A QUANTITATIVE ANALYSIS OF EVAPOTRANSPIRATION IN THE TRADITIONAL OASIS IN THE SOUTH OF TUNISIA

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ATMOSPHERE
LATENT HEAT FLUX
SENSIBLE HEAT FLUX
NET SOLAR RADIATION
GLOBAL SOLAR RADIATION
SAP FLOW
CLIMATIC PARAMETER
FARMING STOREY

ABSTRACT. – Estimating the evapotranspiration is important for many sides. The first is to determine the amount of water really needed by vegetable canopies. The second is to analyse the role of plants in buffering the effects of climatic change. In this work we have tried to evaluate the amount of evapotranspiration inside and above the traditional oasis of Tozeur by monitoring profiles of global radiation, net radiation, sap flow, sensible heat flux, latent heat flux, air temperature and air humidity. We have used fixed captors installed at different heights inside the oasis and mobile captors carried by a meteorological balloon. Results show that evapotranspiration deduced from the total global radiation intercepted inside the oasis is equivalent to 4,4 mm/day. That estimated from global radiation received above the oasis is equivalent to 6,81 mm/day. When using the total net radiation intercepted by all the oasis (respectively the net radiation received above the oasis), the evapotranspiration is equivalent to 3,24 mm/day (respectively about 4 mm/day). The evapotranspiration estimated from daily sap flow transpired is about 3,3 mm/day. We have noticed also, that inside the oasis air temperature follows a decreasing function with the altitude in the early morning and later in the afternoon. It follows an increasing function between 9 and 15 hours. Above the oasis, air temperature, relative humidity and air pressure, follow globally decreasing functions with altitudes. However, considerable levels of fluctuation were recorded for all the parameters throughout the first altitudes above the oasis.

INTRODUCTION

The plant canopies, all types, added to their roles in limiting the soil erosion phenomenon and protecting habitats, projects and infrastructures (roads, dams, hydraulic structure...), they participate actively in the atmospheric water cycle via evapotranspiration (Granier & Loustau 1994, Dang *et al*. 2019, Rui *et al*. 2020). This later represents the response of plants to climatic demand (Granier & Loustau 1994, Gustav 2017). It depends on plant physiological stage, plant morphological parameters, on architecture of the vegetal canopy and on local or regional climatic parameters (solar radiation, air temperature, air humidity, wind speed) (Berbigier *et al*. 2001, Kimball & Bernacchi 2006, Liane & Mingbin 2015, Gkikas *et al*. 2019, Parveen *et al*. 2020, Sellami 2020). Evaluating with high precision the evapotranspiration permits in one side to determine the amount of irrigation water really needed by plants and then we can conceptualise the most efficient watering system. In the other side, it permits to analyse the participation rate of vegetation canopies in reducing the effects of greenhouses gazes and climatic changes (Manninen *et al*. 2018, Moisseev *et al*. 2019). Many studies were realised to estimate the evapotranspiration either by experimental procedures or by modelling approaches (Koen & Guy 1997, Rivalland *et al*. 2005, Zhao & Zhao 2014, Matteucci *et al*. 2015, Cimini *et al*. 2020). But developing models or protocols to evaluate evapotranspiration for high mixed plant canopies is usually a purpose well asked by researchers, specialists and environmentalists and is a goal not yet completely achieved (Jarosz *et al*. 2008, Stella *et al*. 2009, Gustav 2017, Chan *et al*. 2018, Kulmala *et al*. 2019).

We are trying here to participate in fulfilling the gaps by monitoring the evapotranspiration for an intercropping high canopy. In facts, we are presenting a quantitative analysis of evapotranspiration over and inside a kind of high vegetation canopy which is the oasis. The oasis canopies occupy a large area at worldwide, in North Africa and mainly in Tunisia (Sellami 2008, 2020). They are characterised by the cohabitation of many species together (market gardening cereals and forages species, fruit trees for all seasons and palm grove) in an intercropping system.

Our purpose here is to analyse the interaction soil-plant-atmosphere for a traditional oasis in Tunisia and to evaluate the amount of evapotranspiration released by each production layer inside. The global evapotranspiration will be estimated and its influence on the atmosphere above will be studied. Variation of evapotranspiration with the altitude inside the oasis will be deduced from measured and calculated profiles of certain climatic parameters, physiological parameters and heat/mass fluxes exchanged (Sellami & Sifaoui 1998, 1999, 2003, 2008). Above the oasis and until the altitude 20 km we will use profiles of climatic parameters measured by meteorological balloon released from soil at the same time with the experiment conducted inside the oasis.

MATERIAL AND METHODS

Basic equations: our approach here is based on results found from established models and experiments conducted for a traditional oasis in Tunisia (Sellami & Sifaoui 1998, 1999, 2003, 2008). We have tried to estimate the amount of evapotranspiration released by analysing profiles of climatic parameters measured inside the oasis (global radiation, net radiation, air temperature, air humidity, soil temperature) and profiles of sap flow transpired by fruit trees storey and by date palms. To evaluate the rate of interaction between the oasis canopy and the atmospheric boundary layer we have analysed profiles of climatic parameters recorded by a meteorological balloon that can reach the altitude 20 km (data not published).

