Measurements of sap flow for apple trees in relation to climatic and watering conditions

Nasr Z., Ben Mechlia N.

in

Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.).
Water saving in Mediterranean agriculture and future research needs [Vol. 1]

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.I

2007
pages 91-98

MEASUREMENTS OF SAP FLOW FOR APPLE TREES IN RELATION TO CLIMATIC AND WATERING CONDITIONS

Z. Nasr * and N. Ben Mechlia **
*INRAT, Rue Hedi Karray 2049 Ariana Tunisia, e-mail : nasr.zouhair@iresa.agrinet.tn
**INAT, 43 Av. Charles Nicolle 1082 Tunis Mahrajène, netij.benmechlia@iresa.agrinet.tn

SUMMARY - An experiment was conducted in a commercial apple orchard located near Tunis in order to determine the daily rates of sap flow of trees subjected to different watering conditions. The Golden Delicious cultivar planted on rows oriented NW/SE at a density of 1250 trees/hectare was used. Measurements included microclimatic factors and sap flow of two trees. Hourly data showed certain sensitivity to the existing natural thermal gradient in the morning. In spite of these discrepancies, it was possible to observe similarities between the daily course of sap flow and solar radiation although sap flow remained more or less constant when radiation reached a threshold value of about 500 $w.m^{-2}$. However daily values were poorly correlated with radiation, vapour pressure deficit and temperature. These measurements were used to obtain a quantitative approximation of the basal crop coefficient (Kcb) over the entire growing season. Kcb increased from 0.4 at flowering to reach a plateau 60 days later at cell division stage. It remained thereafter constant at 0.75 for more than 60 days before decreasing to 0.5 at ripening. For the tree conducted under deficit irrigation, sap flow rates decreased by 35% in comparison to the fully irrigated one. Such decrease occurred at the end of the season when water supply covered 0.81 and 0.46 ETo for full and deficit irrigation trees respectively

Key words: Apple, Golden Delicious, deficit irrigation, Granier Technique, Transpiration,

INTRODUCTION

In semi arid areas sound irrigation strategies require precise knowledge of water consumptive use by crops. On Fruit species, ideally one should measure transpiration rates and analyze its behavior in relation with climatic factors in order to avoid negative effects of prolonged water stress on trees. Among the methods that have been developed to estimate tree transpiration, the sap flow technique has the potential to measure directly the quantity of water transported in the trunk.

Different thermal methods for measuring sap flow have been developed during the last two decades. The most used techniques are based on heat balance (Sakuratani, 1981; Valancogne and Nasr, 1989; Nasr, 1995), heat pulse (Cohen and al., 1981) and the thermal dissipation probe (TDP). Initially developed by Granier (1985; 1987), TDP is based on a continuously heated probe. It has known a wide adoption (Heiman and Srtickan, 1993; Nasr *et al*., 1999) because of its simplicity, low energy requirement, reliability and low cost. Some improvements of TDP have been proposed recently by Do and Rocheteau (2002).

The present experiment used TDP technique to evaluate the daily course of sap flow on apple trees. The objective was to investigate changes in trees transpiration rates, in relation to microclimatic factors under two water supply conditions, full irrigation and deficit irrigation.

MATERIALS AND METHODS

Experimental field

The experiment was carried out during the 1996 season in a commercial apple orchard located in Mornag, near Tunis (LatN: 36°7'; LongE: 10°2'). Trees of the Golden Delicious cultivar were planted in NW/SE oriented rows at a density of 1250 trees/hectare and drip irrigated. Trees had an average height of 3.5 m with soil coverage of about 50%. Two trees with similar characteristics and approximately the same trunk diameter were selected for sap measurements. The first tree was situated in a plot under full irrigation according to maximum evapotranspiration replacements as currently practiced by the farmer (FI, 100 %ETc), while the second tree was under a deficit irrigation regime (DI, 50%ETc).

