Evapotranspiration and Crop-Water Relations in a Peach Orchard

M. Isabel Ferreira[1], Charles Valancogne[2], François-Alain Daudet[3], Thierry Ameglio[4],
C. Arruda Pacheco[5] and Johannes Michaelsen[6]

ABSTRACT

Transpiration and several water stress indicators were followed in a *Prunus persica* orchard in central Portugal, with the aim of (i) quantifying the water consumption of the orchard and (ii) analysing the usefulness of the variables observed, for irrigation scheduling purposes. The experiments were conducted at Águas de Moura (50 Km east from Lisbon) during June and July 1994. A 4 ha orchard was used and the planting was organised in rows, in a sandy soil. Three treatments were considered: A (well irrigated control, 2.88 ha), B (drought + normal ambient atmosphere, 0.5 ha), C (drought + elevated air humidity, 0.02 ha). The large dimensions of plot A allowed micrometeorological measurements. Drought treatments (B, C) consisted in two successive periods of complete water shortage. Evapotranspiration was measured with eddy correlation method in plot A and the results are compared with the sum of transpiration and soil evaporation measured by means of a sap-flow method and micro-lysimeters, respectively. Since both methods seem to agree reasonably well, their results were took as equivalent.

Sensible (H) and latent heat (LE) fluxes represented 33.4% and 38.5%, respectively, of net radiation, during day-time periods; the remaining 28% were heat flux to the soil (G). The relative average contributions of transpiration and soil evaporation to total evapotranspiration are respectively 82 and 18%. The crop coefficient (Kc) slightly decreased between 0.6 and 0.5 along the two months. The adequation of water stress indicators for irrigation scheduling is discussed using the relationships between stomatal conductance and predawn leaf water potential, as well as, between relative transpiration and predawn leaf water potential or daily shrinkage, as these variables seem to be good tools for irrigation scheduling, in this crop. The relationship between relative transpiration and the total transpiration since last irrigation or the available water in soil, are also discussed.

Keywords. Transpiration, Water stress, Energy balance, Trees, Microclimate.

INTRODUCTION

The evaluation of water and energy balances of the vegetated surfaces allows the understanding of its role in the water cycle and a better use of water, in irrigated crops. Either the validation of some available models or the understanding of the physical and physiological processes related, need good techniques for long-term transpiration measurements. The analysis of water-stress related variables can again be based on transpiration measurements, as a reference. Directly or not, the answer to the classical questions: when to irrigate and how much water to apply requires direct measurements of the water fluxes between trees and the atmosphere.

Information is still lacking concerning water losses from tree stands, either forests, orchards or natural vegetation. This is due to great turbulence in canopies and difficult access to the level above stands or to the entire root volume, making measurements more difficult than with low crops. Further difficulties on modelling are a consequence of the relative importance of stomatal

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[1] and [5] Associate Professor and Assistant Professor, respectively, at the Technical University of Lisbon: Instituto Superior de Agronomia, Tapada da Ajuda, 1399 Lisboa, Portugal

[2] Environmental Physicist at INRA: Station de Bioclimatologie INRA Bordeaux, BP 81, 33883 Villenave d' Ornon, France

[3] and [4] Agronomy Engineer and Biologist, respectively, at INRA: Unité Associée Bioclimatologie - PIAF, Domaine de Crouelle, 63039 Clermont-Ferrand, France

[6] Soil and Water Scientist at the University of Kiel, Institut fur Wasserwirtschaft und Landschaftsokologie der C-A Univ. zu Kiel, Olshausenst. 40-60, 24118 Kiel, Germany

conductance on the determinism of evapotranspiration, as expressed by Jarvis (1985) and Jarvis and Mc Naughton (1986) using the Ω coefficient. The sap flow methods have been, in last years, an excellent tool to get information about the water use by woody species, since other techniques like eddy-covariance methods require much more effort for long-term measurements.

Irrigation scheduling can be achieved using a continuously up-dated soil water balance or following the evolution of some indicators of plant or soil water status. These indicators can be directly measured on plants or soil or observed in atmosphere, the gradients of which are modified as a consequence of soil and plant water stress. After the first approaches using soil measurements, attention has been given, in last decades, to the measurements on plants, as stomatal conductance and leaf water potential. Leaf-to-air temperature difference or temperature gradients in the atmosphere are not commonly used on trees, namely in heterogeneous regions where advection can be important, because of the roughness of these stands and consequent instability of the values observed, with wind. However, physiologically based methods assessing plant water status are laborious and its main use has been in the analysis of the processes, in order to improve the transferability of results from one location to another.

The most commonly used variable, is predawn leaf water potential (ψ_p) as it can be used in plants with different strategies: either avoiding water loss or tolerating it (Katerji et al., 1988). Some limitations had arisen, due to new discussions about the part of this variable on stomatal behaviour, namely following recent work on the effects of ABA (Blackman and Davies, 1985; Zhang et al.,1987; Zhang and Davies, 1990; Wartinger et al., 1990, Fusseber et al., 1992; Correia et al., 1995). Thus, the interpretation of results must be careful, if the wetting of the root volume is highly heterogeneous.

The reversible shrinkage on a daily basis directly related to their water balance. The recognised interpretation of this process is based on a reverse flux of water from the trunk in response to the transpirational pull of the foliage (Kozlowski, 1972, 1982; Lansberg et al.; 1976, Huguet; 1985; Garnier and Berger, 1986; Ameglio and Cruiziat, 1992). During the last decade many attempts have been made using the variations of stem and fruit diameter to schedule irrigation, specially in orchards, where traditional methods are difficult to apply.