The total radiation intercepted will be, in part used by plants for photosynthetic activity and in other part for evapotranspiration to respond to the climatic demand and to regulate its internal temperature and metabolism. In term of energy, the evapotranspiration in a vegetation layer is determined from the balance between the net radiation trapped, the sensible heat flux released, and the latent heat flux disengaged by all the layers or by each plant in the interior. Those fluxes are determined from experimental analysis.

Latent and sensible heat flux exchanged between vegetation layers (i) inside the oasis can be evaluated with the following equations (Sellami & Sifaoui 2008):

$$\sum_i\sum_j F^j_{sens-veg,i} + \sum_i\sum_j F^j_{lat-veg,i} = \sum_i\sum_j F^j_{rad-net,i} \quad (1)$$

$$F^j_{sens-veg,i} = \varrho c_p\,[(T^j_{L,i} - T^j_{a,i})\,/\,r^j_{sens,i}] \quad (2)$$

$$F^j_{sens-veg,i} = \frac{\varrho c_p}{\gamma}\left(\frac{e(T^j_{L,i}) - e(T^j_{a,i})}{r^j_{lat,i}}\right) \quad (3)$$

i: indicates the layer i;
j : indicates the specie j inside a layer i;
$F^j_{sens-veg,i}$ and $F^j_{lat-veg,i}$: sensible heat flux and the latent heat flux corresponding to the vegetation specie j in the layer i;
$F^j_{rad-net,i}$: flux of net radiation intercepted by the specie j in the layer i
ϱc_p : Volumetric heat capacity of air;
γ : psychrometric constant;
$T^j_{L,i}$: temperature of the leaves corresponding to the plant sort j in the canopy layer i;
$T^j_{a,i}$: temperature of the air corresponding to the plant sort j in the canopy layer i;
$e(T^j_{L,i})$ and $e(T^j_{a,i})$: water vapors pressures of the air for the specie j at the canopy layer i for $T^j_{L,i}$ respectively and $T^j_{a,i}$;
$r^j_{sens,i}$: resistance to sensible heat flux displacement for the specie j in the layer i;
$r^j_{lat,i}$: resistance to latent heat flux displacement for the specie j in the layer i.

For each storey i, the total energy balance equation is given by:

$$F^j_{sens-veg,i} + F^j_{lat-veg,i} = F^j_{rad-net,i} - F^j_{rsoil} \quad (4)$$

$F^j_{rad-net,i}$: net radiation received above the plant canopy i;
F^j_{rsoil}: soil heat flux.

Experimental protocols: The plot chosen occupies 1 hectare and it is situated in the center of the traditional oasis of Tozeur (altitude 33°55'N, longitude 8°06'E, altitude 87 m). The zone of measurement is in the South of Tunisia. It's characterized by an arid climate with an average hygrometry of about 54 %. The annual rainfall average is about 96 mm per year. The potential evapotranspiration recorded inside the oasis is about 1643 mm per year. The traditional oasis is an intercropping system containing three exploitation stories. In the lowest storey, we found market gardening, cereals and forages species. For the middle one there are fruits trees for all the seasons. The highest is principally formed from palm grove. The mean height of the date palm is about 10 m, the palm density is about 100 palm/ha, the spacing between them is less than 8 m. The mean height of the fruit trees is 4 m, their spacing is about 3 m, the trees density is 160 trees/ ha. For the market gardening storey the mean height is about 60 cm.

We have conducted three experiments at the same time and in the same plot during the period of measurement (01.X.1995-30.XII.1995).

For the first experiment we have sampled a representative number of palm date and fruit trees for which we have installed sap flow probes. The density of sap flow 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 & Loustau 1994; Sellami & Sifaoui 2003, 2008). The equipment used is the Environment Measurement System IMP 232 sap flow meter.

For the second experiment we have fixed three stems with a 2 m long at the levels 2, 5 and 12 m of a mast installed in the center of the experimental plot. Each stem was equipped with probes to measure air temperature, humidity, wind speed, global radiation and net radiation. The probes mounted at 12 m above ground provided measurements of parameters characterizing the microclimate over the oasis (Sellami & Sifaoui 1998, 1999). Those mounted at 5 m permit to characterize the microclimate over fruit trees storey. Those mounted at 2 m give the specificities of the microclimate over the storey of market-gardening. We have also measured the profile of temperature in the soil (–10 cm, –20 cm, –40 cm, –60 cm, –100 cm).

The total global radiation transmitted across all the oasis is the average of the data loggers by six pyranometers placed on the ground. The net pyrradiometer placed at 30 cm above the ground deals with the total net radiation transmitted across the oasis.

The radiation intercepted by the total oasis is the difference between radiation measured at 12 m and the radiation measured on the ground. The global radiation (respectively net radiation) intercepted by each vegetation storey inside the oasis is the difference between that measured just above and that measured just below the storey.

Profiles of wind speed, air temperature and air humidity permit to analyze the sensible heat and latent heat exchanged inside the oasis and after to evaluate the evapotranspiration. Profiles of net and global radiation intercepted permit to estimate the evapotranspiration by direct conversion.

Data were recorded automatically with two programmer centrals. The Digistrip II for the acquisition of radiate flows, data loggers every 10 seconds and averaged over 60 min. The automatic resort (MIRIA), for the temperature, humidity probes.

For the third experiment, it consisted of to launch in the atmosphere a meteorological balloon containing sensors to measure air temperature, air pressure and wind speed. It permitted to record the climatic parameters every 2 s from the ground up to the height 20000 m. The speed of the balloon displacement is about 4.12 m/s. Profiles of climatic parameters given by the balloon permit to determine the evapotranspiration over the oasis.

