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Measurement of evapotranspiration and development of crop coefficients of olive (olea europaea L.) orchards in semi arid region (Marrakech, Morocco)

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Abstract - Efficient irrigation management requires a good quantification of evapotranspiration. In the case of olives orchards, which are the dominant crop in many semiarid regions around the Mediterranean. Among these regions, the Tensift Alhouz Marrakech which the SUD Med project is focalized. An important parameter, which needs to be determined for estimating the crop water requirement, is the reference crop evapotranspiration (ET0). Five climatological methods were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory and others are empirical methods based primarily on solar radiation, temperature and relative humidity. Crop coefficients (Kc) were estimated for olives trees at different stages of growth, based on eddy correlation measured actual ET and the reference crop evapotranspiration estimated by these methods. According to our results the crop coefficient will vary among locations and even among years, depending on soil evaporation (rainfall, irrigation), vapour pressure deficit (VPD), solar radiation and reference evapotranspiration (ET0). So it is desirable to have a method that estimates the (ET0) consistently.

Keywords : Actual Evapotranspiration, reference evapotranspiration, crop coefficient, eddy correlation.

1 Introduction

Olive orchards are the main component of agricultural systems in many semi arid regions around the Mediterranean. Good irrigation management requires an accurate quantification of olive evapotranspiration. The most common approach to calculate evapotranspiration (ET) has been as the product of reference evapotranspiration by the crop coefficient (Kc), wich depend on ground cover and crop characteristics (Allen et al., 1998[1]). The reference evapotranspiration play an important role for estimating the crop water requirement. Five climatological methods were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory and others are empirical methods based primarily on solar radiation, temperature and relative humidity. Crop coefficients (Kc) were estimated for olives trees at different stages of growth, based on eddy correlation measured actual ET and the reference crop evapotranspiration estimated by these methods. According to our results the crop coefficient will vary among locations and even among years, depending on soil evaporation (rainfall, irrigation), vapour pressure deficit (VPD), solar radiation and reference evapotranspiration (ET_0). So it is desirable to have a method that estimates the (ET_0) consistently well.

2 Methods and materials

2.1 Site description

The study site was located in the 275-ha Agdal olive (*Olea europaea* L.) orchard on the southern end of the ancient walled city of Marrakech, Morocco (31.40, 7.38). Marrakech has a semiarid Mediterranean climate. The Agdal olive orchard is periodically surface-irrigated by diverting flow from a large impoundment through a network of ditches. Water is diverted manually to every tree by manipulation of small earthen check dams. The ∼45 m2 ground surface occupied by each tree is bordered by a small ∼30-cm high earthen levy that retains the irrigation water, allowing precise application of irrigation water to every tree. Plant spacing was about 6.5*6.5 m ; the trees had an average leaf area index (LAI) of 3. Mean tree height was 6 m and ground cover was 55%.

2.2 Measurements

Since September 23th 2002, a 9-m tall instrument tower was placed in the south-eastern portion of the orchard near the centre of the section that was irrigated on DOY 307 during the period of sap flow experiment. Near-continuous measurements of water vapour, carbon dioxide, and sensible heat fluxes were recorded on the tower at 8.8-m height 2 m above the top of the olive canopy. A 3D sonic anemometer (CSAT3, Campbell Scientific, Logan, UT) measured the fluctuations in the wind velocity components and temperature. An open-path infrared gas analyzer (LI7500, LiCor, Inc., Lincoln, NE) measured concentrations of water vapour and carbon dioxide. The wind speed and concentration measurements were made at 20 Hz on CR23X dataloggers (Campbell Scientific, Logan, UT) and on-site portable computers to enable the storage of large raw data files. Air temperature and humidity were measured at 8.8 and 3.7 m heights on the tower with Vaisala HMP45C probes. Total shortwave irradiance was measured at 9.2 m height with a BF2 Delta T radiometer. Net radiation was measured with a Kipp and Zonen CNR1 net radiometer placed over the olive canopy at 8 m height. Soil temperature was recorded at 5 cm depth at two locations approximately 30 m from the tower. Three heat flux plates continuously monitored changes in soil heat storage at the tower site. In addition, five point measurements of soil moisture variables were located throughout the site. Each point contained a pair of steel rods for time domain reflectometry (TDR) measurements at 40, 30, 20, 10 and 5 cm depths to estimate volumetric water content.