The results presented were obtained in the frame of a large team work aiming to study evapotranspiration from several tree stands and to follow-up some of these variables. This paper is oriented to give information concerning practical applications in irrigation, either being the scheduling performed through the direct measurement of a water-stress indicator or through the calculation of the water losses from the soil to the atmosphere, using ET estimates (soil water balance). Therefore, the discussion is pointed towards the following points: (i) which variables can be adequate for that purpose, (ii) which are the respective threshold values and (iii) which are the values for the crop and stress-related parameters needed for the calculation of actual ET. Special emphasis is given to the relationship between the variables with interpretative value and those which can be continuously monitored.

METHODS AND MATERIALS

Site, Plants and Soil

The study site was located at Águas de Moura, 50 km south-east from Lisbon, Portugal (latitude 38° 24', longitude 8° 45', elevation near 0). The climate is of the Mediterranean type, tempered by a maritime influence with mean annual temperature, humidity, rainfall and pan evaporation (class A) of respectively 16 °C, 75 %, 640 mm and 1480 mm, according to long-term averages. The orchard (3.4 ha) consisted of a 4-yr-old *Prunus persica* plantation with an average height of 3.1 m. The leaf area index of the canopy was estimated to be 1.38.

The soil type was a Haplic Arenosols (FAO-Unesco, 1994) with a sandstone lithic contact between 0.8 and 1.0 m of the soil surface (this layer was irregularly disrupted by ripper during preparation of soil tillage plantation). Texture is sand to 0.8 m depth and loamy sand from 0.8 to 1.0 m. The soil bulk density at this depth is 1.71 and 1.75 $Mg.m^{-3}$.

The planting was organised in rows 5 m apart, with 2 m distance between trees in each row. Sprinkler irrigation was usually applied each 3-4 days. Each sprinkler corresponded to an area of 20 m^2 (one for two trees) and was wetting a circle of 2 m^2.

Experimental Treatments

Three plots were considered: plot A, always well irrigated, and plots B and C, submitted to water stress during successive periods of about 16 days. Plot B had an area of 5 000 m2 and plot C an area of 200 m2, small enough to ensure that there were no modifications in the air temperature and humidity of this plot owing to water stress. The large area of plot A (2.88 ha) allowed the measurements of evapotranspiration with a micrometeorological method, as described below. Plot B was without irrigation between the 13th June (j day 164) and the 1st July (j day 182) and between the 8th July (j day 189) and the 24th July (j day 205). Plot C was without irrigation between the 24th June (j day 175) and the 6th July (j day 187) and between the 8th July and the 3th August (j day 215).

Measurements

The measurements started at the beginning of June and lasted till the end of July. The following environmental variables were continuously monitored: incident and reflected solar radiation (thermopile solarimeters CIMEL, CE180, France) at 7.15 m, horizontal wind speed (CIMEL, CE 155, France) at 4.8 m and close to the foliage (1.6 above the soil), wind direction (wind vane Chauvin Arnoux 26D TAVID 87, France), precipitation (tipping bucket rain gauge Précis Méchanique R01 3029/5), net radiation (thermopile net radiometer, REBS QA6, USA) at 7.15 m, dry and wet bulb temperatures (fan-aspirated psycrometers with TC sensors, INRA, France) at the same levels as anemometers and in all plots. All sensors were connected to a data-logger (CR7, Campbell Sc.,Ltd) recording 20 minute averages.

The eddy covariance measurements were sampled at a rate of 10 Hz with a flux averaging period of 10 mn and output every 30 mn. Sometimes the 5 Hz values were stored for a spectral analysis. The eddy fluxes were measured at 2 positions: always at 3.6 m and at a distance of 1.0 from the trees line and at different highs (4.1 m and 3.6 m) above the trees line. A sonic anemometer (Campbell, CA 27 with 127 fine wire thermocouple) and a krypton hygrometer (Campbell, KH20) were connected to a 21X Campbell data-logger. The measurements point corresponded to a fetch of 200 m. These measurements were performed on plot A, during 10 days of July.

Xylem sap flux (m3.s-1) was directly measured using a heat balance method adapted from Sakuratani (1981) and Valancogne and Nasr (1989, 1993) that takes into account the variations in heat storage (in the trunk). The heating is dependent upon the flux, in this last version. The sensors were connected to a CR7 data-logger. The measurements were taken every 10 seconds and 20 mn averages were stored. The measurements were performed on 3 trees from each of the plots A and B and additionally other 3 from plot A, in the wind up-stream direction (in order to compare with eddy-covariance measurements). These values were considered equal to transpiration on a daily basis. The transpiration for the plot is calculated from the average of the individual fluxes corrected to take into account the representativeness of the trees, in relation to the average size in the orchard. Xylem sap flux density (m3.m-2.s-1) on 5 trees from each of the 3 plots, was measured using 2 cm long continuously heated sap flowmeters (Granier, 1985, 1987) . The sensors were connected to a CR10 Campbell data-logger. Frequency and integration were as above. These measurements allowed the calculation of relative transpiration based on a larger sample, as sensors are much cheaper.

