Asian Journal of Plant Sciences 10 (2): 140-146, 2011
ISSN 1682-3974 / DOI: 10.3923/ajps.2011.140.146

Effect of Trunk Locations on Micro-Change of Trunk Girth in Mature Rubber Trees *(Hevea brasiliensis)*

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Abstract: Diurnal variation in trunk girth of rubber trees reflects water status and can be used to estimate trunk increment of the crop. The objectives of this study were to quantify diurnal change in circumference of rubber trees, to estimate growth rate and to determine the efficacy of the electronic dendrometer in measuring micro change in trunk circumference. The experiment was conducted at a commercial plantation on clone RRIM 600 during the onset of the dry season in the Northeast Thailand. Electronic dendrometer bands were installed on rubber plants at 45, 70 and 180 cm from the ground and the device was connected to a data logger. Trunk circumference was recorded daily at 30 min intervals for 13 days in November 2006. A clear and highly reproducible change in trunk circumference caused by diurnal shrinking and contraction was observed during the experiment. Diurnal shrinking and expansion on average were recorded as 471 and 884 μm day^{-1}, respectively. Stem locations were significantly different in trunk shrinking and expansion. The highest shrinking and contraction were observed at 180 cm which were similar to the location at 70 cm but higher than 45 cm. The highest growth rate was found at 45 cm and it was significantly different from those at 75 and 180 cm. The device is very useful for measuring stem circumference of rubber tree with very high accuracy and measurement between 70 and 180 cm from the ground is recommended. The information is useful for irrigation management and breeding.

Key words: Contraction, dendrometer, enlargement, trunk circumference, trunk level

INTRODUCTION

Rubber tree (*Hevea brasiliensis*) is an important economic crop in South-east Asia, valued for the production of not only natural latex but also of timber. It has been grown in climate of the tropical lowland, evergreen rainforest region with the annual rainfall of 2,000-4,000 mm (Vijayakumar *et al*., 2000) evenly spreading through the year and with not more than one dry month. These long term processes of stem increment concern the regulations of water content for deciduous trees facing atmospheric demand and seasonal drought such as rubber trees.

The diurnal change in trunk diameter of trees is related to the cohesion-tension theory. The movement of water through xylems is caused by the difference in pressure gradients between the top and the bottom of the trees. Sap flows from high pressure gradient at the bottom to low pressure gradient at the top as a result of transpiration. The transpiration develops large tension at the top of the trees and the tension pulls up the water. The theory also explains the flow of water in the phloem which transports photosynthetic products (carbohydrates) from places where they are synthesized to the organs where they are used or storage (Taiz and Zeiger, 1998).

Fluctuation in trunk diameter is well known as an early indicator of tree water stress. Change in stem diameter is largely due to cambial growth and change in water content and water tension. Therefore, growth of trees is defined as an irreversible increase in trunk diameter while water content has a diurnal cycle. There is a natural daily cycle of shrinkage and expansion due to tissue water withdrawal for transpiration during day-time and rehydration during night-time. Sufficient rehydration allows high turgor, high water potential (Gholami and Rahemi, 2010) and daily growth. Several studies have indicated the relationships between diurnal changes in stem diameter and shoot water potential (Naor and Cohen, 2003; Ton and Kopyt, 2004),

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transpiration (Peramaki *et al*., 2001; Ortuno *et al*., 2006), relative humidity (Offenthaler *et al*., 2001) and other micrometeorological measurements (Sevanto *et al*., 2003; Ismail *et al*., 2004; Sevanto *et al*., 2005; Xiong *et al*., 2007). Therefore, diameter changes are thought to reflect the water balance inside the stem. Water transport in large old-growth trees occurs over long distance via conducting element that may have low hydraulic conductivities (Gartner, 1995; Sperry, 1995; Martinez-Vilalta *et al*., 2007). In contrast, in short stem virgin-growth trees, there may be a considerable delay between water loss from the leaves and water uptake by the root (Mahall *et al*., 2009; Medeiros and Pockman, 2010).