Comparison between sap flow and radiation profiles for each production level inside the oasis allowed us to establish relationships linking transpiration to radiation measured above the oasis. Those relationships are very important when thinking to extrapolate results to other sites. Also, they could be very useful to determine the irrigation water really needed by species. Here with the principal ones:

– For the global radiation intercepted by date palm storey:

$$E^{glob}{}_{\int-palm} = 0.14E^{glob}{}_{12m} \quad (5)$$

$E^{glob}{}_{\int-palm}$: global radiation intercepted by the date palm storey expressed in mm water;

$E^{glob}{}_{12m}$: global radiation received above the oasis at the level 12 m expressed in mm water.

– For the global radiation intercepted by fruit trees storey:

$$E^{glob}{}_{\int-fruit} = 0.19E^{glob}{}_{12m} \quad (6)$$

$E^{glob}{}_{\int-fruit}$: global radiation intercepted by the fruit trees storey.

– For the global radiation intercepted by market gardening storey:

$$E^{glob}{}_{\int-mark} = 0.30E^{glob}{}_{12m} \quad (7)$$

$E^{glob}{}_{\int-mark}$: global radiation intercepted by the market gardening storey expressed in mm water.

– For the global radiation intercepted by the total oasis:

$$E^{glob}{}_{\int-oasis} = 0.63E^{glob}{}_{12m} \quad (8)$$

$E^{glob}{}_{\int-oasis}$: global radiation intercepted by all oasis expressed in mm water.

– For the net radiation intercepted by date palm storey:

$$E^{net}{}_{\int-palm} = 0.19E^{net}{}_{12m} \quad (9)$$

$E^{net}{}_{\int-palm}$: net radiation intercepted by the date palm storey expressed in mm water;

$E^{net}{}_{12m}$: net radiation received over the oasis at 12 m level.

– For the net radiation intercepted by fruit trees storey:

$$E^{net}{}_{\int-fruit} = 0.20E^{net}{}_{12m} \quad (10)$$

$E^{net}{}_{\int-fruit}$: net radiation intercepted by the fruit trees storey expressed in mm water.

– For the net radiation intercepted by market gardening storey:

$$E^{net}{}_{\int-mark} = 0.42E^{net}{}_{12m} \quad (11)$$

$E^{net}{}_{\int-mark}$: net radiation intercepted by the market gardening storey expressed in mm water.

– For the net radiation intercepted by the total oasis:

$$E^{net}{}_{\int-oasis} = 0.81E^{net}{}_{12m} \quad (12)$$

$E^{net}{}_{\int-oasis}$: net radiation intercepted by the total oasis expressed in mm water.

– For the transpiration by the date palm storey deduced from the sap flow:

$$E^{trans-sap}{}_{dat-palm} = 0.43E^{net}{}_{\int-palm} + 0.15 \quad (13)$$

$E^{trans-sap}{}_{dat-palm}$: transpiration by the date palm storey deduced from the sap flow expressed in mm water;

$E^{net}{}_{\int-palm}$: net radiation intercepted by the date palm storey expressed in mm water.

– For the transpiration by the fruit trees storey deduced from the sap flow:

$$E^{trans-sap}{}_{fruit-trees} = 0.21E^{net}{}_{\int-fruit} + 0.15 \quad (14)$$

$E^{trans-sap}{}_{fruit-trees}$: transpiration by the fruit trees storey deduced from the sap flow expressed in mm water.

– For the total transpiration by the combination fruit trees-date palm stories deduced from the sap flow:

$$E^{trans-sap}{}_{fruit-date} = 0.21E^{net-inter}{}_{\iint fruit-date} + 0.15 \quad (15)$$

$E^{trans-sap}{}_{fruit-date}$: total transpiration of fruit trees and date palm stories deduced from the sap flow expressed in mm water;

$E^{net-inter}{}_{\iint fruit-date}$: total net radiation intercepted by both fruit trees storey and date palm storey expressed in mm water.

Quite so, Berbigier *et al*. (2001) notified that evapotranspiration of a forest canopy represents 64 % of the intercepted radiation. Tournebize & Sinoquet (1995) reported that for a canopy with two stories (trees and grass), evapotranspiration varies from 88 % to 93 % of the net radiation measured above the canopy.

RESULTS

Analysis of evapotranspiration inside the oasis from profiles of solar radiations intercepted and sap flow transpired

Hour evolutions of evapotranspiration (mm water) deduced from profiles of respectively global solar radiation (Fig. 1) and net solar radiation (Fig. 2) are as follow.

