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Estimating transpiration in an intercropping system: measuring sap flow inside the oasis

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Abstract

The quantity of water transpired by a plant is an important factor in investigating irrigation control, biomass production, and, in studies of plant–water relations. Measuring sap flow in plant stems provides a method for estimating transpiration. Sap flow within the xylem of date palm and apricot, inside an oasis in the south of Tunisia, was monitored continuously using the Granier's method. We have been able to calculate transpiration of the date palm and fruit canopies alone and both combined. The daily average values of transpiration are about 1.91 and 1.2 mm per day for date palm and fruit trees, respectively. We have also established the relationship between transpiration and global and net radiation inside the oasis. These relationships are important for control irrigation on an hourly and daily scale. We can show that transpiration for date palms represents 32% from global radiation received above the oasis and 53% from net radiation. Transpiration in the fruit trees canopy represents 21% from global radiation above the oasis and 33% from net radiation.

Keywords: Oasis; Intercropping; Date palm; Solar radiation; Sap flow; Transpiration

1. Introduction

Water resource management is becoming a critical issue of the land management policies in North Africa. The predicted climate changes will result in an increase in duration and intensity of summer drought. Hence, there is an urgent need to improve our knowledge concerning the water use and response to drought of the main perennial vegetation types such as date palm and fruit trees.

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Nomenclature

dT_j	instantaneous thermal change (°C)
dT_m	maximal thermal change in (°C)
E	canopy transpiration (kg m^{-2} s^{-1})
E_{dp}	date palm transpiration
E_{ft}	fruit trees transpiration
J	total sap flow in the trunk (kg s^{-1})
$\bar{J}$	mean sap flow in a stand (kg s^{-1})
$\bar{J}_{dp}$	mean sap flow density per unit area of sapwood for date palm (kg dm^{-2} s^{-1})
$\bar{J}_{ft}$	mean sap flow density per unit area of sapwood for fruit trees (kg dm^{-2} s^{-1})
J_s	sap flow density expressed per unit of sap wood surface of the trees S_w (kg dm^{-2} s^{-1})
$\bar{J}_s$	mean sap flow density (kg dm^{-2} s^{-1})
R_{inc}	global incident radiations
R_{int}	radiation intercepted
R_t	total global radiation transmitted
$\bar{S}$	cross-sectional sapwood area of the stand per unit of the ground (dm^2 m^{-2})
S_{ft} and S_{dp}	cross-sectional sapwood area of fruit trees and date palm, respectively (dm^2 m^{-2})
S_w	sapwood per unit ground area (m^2 ha^{-1})

Oasis plantations cover large areas of Southern Tunisia. Assessing evapotranspiration from palm groves is critical not only because of its importance in regional water economy but also because of the development of oases and their renewal.

More important, irrigation should be applied in a controlled manner in order to provide an optimum situation for crop transpiration and to avoid percolation losses. In the oases of South Tunisia, where water is scarce, the irrigation practice of farmers depends more on the amount of water that is available than on the real water requirement of plants. To improve this water management system, a profound understanding of water use by plants in the three-layered cropping system inside the oasis is needed. Measurement of sap flow carried out directly on the plant can be an adequate method to estimate the amount of water transpired and thereby deducing the water need of plants inside the oasis. Also, it can be continuously monitored with minimal maintenance. Moreover, the sap flow method is accurate for determining the transpiration of the over storey in multi-storey farming and allows the transpiration of a single layer in a given canopy to be measured separately (Robert, 1994; Vikki et al., 1995). Also, the sap flow method was considered as a baseline to validate many models developed to estimate tree's transpiration (Stewart, 1988; Dye and Olbrich, 1993; Granier and Loustau, 1994; Chuah and Kung, 1994). However, despite its environmental and economical importance in this area, the real requirement of water for date palm in Tunisia is poorly documented (El Amami and Laberche, 1973). The few studies that have attempted to determine the real water requirements of date palm have used only soil methods (neutron probe and tensiometer). However, those methods are not accurate for an intercropping canopy (Riou, 1990; Hamlyn, 1992). The present study attempts to analyse the evapotranspiration phenomenon inside the oasis. Its objective is to determine the sap flow in the trunks of date palms and fruit trees, to estimate transpiration on a daily and hourly scales, and to establish the relationship between sap flow and net and global radiation.