The trunk diameter of tree during the night is bigger than during the day when transpiration is high (Ortuno *et al*., 2005, 2006). However, little works have been reported so far on the details of diurnal changes in trunk diameter despite technology improvements (Felker and Leon, 2005; Silpi *et al*., 2006). Most studies used diameter as a growth parameter and done on juvenile nursery plant and virgin-growth trees (Nortes *et al*., 2005; Luvaha *et al*., 2008). Girth bands have been used to study growth of tree crops (Schroeder and Wieland, 1956; Silpi *et al*., 2006) and forest trees (Scholz *et al*., 2008) because it is user-friendly and more accurate than other methods. It is used to measure circumference instead of plant diameter.

In the pioneer research on dendrometric study in rubber tree, the device was used to study the effects of the trunk location and tapping on trunk diameter and the author did not reported trunk growth (Gooding, 1952). After the pioneer research, Silpi *et al*. (2006) reported the seasonal change of trunk girth and the effect of tapping on trunk shrinkage and growth. Dendrometer is assumed to provide better estimation of average radial increment because the measurement represents a mean of all radial over all directions (Keeland and Sharitz, 1993). The objectives of this study were to quantify the magnitude of shrinkage and growth at three locations along the trunk (top, middle and bottom) and to test the accuracy of girth band in measurement of trunk girth change under the onset of the dry season when the trunk growth is slow and the weather is less fluctuated. The technique can be used for estimation of rubber growth, rubber water requirement for irrigation and screening of rubber germplasm and breeding population for drought resistance.

MATERIALS AND METHODS

Experimental conditions: The experiment was conducted at a rubber plantation of the clone RRIM 600 in Satuk district, Burirum province in the Northeast of Thailand (N15° 16' 23.6" E103° 04' 51.3") in the onset of the dry season 2006. The yearly rainfall is approximately 1,176 mm with the wet season from April to October, 2006. Five plants with 11 years old were selected for the experiment. The measurements were taken for 13 days from 10th to 23th of November, 2006 when the leaves of the trees were initially felt.

Meteorological data: Weather data were recorded using an automatic weather station (Minimet automatic weather station, Skye Instruments Ltd, UK) installed in an open field approximately 50 m away from the plantation. The data were recorded every 30 min for air temperature, rainfall and relative humidity using a Campbell CR10 data logger. The data were synchronous with plant growth data at the times of measurement. However, the data loggers used for collecting weather data and plant data were different sets. Air Vapour Pressure Deficit (VPD) was calculated according to the formula of Allen *et al*. (1998) and the values were separated into a daily maximum air vapour pressure deficit value (max VPD) and a daily mean air vapour pressure deficit value (mean VPD). The period of experiment was select because of low variation in rainfall and slow growth of the tree that allowed more precision and more accuracy of the measurement.

Measurement of trunk circumference: Circumference of trunk girth was measured with a dendrometer (D6 strain-Gauge Dendrometer, UMS GmbH, Germany). The dendrometer sensors which are belt-like, were fit permanently at the three locations on five rubber trees and connected to a data logger (model CR10X, Campbell Scientific, Leicester, UK). The data were recorded every 30 min at synchronous times when weather data were recorded (Fig. 1). The trunk locations included at 180 cm from the ground where girth are usually measured, 70 cm from the ground and below tapping panel and 45 cm from the ground.

Three trunk locations were used as treatments and five plants were used as replications. Thus, a completely randomized design with five replications was arranged. The data for plant parameters and weather data were recorded across a time series for 13 days at 30 min intervals.

The Maximum Daily Trunk Shrinkage (MDS) was determined by taking the difference between the maximum trunk girth reached early in the morning and the minimum trunk girth displayed normally during the afternoon. The Trunk Growth Rate (TGR) was calculated as the difference between two consecutive maximum daily trunk girths.