Measurements and calculations of sap flow rates

The TDP method, extensively described by Granier (1987) was used. The sap flow density J (10^{-6} m s^{-1}) was calculated using the calibration equation, which was validated for apple species by Cabibel and Do (1991).

$$J = 136.828 * [K]^{1.2997} \quad (1)$$

The flow index K is obtained by

$$K = (dTmax–dT)/dT \quad (2)$$

Where:

dTmax: is the temperature difference at zero flow
dT: the measured temperature difference at a given flow density J. A cut trunk section was used to estimate the portion of conducting xylem section (Sc), which was representing 75% of the external section. Finally, the sap flow rate F (l h^{-1}) can be calculated as:

$$F = J * Sc = 2,645*[K]^{1.2997} \quad (3)$$

Measurement of climatic parameters

In addition to the common climatic factors measured in a nearby station, precision weather sensors were placed at 0.5 m above canopy for continuous monitoring. CIMEL pyradiometer CE180 was used for solar radiation (Rs, W $m-^{2}$), ventilated cupper-constantan thermocouples for dry and wet bulb temperatures (Ta and Tw, °C), and the AR100 anemometer for wind speed (U, m s^{-1}). All measurements along with sap flow data were collected by a Campbell CR21X data-logger allowing for hourly and daily values calculations. ETo was estimated using the FAO-PM formula (Allen et *al*., 1996).

RESULTS AND DISCUSSIONS

Natural thermal gradient

The course of dT, measured without heating, clearly indicates the existence of natural thermal gradient. Temperature differences reached 1°C during the night. However at mid-day, high sap flow density reduced this gradient by convection effect to near zero. Peaks appeared to occur during transitional periods (Fig. 1). The magnitude of natural gradients over such a short distance (0.1 m) shows that the trunk is a site of important heat exchange. Peaks seem to be related to high sap fluxes occurring during mid-day. Under conditions of low sap flow densities, Do and Rocheteau (2002) observed continuous negative values without peaks throughout daytime.

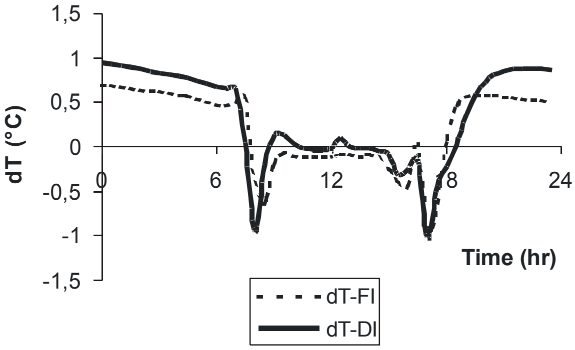

Fig. 1. Hourly variation of dT measured on a well irrigated apple tree (FI) and on a deficit irrigation tree (DI) without heating during a sunny day of the 1996 growing season, Mornag Tunisia.

dTmax discrepancies and errors on sap flow rates

The maximum temperature difference between heated and reference trunk tissue, dTmax, is a critical parameter in sap flow calculation. In our case, dTmax varied from 10.7°C to 8.1°C for FI tree and from 9.1°C to 7.6°C for DI tree, from day 125 to day 310; therefore showing respectively a decrease of about 0,014°C d^{-1} and 0.008°C d^{-1} (Fig. 2). It should be noticed that an error of 1°C on dTmax would result in an error of 20% for sap flow rate coming close to 0.5 l h^{-1} and an error of 60% for flow rates as high as 5 l h^{-1}. The observed continuous decrease in dTmax can be attributed to i) natural thermal gradient changes, to ii) a decrease in the thermal conductivity of the wood and to iii) the trunk growth. In fact, at the end of the growing season, trunk circumference increased by about 0.035 m which could explain 30% of the decrease in dTmax.