2. Materials and methods

2.1. Sites

The experimental plot (latitude 33°55′N, longitude 8°6′B, altitude 87 m), an irrigated field, was located in the centre of a traditional oasis in Tozeur (Southern Tunisia). The average hygrometry degree in Tozeur is about 54%. Annual rainfall average is about 96 mm per year. The potential evapotranspiration recorded inside the oasis is about 1643 mm per year. Further details about the climatic regime are given in a previous paper (Sellami and Sifaoui, 1998). Sap flow measurements were carried out at the same time and in the same plot as the micrometeorological measurements. The plot had an area of 1 ha. For the palm grove, all the date palms were nearly the same age (20 years old) and the same degree of pruning. The mean height and diameter of their trunks are, respectively, about 10 m and 80 cm, with a density of 80 palm ha^{-1} and spacing close to 8 m. For the fruit trees, apricot is the most common; they always have the same pruning and a density of 160 trees ha^{-1}. Their spacing is about 3 m and the mean height and diameter of their trunks is, respectively, about 4 m and 30 cm (Sellami and Sifaoui, 1999). The measurement regime of sap flow and climatic parameters was carried out between 20 September and 7 November.

2.2. Measurement methods

During the period of measurement, the density of sap flow J_s (kg dm^{-2} s^{-1}) within the xylem of the palm grove and the fruit trees, expressed on a sapwood area basis, was monitored continuously using the Granier's method (Granier, 1985, 1987). This method was widely used for measuring sap flux density in forest trees (characterised by a large diameter) and was already shown to be robust, sensitive and accurate in estimating the sap flux within the stem of large trees in the field (Diawara et al., 1991; Granier and Loustau, 1994). Briefly, its principle relies on the fact that the sap flow is deduced from the thermal difference between a probe continuously heated at a constant power and a reference probe, using an empirical relationship determined in laboratory conditions. The equipment used is the environment measurement system IMP 232 sap flow meter. The measuring element consists of two cylindrical probes (2 cm long and 2 mm in diameter). Each of them containing a copper–constantan thermocouple. Those probes are radially inserted in the sapwood of the trunk at a distance of 15 cm from each other. The upper probe, which contains a heating element of constantan, is heated at a constant power (0.2 W) and the other probe is considered as temperature reference. The two thermocouples are mounted in opposition so the temperature difference between the two probes can be measured. The temperature difference between the two probes is influenced by the sap flow. The theoretical basis is that the electricity currant supplied to the upper probe is transmitted as heat to the sapwood. When no transpiration takes place (sap flow is null), a maximal temperature difference, is established between the heated and unheated probe. When sap flow occurs in the xylem the passing sap will transport some of the heat (convection transfer) and consequently the temperature change of the heated probe will decrease. This later depends on sap flow density across the trunk. The larger the sap flow in the tree, the smaller the temperature difference between the two probes.

An empirical formula established by Granier (1985, 1987) and used by many authors gives the sap flow density J_s (kg dm^{-2} s^{-1}) expressed per unit of sap wood surface of the trees S_w. By measuring the maximal (dT_m) and instantaneous (dT_j) thermal changes between the two probes, we can express the sap flow density as follow:

$$J_s = 4.284\left[\frac{dT_m - dT_j}{dT_j}\right]^{1.231}$$

where dT_m is the maximal thermal changes (°C), and dT_j the instantaneous thermal changes (°C).

The total sap flow J (kg s^{-1}) in the trunk was obtained by the cumulative products of flux densities and associated cross-sectional areas S_w:

$$J = J_s S_w$$

The mean sap flow in a stand $\bar{J}$ (kg s^{-1}) and the mean sap flow density $\bar{J}_s$ (kg dm^{-2} s^{-1}) are given as the arithmetic average of those measured on each trees.

The canopy transpiration E (kg m^{-2} s^{-1}), was estimated by multiplying the mean sap flow density $\bar{J}_s$ and the cross-sectional sapwood area of the stand per unit of the ground $\bar{S}$ (dm^2 m^{-2}):

$$E = \bar{J}_s \bar{S}$$

The sap flow method for determining trees transpiration was compared with net radiation measured at different levels inside the oasis and will be used as a method to validate a model for trees transpiration inside the oasis.

2.3. Measurement of solar radiation

Net and global radiations were measured, respectively, with pyrradiometer (Minor MKII) and a Kipp Zonen pyranometer at different levels inside the oasis (Sellami and Sifaoui, 1998, 1999). Radiation sensors were mounted at three levels of a 12 m mast. The probes installed at 12 m level deals with the total net radiation and global incident radiation R_{inc} received above the oasis. Those mounted at the 5 m level, provided measurement of global and net radiations transmitted across the palm canopy and received by the fruit trees. Sensors set-up at the 2 m level, give us the mean net and global radiation transmitted through the fruit trees and trapped by the market garden level. The total net radiation transmitted across all the oasis was measured by a pyrradiometer placed 30 cm above the ground. At ground level, we placed six pyranometers. The average of the data loggers from these probes represents the total global radiation transmitted R_t across the entire oasis.