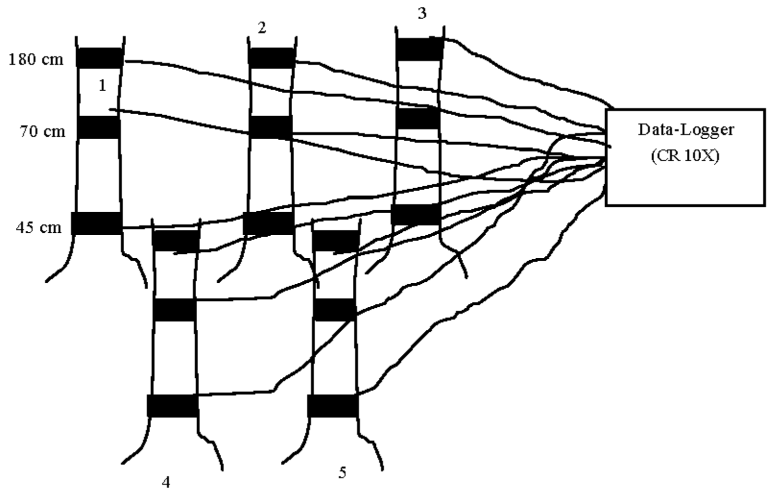

Fig. 1: Photograph of electronic dendrometer bands for measuring micro trunk girth variations and setting management in the different trunk locations: (1) the top location at 180 cm where girth are usually measured; (2) the middle location at 70 cm where girth are usually tapped and (3) the trunk bottom at 45 cm above the ground. Dendrometer sensor attached to each mature rubber tree at three locations along the trunk, that connected to the data logger (CR 10X)

Data analysis: Analysis of variance was performed for individual datasets which were collected at 30 min intervals. A series of analyzed data were used to evaluate the diurnal variation in circumference of rubber trunk and the growth rate of the trunk which were averaged from the data of 13 days for single values. Then, t-test statistics performed using SPSS Version 11.5 was used to compare mean differences for on MDS and TGR by one way ANOVA.

RESULTS

Environmental conditions: During the experimental period (10th to 23th November, 2006), zero rainfall was observed and mean air Vapour Pressure Deficit (VPD) ranged between 1.10 and 1.56 kPa which were related to the dry season (Fig. 2). Mean VPD values reached maximum on 19th November, 2006 (1.56 kPa). Moreover, ETo during the study period ranged between 1.46 and 2.26 mm day^{-1}.

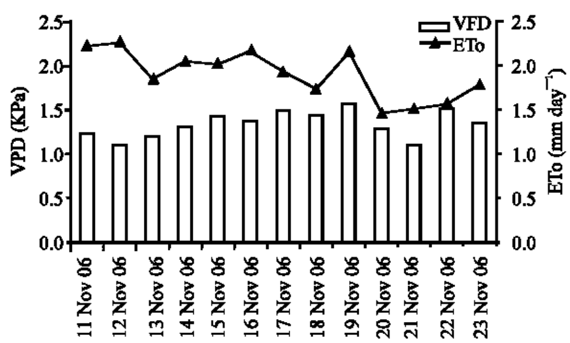

Fig. 2: Mean daily air Vapour Pressure Deficit (VPD) and reference evapotranspiration (ETo) at rubber tree plantation during the experiment period (11th to 23th November, 2006). The measurement period was the onset of dry season with no rainfall

Diurnal pattern of trunk girth fluctuation: During the onset of the dry period for 13 days, the dynamic growth of the three locations along the trunk of rubber trees showed progressive increase from the beginning to the end of the measurement period (Fig. 3). The circumference values of the three positions were set at zero at the beginning of the measurement to compare the growth of the three positions of the trunk during the short period of 13 days. The highest growth was observed at the base of the trunk (45 cm) which was significantly higher than the growth at the middle (70 cm) and the top (180 cm) locations especially at the end of the measurement period. The increases in trunk circumference of the middle and the top locations were rather similar. However, the growth of the middle location was somewhat higher than that at the top location and this difference was not noticeable without the use of more precise device for fine measurement of the growth. The diurnal shrinkages of the trunk at the middle and top locations were rather similar and higher than that at the bottom location. Stem girth variation of three parts ranged from -400 to 2,700 μm.