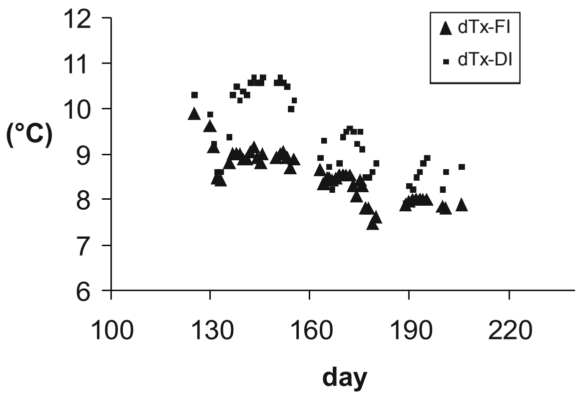

Fig. 2. Seasonally evolution of dTmax measured on (FI) and on (DI) apple trees during the 1996 growing season, Mornag Tunisia.

To avoid systematic errors, dTmax should not be considered for the entire season, but only for periods not exceeding 10 days to one month. In this case, errors attributed to dTmax on sap flow rates can be less than 5%.

Daily course of sap flow under full irrigation

Sap flow of the well irrigated tree (FI) followed a typical pattern during the day 180, which was a hot sunny day (Figs 3 and 4). It increased in the morning with a delayed response to radiation to reach a threshold value when radiation arrived to about 500 w m^{-2}. Two peaks characterize the sap flow pattern, one in the morning and the second in the afternoon. This behavior of sap flow during transitional periods involving peaks can be attributed to 3 factors.

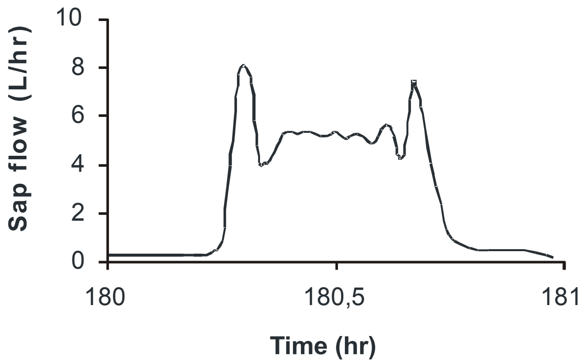

Fig. 3. Hourly course of sap flow on a well watered apple tree during a hot and sunny day (180, 1996), Mornag,-Tunisia.

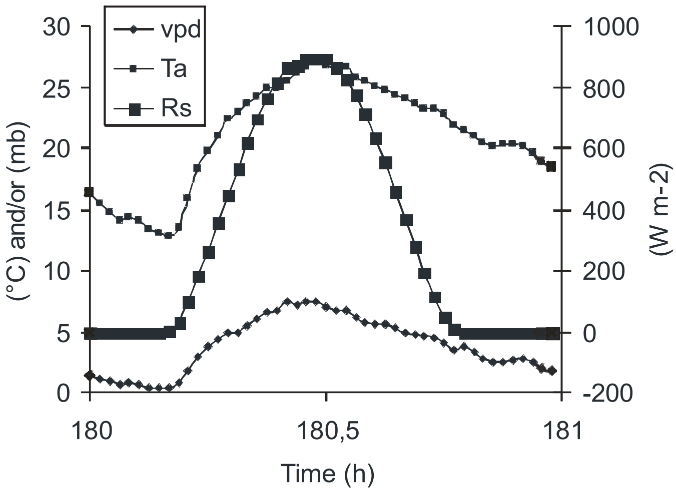

Fig. 4. Air temperature, radiation and vapor pressure deficit courses in an apple orchard during the day (180, 1996) Mornag, Tunisia.

* The orientation and the shape of rows indicate that trees intercept more radiation in the morning than in mid-day. Valancogne et *al*. (1993) using an interception radiation model tested on vineyard demonstrated that the sap flow is closely correlated with intercepted radiation for an apple orchard.

* The stomata conductance could be higher in the morning. Indeed, Cohen et *al*. (1993) illustrated in the case of Citrus the difference in stomata conductance between morning and mid-day.

