young fully expanded leaves were used for the measurements, which were done during 08:00-16:00 hours.

Latex yield of the trees in each treatment (12 trees/replicate) was recorded, then the average yield (g/tree/tapping) in each month was calculated. The weather conditions

Figure 1. Installation of the sap flow sensors on the rubber tree in the experimental plot.

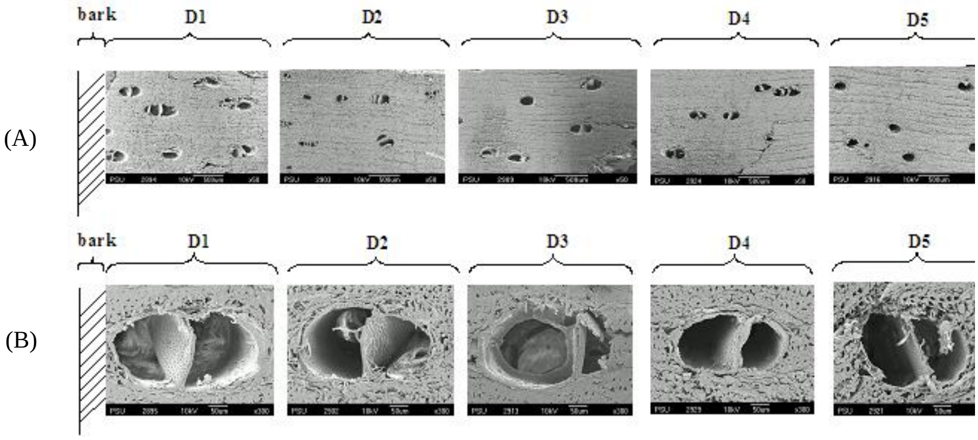

Figure 2. Scanning electron micrographs of transverse section of rubber sapwood (A) xylem arrangement and (B) xylem vessel at 5 depths (D1 =10 mm, D2 = 20 mm, D3 = 30 mm, D4 = 40 mm and D5 = 50 mm) beneath cambium.

from January to July 2006 were recorded by the Koh Hong Meteorological Station, Hat Yai, Songkhla. During the experimental period, soil moisture conditions (10 cm depth from soil surface) in each treatment were measured by a Theta Probe, type ML2 (Delta-T Device, UK).

3. Results

3.1 Anatomical study of sapwood

Xylem structure and xylem vessel arrangement in the sapwood portion were investigated. It was found that the xylem vessel arrangement was homogeneous along the sapwood portion from cambium to 50 mm beneath the cambium as shown in Figure 2A. The shape of the xylem vessel was oval, and vessel size in the portion of 0-10 mm from bark was significantly larger (429 μm) compared with the remaining portions (Figure 2B and Table 1). Further, the density of xylem vessels in the portion of 0-10 mm from the bark were also significantly higher (7 vessels 4 mm^{-2}) (Table 1).

3.2 Determination of volumetric fraction of wood and water

Table 2 shows that the average values of the stem diameter, the bark thickness and the sapwood radians were 23.59 cm, 0.52 cm and 11.80 cm, respectively. The average volume fraction of wood (Vw) and the volume fraction of water (Vh) sampled from the rubber sapwood were 0.58 and 0.42, respectively (Table 2). These parameters were used in the calculation of sap flow.

3.3 Optimum depth of implanting the probes

Figure 3 shows that the sap flow from the sensor probe implanted at 10 mm beneath cambium was significantly higher compared with those of the other depths. This indicated that at 10 mm depth beneath the cambium is the optimum depth for implanting the probe on the rubber trunk.

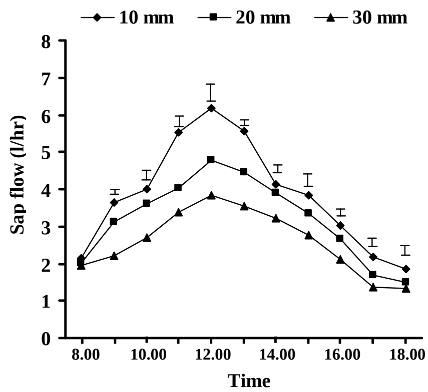

Figure 3. Diurnal changes of sap flow in the stem of rubber tree when the probes were implanted at 3 depths (10, 20 and 30 mm) beneath cambium. (Vertical lines indicate $LSD_{.05}$)

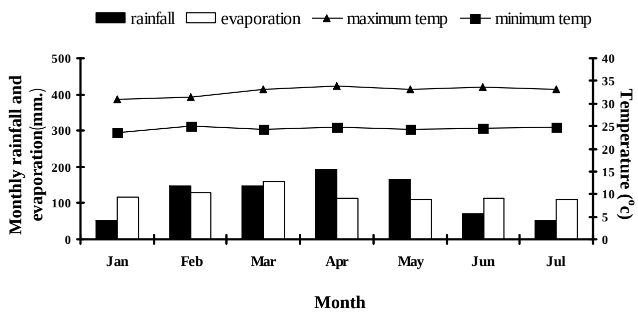

Figure 4. Monthly rainfall, evaporation, maximum and minimum temperature from January to July 2006. Data from the Koh Hong Meteorological Station Hat Yai, Songkhla.