Maximum daily trunk shrinkage (MDS) and Trunk Growth Rate (TGR): Trunk locations were significantly different for MDS ($p \le 0.01$) (Fig. 4). Trunk shrinkages in

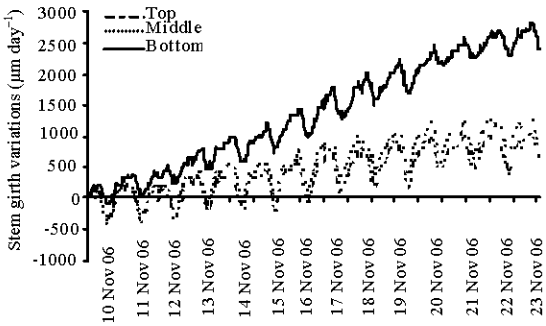

Fig. 3: Fine scale dynamics of stem girth variations at three trunk locations; top, middle and bottom of mature rubber trees during the experiment period. (1) above the tapping panel at 180 cm where girth are usually measured; (2) just below the tapping panel at 70 cm where girth are usually tapped and (3) the trunk bottom at 45 cm above the ground

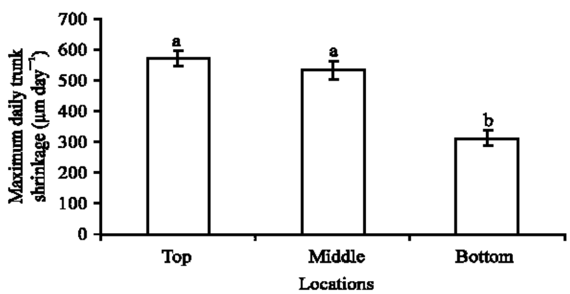

Fig. 4: Mean Maximum Daily Trunk Shrinkage (MDS) for mature rubber trees during the onset of dry season. MDS was significantly higher at the top and middle than bottom locations during the experiment period. Vertical bars indicate standard error of mean. Mean in each bar with the same letter are not significant different at p≤0.01

the top (180 cm) and middle (70 cm) locations were significantly higher than in the bottom (45 cm) location. The highest MDS was 569 µm day^{-1} at 180 cm from ground level and similar to 533 µm day^{-1} at 70 cm from the ground but the shrinkages of the middle and the top locations were significantly higher than 312 µm day^{-1} at 45 cm from ground level.

In contrast to MDS, the increases in TGR were rather low at the middle (70 cm) and top (75 cm) locations (701 and 502 µm day^{-1} for middle and top locations, respectively), whereas the increase in TGR (1,141 µm day^{-1}) at the base (45 cm) was significantly higher than at the middle and the top locations (p≤0.01) (Fig. 5).

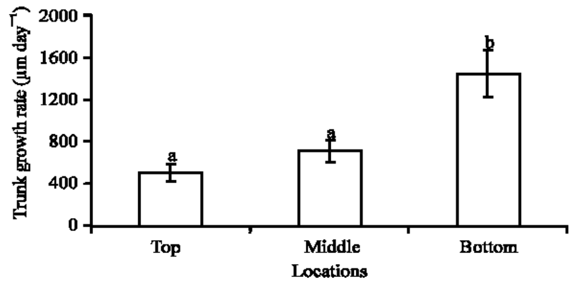

Fig. 5: Mean Trunk Growth Rate (TGR) for mature rubber trees during the onset of dry season. TGR was significantly higher at the bottom than the top and middle locations during the experiment period. Vertical bars indicate standard error of mean. Mean in each bar with the same letter are not significant different at p≤0.01

DISCUSSION

The daily variation in stem girth was generally related to the variation in the max VPD also with Mclaughlin *et al*. (2003) found that daily diameter increments were related negatively to VPD. On the other hand, the variation in stem girth is dependent on daily transpiration and high variation was found at higher girth locations than at lower locations. This could be due to the fact that high locations were closer to the leaves where most of water was transpired, whereas lower locations were closer to the roots that supplied water to the plants (Domec *et al*., 2005). There is the natural daily cycle of shrinkage and expansion due to tissue water withdrawal for transpiration during day-time and rehydration during night-time. The shrinkage of the bark is, therefore, related to the relative distance to the leaves and the roots and the proximity of the canopy likely induced high turgor pressure (Pallardy, 2008).

