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USE OF THE HEAT DISSIPATION TECHNIQUE FOR ESTIMATING THE TRANSPIRATION OF OLIVE TREES

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SUMMARY - The heat pulse method is used on olive trees for determination of transpiration. It consists of generating heat pulses at a point in the trunk and detecting their effect in another point. In spite of its usefulness its precision has not been demonstrated since the integration from one point measurement to the trunk cross section area could result in large errors. The more recently developed heat dissipation method, which is based on measuring temperature differences between heated and non heated probes, has been used on many forest species. Because it uses long probes (20 mm to 80 mm) it allows for better integration of the radial flow. The objective of this work is to investigate the practicality of using this technique for sap flow measurements of olive trees. To this end an experiment has been carried out on twelve year olive trees grown in central Tunisia. Four trees were selected for transpiration monitoring under changing water regime. On each tree three probes placed at different exposures were used, North (N), South East (SE) and South West (SW). Measurements of all twelve probes were collected every thirty minutes, over a complete growing season. Results obtained over periods where all probes were operating properly show a good coherence between sap flow estimates and environmental conditions. For the 95 days, during which all sensors were operational, daily values of sap flow density vary from 10 to 120 l dm-2 d^{-1}, about one to five ratio is observed between sensors. The mean value of sensors installed on each tree is highly correlated with the 12 sensors average values. When considering each direction separately, it seems that flux density is not related to the direction of the sensor, correlation between sap flow density of a sensor placed in a given direction and average value within that direction is variable. Variability of sap flow density between probes seems to be related rather to sapwood area heterogeneity. Regression equations relating sap flow density of each probe to the 12 probes average values were established and correlation coefficient exceed 0.85. With such calibrated equations, estimation of olive tree transpiration from a single probe and reconstitution of missing data becomes possible.

Key words: olive tree, transpiration, sap flow, heat dissipation technique, model.

INTRODUCTION

Estimation of transpiration is required for appropriate irrigation management, particularly for crops with variable planting densities. In orchards, quantifying water used by trees cannot be performed easily by methods based on water balance and micrometeorological measurements. However sap flow methods seem to have the potential of estimating the course of transpiration flux in a continuous manner. Presently a variety of methods are used successfully on many forest and fruit tree species. These methods can provide direct measurements and are easily automated, so continuous records of plant water use with high time resolution can be obtained. Sap flow measurements are also versatile because complex terrain and spatial heterogeneity does not limit their applicability. Sap flow can be estimated by heat-pulse, heat-balance or thermal dissipation methods. All of these techniques use the heat as a tracer for sap movement, but they are fundamentally different in their operating principals and each one have its merits and drawbacks.

On olives, a modified heat pulse technique (Compensation Heat Pulse Velocity, CHPV) was first used by Moreno et al (1996) and Fernandez et al. (1997) on either roots to study hydraulic behavior or trunks to estimate whole-tree water consumption respectively. A good agreement was found between the transpiration determined by CHPV system and that predicted by the Penman-Monteith equation. However, Fernandez et al (1998) reviewed the performance of the CHPV technique and outlined its advantages and limitations. Indeed, this system is reliable and of low maintenance, it provides information on the dynamics of both water uptake by roots and tree transpiration and determines the effect of meteorological conditions and soil water status on both processes. Nevertheless, the capability of the technique to estimate the tree transpiration is limited by the considerable heterogeneity of the conductive area in mature olive trees. Because this system uses point sampling, radial variability of sap flow results in large errors when scaling up to the whole tree. Consequently, many probes have to be installed at different depths and azimuths to account for radial variations.

Girorio and Giorio, (2003) used the CHPV with six gauges and found a strong correlation between the sap flow measured by each gauge and the average of the remaining ones. Estimation of average sap flow is therefore possible using measurement of a single probe. However, the validity of such models requires appropriate calibration over long period to provide a high resolution response to the physiological and environmental factors.

The heat dissipation technique developed by Granier, (1987) is based on the measurement of temperature differences between a heated and unheated probes. Use of probes with high temperature conductance allows integration of radial variability of flow along the probe length, but does not solve problems related to natural temperature gradients and sap flow density across the trunk as reported in the literature. The original method using continuous heating was therefore modified by Do et Rocheteau (2002) to avoid natural gradient effect on measurements.