Soil evaporation was measured with lysimeters, built and used as described by Daamen et al. (1993). A number of 16 lysimeters was used, in different positions in relation to the sprinkler and trees around. The evaporation was obtained by a weighed average considering the area represented by each lysimeter.

Reference evapotranspiration (ETo) was estimated using Penman-Monteith equation with grass parameters: stomatal resistance of 70 s.m-1 and grass height of 0.12 m for the calculation of aerodynamic resistance, as described in Allen et al. (1994) and also using the Penman (1948) formulation (with Rn measured over the orchard).

Volumetric soil water content was measured with neutron probe (SOLO 40-France) and TDR probes (Trime system, IMKO, Germany and Trase System, Soil Moisture, USA). Neutron probe access tubes as well as tubes for a multi-level TDR probe were installed in different locations from plant of each plot (A, B and C). The area wetted by sprinkler irrigation was studied using TDR single probes. Field root distribution was studied by the interseption profile method.

Stomatal conductance was measured with a steady-state porometer (LI-1600, LI-COR Ltd., Lincoln, NE, U.S.A.). These measurements were replicated 14 times in each plot. Concurrent measurements of leaf water potential, replicated 10 times in each plot, were obtained with a Scholander-type pressure chamber (Scholander et al., 1965) with 2 manometers (in order to get better precision for low pressures). Stomatal conductance after noon and predawn leaf water potential were measured at least about every 3 days, with almost daily measurements and some daily courses, in all plots, during the drought cycles.

Changes in diameter were continuously recorded measured, in two trees in each plot (A and B), with linear variable displacement transducers (LVDT, DF2.5, 2.5±0.01 mm, Schlumberger /Solartron Metrology, France), each one mounted on an invar alloy frame to reduce the effect of temperature changes. The relative magnitude corresponds to the maximum daily shrinkage of stressed trees divided by the correspondent value on irrigated trees.

RESULTS

Crop and Soil Parameters

The value of 1.38, for LAI, corresponds to the average of the total leaf area in 15 trees of the orchard (5 trees from each experimental plot) obtained through (1) the relationship between leaf area (A) and leaf length (l), $A=0.145*l^2$ ($r^2=0.96$), (2) the relationship between the total area of n leaves (A_t) and the number of leaves (n) in random samples, $A_{t}.=9.33+21.1*n$ ($r^2=0.998$) measured in this stand and (3) the leaves counting in each tree. These relationships were obtained for the variety *Maybelle* used in this experiment. Canopy cover was 60±5% (n=32), by the end of July.

Soil profile is free from root-resctriting features up to 0.9 m. Root distribution is limited to soil bulk watered by sprinkler with the major root mass concentrated at a depth of 0.3 to 0.5 m. Over the sandstone layer the roots were horizontally spread. Very few thick roots penetrate this layer. Grounwater lies deeper than 2 m below the surface. The available water, up to 1 m depth, was 45 mm, calculated as the difference between field capacity and the lower limit of water uptake, reached after 12 days of withholging water. Simulations showed that cappilary rise, with a flux of 0.1 mm/day is restricted to a heigh of 47 cm above groundwater level. It may be concluded that there will be no contribution from the grounwater to the water balance of the root zone.

Water and Energy Flux Measurements

The flux values obtained with eddy covariance measurements, in the 2 positions described above, were almost the same and are reasonably good as the normalised cospectra were found very close to the universal value given by Kaimal and Finnigan (1994). The computed fluxes were corrected a posteriori for the temperature effect (Webb et al., 1980) and the krypton O_2 absorption effect (Tanner et al., 1993). The results obtained for the direct measurements of sensible (H) and latent heat (LE) fluxes are presented in Table 1. As an average H and LE represent 33.4% and 38.5%, respectively, of net radiation, during these day-time periods; the remaining 28% is heat flux to the soil (G).

The values observed as transpiration (Tr) and soil evaporation (Es), for the same periods, are indicated and the sum is compared with the evapotranspiration from the orchard. The results show a reasonable agreement between the two independent measurements. In the following, as longer periods are to be considered, only the sap flow data are used.

Figure 1 shows the results obtained using this sap flow method to follow the transpiration throughout the season considering, for this purpose, only 3 trees on plot A (variety *Maybelle*). Net radiation and reference evapotranspiration (ETo) are also shown. The relationship between Tr and ETo, is presented in Fig. 1. Values for the running average are between 0.46 and 0.36. It approaches the crop coefficient, as the relative importance of soil evaporation is low: 0.5 mm/day is the average evaporation in the well irrigated plot (A) which corresponds to about 22% of transpiration or 18% of ET. The crop coefficient, Kc = (Tr+Ev)/ETo), slightly decreases between 0.6 and 0.5 along these two months. Higher values are observed (from 1.2 to 0.8), if expressed on a projected area basis, according to variation in canopy cover between 0.5 and 0.6, during the same period.

Table 1. Measurements of energy balance (Rn, H and LE) and evapotranspiration (Tr and Ev) components, in a peach orchard, at Águas de Moura, 1994.