The experiment was carried out at the onset of the dry season and there had been alternatives between cloudy and sunny days that affected ETo and transpiration (Sarker and Hara, 2004; Ainuddin and Nur Najwa, 2009). Furthermore, there had been free from rain during experiment period that affected the variation in contraction and expansion of rubber stems. Therefore, the daily variations in stem contraction and expansion were similar across days but the variations in stem shrinkage and expansion were rather different among trunk locations. High shrinkage and expansion were observed in higher trunk locations and vice versa for high growth rate. The reversible daily shrinkage was clearly dependent on the changes in the tree water status that resulted from the changes in the relatively evaporative demand or environmental conditions (Moreno *et al*., 2006; Ortuno *et al*., 2006; Swaef *et al*., 2009).

The patterns of trunk shrinkage and expansion observed in this study were similar to those reported by Silpi *et al*. (2006) who studied rubber trunk diameter. The differences between the results are that the diameter was used by Silpi *et al.* (2006) while this study used circumference by more advanced technique. Measurement of circumference is more accurate than that of diameter because the value is greater. The differences among trunk locations for trunk shrinkage and expansion also indicated that the trees were subjected to drought stress. This information is useful for scheduling of irrigation for fruit trees. For rubber trees that are usually planted in the rainfed areas, the information might be used for screening of plants with resistance to drought and evaluation of plant growth when annual records are available.

The patterns of trunk recovery were rather different for the rubber trees that had water loss as a result of tapping. In this case, the water loss was at the tapping location. The shrinkage at this location was faster than the lower locations but water loss did not affect the locations above the tapping location. The shrinkage at this location was replenished faster than the lower locations (Gooding, 1952).

Although water losses were similar for the two cases, the water replenishment was rather different. The replenishment of water loss from transpiration was replenished solely from root system but water loss caused by tapping can be restored from stored water in the trunk and from root systems.

The dry season induced reduction in radial growth (Gooding, 1952; Kozlowski, 1971). The proximity of the canopy likely induces higher daily dehydrations in accordance with histological studies which reported a pressure fall down to 1.20 m below the tapping cut during the day (Buttery and Boatman, 1964). Nevertheless, the location of the latex regeneration bark area mostly on tapped panel was distributed 40 cm below and above the tapping cut (Silpi *et al*., 2004).

In contrast to contraction, the daily girth expansion was greater at the bottom of the trunk than above the tapping cut. This could be due to the fact that the lower parts of the trunk were less affected by water loss. A certain degree of hydration or turgor pressure is essential for cell enlargement and growth (cell division and cell expansion). The daily pattern of diameter variation was similar to that found by Daudet *et al.* (2005) and following the model of Lockhart (1965). Thereby, hydrostatic pressure at the lower level on the tree is greater than the upper level. It is likely that for the bottom of the trunk, the proximity of the roots favour rehydration and reduce dehydration as shown by the rate of shrinkage.

CONCLUSION

In conclusion, the results from this study suggest that the hydraulic consequences would change according to the locations of the cut along the trunk and also confirm that water is a major factor of trunk growth. The water potential in top level during transpiration leads to substantial reduction leaf water potential. The automatic recording of girth changes by high accurate dendrometer proved to be sensitive enough to monitor trunk hydration and daily growth. Finally, the monitoring of trunk hydration trough volume change appears as a promising path to improve the management of rubber plantation and further studies on yearly measurement of trunk girth are still required.

ACKNOWLEDGMENTS

This work was funded by the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0107/2547) from Thai Research Fund, Thai-French program by the French institute for rubber (IFC) and Khon Kaen University, by Michelin/Scofinco/SIPH Plantations Companies. Many thanks also to French and Thai technical assistances from Institute de research pour le development (IRD) and smallholder (Mr. Chaipat Sirichaiboonwat) who welcomed us so kindly in his rubber tree plantation.

REFERENCES

Ainuddin, N.A. and D.A. Nur Najwa, 2009. Growth and physiological responses of *Asplenium nidus* to water stress. Asian J. Plant Sci., 8: 447-450.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. UN-FAO, Rome, Italy, pp: 56.