The heat dissipation technique using alternative heating is presently used in two sites in Tunisia having contrasting climates. This paper concerns the work carried out in the arid environment of central Tunisia on four olive trees. The objective is to investigate the variability of measurements among probes on a given tree and the inter-variability of sap flow density among trees. Relationships between single probe measurements and averaged values will be analyzed. It assumed that with quantitative inter-relationships between probes and appropriate calibration good quality data could be derived with fewer sensors and therefore an easy to manage monitoring system could be obtained.

EXPERIMENTAL LAYOUT

The experimental work was carried out in a commercial orchard at Chebika near the city of Kairouan in central Tunisia (latitude 35°37'N, longitude 9°55'W, altitude 110 m). The climate is arid with an average annual rainfall of 280 mm. Four olive trees (Olea europea L., cv Chemlali) planted in 1993 and spaced 11×11 m, having similar shape (canopy and trunk diameter) have been chosen to be representative of the plot. Three probes are placed in each tree at three exposures: North (N), South East (SE) and South West (SW).

The sensors, associated electronics and worksheets software have been developed locally (Masmoudi et al, 2004). Two data loggers (Campbell CR10X) have been used for continuous monitoring and recording of sensors signals. Measurements of the twelve sensors were collected every fifteen minutes, over a complete growing season from 01/01/2003 to 31/12/2003.

The sensors are two cylindrical probes with 2 mm diameter and 20 mm length equipped with heating resistance and thermocouple and associated electronic modules for current regulation and control. Probes are inserted radially in the xylem and spaced vertically by 8 to 10 cm (Granier, 1987). The upper probe is heated with a constant power with an alternative 15 mn heating and cooling cycles while the lower probe is unheated. Sap flow density is calculated according to the Do and Rocheteau equation recalibrated for olive trees.

RESULTS

A sample of 95 days of data has been selected and used for investigation. As it was mentioned previously measurements on all 12 sensors were taken every 15 minutes, and half an hour sap flow density were calculated and daily cumulative values were derived. A typical course of sap flow density during a summer day is given in Figure 1.

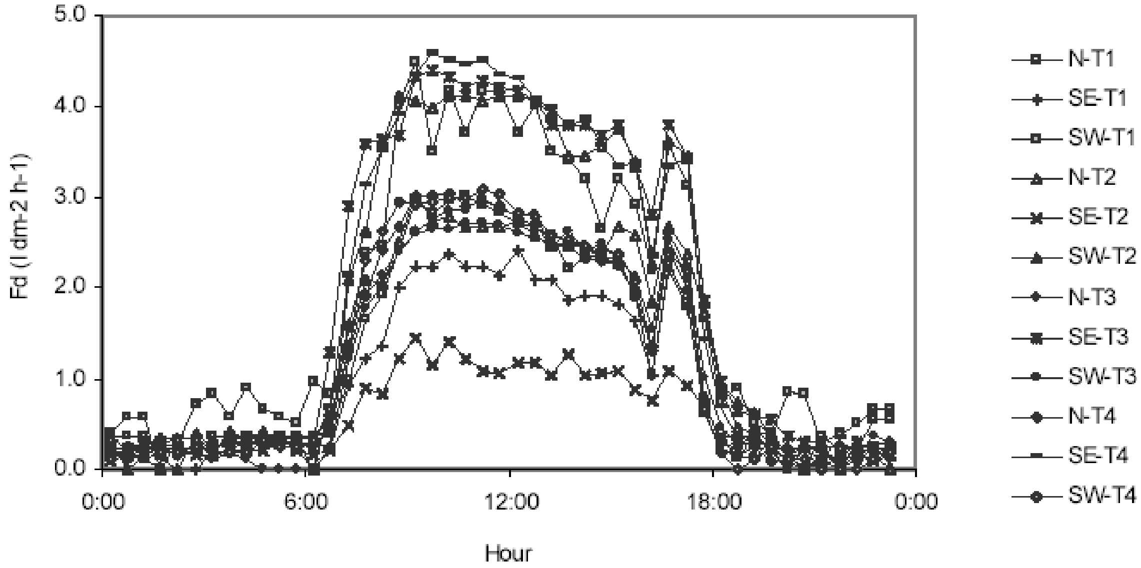

Fig. 1.Sap flow density (Fd) measured on four trees (T1 to T4) on three directions: North (N), South East (SE) and South West (SW) on 31/08/05