- The third important factor, considered as inherent to TDP and heat balance methods (Valancogne et *al.,* 1993), is related to natural thermal gradient between the soil and the trunk.

The overall pattern of sap flow, although it was distinct from those of individual climatic parameters, showed some similarity with that of radiation.

Relationship between daily sap flow and climatic parameters.

For sap flow values less than 4 mm/d exponential correlation was observed between daily sap flow and individual climatic parameters. The best correlation was obtained with air temperature (Fig. 5) and poor correlation was observed with vapor pressure deficits (Fig. 6). For radiation, the pattern confirms the existence of a threshold value of sap flow when radiation reaches values as high as 22-25 MJ m^{-2} (Fig. 7).

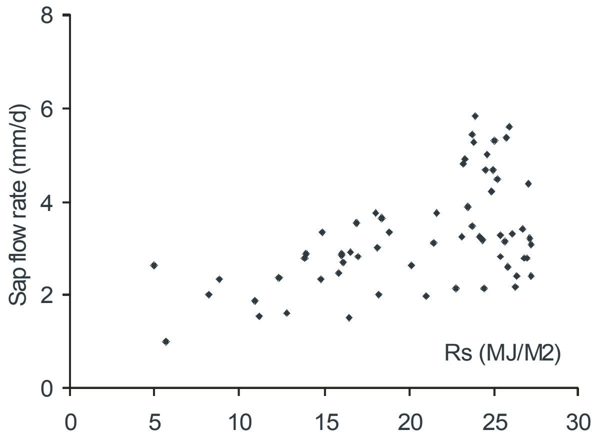

Fig. 5. Correlation between daily sap flow (Fl) and solar radiation (Rs) in an apple orchard, Mornag Tunisia, 1996.

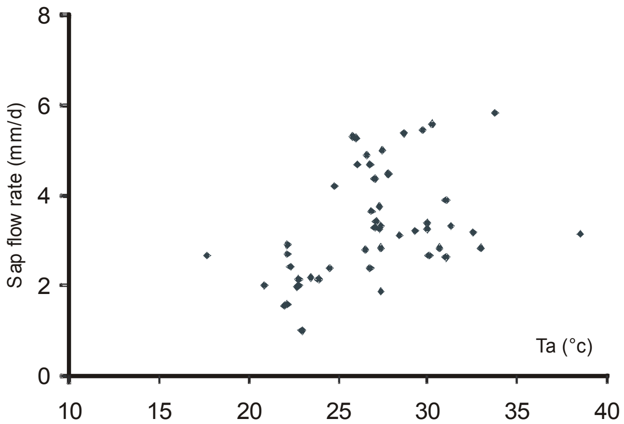

Fig. 6. Correlation between daily sap flow (Fl) mean air temperature (Ta) in an apple orchard, Mornag Tunisia, 1996.

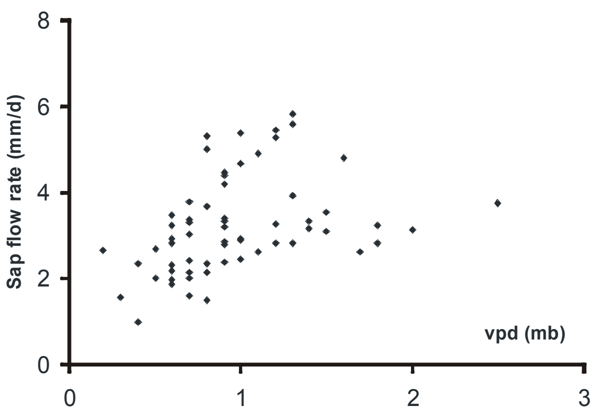

Fig. 7. Correlation between daily sap flow and mean vapor pressure deficit (vpd) in an apple orchard, Mornag Tunisia, 1996.