Radiative flows were recorded automatically with a programmer centre (Digistrip II) and averaged over 60 min. Results for radiation measurement and its interpretation was shown previously (Sellami and Sifaoui, 1998, 1999).

Many authors (Tournebize and Sinoquet, 1995; Berbigier and Bonnefond, 1995) consider that intercepted and absorbed radiation are equivalent. They believe that only the balance between incident and transmitted radiation can estimate the intercepted radiation.

The radiation intercepted R_{int} by each farming storey in the oasis is determined by the difference between the received (radiation measured above the storey) and the lost radiation (radiation measured below the storey). The balance between radiation measured at the 12 m level, and that measured below the market garden level gives the radiation intercepted by the entire canopy:

$$R_{int} = R_{inc} - R_t$$

Profiles of global radiation measured above and inside the oasis permit the determination of the relationship between radiation and sap flow transpired by the three plant storeys. The flow of net radiation intercepted, expressed in mm water (1 mm water is equivalent to 700 W m^{-2}) gives the amount of water transpired. Tournebize and Sinoquet (1995) reported that for a canopy with two storeys (trees and grass), evapotranspiration varies from 88 to 93% of net radiation measured above the canopy.

2.4. Measurement of trees characteristics

The distribution of the sapwood cross-sectional area, tree health, stem shape and contact with neighbouring crowns of the trees sampled were considered as criteria for determining the selection of a sample in the oasis. The sapwood per unit ground area S_w (m^2 ha^{-1}) was estimated by using a sampling procedure: The sapwood surface S_w of 20 date palms (respectively 20 apricots) that represented the circumference's range of the plot was estimated by heart stealing at the level where the probe was inserted. The sapwood–heartwood transition was located by holding the cores in diffuse light, sapwood being translucent and heartwood opaque. Then, the cross-sectional area of sapwood of each tree, S_w, was calculated from its total circumference. The cross-sectional sapwood area of the stand per unit of the ground $\bar{S}$ (dm^2 m^{-2}) was given by the arithmetic mean of S_w values, expressed per unit of ground area. Sap wood section of the total stand was assessed with an error of 10%. The characteristics of the trees are summarised in Tables 1 and 2.

2.5. Experimental protocol for sap flow measure in the oasis

The sap flow density at 1.3 m above ground level for two fruit trees (apricot) and at 1.5 and 6 m above ground level for two date palms was continuously monitored during the period of data collection (Table 3). We have also installed probes at two different depths of

Table 1
Characteristics of the tree sample used for sap flow determination in date palms

Number	Height (m)	Circumference at 1.5 m (m)	Circumference at 6 m (m)	Sapwood section at 1.5 m (m^2)	Sapwood section at 6 m (m^2)
1	10	1.5	0.75	0.37	0.034
2	11	1.5	0.8	0.37	0.036
3	11.5	1.25	0.75	0.31	0.034
4	12	1.5	0.75	0.37	0.034
5	7	1.15	1	0.28	0.045
6	10.5	1.4	0.75	0.35	0.034
7	12.5	1.6	0.85	0.4	0.038
8	11.3	1.5	0.85	0.37	0.038
9	9.5	1.6	0.8	0.4	0.036
10	7.5	1.2	0.75	0.3	0.034

Apart from height, all dimensions were determined at 1.5 and 6 m.

the sapwood for every date palm. The out-puts were monitored every 10 s with programmable data loggers. The measurement signals were averaged over periods of 1 h and stored with a modular system (INMEW A) implanted on a computer (PC).

The variation of water content in the aerial part of trees was ignored. As patterns of water storage and release in date palms under changing climatic conditions are not known, no attempt was made to estimate the hourly transpiration under variable climatic conditions (days with cloudy periods, or days with rainfall storms).

The total sap flow transpired on a day is equal to the sum of the sap flow transpired every hour. The transpiration for the entire stands and for every storey of the oasis (expressed as mm h^{-1} or mm per day) is assimilate for its total sap flow.