From Fig. 1, we observe that at sunrise, the amount of water delivered is the same for the three levels and is about 0.0171 mm water. It begins to increase to reach at 10:00 the following values 0.571 mm water at the level 12 m, 0.357 mm water for the level 5 m, 0.242 mm water for the level 2 m and 0.142 mm water on the soil. The maximum of water released was recorded at 13:00 and is about 1.214 mm water above the date palm (at the level 12 m), about 1.082 mm water above the fruit trees storey (at the level 5 m) and about 0.942 mm water over the market gardening (at the level 2 m). The amount of water released measured on the soil is about 0.571 mm water

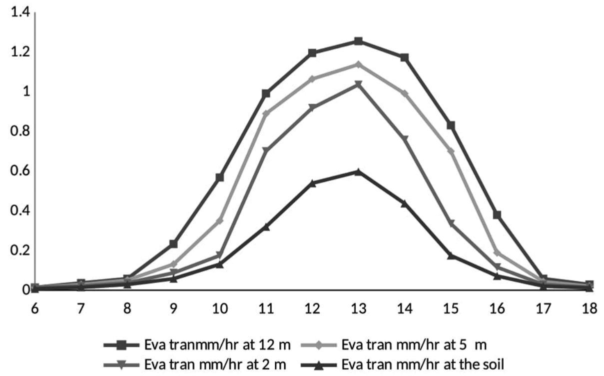

Fig. 1. – Evapotranspiration inside the oasis deduced from Profile of global radiation.

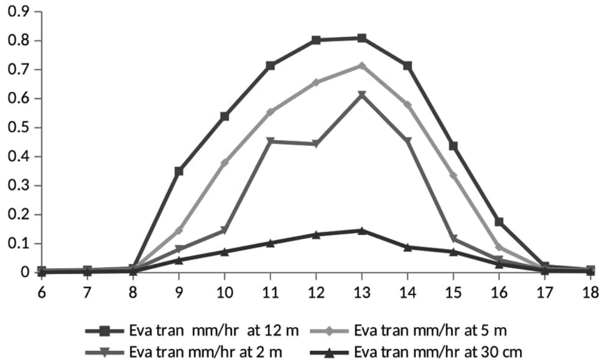

Fig. 2. – Evapotranspiration inside the oasis deduced from Profile of net radiation.

at 13:00. After, the global trend is oriented toward the decrease to cancel at 18:00. The daily evolution of global solar radiation was calculated as the sum of its hourly evolution. We noticed that over the oasis, the equivalent of water released is about 6.82 mm /day which is equal to 0.78 L/s/ha. Over the fruit trees storey, the equivalent of water released is about 5,61 mm/day which is equal to 0.65 L/s/ha. Over the market gardening we have recorded as equivalent of water released about 4.24 mm/day which means about 0.49 L/s/ha. On the soil, the daily equivalent amount of water released is 2.41 mm/day which is equivalent to 0.279 L/s/ha.

Fig. 2 shows that, during sunny days, the gait of the net radiation expressed in mm water followed the course of the sun. At sun rise, it's clear that the amount of water released by the different stories is the same and it is very feeble. At 9:00, a difference between the three levels was recorded. We noted about 0.34 mm water at the level 12 m, 0.14 mm water at the level 5 m, 0.0785 at the level 2 m and 0.004 mm water at the level 30 cm. At 11:00, the gap becomes more and more important. In fact, the water released is about 0.7 mm water over the palm grove (12 m), close to 0.54 mm water over the fruit trees (5 m), about 0.44 mm water over the market gardening (2 m) and 0.1 mm water at the level 30 cm. Maximums are at 13:00: around 0.75 mm water over the oasis (12 m), 0.64 mm water above the fruit trees (5 m), 0.5 mm water above the market gardening (2 m) and 0.12 mm water that attends the level 30 cm from off the soil. After, it begins to diminish to reach at 18:00 very low values in the four level of measurement.

The daily amounts of evapotranspiration deduced from net radiation measured above each vegetation storey are as follow: above the date palm about 4 mm/day equivalent to 0.46 L/s/ha, that received over the fruit trees is around 3.2 mm/day equal to 0.37 L/s/ha, that reaching the gardening storey is close to 2.4 mm/day equal to 0.28 L/s/ha.

The net radiation intercepted by a farming storey is equal to the difference between the radiation measured above the storey and that measured below it. The daily amounts of evapotranspiration deduced from the net radiation intercepted are: about 3.24 mm/day which is equal to 0.375 L/s/ha for all the canopy, 0.77 mm/day (0.089 L/s/ha) for the palm storey, 0.81 mm/day (0.0939 L/s/ha) for the fruit trees and 1.66 mm/day (0.192 L/s/ha) for the market gardening.

The analysis of evapotranspiration inside the oasis was also done by monitoring the sap flow transpired by a number of sampled trees and a number of sampled date palms. The sap flow transpired by both fruit trees storey and date palm storey was determined as the sum of the sap flow recorded in each storey.

Fig. 3 presents the compared evolution of the walk of the evapotranspiration deduced from the total sap flow (fruit trees and date palm) to that deduced from profiles of net and global radiation measured above the oasis.

The transpiration deduced from sap flow is about 0.02 mm h^{-1} at 06:00. It increases slowly to attain

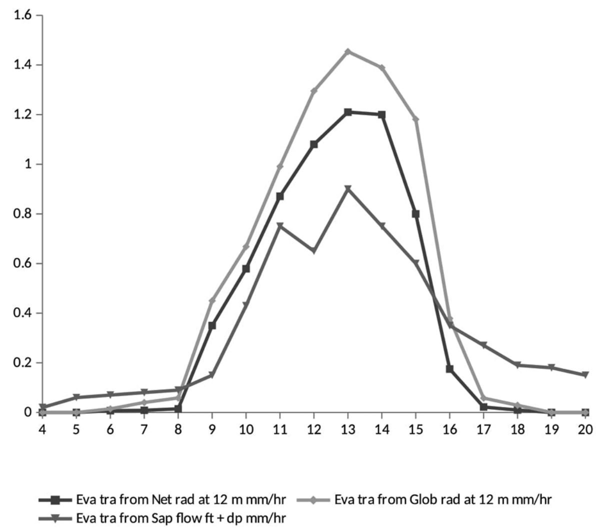

Fig. 3. – Compared evolution of evapotranspiration estimated from global radiation measured at 12 m, net radiation measured at 12 m and the total sap flow (fruit trees (ft) + date palm (dp)) inside the oasis.