Day / Hr (UT)	**20/7/94 (j201) 10.75 to 21.25**	**21/7/94 (j202) 6.25 to 18.75 (w 10.75 and 11.25)†**	**23/7/94 (j204) 5.75 to 20.25**	**24/7/94 (j205) 5.93 to 21.43**	**25/7/94 (j206) 6.25 to 20.25 (w 13.25 and 14.25)**	**26/7/94 (j207) 5.25 to 14.75**	**27/7/94 (j208) 6.75 to 19.75 (w 12.75 and 13.25)**	**28/7/94 (j209) 6.25 to 19.75**	**30/7/94 (j211) 8.75 to 21.25**
ΣRn (MJ/m2)	12.26	14.76	11.72	12.45	13.87	12.76	13.75	15.35	13.58
ΣH (MJ/m2)	4.11	5.05	4.32	4.43	4.64	3.43	3.93	4.60	5.23
ΣLE (MJ/m2)	4.41	4.73	4.59	5.48	5.78	5.06	5.99	6.00	5.01
ΣE (mm)	1.76	1.89	1.84	2.19	2.31	2.02	2.40	2.40	2.00
ΣEs (mm)	-	0.50	0.26	0.50	0.50	0.38	0.32	0.12	*
ΣTr (mm)‡	1.58	1.71	1.65	1.78	1.75	1.55	2.17	2.14	1.72
ΣEs+Tr (mm)	-	2.21	1.91	2.28	-	1.93	2.49	2.26	-

† except during the period indicated
.‡ the number of trees considered is 6

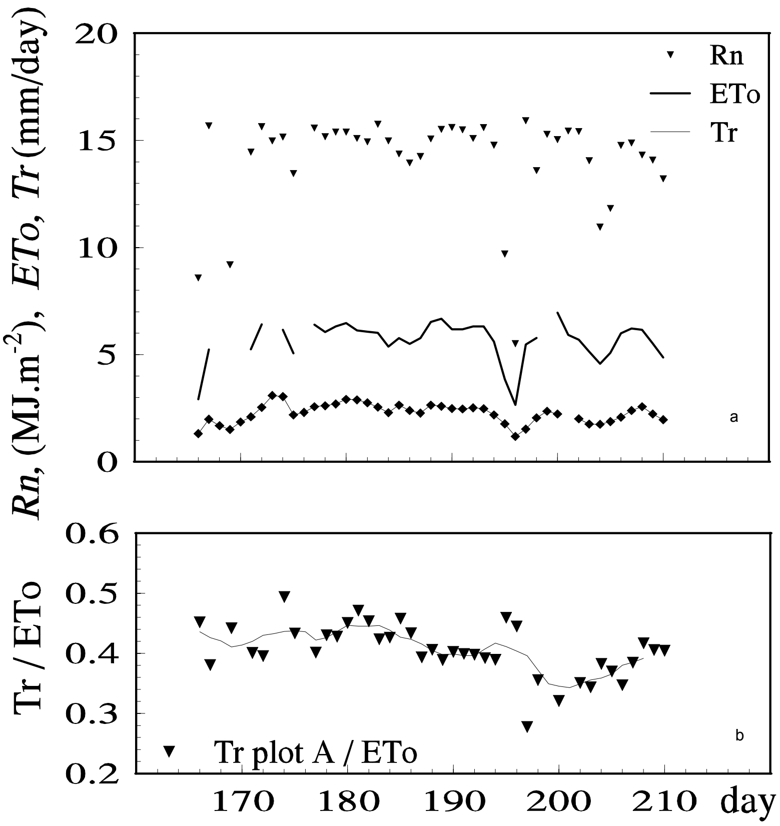

Figure 1. Seasonal courses of (a) transpiration (Tr), reference evapotranspiration (ETo) and net radiation (Rn) and (b) transpiration over reference evapotranspiration (and running average), in *Prunus persica*, at Águas de Moura, 1994.

Stomatal conductance and leaf water potential. The stomatal conductance (gs) is often considered as the water-stress-related variable more closely connected with the CO2 assimilation rate (Schulze, 1986; Chaves, 1991; Jones, 1992). As reliable methods, for a continuos monitoring of gs, are not currently available, the values from a limited period, during the day, are usually considered. This choice is dependent on the aim of the study: the maximal value, in the morning, or the minimum, after noon, are often used. It was observed, in this experiment, that more important differences existed between the well irrigated plot and the stressed plot at 13:30 solar time, about 1 hour after the minimum noon g_s was measured. This was due to a re-opening of stomata in the afternoon, for the watered plants, not observed in the stressed plants. For this reason, the g_s at 13:30 was selected as the more adequate for an analysis, with irrigation scheduling purposes. Figure 2 shows the relationship between g_s at 13:30 (sunlit leaves) and predawn leaf water potential (ψ_p), for the 3 plots, considering the average in the plot and both drought cycles. There is a continuos decrease but more scattering for ψ_p > -0.4 MPa and an important decrease of g_s below that value. For ψ_p <-0.4 MPa g_s is always below 50% of the correspondent value measured in the well irrigated plot (Fig.2b).