The mean sap flow density per unit area of sapwood in the oasis $\bar{J}$ (kg dm^{-2} s^{-1}) was estimated from the arithmetic mean of the sample averaged by the cross-sectional area of sapwood. The confidence interval error on $\bar{J}$ did not exceed ±15% of the mean. The cross-sectional area of sapwood per unit ground area S_{dp} (dm^2 m^{-2}) for date palms

Table 2
Characteristics of the tree sample used for sap flow determination in fruit trees

Number	Height (m)	Circumference (m)	Sapwood section (m^2)
1	1.7	0.4	0.1
2	1.75	0.3	0.075
3	1.73	0.31	0.077
4	1.75	0.58	0.145
5	1.77	0.37	0.092
6	1.5	0.45	0.11
7	1.2	0.27	0.07
8	1.6	0.57	0.14
9	1.7	0.55	0.13
10	1.75	0.85	0.21

Apart from height, all dimensions were determined at 1.3 m.

Table 3
Comparison between trees transpiration's and net radiation, expressed in mm water for 10 days

Period	Date palms transpiration (mm per day)	Fruit trees transpiration (mm per day)	Total transpiration (mm per day)	Total net radiation intercepted (mm per day)
12 October 1995	2.02	133	3.35	3.44
13 October 1995	2.2	0.95	3.15	3.62
15 October 1995	2.07	1.12	3.19	3.45
22 October 1995	1.96	1.28	3.24	3.4
23 October 1995	2.04	0.94	2.98	3.53
26 October 1995	1.86	1.08	2.94	3.46
27 October 1995	1.75	1.29	3.04	3.87
28 October 1995	1.33	1.2	2.53	3.65
29 October 1995	2.1	1.3	3.4	3.48
30 October 1995	1.8	1.5	3.3	3.55
Average	1.91	1.2	3.11	3.24

and S_{ft} ($dm^2\,m^{-2}$) for fruit trees were estimated from a sample of 20 date palms and 20 apricots. The transpiration for respectively fruit trees E_{ft} and date palm E_{pd} ($kg\,m^{-2}\,s^{-1}$) were estimated from

$$E_{ft} = \bar{J}_{ft} \times S_{ft}$$

and

$$E_{dp} = \bar{J}_{dp} \times S_{dp}$$

where E_{ft} is the fruit trees transpiration, E_{dp} the palm date transpiration, $\bar{J}_{ft}$ the mean sap flow density per unit area of sapwood for fruit trees expressed as $kg\,dm^{-2}\,s^{-1}$, $\bar{J}_{dp}$ the mean sap flow density per unit area of sapwood for date palm expressed as $kg\,dm^{-2}\,s^{-1}$, S_{ft} and S_{dp} are, respectively, the cross-sectional sapwood area of fruit trees and date palm expressed as $dm^2\,m^{-2}$.

3. Results and discussion

3.1. Daily course of sap flow inside the oasis

Fig. 1 illustrates the diurnal time course of sap flow for the fruit tree storey, date palm storey and both combined for two successive days. We notice that, for the apricot, the sap is released at sunrise, increased rapidly at 08:00 h, reaching its maximum at a little after 13:00 h. Then it began to decrease and reached zero at 22:00 h. During night the sap flow remains low and constant. The sap flow transpired by the apricot is about 0.15 $l\,h^{-1}$ at 06:00 h, reached a maximum of 1.5 $l\,h^{-1}$ at about 13:00 h. In the afternoon, the sap flow decreased and reached a level of 0.5 $l\,h^{-1}$ at 18:00 h. The daily average of sap flow for the apricot trees is about 16.5 l per day. This allowed us to assess the amount of water transpired daily by the fruit tree storey at about 1.3 mm per day.