Buttery, B.R. and S.G. Boatman, 1964. Turgor pressure in phloem: Measurement on hevea latex. Science, 145: 285-286.

Daudet, F.A., T. Ameglio, H. Cochard, O. Archilla and A. Lacointe, 2005. Experimental analysis of the role of water and carbon tree stem diameter variations. J. Exp. Bot., 56: 135-144.

Domec, J.C., M.L. Pruyn and B.L. Gartner, 2005. Axial and radial profiles in conductivities, water storage and native embolism in trunks of young and old-growth ponderosa pine trees. Plant Cell Environ., 28: 1103-1113.

Felker, P. and V.D. Leon, 2005. An improved tool for the fabrication of dendrometer bands to estimate growth as function of treatments in slow growing native *Prosopis* stands. For. Ecol. Manage., 209: 353-356.

Gartner, B.L., 1995. Plant Stems: Physiology and Functional Morphology. Academic Press, San Diego.

Gholami, M. and M. Rahemi, 2010. Effect of water stress and recovery on the water status and osmotic adjustment of miniature rose meshkinjan. Res. J. Environ. Sci., 4: 288-293.

Gooding, E.G.B., 1952. Studies in the physiology of latex. II. Latex flow on tapping *Hevea brasiliensis* associated changes in trunk diameter and latex concentration. N. Phytol., 51: 11-29.

Ismail, M.R., M.K. Yusoff and M. Mahmood, 2004. Growth, water relations, stomatal conductance and proline concentration in water stressed banana (*Musa* sp.) plants. Asian J. Plant Sci., 3: 709-713.

Keeland, B.D. and R.R. Sharitz, 1993. Accuracy of tree growth measurements using dendrometer bands. Can. J. For. Res., 23: 2454-2457.

Kozlowski, T.T., 1971. Growth and Development of Trees. Vol. II, Academic Press, New York, London.

Lockhart, J.A., 1965. An analysis of irreversible plant cell elongation. J. Theor. Biol., 8: 264-275.

Luvaha, E., G.W. Netondo and G. Ouma, 2008. Effect of water deficit on the physiological and morphological characteristics of mango (*Mangifera indica*) rootstock seedlings. Am. J. Plant Physiol., 3: 1-15.

Mahall, B.E., C.M. Tyler, E.S. Cole and C. Mata, 2009. A comparative study of oak (*Quercus*, Fagaceae) seedling physiology during summer drought in southern California. Am. J. Bot., 96: 751-761.

Martinez-Vilalta, J., E. Korakaki, D. Vanderklein and M. Mencuccini, 2007. Below-ground hydraulic conductance is a function of environmental conditions and tree size in Scots pine. Funct. Ecol., 21: 1072-1083.

Mclaughlin, S.B., S. Wullschleger and M. Nosal, 2003. Diurnal and seasonal changes in stem increment and water use by yellow poplar trees in response to environmental stress. Tree Physiol., 23: 1125-1136.

Medeiros, J.S. and W.T. Pockman, 2010. Carbon gain and hydraulic limits on water use differ between size classes of *Larrea tridentate*. J. Arid Environ., 74: 1121-1129.

Moreno, F., W. Conejero, M.J. Martin-Palomo, I.F. Giron and A. Torrecillas, 2006. Maximum daily trunk shrinkage reference values for irrigation scheduling in olive trees. Agric. Water Manage., 84: 290-294.

Naor, A. and S. Cohen, 2003. Sensitivity and variability of maximum trunk shrinkage, midday stem water potential and transpiration rate in response to withholding irrigation from field-grown apple trees. Hort. Sci., 38: 547-551.

Nortes, P.A., A. Perez-Pastor, G. Egea, W. Conejero and R. Domingo, 2005. Comparison of changes in stem diameter and water potential values for detecting water stress in young almond trees. Agric. Water Manage., 77: 296-307.

Offenthaler, I., P. Hietz and H. Richter, 2001. Wood diameter indicates diurnal and long-term patterns of xylem water potential in Norway spruce. Trees Struct. Funct., 15: 215-221.