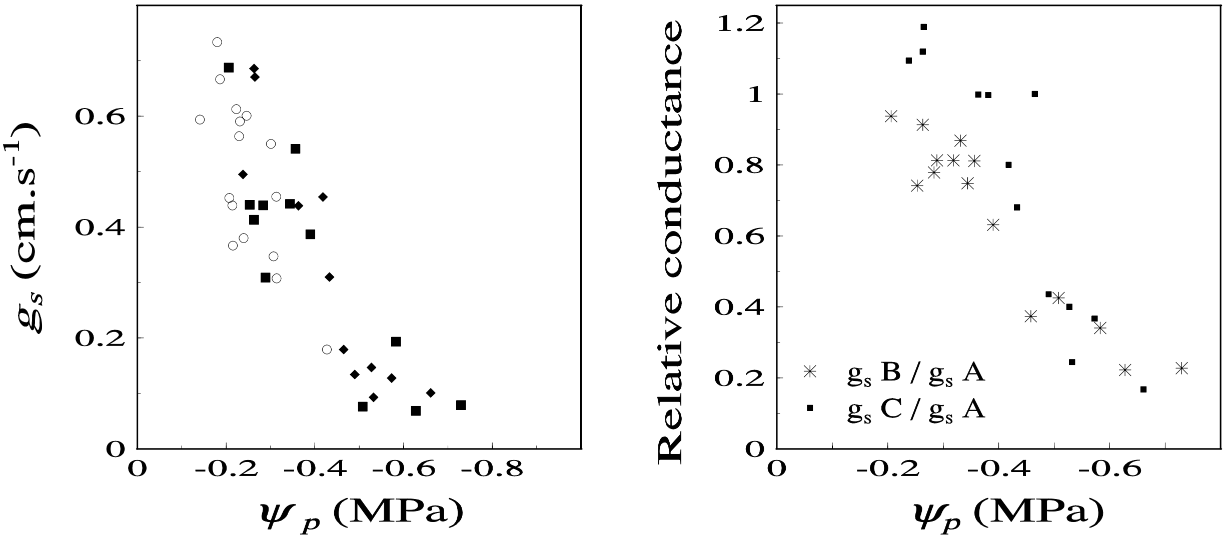

Figure 2. Relationship between predawn water potential (ψ_p) and stomatal conductance (g_s): (a) absolute values, on all plots and (b) relative values, in the stressed plots (see text for description of conditions on plots B and C). Águas de Moura, 1994.

The difference observed between the response of relative g_s in plots B and C (g_s of plots B or C over g_s of plot A) is probably explained by the difference on air humidity on those 2 plots which has less influence when ψ_p is lower (Ferreira and Katerji, 1992). As a result, the value of 0.4 MPa was considered a threshold value, for practical applications. This variable, though easier to measure that g_s, is not automatizable for practical purposes. Thus, that threshold value will be used in the discussion concerning its relationship with other water-stress indicators, whose measurement is possible by means of automated systems.

Relative transpiration and trunk diameter magnitude. The relative transpiration and the micromorphometric variations in the trunk of the tree were the variables used in this study. Furthermore, the total transpiration integrates the plant behaviour during all day.

Figure 3a shows the evolution of relative transpiration (Tr plot B or C / Tr plot A) during both stress cycles. After a first period of stress, the transpiration didn't reached the initial level which can be a consequence of limited but noticeable leaf fall, during drought. The relative transpiration was calculated with all the values of transpiration (both sap flow methods, 8 trees on plot B and 5 on plot C) thought the values obtained with the two sap flow methods used in this study, were not significantly different, for relative transpiration. Figure 3b shows the evolution of relative magnitude during the same cycles. Both Figures 3a and 3b look very similar, suggesting that the relative amplitude of varaiation of trunk diameter is in close relation with water shortage.

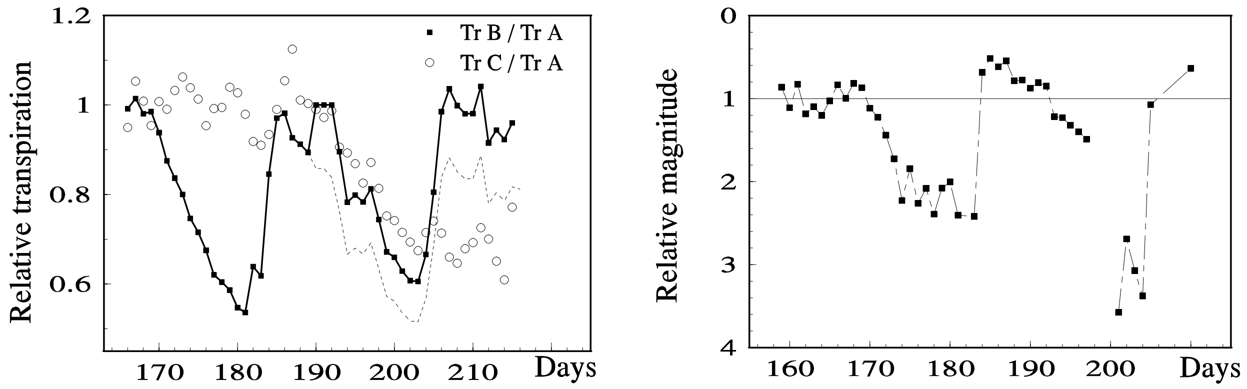

Figure 3. Evolution with time of (a) relative transpiration and relative magnitude, during two sucessive drought cycles, at Águas de Moura, 1994.

Figure 4a presents the results obtained for the average values of relative transpiration on plot B and the correspondent ψ_p average, in the orchard. The value of -0.4 MPa corresponds to a relative transpiration of 70%. Fig.4b presents the relationship between the relative magnitude of trunk diameter and the relative transpiration, for individual values. When the transpiration has decreased down to 70% of its value on irrigated plot, the relative magnitude is about 2. This value seems indeed to correspond to a threshold value, also in this relationship (as already been observed in other experiments), since scattering of the experimental points for lower relative transpiration seem very high and a discontinuity is apparent at this level. It should be noted that the lower values observed either for relative transpiration or relative magnitude were above 50%; this corresponded to a much higher decrease (80%), on g_s (Fig. 2b).