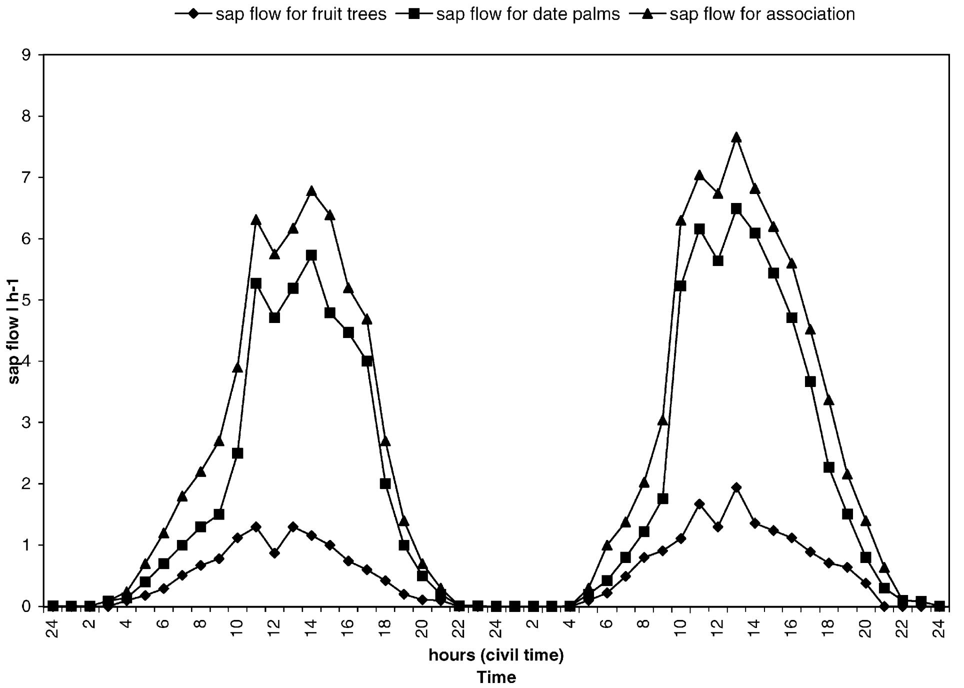

Fig. 1. Diurnal time course of sap flow for the fruit trees storey, date palm storey and the combination of both on 29 and 30 October 1995.

For the date palm, we can affirm that the same procedure is repeated and it is similar to that for the apricot. However, a dephasing and an amplitude difference was often observed.

Even so, the sap flow transpired by the date palm reaches a maximum of about 6.5 l h^{-1} at 13:00 h, whereas the apricot sap flow reached its maximum a little after 13:00 h. This is explained as follow. The amplitude difference means that the amount of water transpired by the date palm storey exceeds that transpired by the fruit tree storey. This is because the exchange surface of the date palm (palms) is bigger and is directly exposed to solar radiation, whereas the fruit trees are subjected to the shade effect of the date palm. The sap flow of the date palm is about 46 l per day and the amount of water transpired for the entire plot is about 2 mm per day. The transpiration of the combination is equal to the sum of the amount of water transpired by each storey (fruit trees and date palms). We note that the contribution of date palms is always more important. Indeed, transpiration of date palm represents 61% of the total transpiration while that of the fruit trees represents only 39%. This is due to the fact that the fruit trees were in the shade of the date palm. This caused the automatic reduction of the climatic requirement in this storey and consequently its transpiration. These results are similar to those found by Tournebize (1994). In studying the transpiration from a plant canopy formed by two farming level (trees and grass), he founds that the tree storey accounted for 55% of the total transpiration while the grass accounted only for 41%. Comparison between sap flow transpired by the two date palms (Fig. 2) and two apricots (Fig. 3), show a clear sap flow difference. This is attributed to the

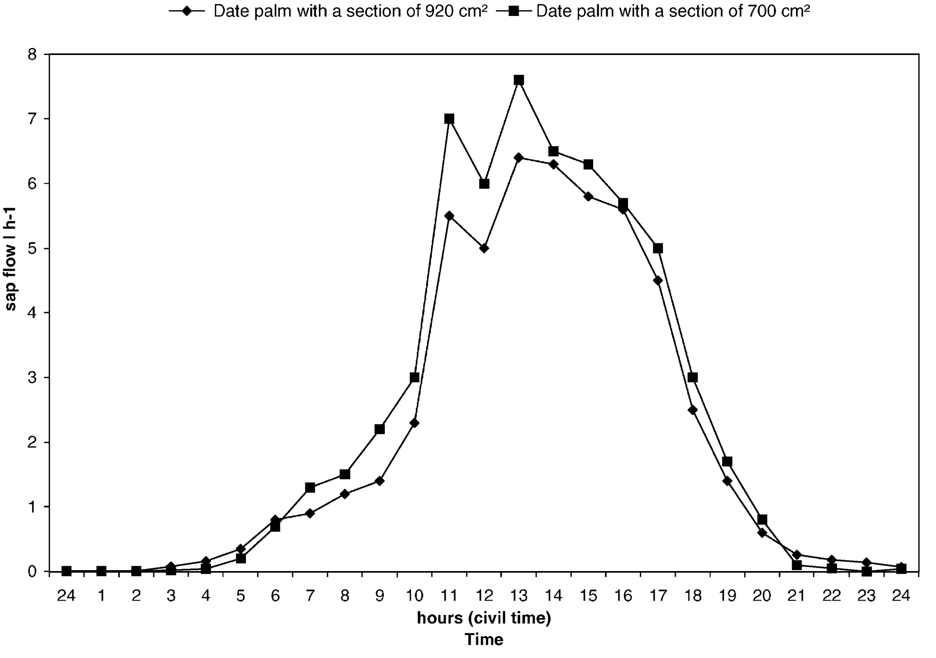

Fig. 2. Comparison between sap flow transpired by the two date palms on 25 October 1995.