Sap flow given by all sensors increased rapidly after 7h15 to peak at about 09h15 and decline from 17h45 when solar radiation decreases. While there is a general consistency between the pattern of hourly measurements, absolute values of sap flow density obtained by individual sensors varied in high proportions. For instance, maximum value given by South Est (SE-T2) oriented sensor of tree 2 was 1.4 l dm^{-2} day^{-1} while the North oriented one on the same tree (N-T2) indicated 4.1 l dm^{-2} day^{-1}.

In order to characterize variability between sensors, daily values for individual sensors (Fd_i) were compared to average values of all sensors (Fd_m). Figure 2 shows that the sensors have the same behavior for the wide range of transpiration levels as observed over the 95 selected days.

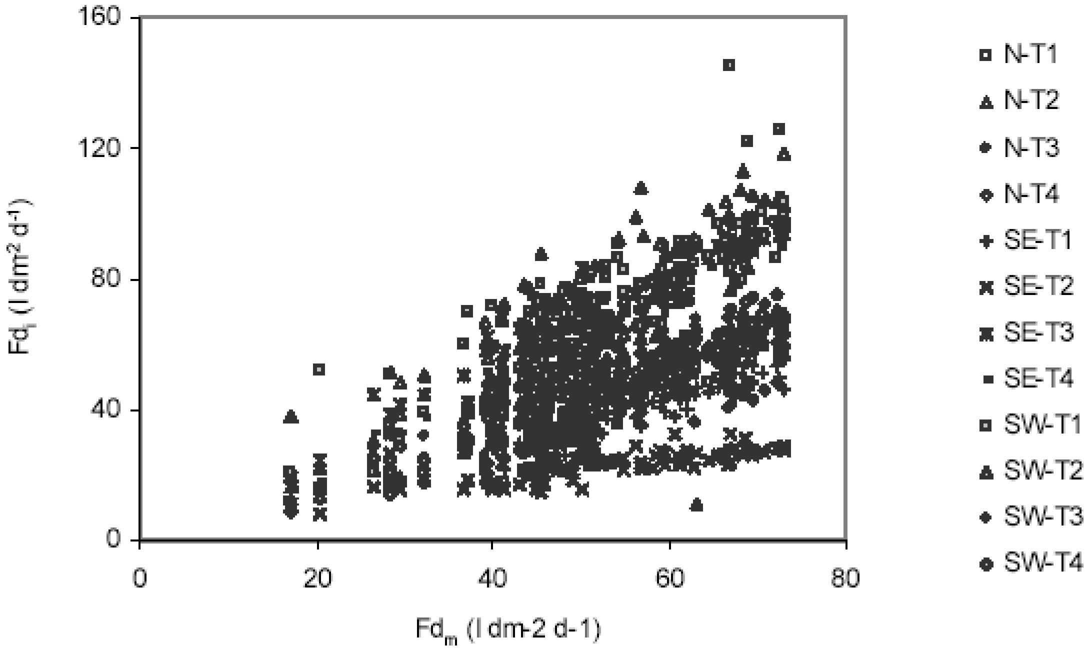

Fig. 2. Sap flow density (Fd_i) of individual probes (12) in relation to mean sap flow density (Fd_m), data relates to 95 days covering a large range of environmental conditions.

Overall sap flow patterns seem to be related to the probe orientation or position and to the local conditions of sap flow within the trunk. Consistency in the sensors relative change exclude any of random variation. Indeed, Table 1 gives the regression coefficients and shows that apart from sensors on tree 2 (T2) the regression coefficient is higher than 0.6.