0.12 mm/h at 8:00 and 0.4 mm/h at 10:00. The maximum was reached at about 13:00 and is close to 0.92 mm/h. In the afternoon, the sap flow decreases to reach 0.33 mm h^{-1} at 16:00 and about 0.2 mm/h at 18:00. The amount of water daily transpired by both storeys is about 3.3 mm/day which is equivalent to 0.38 L/s/ha (1.3 mm/day for the fruit trees and 2 mm/day for the date palm). We note that transpiration of date palm represents 61 % of the total transpiration while that of the fruit trees represents only 39 %.

Analysis of evapotranspiration inside the oasis from profiles of air relative humidity, air temperature, sensible heat flux and latent heat flux

The hourly variation of the relative humidity and air temperature inside the oasis are presented in Fig. 4 and Fig. 5. We noticed that the walk of the profiles of relative humidity (respectively air temperature) in the three measurement levels is the same for the three levels. Both relative humidity and air temperature begin to increase at 6:00 and follow the global walk of the solar radiation intercepted with certain opposite phase. In fact, air temperature for the three measurements levels has the lowest values at the beginning and at the end of the day and the highest values at 13:00. While relative humidity attains its maximum one hour after sun rise. After it brings down as

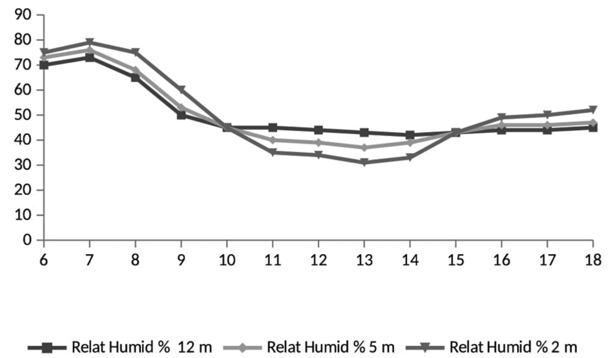

Fig. 4. – Profile of relative humidity inside the oasis.

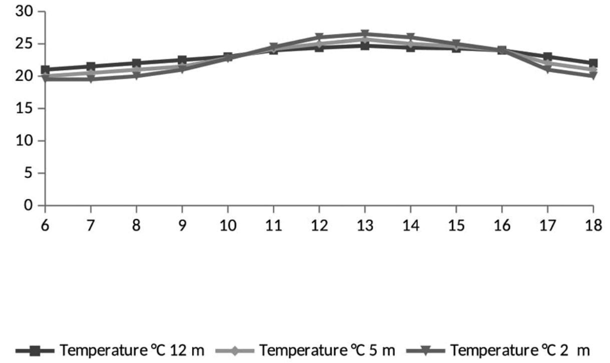

Fig. 5. – Profile of air temperature inside the oasis.

fact as the intercepted radiation increases. It reaches minimum values at 13:00 and rises again.

The difference between the humidity profiles (respectively air temperature profiles) for the three levels is clean. From sunrise to 9:00 of the morning, relative humidity is more important over market gardening (2 m, it reaches 76 % at 7:00), followed by its value above the fruit trees (5 m, about 73 % at 7:00) and finally on top of the date palm (12 m 71.5 % at 7:00). From 10:00, the order reverses, the relative humidity is higher at 12 m, followed by its value at the level 5 m and eventually at 2 m. The humidity degree, for the three stories, continues in decreasing to reach around 13:00 the following values: 43 % above the palm storey, 38 % over the fruit trees storey and 35 % over the market gardening. At 15:00, the order takes back that shown in morning (between 6:00 and 9:00).

The walk of air temperature is the opposite of the gait of the relative humidity. In fact, between 6 :00 to 10 :00 of the morning, the temperature recorded above the oasis was the highest (about 16.5 °C, at 7:00), followed by the temperature recorded over the fruit trees (about 15.5 °C, at 7:00) and finally that from off the market gardening (about 13.5 °C, at 7:00). From 10:00, we observed that the order inverts. The temperature registered is the most important at 2 m (29.4 °C, at 13:00), behinds by that at 5 m (27.7 °C, at 13:00) and eventually that memorized at 12 m (25.6 °C, at 13:00). This order remains up to 16:00. Just after, the order takes back that observed in the morning.

In figure 6, we present profiles of temperature for four different depths in the soil of the oasis (5 cm, 10 cm, 20 cm, 50 cm).

We have evaluated that in the early morning, between 6:00 and about 10:00, the temperature is the most important in the depth 50 cm, followed by the depth 20 cm, the depth 10 cm and finally the depth 5 cm. After that we record a change in the order and the temperature is the highest for the depth 5 cm, followed by the depth 10 cm, the depth 20 cm and finally the depth 50 cm. This order persists until 22:00. After, there is orientation toward that observed in the morning.