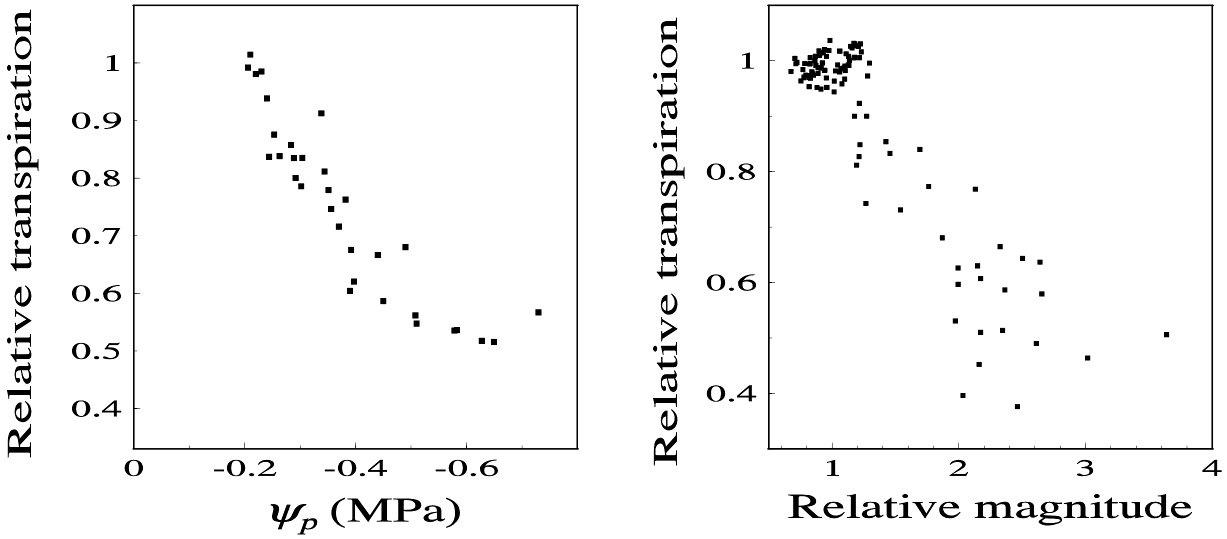

Figure 4. Relationship between (a) relative transpiration and predawn water potential (ψ_p) and (b) relative transpiration and relative magnitude, on a stressed plot (B), at Águas de Moura, 1994.

<u>Soil water balance</u>. Irrigation scheduling can also be achieved using a continuously up-dated soil water balance. Thus, the estimation of actual evapotranspiration is needed. It is often obtained using the reference evapotranspiration (ETo), crop (Kc) and stress (Ks) coefficients. Thus,

the relationship between the decrease in transpiration and the sum of transpiration since last irrigation answers to both questions: when and how much to irrigate. At the same time, there is information about the level of decrease of transpiration for irrigation scheduling and water management decisions and still a day-by-day transpiration estimate is possible, if ETo and Kc are available (considering that the relative transpiration corresponds approximately to Ks, in the relationship ETa=ETo.kc.ks). This relationship is presented in Fig.5, for both cycles, after normalisation of the relative transpiration during the second cycle, relative to the period between the two cycles (excluding the first days, when part of the water up-take was for re-watering, and not only for transpiration). Total transpiration was calculated since irrigation was stopped on plot B (when first irrigation on A, and not on B, occurred). The relative transpiration of 70% is reached when the sum of Tr was about 15 mm.

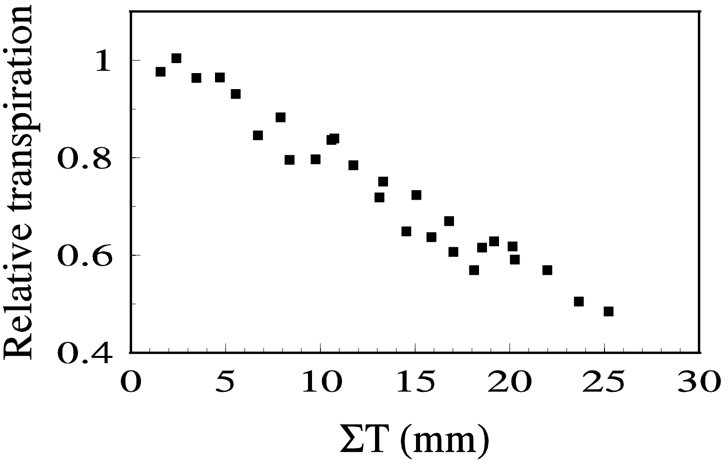

Figure 5. Relationship between relative transpiration and the total transpiration since last irrigation (after difference between plots was established) at Águas de Moura, 1994.

The total transpiration do not corresponds to the soil water depletion in the root zone. Figure 6 shows the evolution of relative transpiration with the available water (AW) remaining in soil, in plots B and C. When plot B (and C) is not irrigated, the differences between plots become immediately obvious (AW < 40%). This is roughly about 3/4 days after irrigation in both plots. During the first 1 or 2 days drainage is important (AW > 100%); during the next 1 or 2 days transpiration in both plots is enough to take from the soil 60% of AW (2.7 mm of ET). Then it was considered that plot A has to be irrigated and since this moment differences between plots appear clearly. This level of 60% is, here, the result of our lay-out: it is the threshold value used for the irrigation decision on plot A (whose transpiration could be also slightly decreasing during these 3 days).