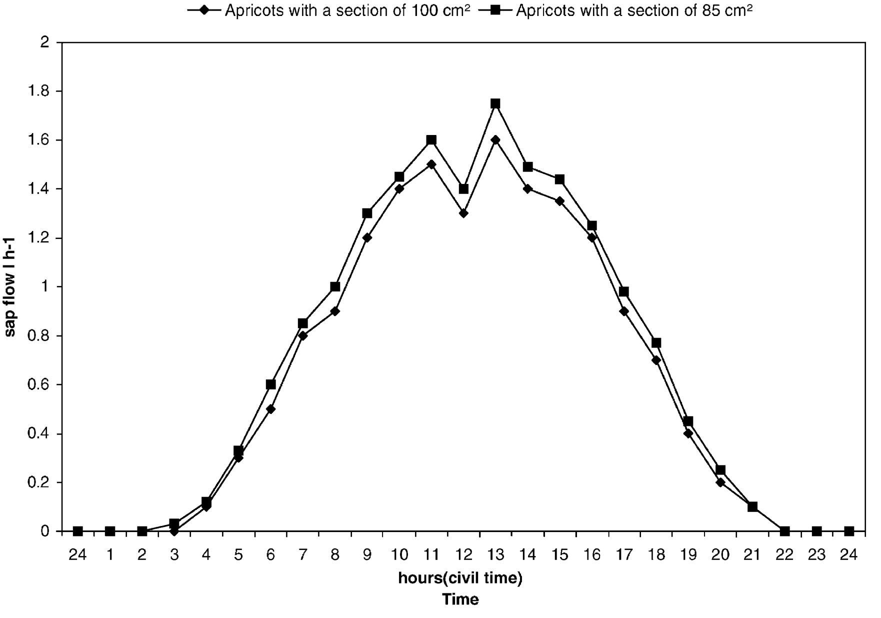

Fig. 3. Comparison between sap flow transpired by two apricots on 25 October 1995.

difference in trunk height, diameter and the number of leaves that characterise each trees. This is a problem of sampling the trees that represent all the plot releases. Although, the relatively low variability in sap flow density between trees allowed assessment of the daily value for transpiration of the stand from sap flow data with an error not exceeding 12% of experiment mean most.

3.2. Measurement of sap flow at two different levels and two different depths of the date palm's trunk

For the two date palms, data of sap flow have been measured at two different levels in the trunk (1.5 and 6 m above the soil) (Fig. 4). We can verify that the sap flow has the same regime for the two levels. However, we note a difference in amplitude and that flow is, for all the hours of the day, more important at the top of the trunk than that at the bottom (the flow measured at 6 m is twice or three times as much as that recorded at 1.5 m). Even so, at the 6 m level, sap flow rises fast after sunrise, reaches its maximum at 13:00 h (about 6.5 $l\,h^{-1}$), after that, it decreases. For the 1.5 m level, sap flow attains its maximum (about 3.3 $l\,h^{-1}$) at 12:30 h. It decreases slowly, reaching a minimum value of about 0.3 $l\,h^{-1}$ at 17:00 h. It maintains the same value during the night.

Difference between sap flow recorded at the two levels represents the variation in water reserve in the trunks. This reserve runs down in the morning up to early afternoon and refills during the night. Sap flow at a high level of the trunk represents the real amount of water transpired (Robert, 1994; Vikki et al., 1995). The water flow necessary for transpiration is taken from water stored inside the trunk and absorbed by the roots. The amount of water originating from storage was closely dependent on climatic demand and soil moisture.

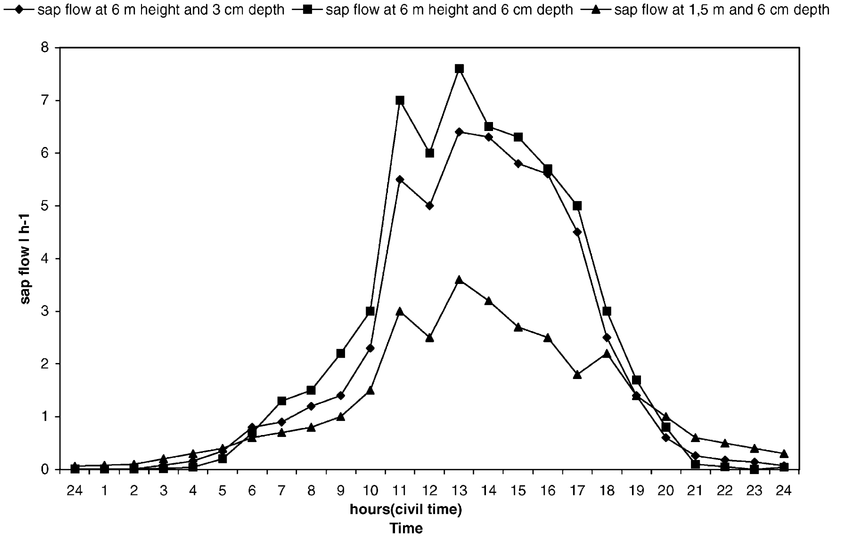

Fig. 4. Comparison between sap flow measured at two different depths and at two different heights on 20 October 1995.