The trends observed for both air temperature and relative humidity can be explained as follow. In the morning, there is a continuity of the nocturnal effect. This is characterized by absence of evapotranspiration and a constant stratification for the air layer just above the ground. That stratification opposes to vertical air displacement (negative balance in night, soil cooling). For that, relative air humidity is the highest at 2 m level in the morning, followed by that recorded at 5 m and finally that recorded at 12 m which is the lowest.

Between 10:00 and 15:00, as fast as the intercepted net radiation increases, trees transpire more and more. The amount of water transpired is directly connected to leaves density and to the intercepted net radiation. That's why humidity rate was the highest over date palms, followed

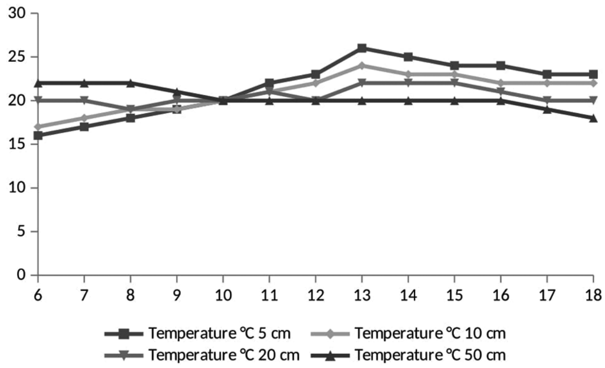

Fig. 6. – Profiles of temperature for four different depths in the soil of the oasis (5 cm, 10 cm, 20 cm, 50 cm).

by the rate above fruit trees and finally that over the third storey.

We noticed that the temperature decreases when the height increases between 10:00 and 15:00. While it increases with the height inside the oasis in the morning (6:00 to 10:00) and in the afternoon (15:00 and 20:00). This behavior is the opposite of that for the humidity. So, we can say that air temperature amplitude's is directly linked to the radiation rate intercepted in every storey. The leaves behave as heating surfaces. They have varied the temperature in altitude. Sure enough, a part of the intercepted radiation is used to release water from the leaves stomata's. The other part is used for heating the leaves. So, they yield to the ambient air simultaneously with sensible heat and latent heat.

Profiles of temperature and humidity inside the oasis have permitted to analyze profiles of heat and mass exchanged between the different farming stories. In fact, by applying the thermal balance equation inside the oasis we have determined the profiles of sensible and latent heat. Fig.7A (respectively Fig. 7B) presents, for one day, the hourly evolution of latent heat flux (respectively sensible heat flux) inside the oasis expressed in unity of mm water. The other days present a similar trend. The same behavior is advisable for the different levels. Meanwhile, we recorded clear difference between fluxes values for the three farming storeys.

We notice that at sunrise (early in the morning before 8:00) and at sunset (later in the afternoon after 17:00) latent heat fluxes (respectively sensible heat fluxes) in the three stories are always feeble with small differences between the values recorded in each level. In fact, the heat fluxes (latent heat flux and sensible heat flux) disengaged are the most important for the level 2 m, followed by those recorded at the level 5 m and finally the least values are those recorded at the level 12 m. Which mean that heat fluxes follow a decreasing function with the height inside the oasis.

Later in the day, between 8:00 and 16:00, we have observed that both latent heat flux and sensible heat flux increase with the rise of the height. In fact, from about

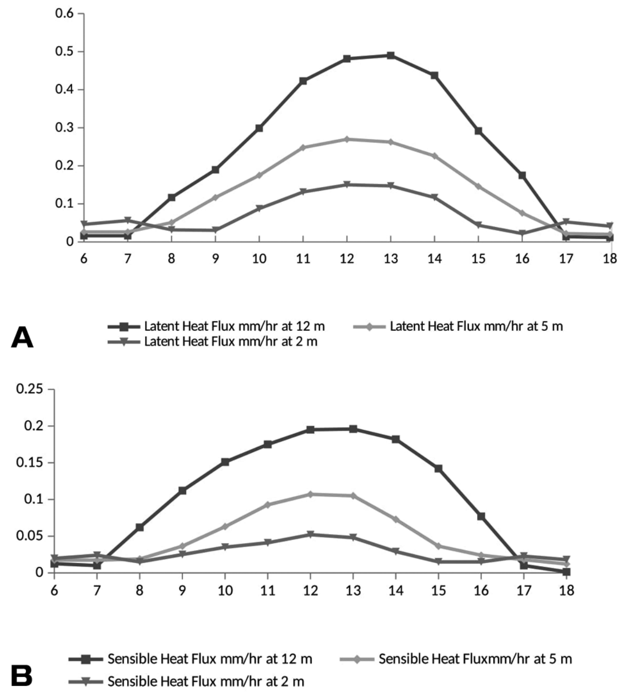

Fig. 7. – Hourly evolution of latent heat flux (**A**) and sensible heat flux (**B**) inside the oasis