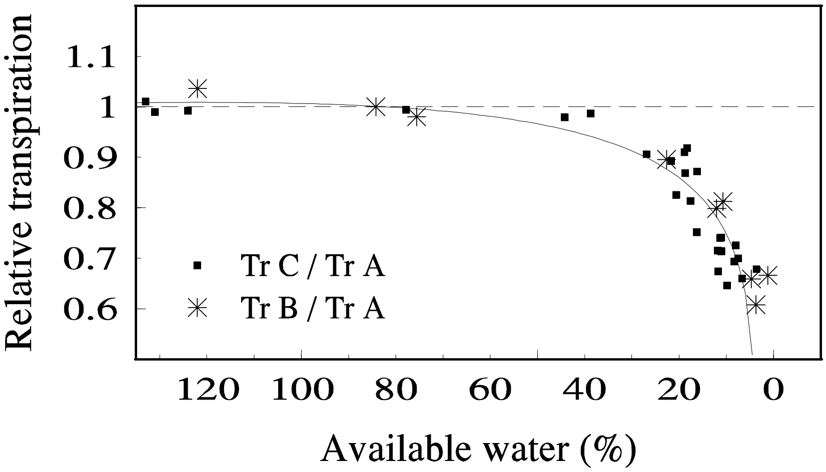

Figure 6. Relationship between relative transpiration in stressed plots B and C and the avaliable water, in the root zone, at Águas de Moura, 1994.

The important feature is that transpiration during the following days is much higher then the water remaining in the soil (enough to ensure 1 day of transpiration, in the beginning, or two days, by the end of the cycle). The conclusion of these observations is that water should come from some rare roots penetrating the sandstone layer, below 1 m, as capillarity from groundwater seems to be unlike. This water taken up from the deeper layer slows down the decrease of transpiration but the quantity of water is not enough to prevent the tree from wilting. If a deeper zone is taken into account for the calculation of AW, the curve of the relationship between AW and relative transpiration (Fig. 7) will be shifted to the left, which leads to a decrease of relative transpiration at a higher value of AW. Due to the restription to the upper meter of the soil profile, results do not allow a comparison with other soils or plants. Nevertheless, for the purpose of irrigation scheduling, measurements in the main root zone, seem to be sufficient.

The results indicate that the threshold value correspondent to the 60% of AW in Fig. 6 is adequate, for a maximal production. Yet, because of the competition among water users and for the sake of fruit quality it is important to impose a moderate and controlled water stress. Thus, as before, we have to consider a lower critical threshold which was shown to correspond to 70% of relative transpiration.

CONCLUSION

The sap-flow method used in this experiment provided good results when compared to eddy-covariance measurements of evapotranspiration. Sensible (H) and latent heat (LE) fluxes and heat flux to the soil (G) represented respectively 33.4%, 38.5% and 28%, of net radiation, during day-time periods. The relative average contributions of transpiration and soil evaporation to total evapotranspiration are respectively 82 and 18%. The crop coefficient (Kc) slightly decreased between 0.6 and 0.5 along the two months The relationship between stomatal conductance and predawn leaf water potential indicate that the value of -0.4 MPa is a threshold value with practical interest for irrigation scheduling. It was found a good relationship between relative transpiration and predawn leaf water potential or trunk daily shrinkage. These variables seem to be good tools for irrigation scheduling, in this crop. The advantage of the micromorphometric approach is that changes in trunk diameter are not only a very sensitive indicator of the plant response to water supply conditions but they can be recorded continuously and thus are easy to use in computer controlled irrigation.

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REFERENCES

1. Allen, R. G., M. Smith, L. S. Pereira, and A. Perrier.1994. An update for the calculation of reference evapotranspiration. ICID bulletin 43, 2:1-34.
2. Ameglio T. and P. Cruiziat 1992. Daily variations of stem and branch diameter: short overview from a developped example. NATO ASI Series, Vol. H64. Mechanics of Swelling. Ed T.K. Karalis. Springer-Verlag Berlin Heidelberg:193-204.
3. Blackman, P. G. and W. J. Davies. 1985. Cytokinins, abscisic acid and the control of plant balance. Acta Hortic*,* 11: 255 - 261.
4. Boyer, J. S. 1989. Water potencial and plant metabolism: coments on Dr P.J. Kramer's article 'Changing concepts regarding plant water relations', 11(7):565-568, and Dr J. B. Passioura's Response, 11(7):569-571. Plant, Cell and Environment 12: 213-216.