For days with high sap flow rates (4 to 6 mm d^{-1}), no correlation was obtained with climatic data. It is important to note that such high sap flow rates were obtained under conditions of high radiation (22-25 MJ m^{-2}) and moderate values of vapor pressure (70 to 130 Pa) and also moderate mean air temperature (20 to 25°C). Apparently, days with high evaporative demand, i.e. days with high radiation, high vapor pressure deficits and high temperatures do not result in the highest rates of sap flow. Probably, because stomata closure is playing a major role in reducing transpiration under harsh conditions in spite of good soil water supply.

Kcb estimates

Despite the reported constraints related to dTmax errors and natural gradient, an attempt was made to compute daily values of the basal crop coefficient (Kcb) defined here as the ratio between sap flow and ETo (Fig. 8). Results show that on the average, Kcb varied from 0.4 at the flowering stage to 0.75 at the cell division stage (flowering + 60 days). It then remained approximately constant at around 0.75 at the expansion fruit stage (60 days later). Finally, it decreased to 0.5 at the ripening stage as a consequence of leaf senescence.

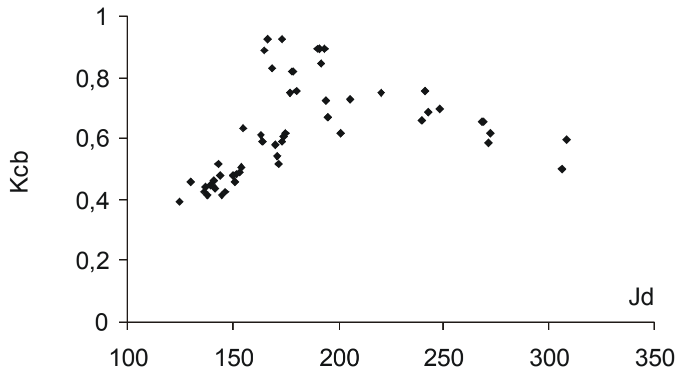

Fig. 8. Seasonally variation of Kcb on an apple orchard during the 1996-growing season.

Analysis of Kcb changes according to local microclimatic factors showed also a net sensitivity to wind direction. Peak values as high as 0.9 were observed for days dominated by hot and dry winds blowing in the same direction as tree rows (NW/SE). It is known that when the wind moves in the direction of rows, turbulence effect is increased compared to situation of winds of the same speed but blowing in different directions from that of rows. Increased turbulence seemed to result in 15% increase in Kcb.

Sap flow under deficit irrigation

Under deficit irrigation regime, sap flow of tree (DI) showed lower values, despite its higher leaf area (25,8 m^2) as compared to that of tree FI (23,5 m^2). Fig.9 shows how sap flow could be affected by deficit irrigation regimes. Peaks of sap flow were lower for DI, apparently because of a lower amplifying effect of convective processes.

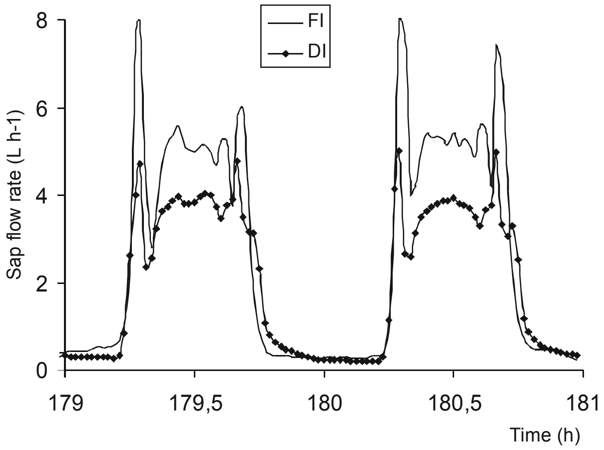

Fig. 9. Hourly Sap flow rate variations for apple trees under full irrigation (FI) and deficit irrigation (DI) during two successive days (179-181 1996), Mornag, Tunisia.