8:00 the fluxes continue to rise in order to reach, at 9:00, the following values:0.12 mm/h as latent heat (respectively 0.062 mm/h as sensible heat flux) for the date palm (level 12 m), 0.5 mm/h as latent heat (respectively 0.0189 mm/h as sensible heat flux) over the fruit trees (level 5 m), 0.02 mm/h as latent heat (respectively 0.015 as sensible heat flux) over the market gardening (level 2 m). At 10:00 we have recorded 0.3 mm/h as latent heat (respectively 0.15 mm/h as sensible heat flux) for the level 12 m, 0.18 mm/h as latent heat (respectively 0.06 mm/h as sensible heat flux) for the level 5 m and 0.018 mm/h as latent heat (respectively 0.04 mm/h as sensible heat flux) for the level 2 m. They attain their maximums at 13:00 (0.49 mm/h for the latent heat and 0.18 mm/h as sensible heat flux on top of the oasis.0.28 mm/h as latent heat flux and 0.11 mm/h as sensible heat flux over the fruit trees, 0.15 mm/h as latent heat flux and 0.05 mm/h as sensible heat flux over market gardening). From 14:00, the fluxes exchanged by the three storeys begin to diminish in order to attain at 16:00 the value 0.18 mm/h as latent heat flux and the value 0.057 mm/h as sensible heat flux at the level 12 m, the value 0.08 mm/h as latent heat flux and the value 0.024 mm/h as sensible heat flux at the level 5 m, the value 0.02 mm/h as latent heat flux and the value 0.015 mm/h as sensible heat flux at the level 2 m. We can signal that market gardening evaporates daily about 0.955 mm/day as latent heat flux and 0.359 mm/day as sensible heat flux. The fruit trees evaporate about 1.658 mm/day as latent heat flux and 0.6219 mm/day as sensible heat flux. When the palm-grove releases the important share (2.954 mm/day as latent heat flux and 1.32 mm/day as sensible heat flux).

This is expounded as follows, as fast as the intercepted net radiation increases, trees transpire more and more. The amount of water transpired is directly connected to leaf density and to the quantity of net radiation intercepted. Those parameters (leaf density and net radiation) are higher for date palms canopy, followed by fruit trees canopy and finally the market gardening. We must signal the importance of the windbreak effect exercised by each storey in reducing the wind speed inside the oasis. That effect depends on the number of plants in the plot and the leaf density in each storey. This reduction may cause the reduction of evapotranspiration and the climatic requirement. The windbreak, in reducing the air motion, reduces the transferral of water vapour. This can involve the slowing down of the function of heat. The wind renews the ambient air quickly and the thickness of the laminar boundary layer around the leaves phenomenon that is influenced directly by relative humidity and by air temperature profiles.

Analysis of climatic parameters above the oasis

Climatic parameters above the oasis were measured via sensors transported in a balloon. The balloon starts from the soil with a speed of about 4.15 m/s and it can reach the altitude 20 km in the atmosphere. Data were recorded every 2 s. Fig. 8A, B, C presents respectively the profiles of air temperature, relative humidity and pressure.

We have evaluated that the temperature is the highest for the levels close to the oasis and it's between 14 °C and 17 °C. We notice variability in the global trend of the temperature up to altitude 504 m. In fact, it begins to decrease to reach 13.8 °C at the altitude 202 m. Just after, it increases to attain 16.5 °C at the altitude 504 m. From this altitude it decreases as the altitude increases to reach 0 °C at the altitude 3340 m and about –60 °C at 19905 m.

The global walk of the relative humidity (Fig. 8B) above the oasis is variable until the altitude 1380 m. After, it follows a decrease function with the altitude. In fact, it is about 48 % just above the oasis, it decreases to reach about 32 % at the altitude 504 m and it increases to attain about 42 % at the altitude 1380 m. After that altitude we observe that the relative humidity begins to decrease continuously to attain 1 % for altitudes superior to 3670 m.

The air pressure describes from the beginning a decreasing function with the altitude. In fact, it begins with the value 1009.6 hPa just above the oasis when the temperature is about 16.9 °C. It reaches 905.7 hPa at the altitude 1005 m for a temperature of about 12.7 °C. At the altitude 3340 m, the pressure becomes 681 hPa when the temperature is close to zero. Finally, it ends with 55 hPa at the altitude 19905 m when the temperature is about –60 C°.