Olive transpiration was measured by sap flow method following the procedure of Williams et al., 2003[7]. Soil evaporation was computed as the difference between evapotranspiration measured by eddy correlation system and transpiration measured by sap flow method.

3 Calculation of reference evapotranspiration (ET_0)

Five climatological methods were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory (FAO-Penman Monteith and Penman methods) and others are empirical methods based primarily on solar radiation, temperature and relative humidity like : Priestly Taylor method, Makkink method and Turc-Radiation method.

3.1 FAO-Penman Monteith method (Allen et al., 1998[1])

The reference crop evapotranspiration, ET_0, was calculated according to the FAO Penman-Monteith equation. ET0 is the evapotranspiration rate from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 $s.m^{-1}$) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover that is in uniform height, actively growing, completely shading the ground and with adequate water supply. Thus, the Penman-Monteith equation was used for 24 h calculation of ET_0 (mmper day). Using daily mean data it can be simplified as following (Allen et al., 1998[1]) :

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2.D}{\Delta + \gamma\left(1 + 0.34u_2\right)} \qquad (mm/jour) \tag{1}$$

Where R_n is the net radiation at the crop surface (MJ m^{-2}per day), G the soil heat flux (G=0), T the average air temperature ($^\circ$ C), u_2 the wind speed at 2 m height (m s^{-1}), D the vapour pressure deficit (kPa), $\Delta$the slope of the vapour pressure curve (KPa $^\circ C^{-1}$), γ is the psychrometric constant (kPa $^\circ C^{-1}$), and 900 is the conversion factor.

3.2 Penman method (Penman, 1948[4])

The general form of Penman equation is given as :

$$ET_0 = 0.408\frac{\Delta\left(R_n - G\right) + \gamma * 6.43 * \left(1 + 0.0536u_2\right).D}{\Delta + \gamma} \qquad (mm/jour) \tag{2}$$

3.3 Priestly Taylor method (1972[?])

Priestly and Taylor (1972) presented an equation for no or low advective conditions. The priestly and Taylor equation is given as :

$$ET_0 = 0.408\alpha\frac{\Delta\left(R_n - G\right)}{\Delta + \gamma} \qquad (mm/jour) \tag{3}$$

Where α is a constant (1.26).

3.4 Makkink method (1957[3])

Makkink presented a method for computing ET_0 using solar radiation, and is given as :

$$ET_0 = C_m\frac{\Delta}{\Delta + \gamma}R_s \qquad (mm/jour) \tag{4}$$

Where R_s is solar radiation and C_m is constant (0.65).

3.5 Turc-Radiation method (1961[6])

Turc (1961[6]) presented a method for computing ET_0 using solar radiation and temperature data ; which is known as Turc-Radiation method and is given as :

$$ET_0 = 0.013.\frac{T}{T+15}.(Rs+50) \quad (mm/jour) \tag{5}$$

Where $Rs$is in cal.cm^{-2} per day.

4 Crop coefficient (Kc)

Crop coefficient (Kc) is defined as the ratio of the crop evapotranspiration to the refernce evapotranspiration and can calculated by different methods (e.g. single crop coefficient method and dual crop coefficient method) (Jensen et al., 1990[2] ; Allen et al., 1998[1]). In this study, crop coefficient was calculated from the measured (ET) by eddy correlation and (ET_0) by different methods mentioned before.

5 Results and discussions

5.1 Comparison of (ET_0) estimated by different methods

The trends of average weekly reference evapotranspiration (ET_0) calculated by different methods (see above) is presented in figure 1 (the beginning of measurement is 15 October 2002). The weekly evapotranspiration (ET) measured by eddy correlation are also shown in that figure. The temporal variation of (ET_0) and (ET) was closet to temporal variation of solar radiation ; the minimum (ET_0) and (ET) correspond to the minimum of solar radiation. (figure 2). The FAO-PM and Penman methods give the same value of (ET_0), sometimes we fine some difference between two methods. This difference is due to wind function used in each method. Because these methods use data of maximum number of weather variables to estimate (ET_0), it is possible to consider that these methods give o good estimate of (ET_0). The others method (Priestly-Taylor, Makkink, Turc-Radiation) under estimated the (ET_0) values because the aerodynamic term is negligible.