Table 1. Values of slope (a), intercept (b) and R^2 of linear regression between sap flow density of each probe (Fd_i) and 12 probes average (Fd_m)

Tree	orientation	a	b	R^2
T1	N	0.99	-9.87	0.79
	SE	0.71	-0.80	0.81
	SW	1.39	-1.36	0.65
T2	N	1.37	-7.94	0.55
	SE	0.28	8.56	0.48
	SW	0.77	19.70	0.35
T3	N	1.03	-9.77	0.82
	SE	1.28	2.96	0.90
	SW	0.80	2.68	0.80
T4	N	0.92	-6.62	0.61
	SE	1.48	-11.93	0.89
	SW	1.00	-3.32	0.87

As transpiration is related to solar radiation, the existence of preferential orientation of the flow related to sun position is tested. To this end, regression equations have been established for each tree between values corresponding to the different directions (N, SE and SW) and the average sap flow of the considered tree. Figure 3 give results concerning the sap flow density on the three directions (Fd_i-T4) versus mean sap flow density for tree 4 (Fd_m-T4).

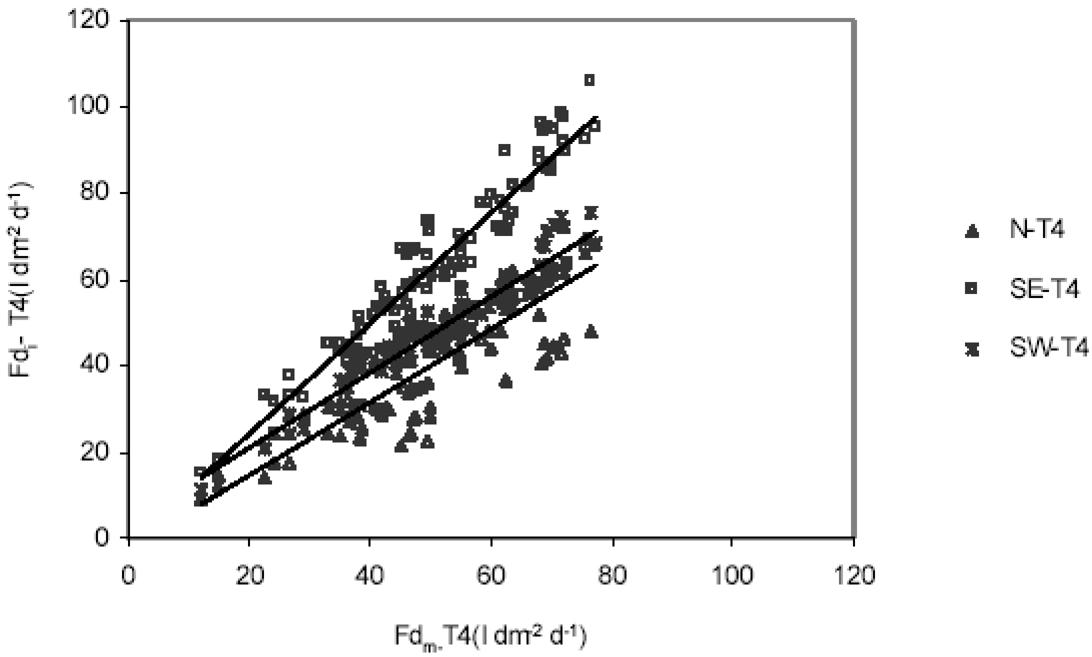

Fig. 3. Sap flow density for the three directions : North (N), South East (SE) and South West (SW) for tree (Fd_i-T4) versus mean sap flow density of tree 4 (Fd_m-T4)

Table 2 gives the slope coefficients and R^2 of all regressions. Correlation between individual sensors values and 12 sensors mean exceeds 0.7 except for tree 2 (T2). The slope of regression equation indicates that the relative weight of directions is quite random, there is no influence of the direction of the probe on average value of transpiration. The variability observed between signals from different probes is not due to the effect of exposure but to the variability of sap flow conductivity within the trunk section area.