In fact, on wet soil, trunk refilling was completed 1 or 2 h after dusk, and there was no more variation in trunk water content during the rest of the night. On the contrary, on dry soil, the refilling of the trunk lasted to the next morning (Cabibel, 1991). The transpiration process is activated at sunrise and decreases when the water reserve in the trunk diminishes. The absence of this latter does not induce systematically the absence of sap flow in the trees. Nocturnal flows can have their beginning for the reconstitution of water reserve in the aerial part of the trees. This reserve, in the initial phase of evapotranspiration, participates in the satisfaction of the climatic requirement. In similar recent studies, the diurnal course of water storage and release between the ground and the leaves in the crown of broad-leaved trees for a forest canopy was disregarded in estimating whole tree transpiration from sap flow measurements (Loustau et al., 1990; Köstner et al., 1992).

Measurement of sap flow at two different depths of the palm trunk (3 and 6 cm from the surface) (Fig. 4) shows a clear difference between the values recorded in each depth during the day. We can deduce that the measurements on the surface are more important at the beginning and at the end of the day, while it becomes less important between 12:30 and 14:30 h. This has the effect to compensate for the difference over all the day.

3.3. Comparison between sap flow transpired and solar radiation intercepted inside the oasis: establishment of relationships

Fig. 5 presents the comparison between sap flow and global and net radiation on 2 days inside the oasis. For both date palm and apricot, we can see a decrease of sap flow at noon. This is perhaps due to the diminution of direct radiation at this hour. We can also noticed that the sap release begins just before sunrise and stops after sunset. This is due to the phenomenon of storage of water and to the evaporation of water condensed in leaves often observed in the early morning. Research into the correlation between sap flow transpired

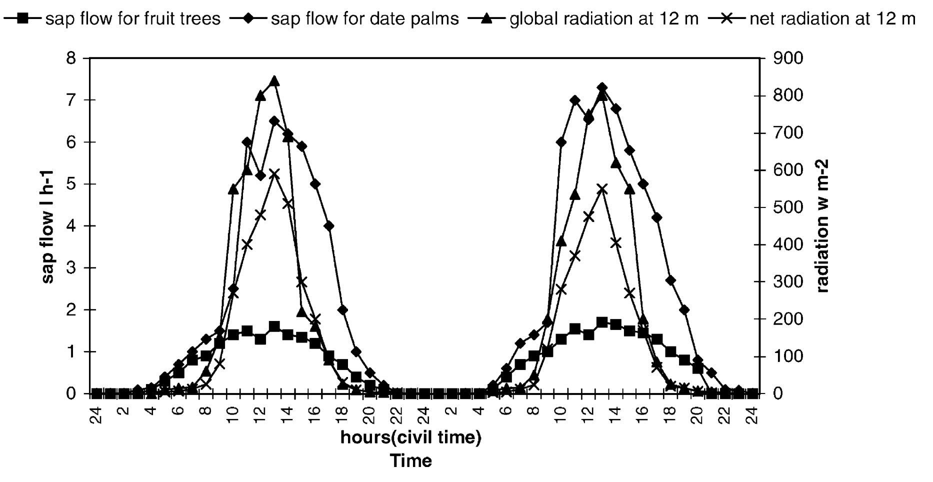

Fig. 5. Comparison between sap flow transpired and global and net radiation intercepted on 16 and 17 October 1995.