5. Chaves, M. M. (1991) Effects of water deficits on carbon assimilation. Journal of Experimental Botany 42: 1-16.
6. Correia, M. J., J. S. Pereira, M. M. Chaves, M .L. Rodrigues, and C. A. Pacheco. 1995. ABA xylem concentrations determine maximum daily leaf condutance of fieldgrown *Vitis vinifera L.* plants. Plant, Cell and Environmen, 18:511-525.
7. Daamen, C. C., C. P. Simmonds, J. S. Wallace, K. B. Laryea, M. V. K. Sivakumar. 1993. Use of microlysimeters to measure evaporation from sandy soils. Agricult For. Met. 65: 159:173.
8. Denmead, O.T.and R. H.Shaw. 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. Agron. J. 54: 385-390.
9. Doorenbos, J. and W. O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrig. Drain. Paper 24 (revised), Rome, 156 pp.
10. Ferreira, M. I. and N. Katerji. 1992 Is stomatal control in a tomato crop controlled by soil or atmosphere? Oecologia 92:104-107.
11. Fusseber, A. Wartinger, A. W. Hartung W, E.D. Schulze, and H. Heilmeier. 1990 New Phytologist 122, 45-52.
12. Garnier, E. and A. Berger A. 1986. Effects of water stress on stem diameter changes of peach trees growing in the field. Journal of Applied Ecology 23, 193-209.
13. Granier, A. 1985. Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Ann. Sci. For. 42: 193-200.
14. Granier, A. 1987. Mesure du flux de sève brute dans le tronc du Douglas par une nouvelle méthode thérmique. Ann. Sci. *For.* 44: 1-14.
15. Huguet J. G. 1985. Appréciation de l' état hydrique d'une plante à partir des variations micrometriques de la dimension des fruits ou des tiges au cours de la journée. Agronomie 5(8): 733-741.
16. Itier, B.; N. Katerji, D. Flura, and M.I. Ferreira.1990. Relative evapotranspiration in relation to soil water deficit and predawn leaf water potencial-application to tomato crop. Acta Horticulturae 278: 101-111.
17. Jarvis, P.G. 1985. Coupling of transpiration to the atmosphere in horticulture crops: the omega factor. In: *Water Relations in Fruit Crops.* Acta Horticulturae 171: 187-205.
18. Jones, H.G. 1992. *Plants and microclimate. A quantitative aproach to environmental plant physiology (*2dn edition). Press Syndicate of the University of Cambridge, Cambridge, Great-Britain.
19. Kaimal, J. C. and J. J. Finnigan.1994. *Atmospheric boundary layer flows. Their structure and measurement*. Oxford University Press. New York, 289 pp.
20. Katerji, N., B. Itier, M. I. Ferreira and L. S. Pereira. 1987. Water stress indicators for tomato crop. Soil and Plant Water Status (Proceed. Int. Conf.) Logan, Utah.
21. Kozlowski T.T. 1972. Shrinking and swelling of plant tissues. In: Water Deficit and Plant Growth, vol III (Ed Kozlowski T.T.), pp.1-64. Academic Press, New-York.
22. Kozlowski T.T. 1982. Water supply and tree growth. Part I: Water deficits. Forestry Abstracts, 43, 57-95.
23. Landsberg J.J., T. W. Blanchard, and B. Warrit. 1976. Studies on movement of water through apple trees. Journal of Experimental Botany 132, 67-77.
24. Mc Naughton, K.G. and P. G. Jarvis. 1983. Predicting effects of vegetation changes on transpiration and evaporation. In: *Water deficits and plant growth*, VII (Kozlowski, T.T., ed), Academic Press, New York: 2-48.
25. Penman, H.L. (1948) Natural Evaporation from open water, bare soil and grass. *Proc. Roy. Soc.*, ser. A, 193: 120-145.
26. Sakuratani, T. (1981) A heat balance method for measuring water flow in the stem of intact plant. J. Agric. Meteorol. 37: 9-17.
27. Scholander P F, H. T. Hammel, E. D.Bradstreet, and E. A. Hemmingsen.1965. Sap pressure in vascular plants. Science 148, (3668), 339-346.
28. Schulze, E.-D. 1986. Carbon dioxide and water vapor exchange in response to drought in the atmosphere and in the soil. Ann. Rev. Plant Physiol. 1986: 247-274.

29. Tanner, B. D., E. Swiatek, and J. P. Greene. 1993. Density fluctuations and use of krypton hygrometer in surface flux measurements. Proceedings of the 1993 Nat. Conf. on Irrig and Drainage Engineering, Irrig. and Drain. Division, ASCE.
30. Valancogne C., Z. NASR. 1989. Une méthode de mesure du débit de sève brute dans de petits arbres par bilan de chaleur. Agronomie 9, (6), 609-617.
31. Valancogne C., Z. NASR. 1993. A heat balance method for measuring sap flow in small trees. In ""Water Transport in Plants under Climatic Stress"" Proceeding of International Workshop, held in Vallombrosa, Firenze (I), Ed. M.BORGHETTI, J. GRACE and A. RACHI. Cambridge University Press 1993, 166-173.
32. Wartinger, A.; Heilmeier, H.; Hartung, W.; Schulze, E.-D. (1990) Daily and seasonal courses of leaf conductance and abcisic acid in the xylem sap of almond trees (*Prunus dulcis* (Miller) D.A.Webb) under desert conditions. New Phytologist, 116: 581-587.
33. Webb, E. K., G. I. Pearman, and R. Leuning. 1980. Correction of flux measurements for density effects due to heat and water vapour transfer. Quart. J. Royal Met. Soc. 106:85-100.
34. Zhang, J. and W. J. Davies. (1990) Changes in the concentration of ABA in xylem sap as a function of changing soil water status can account for changes in leaf conductance and growth. Plant, Cell and Environment 13: 277-285.
35. Zhang, J.; Schurr, U.; Davies, W.J. 1987. Control of stomatal behaviour by abcisic acid which apparently originates in roots. Journal of Experimental Botany, 38: 1174-1181.