Though, Penman method is considered as the most rational and elaborate approach, it requires a large number of climatological data. Often such data are very scanty forcing the user to choose some other alternative empirical methods for reliable estimation of (ET_0) like the Makkink method which gives o good estimation of (ET_0) in our case.

5.2 Orchard (ET) and crop coefficient

Crop coefficients of olives were taken as the ratio of evapotranspiration (ET) of well-watered olive and the reference evapotranspiration computed by different estimation methods. Minimum values of (ET) are close to 0.75 mm per day during the winter, while maximum values around 4.51 mm per day occurred in June. The annual course of calculated average weekly crop coefficient (Kc) by different methods is presented in figure 3 The (Kc) values recommended by Allen et al. (1998[1]) for olives were also shown in this figure. **C**rop coefficients computed by all methods varied substantially through the year and varied around the mean value (0.68) recommended by

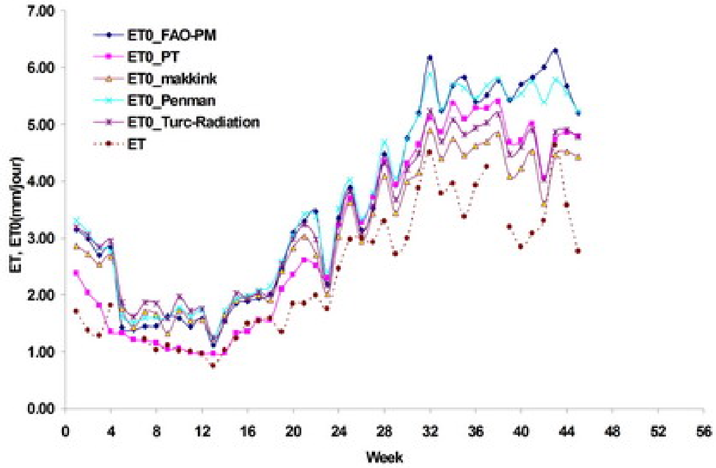

FIG. 1 – Computed average weekly ET0 by different methods : combination and empirical methods.

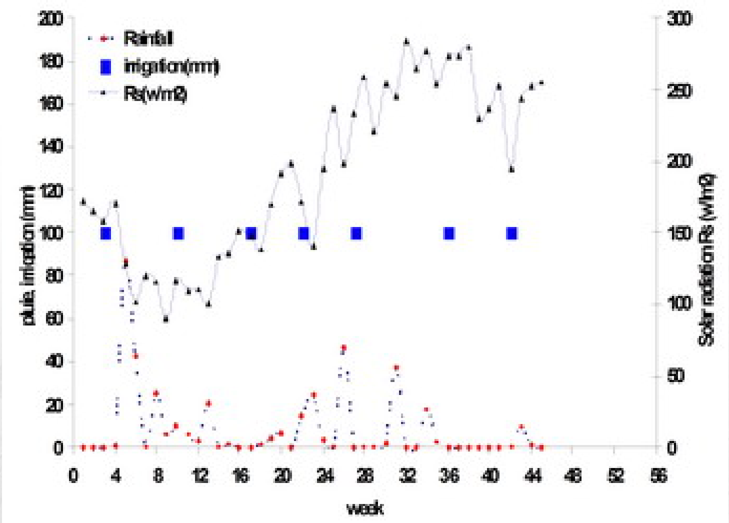

FIG. 2 – Average weekly climate of olive orchards, Agdal, Marrakech.

Allen (1998[1]). The crop coefficients computed by the Priestly-Taylor method were high during the winter because the reference evapotranspiration calculated by this method was very low (1). So this method over estimated the crop water requirement of olives. We observed also in the figure 3 that the crop coefficient depends of soil evaporation (the peak observed in weeks 26, 31 and 43 correspond to rainfall or irrigation events). These peaks were much observed in daily variation of (Kc) than weekly variation.