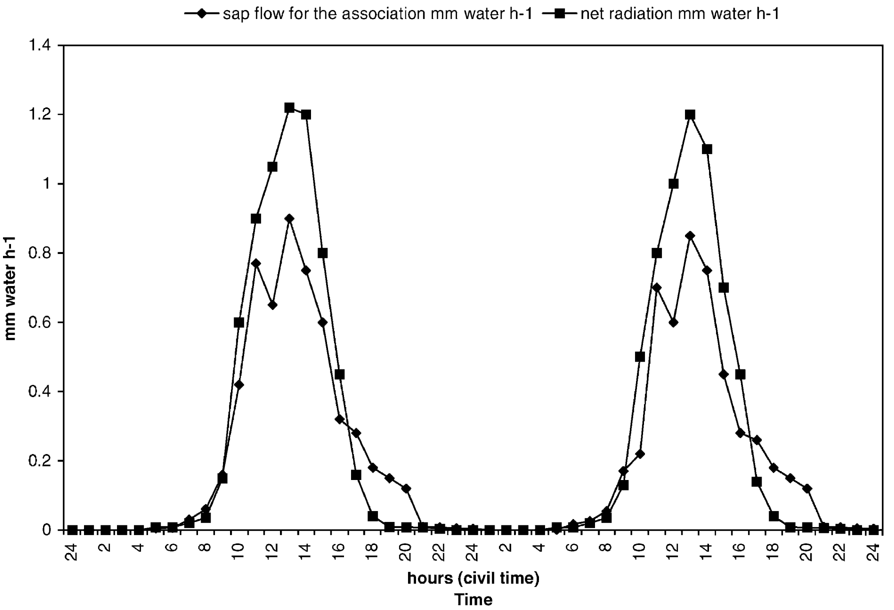

Fig. 6. Comparison between net radiation (mm water h^{-1}) intercepted and transpiration inside the oasis on 15 October 1995.

and radiation intercepted on an hourly scale is an important implement to estimate the real water need of trees in the hours of strong climatic requirement (11:00–14:00 h) during day.

Fig. 6 presents the progress of sap flow expressed in mm h^{-1}, coupled to the net radiation intercepted (mm water h^{-1}). We notice a good correlation between net radiation and the amount of water transpired. We can show that at 13:00 h, transpiration for date palms represents 43% of the total net radiation intercepted, for the fruit trees it represents 21%. For the combination (palm + apricot), transpiration represents 64% of the radiation trapped inside the oasis. We know the error for calculated E is 0.15 so we can write the following relationships:

$$E = 0.43R_{\text{int}} + 0.15 \quad \text{(for date palms)}$$

$$E = 0.21R_{\text{int}} + 0.15 \quad \text{(for fruit trees)}$$

$$E = 0.64R_{\text{int}} + 0.15 \quad \text{(for the combination)}$$

We must point out that it is difficult to extrapolate the transpiration from sap flow data on an hourly basis in this stand especially during rapid changes of transpiration in the morning. So we implicitly decide to neglect the time lag between tree transpiration and sap flow due to changes in the water content of trunk, branches and leaves (Cermak et al., 1982; Tournebize, 1994). Table 3 presents the daily average of transpiration and radiation intercepted. We note an agreement between the values, the daily amount of water transpired for the date palm storey represents 59% of the net radiation intercepted inside the oasis and 53% of that measured over the oasis. Fruit tree transpiration represents 37% of net radiation intercepted and 33% from that measured at 12 m. For the combination, transpiration represents 86% from net radiation received above the oasis and 96% from that intercepted. Many authors (Diawara et al., 1991; Tournebize, 1994; Granier and Loustau, 1994) found similar results for forest canopies. We can also deduce daily transpiration only by measuring global radiation over the oasis. We have established the following relations:

- date palm transpiration represents 32% of global radiation measured above the oasis;
- fruit tree transpiration represents 21%;
- transpiration of the combination represents 53%.

4. Conclusion

The use of thermal methods to assess the transpiration in the oasis enables us to analyse carefully the amount of water transpired by each storey separately. We have also established relations between the amount of water transpired and the net and global radiation received. These correlations are of great importance for the conduct of tree irrigation. As a matter of fact, air temperature and solar radiation are the determining factors for the climatic requirement so their measurements indicate the water need of trees. In fact, the variation of sap flow is governed by climatic requirements. Sure enough, every increase or decrease in solar radiation intercepted corresponds to a heightening or reduction in sap flow. Also, transpiration is sensitive to environmental variables such as soil moisture deficit and vapour pressure deficits.

However, the sap flow method presents some problems that can influence the results. For example, the positioning of the probe on the trunk or choosing the trees that properly represent the plot. Moreover, the sap flow method applied at the scale of one tree and its extension to the canopy is difficult, the greatest sources of error being estimation of sapwood surface per unit soil surface and the assumption concerning the time lag between transpiration from the leaves and sap flow in the stems. Repeating the measurement on a great number of trees and taking the average can solve those problems.

Another interesting consequence of the present study is the opportunity to compare the performance of a model built from selected data obtained during a single experiment and a short period for predicting the canopy stomatal conductance and hourly transpiration at many types of oases.

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