Table 2. Slope coefficients (a) and R^2 of regressions between sap flow density of a given direction (North, South Est and South West) and mean sap flow density of the correspondent tree (T1, T2, T3, T4)

	N		SE		S W	
	a	R^2	a	R^2	a	R^2
T1	0.91	0.82	0.66	0.84	1.42	0.82
T2	1.67	0.71	0.30	0.49	1.01	0.52
T3	0.99	0.87	1.22	0.95	0.78	0.88
T4	0.84	0.70	1.28	0.92	0.87	0.92

With increased number of sensors, average values will better represent the effective sap flow and take into account the heterogeneity of flow within the cross section. As shown in figure 4 a good correlation is observed between mean sap flow of each tree (Fd_m-Ti) and the value obtained with all sensors (Fd_m). The number of three sensors seems to be a good compromise between the validity and the complexity of the measurements.

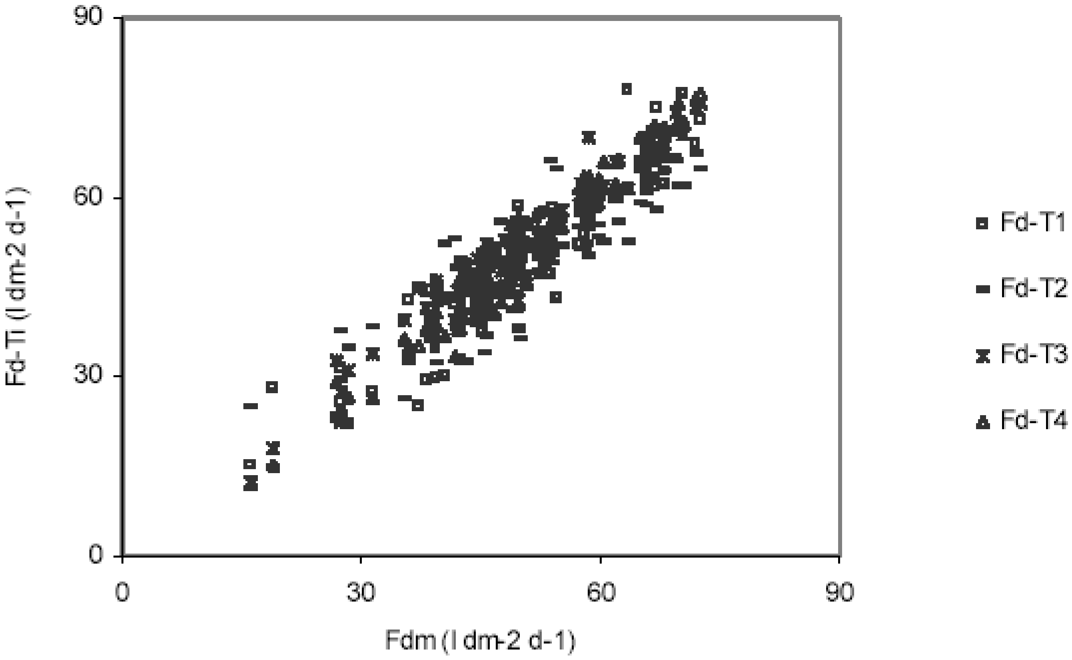

Fig. 4. Mean sap flow density of each tree (Fd_m-Ti) as related to mean sap flow density of all sensors (Fd_m)

CONCLUSION

The use of heat dissipation technique for measurement of sap flow is known as a technique which reduces the effect of radial sap flow heterogeneity as it integrates radial variability of flow along the probe length. The present work concerns the representatiness vity of a single or a set of sensors when installed on one tree or on several trees.

Continuous measurements of 12 sensors installed on 4 similar trees grown under the same conditions showed that sap flow densities obtained are coherent with climatic conditions but large differences are observed between absolute values produced by different sensors.

It was found that behavior and relative importance of a single sensor was consistent with reference to overall average for a wide range of transpiration. Mean values are well correlated to individual sensor outputs. There is no apparent relationship between orientation of sensors and the flow distribution within the trunk cross section.

A number of three sensors seems to be adequate to produce good estimates of effective sap flow and cover heterogeneity of flow in the trunk cross section. Methodology using regression equations seems to be appropriate and could be used for reconstitution of missing values in case of failure of sensors or to reduce the number of sensors for long term monitoring. However the use of such models needs calibration for local ranges of transpiration.

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