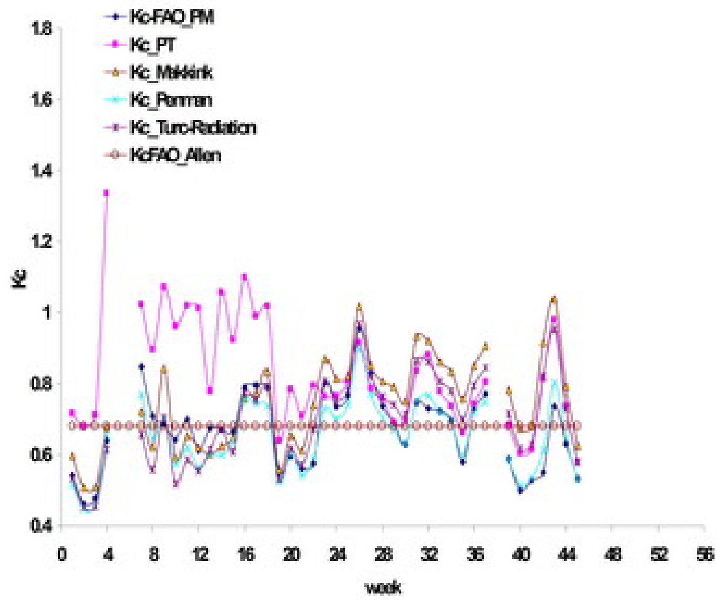

Fig. 3 – Average weekly crop coefficients (Kc) calculated by different methods : combination and empirical methods.

Sap flow measurements was allow to determine olives transpiration and the soil evaporation was computed as the difference between evapotranspiration (LE) measured by eddy correlation system and transpiration measured by sap flow method. figure 4 presents the daily course of total heat flux (LE) measured by eddy correlation and transpiration (LEp) measured by sap flow method. Both (LE) and (LEp) were close to 0 during the night, and reached maximum values around solar noon. Before irrigation, these two components were identical (LEp present 100% of LE) ; but after irrigation, the olive transpiration was low than total evapotranspiration LE (LEp present only 72 to 80 % of LE). This difference is due to contribution of soil evaporation. We conclude that the crop coefficient depend on soil evaporation (wetting events). It is better to split (Kc) into two separate coefficients, one for crop transpiration, i.e., the basal crop coefficient (Kcb), and one for soil evaporation (Ke), the last term depend essentially of type of irrigation. To reduce the soil evaporation it is better to use drip irrigation and no furrow irrigation applied in our case.

For mean annual values, the crop coefficient was 0.67 for FAO-PM method, 0.83 for Priestly-Taylor method, 0.75 for Makkink method, 0.65 for Penman method and 0.7 for Turc-Radiation method. We conclude that the combination methods give the values of (Kc) near to values recommended by Allen et al. (1998[1]). The variation of the olive (Kc) throughout the year and its dependence on vapour pressure deficit (VPD), soil evaporation (rainfall) clearly indicates the difficulty in proposing a unique (Kc) value valid for different locations. Even in a given area, interannual variability in rainfall dates and amount will lead to changes (Kc).

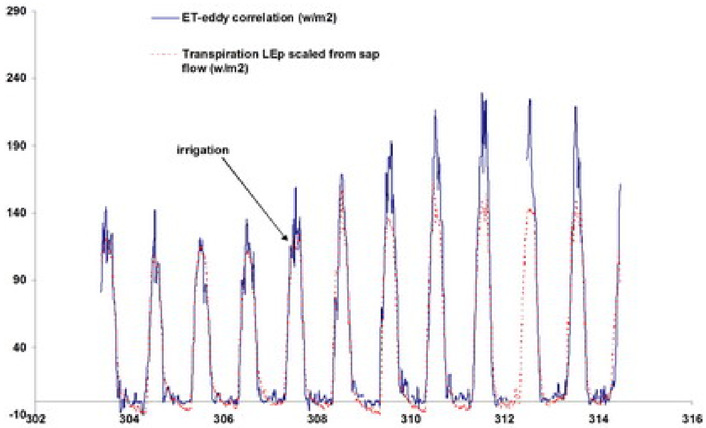

FIG. 4 – Daily course of latent heat flux measured by eddy correlation and transpiration measured by sap flow method of olive orchards in Agdal south Morocco.

6 Conclusion

Crop coefficients of olives orchards in southern Morocco change during the year in response to changes in net radiation, air temperature, wind speed, vapour pressure deficit and evaporation from the soil surface. The average crop coefficient computed basing on combination theory to calculate reference evapotranspiration is correctly estimated compared with empirical methods. These results indicate that the use of no adequate method to estimate reference evapotranspiration allowed overestimating or underestimating the water requirements. So it is desirable to have a method that estimates the (ET_0) consistently well.

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