3.4 Physiological responses and latex yield

Figure 4 shows that in 2006 the drying period

Table 1. Average xylem diameter and density of xylem vessels in rubber sapwood at 5 depths (10, 20, 30, 40 and 50 mm) beneath cambium.

Depths beneath cambium (mm)	Diameter of xylem vessel (μm)	Density of xylem vessels (xylem vessels per 4 mm^2)
10	428.5[a*]	7[a]
20	341.7[ab]	6[a]
30	336.7[ab]	5[b]
40	275.0[b]	5[b]
50	258.3[b]	4[b]

* Means with different letter in each column were significantly different (p<0.05) by LSD

Table 2. Average stem diameter, bark thickness, sapwood radius, volume fraction of wood (Vw) and water(Vh) of the 5 sampled trees (14 year-old) in the experimental plot.

Tree No.	Stem diameter (cm)	bark thichness (cm)	sapwood radius (cm)	Volume fraction	
				Vw	Vh
1	21.33	0.5	10.17	0.57	0.43
2	23.25	0.5	11.13	0.59	0.41
3	25.62	0.6	13.81	0.57	0.43
4	25.79	0.5	13.40	0.58	0.42
5	21.97	0.5	10.49	0.59	0.41
Mean	23.59±0.52*	0.52±0.04	11.80±1.69	0.58±0.01	0.42±0.01

* = X + S.D

occurred in January which induced leaf shedding of the rubber trees in February. At the mid of March, the trees in all treatments exhibited leaf-flushing with rainfall in April and May. However, water deficits occurred in June and July. During the experimental period, it was found that the physiological responses of stomatal conductance and sap flow synchronized with the diurnal changes of photosynthetic photon flux (PPF) (Figure 5). However, it was prominent that the values of stomatal conductance and sap flow of T2 was highest followed by those of T3 and T1, respectively. The leaf water potential of T1 was lowest followed by those of T3 and T2. Figure 6 illustrates that the soil moisture in T2 remained highest throughout the experimental period, followed by those of T3 and T1.

It was remarkable that the average latex yield of T2 was significantly higher from April to July (Figure 7) compared with those of T3 and T1.

4. Discussion

The xylem vessel arrangement in the portion of the sapwood of rubber is homogeneous and suitable for the measurement by the heat-pulse method. Sdoodee *et al.* (2003) also found that the xylem vessel arrangement of the sapwood of rambutan and longkong were homogeneous and heat-pulse sap flow sensors could be used for the determination of their water use during phenological development. However, Ormsubsin (2000) reported that the heterogeneous sapwood in durian caused unreliability of the measurement by heat-pulse technique. In rubber, both the high density of the xylem vessels and the large size of the xylem vessels at the portion of the sapwood beneath the cambium to 10 mm depth, contributed mainly to the sap flow during the measurements compared with other depths. Lu (2002) measured sap flow of some tropical and subtropical trees by the Garnier system, and he found that a depth of 1-2 cm beneath the cambium is suitable for implanting the probes.

Figure 5 and 6 illustrate that levels of soil moisture are related to sap flow rate and the other physiological responses. This was due to the limitation of water in the control or under rainfed condition. Generally under water limitation, water deficit causes the decrease of leaf water potential and stomatal conductance. This is an adaptive mechanism to water deficit allowing the plant to regulate water loss more effectively (Ruiz-Sanchez *et al.*, 2000). This leads to the reduction of transpiration and the sap flow density decreases. Lu (2002) suggested that a sap flow measurement was proved to be effective in revealing the