Sap flow rates of the two trees were approximately equal up to Julian day 165 (80 days after flowering), thereafter, transpiration of tree (DI) started to decrease. During the season, the average ratio of sap flow rates (DI/FI) varied successively from 0.97 at fruit set, 0.81 at cell division, 0.67 at cell expansion to 0.64 during ripening stages. This variation indicates that deficit irrigation applied following a rainy season, does not imply necessarily a reduction in transpiration during the first stages of growth, but can affect it seriously during later stages.

CONCLUSIONS

Measuring water consumptive use of trees by the Thermal Dissipation Probe (TDP) seems to be an appropriate method. The present experiment showed however the difficulty of predicting trees transpiration from individual climatic data, especially for conditions requiring high sap flow rates. Characteristics of the orchard, such as orientation of rows, have major effects on the daily course of transpiration and on the basal crop coefficient (Kcb). Obtained Kcb values seem to be adequate and could be considered for computing orchard water requirements. With deficit irrigation, relative transpiration was reduced gradually from 100% after flowering to 64% at maturation for 50% cut in irrigation water.

REFERENCES

ALLEN,R.G., SMITH,M., PERREIRA, L.S. and PERRIER, A.. (1994). An update for the calculation of reference evapotranspiration. ICID Bulletin, 4(2), 35-92.

CABIBEL,B. and DO,F. (1991). Mesures thermiques des flux de sève dans les troncs et les racines et fonctionnement hydrique des arbres. I. Analyse théorique des erreurs sur la mesure des flux et validation des mesures en présence de gradients thermiques extérieurs. Agronomie, 11, 669-678.

COHEN,Y., FUCHS,M. and GREEN, G.C. (1981). Improvement of the heat pulse method for determining sap flow in trees. Plant Cell Environ, 4, 391-397.

COHEN,Y., FUCHS,M. and MURESHET,S. (1993). Estimating citrus orchard canopy resistance from measurement of actual and potential transpiration. In: Water Transport in Plants under Climatic Stress. (Borghetti, M., Grace, J. and Raschi, A., Eds). Cambridge University Press, UK, 228-237.

DO,F. and ROCHETAU, A.(2002). Influence of natural temperature gradients on measurements of xylem sap flow with thermal dissipation probes. 1. Field observations and possible remedies. Tree physiology, 22, 641-648.

GRANIER,A. (1985). Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Ann. Sc. Forest., 42(2), 193-200.

GRANIER,A. (1987). Mesure de flux de sève brute dans le tronc du *Douglas* par une nouvelle méthode thermique. Ann. Sci. forest., 44 (1), 1-14.

HEIMANN,J. and STICKAN, W.(1993). Heat pulse on beech *Fagus sylvatica L.* in relation to weather conditions. In : Water Transport in Plants under Climatic Stress. (Borghetti, M., Grace, J. and Raschi, A., Eds). Cambridge University Press, UK, 174-180.
NASR, Z.(1995). Mesure de débit de sève au niveau des troncs d'arbres, application dans la recherche des modèles climatiques de Consommation d'eau des vergers. Alwamia, 88, 35-41.
NASR,Z., BENISSA,I. and BENMECHLIA, N.(1999). Estimation de la transpiration de pommiers sous climat semi-aride, par la mesure de flux de sève brute. Fruits, 54, 271-276.
SAKURATANI,T.(1981). A heat balance method for measuring water flux in the stem of intact plants. J. Agr. Met., 37(1), 9-17.
VALANCOGNE,C. and NASR,Z.(1989). Measuring sap flow in the stem of small trees by a heat balance method. Hortscience, 24, 383-385.
VALANCOGNE,C., AMEGLIO,T., ANGELOCCI,L. and Cruziat,P.(1993). Evaluation of transpiration of apple trees and measurement of daily course of water flow within the main branches of walnut trees. In : Water Transport in Plants under Climatic Stress. (Borghetti, M., Grace, J. and Raschi, A., Eds). Cambridge University Press, UK, 219-227.