Ortuno, M.F., J.J. Alarcon, E. Nicolas and A. Torrecillas, 2005. Sap flow and trunk diameter fluctuations of young lemon trees under water stress and rewatering. Environ. Exp. Bot., 54: 155-162.

Ortuno M.F., Y. Garcia-Orellana, W. Conejero, M.C. Ruiz-Sanchez, J.J. Alarcon and A. Torrecillas, 2006. Stem and leaf water potentials, gas exchange, sap flow and trunk diameter fluctuations for detecting water stress in lemon trees. Trees Struct. Funct., 20: 1-8.

Pallardy, S.G., 2008. Physiology of Woody Plants: In Transpiration and Plant Water Balance and Adaptation to Drought. 3rd Edn., Academic Press, San Diego, ISBN: 978-0-12-088765-1, pp: 325-366.

Peramaki, M., E. Nikinmaa, S. Sevanto, H. Ilvesniemi, E. Siivala, P. Hari and T. Vesala, 2001. Tree stem diameter variations and transpiration in Scots pine: An analysis using a dynamic sap flow model. Tree Physiol., 21: 889-897.

Sarker, B.C. and M. Hara, 2004. Periodic drought stress effect on evapotranspiration, root hydraulic conductance and fruit yield efficiency of eggplant. Asian J. Plant Sci., 3: 132-139.

Scholz, F.G., S.J. Bucci, G. Goldstein, F.C. Meinzer, A.C. Franco and F.M. Wilhelm, 2008. Temporal dynamics of stem expansion and contraction in savanna trees: Withdrawal and recharge of stored water. Tree Physiol., 28: 469-480.

Schroeder, C.A. and P.A. Wieland, 1956. Diurnal fluctuation in size in various parts of the avocado tree and fruit. Proc. ASHS., 68: 253-258.

Sevanto, S., T.N. Mikkelsen, K. Pilegaard and T. Vesala, 2003. Comparison of tree stem diameter variations in beech (*Fagus sylvatica* L.) in Soro Denmark and in Scot pine (*Pinus sylvestris* L.) in Hyytiala, Finland. Boreal. Environ. Res., 8: 457-464.

Sevanto, S., T. Holtta, T. Markkanen, M. Peramaki, E. Nikinmaa and T. Vesala, 2005. Relationships between diurnal xylem diameter variation and environmental factors in Scots pine. Boreal Environ. Res., 10: 447-458.

Silpi, U., P. Chantuma, P. Kasemsap, P. Thaler and S. Thanisawanyangkura *et al*., 2004. Spatial distribution of sucrose and metabolic activity in the laticiferous tissue of three *Hevea brasiliensis* clones: Effects of tapping and ethephon stimulation at trunk scale. Proceedings of the IRRDB Annual Meeting, Sept. 7-8, Kunming, China, pp: 1-18.

Silpi, U., P. Thaler, P. Kasemsap, A. Lacointe and A. Chantuma *et al*., 2006. Effect of tapping activity on the dynamics of radial growth of *Hevea brasiliensis* trees. Tree Physiol., 26: 1579-1587.

Sperry, J.S., 1995. Limitations on Stem Water Transport and their Consequences. In: Plant Stems: Physiology and Functional Morphology, Gartner, B.L. (Ed.). Academic Press, San Diego, pp: 105-124.

Swaef, T.D., K. Steppe and R. Lemeur, 2009. Determining reference values for stem water potential and maximum daily trunk shrinkage in young apple trees based on plant responses to water deficit. Agric. Water Manage., 96: 541-550.

Taiz, L. and E. Zeiger, 1998. Plant Physiology. 2nd Edn., Sinauer Associates Inc., Publishers, Sunderland, Massachusetts, USA.

Ton, Y. and M. Kopyt, 2004. Grapevine trunk and Shoot diameter mocrovariations and trends as indicators of water potential. Acta Hort., 652: 161-165.

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

Xiong, W., T. Wang, P. Yu, H. Liu, Z. Shi and W. Guan, 2007. Growth in stem diameter of *Larix principis-rupprechtii* and its response to meteorological factors in the South of Liupan Mountain, China. Acta Ecol. Sin., 27: 432-440.