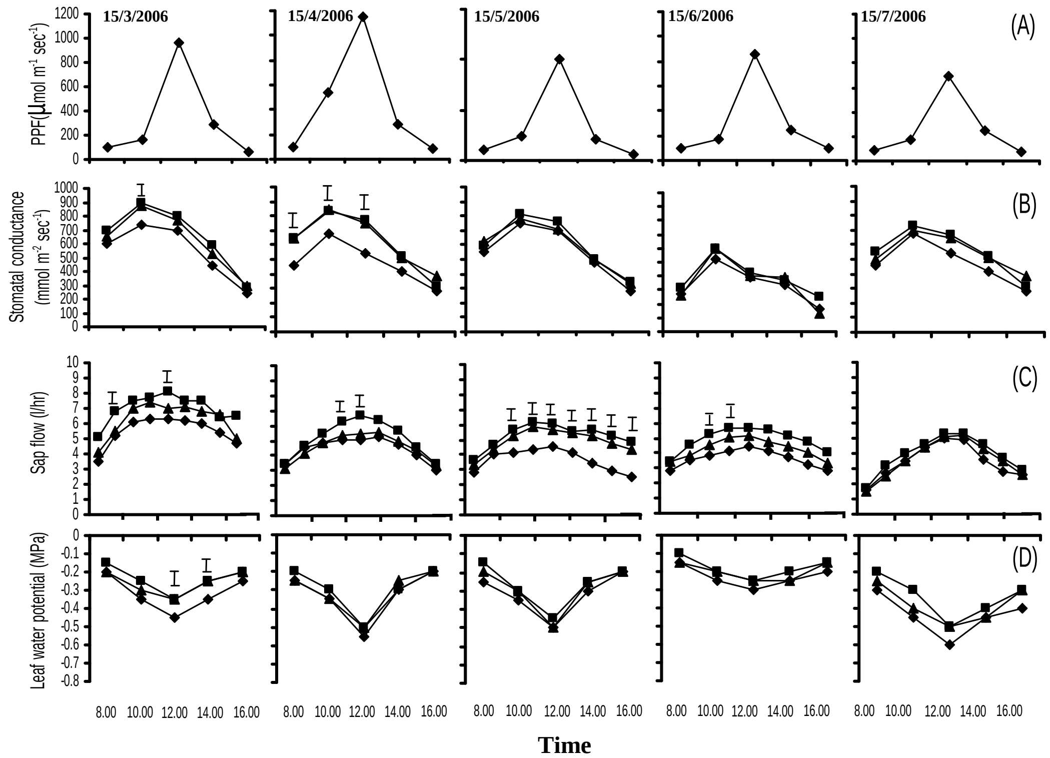

Figure 5. Diurnal changes of photosynthesis photon flux (PPF) (A), stomatal conductance (B), sap flow (C) and leaf water potential (D) in the treatments of (T1 (◆) : control , T2 (■) : 1.0 ETc, T3 (▲) : 0.5 ETc during March to July 2006. (Vertical lines indicate $LSD_{.05}$)

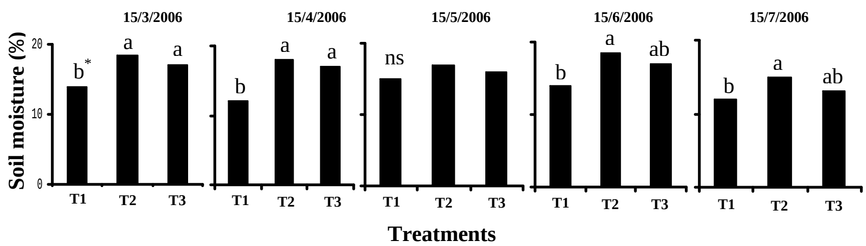

Figure 6. Average soil moisture at 10 cm depth from the soil surface in the treatment of T1(control), T2 (1.0 ETc) and T3 (0.5 ETc) during the experimental period.
* : Columns with difference letters are significantly different (P<0.05) by LSD
ns : non-significant difference

occurrence of plant water stress.

Latex yield in the treatment of T2 was prominently highest, which seemed to be related to the high soil moisture content under the 1.0 ETc irrigation, followed by the 0.5 ETc irrigation and the control group, respectively. This implied that trees under the condition of high transpiration have a higher sap flow. Therefore, stomatal aperture in this condition may lead to higher CO_2 uptake for the photosynthesis. Then a higher photosynthesis rate will be benefit for the production of latex yield. Results implied that latex yield increases with an increase of the sap flow, which suggests that latex yield may related to sap flow. It points out that sap flow may be considered as an index for the estimation of latex yield of rubber. Therefore, this aspect needs to be studied further.

5. Conclusions

Among the three treatments, with 1) no irrigation, 2) 1.0 ETc irrigation, and 3) 0.5 ETc irrigation in the rubber trees, it was found that the 1.0 ETc irrigated rubber trees could maintain the highest sap flow, leaf water potential, and stomatal conductance. This led to a significant increase of the latex yield in the rubber trees exposed to 1.0 ETc irrigation.

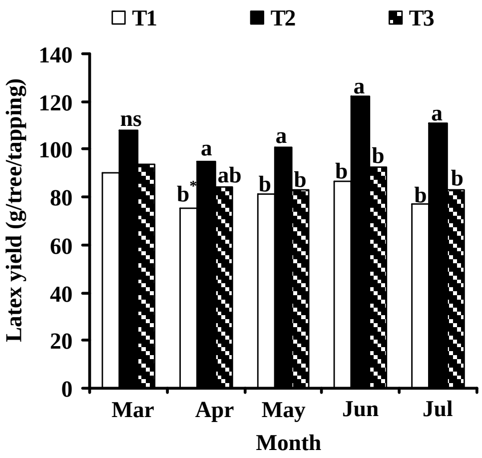

Figure 7. Average latex yield (g/tree/tapping) in the treatment of T1(control), T2 (1.0 ETc) and T3 (0.5 ETc) during March to July 2006.
* : Columns with different letters are significant difference ($P<0.05$) by LSD
ns : non-significant difference

Acknowledgements

We are grateful to the Graduate School, Prince of Songkla University, for financial support of this research. We also thank the Scientific Equipment Centre, Prince of Songkla University for providing laboratory facilities.

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