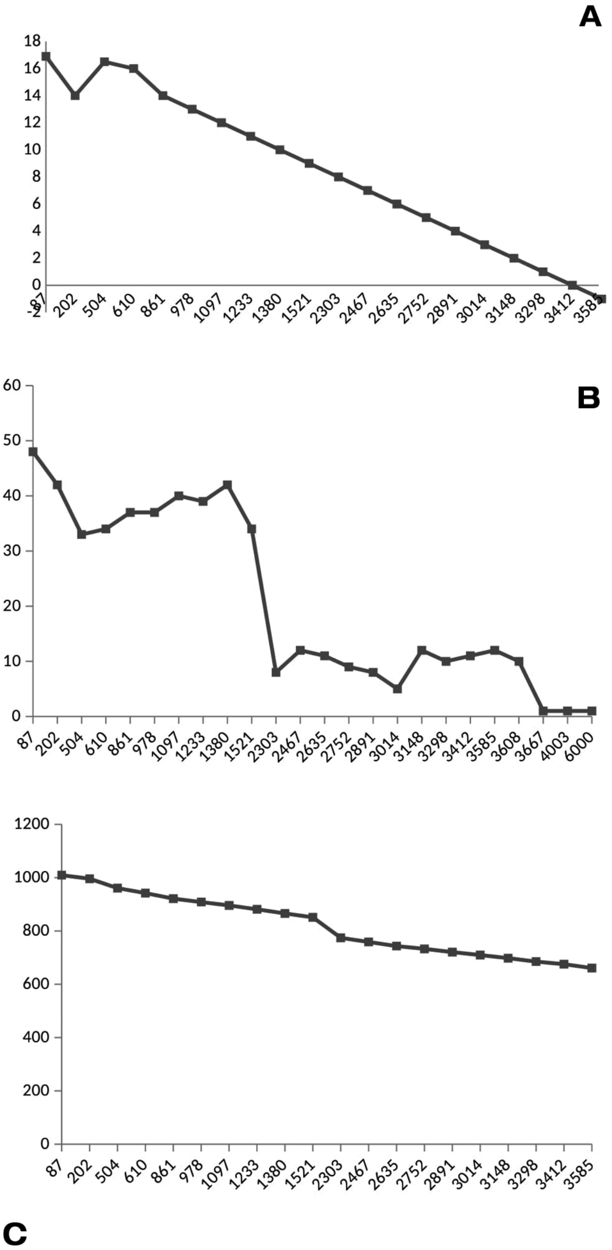

Fig. 8. – Profiles of air temperature (**A**), relative humidity (**B**) and air pressure (**C**) over the oasis.

DISCUSSIONS

Many studies indicated that the atmospheric layers can be directly influenced by the flux provided by plant canopies. But there are no results indicating exactly the amplitude of that influence and the amount of the impact exchanged (Stull 1988, Montheith & Unsworth 1990, Mattar *et al.* 2015, Talla *et al.* 2018, Bau-Show *et al.* 2020). The atmosphere is subdivided by specialists in many layers. That which is affected directly by plant canopies is the surface boundary layer. Over high canopies many researchers distinguish two parts: the inertial sub layer situated at a level roughly equal two to a few times the canopy height and the roughness sub layer below this level. Many equations describe the mutual exchange between the atmosphere and plants but they consider only a global scale without estimating the effect of the specie itself (Baars *et al.* 2008, Baklanov *et al.* 2011, Sheng *et al.* 2015, Theeuwes *et al.* 2019). The nature of heat and mass transport inside and above oasis canopies is not fully understood. Analyse of profiles of climatic parameters and estimation of evapotranspiration through and over these kinds of stands can help to analyse the interaction between the different farming stories and the atmosphere.

We have studied in this work the flows (water and heat) emitted by every farming storey inside the oasis canopy. We have also analyzed the effects of those flows on profiles of climatic parameters (relative humidity, air temperature and air pressure) in and above the oasis. The method used consisted to evaluate the amount of evapotranspiration released from each storey by analyzing profiles of solar radiations intercepted (net and global) and the sap flow transpired. Then we have deduced the walks of sensible heat flux and latent heat flux expressed in unity of mm water. Hence, we have analysed the interaction between the oasis and the near atmosphere.

Results show that evapotranspiration deduced from the total global radiation intercepted inside the oasis is equivalent to 4.4 mm/day. That estimated from global radiation received above the oasis is equivalent to 6.81 mm/day. When using the total net radiation intercepted by all the oasis, the evapotranspiration is equivalent to 3.24 mm/day. It is equivalent to 4 mm/day when using the net radiation received at the height 12 m.

The evapotranspiration estimated from daily sap flow transpired by both date palm storey and fruit trees storey is about 3.3 mm/day. We note that transpiration of date palm represents 61 % of the total transpiration while that of the fruit trees represents only 39 %. Also, by using the sap flow, we can say that evapotranspiration for all the oasis represents 52 % from the net radiation received above the oasis and 33 % from the global radiation.

We have noticed that inside the oasis air temperature follows a decreasing function with the altitude in the early morning and later in the afternoon. However, it follows and increasing function with the altitude between 9:00 and 15:00. For the relative humidity, we have noticed that inside the oasis it follows the opposite walk of air temperature. In fact, it increases with altitudes in the early morning and later afternoon and it decreases with altitudes between 9:00 and 15:00. Above the oasis, for air temperature, relative humidity and air pressure, we have noticed that they follow globally decreasing functions with altitudes. But we have recorded certain fluctuation particularly in the first altitudes for which the influence of vegetation canopies is important.

For the sensible heat flux and the latent heat flux, we have observed that inside the oasis they decrease with the altitude in the early morning and in the later afternoon. But they increase with the height during the day. Expressed in equivalent of water released, the daily amount of sensible heat flux for all the oasis is about 2.3 mm/day. The daily amount of latent heat flux is about 5.56 mm/day.

The scaling problem in land-atmosphere interaction is essentially the problem of using information about exchange processes at one scale to characterize the same processes at a larger scale. Since general circulation models require estimates of energy fluxes at a large scale, the problem of averaging surface energy fluxes at a regional scale constitutes an important issue of international collaborative research. Results presented in this study can be very useful. Also, the demand to advance understanding of the interactions between land surfaces and the atmosphere has been heightened greatly by recent global climate change.

As continuity, these research activities are in progress. In fact, we are monitoring the impacts on microclimatic factors of introducing many localised irrigation system to water the different species inside the Nefzawa oasis (Sellami 2020, Tiba *et al.* 2020a, b).

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Highlights. – Estimations of evapotranspiration; Analyze of interaction between oasis canopy and the atmosphere; Influence of crop stories inside the oasis on climatic parameters; Estimation of irrigation gifts inside the oasis.

Author signals that there is no conflict of interest.

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