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CROP EVAPOTRANSPIRATION: METHODOLOGY AND APPLICATION IN MEDITERRANEAN REGION

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SUMMARY - This study analyses methods for measuring and estimating ET in the particular conditions of the Mediterranean region. The first part of the work presents the ET measurement methods, at plant and canopy scale. In particular for the canopy scale we illustrate the direct method (weighing lysimeter) and the indirect methods (micrometeorological techniques, hydrological approaches). For these methods advantages and disadvantages are given for the use in the Mediterranean region, together with the precautions to be used for minimizing the measurement errors. The second part of the study presents methods to estimate the ET; the methods are divided in direct (the Penman-Monteith one step technique) and indirect (mainly the Kc approach). The Penman-Monteith method is analysed and a model of canopy resistance is presented in detail. This model was developed in three steps: for crops under well watered conditions, for crops under water stress and a multi-local tests. Here the good performances of this model are presented for a Mediterranean site (south Italy). Lastly, the Kc-approach for determining ET is presented. Here we demonstrate that this method does not work properly in Mediterranean region for two reasons: the canopy resistance for the reference grass can not be considered as constant and the values of the crop coefficients can be very different in different sites for a given crop. In conclusions some suggestions for the future research needs are given for the different methods of determining ET in Mediterranean region.

Key words: crop coefficient, direct ET methods, indirect ET methods, micrometeorology.

INTRODUCTION

The denominator of the Water Use Efficiency (WUE) in its more common definition is the water applied to obtain a given yield. Since usually the 99% of this water is lost by a crop by evapotranspiration (ET), for correct comparisons of WUE in different environments, it is worth to determine this value instead of the water supply.

The actual evapotranspiration of a crop (ET) is the amount of water actually lost as vapour as a result of both soil evaporation and plant transpiration. It is not the potential moisture loss in the presence of a non-limiting amount of water in the soil. For a given period of time, this factor can be expressed as unit mass or volume per unit area, or by equivalent water height.

Many European institutes, particularly INRA in France and CRA in Italy, have done much research into the measurement or estimation of ET at various scales (plot, region). These studies were firstly reviewed by Itier and Perrier (1982) and, more recently by Rana and Katerji (2000), especially for application in the Mediterranean region.

The methods presented here are applied essentially in small plots of one or several hectares. Application to a larger scale can only be obtained by establishing the spatial representativeness of the situations actually measured.

ET MEASUREMENT IN FIELD PLOTS

Procedures for determining ET should be easy to apply and should enable accurate measurement without disturbing the environment. Thus the methods developed over the past three decades initially involved direct measurement of ET with a sensitive weighing lysimeter and then indirect determination with microclimatic methods or with technique relative to the soil water status.

We will present the main methods of ET determination that have been tested over several years with emphasis on their respective strengths and weaknesses.

Direct ET measurement

The only direct measurement of ET involves determining the variation in weight of a cropped soil, i.e. of the crop including the soil zone supplying water to crop, within a given time interval (Slatyer and McIlroy, 1961). On flat land and without irrigation or rain, weight variation is almost entirely due to ET. Plant matter varies to a minimal extent compared to water.

Lysimeters are used for direct AET measurement (Tanner, 1967; Aboukhaled *et al.*, 1982). They consist of sensitive weighed tanks which are placed in the field and cropped in the same way as the surrounding land. Perrier et al. (1974) reviewed the results obtained with this technique over a 9-year period. Accuracy of measurement was reported as satisfactory on a daily scale (10% difference between lysimeters), but less satisfactory on an hourly scale. However, a number of limitations were observed:

- The device is heavy and fixed into the soil (5 metric-tons for the lightest), and cannot be repaired easily.
- Under arid and semi-arid climates, problems linked to the atmospheric evaporation demand can worsen the performances. In fact, if the soil inside lysimeters has deep cracks (often along the border in contact with the soil), the water evaporation continues from the deepest layers, so that lysimeter can overestimate ET in these periods and underestimate ET in the following periods, when the water depletion inside is greater than that in the field, due to water stress condition of inner plants (Jensen et al., 1990). Conversely, irrigation and rainfall infiltrate into these lysimeters; this, along with lack of root extraction of water, caused the soil within the lysimeters to be much wetter than the surrounding field soil (Klocke *et al.*, 1991).
- A lysimeter represents a closed environment (Grebet and Cuenca, 1991): it does not take into account later or upward movement. This latter point is particularly troublesome in case of prolonged drought. Katerji et al. (1977) showed that during the exceptionally dry summer of 1976, a third of the water transpired under a wheat canopy came from the 0-1,7 m soil depth. This phenomenon could not have been observed with the use of lysimeter which blocks upward water movements. In spite of all precautions with which lysimeters data bust be considered, this method remains nevertheless essential in verifying or testing other methods of ET measurement.
- The lysimeter rim can also influence ET measurements. One of the most important effects, mainly in arid environments, is the heating of the metallic rim by radiation resulting in microadvection of sensible heat into the lysimeter canopy. Moreover, if the lysimeter rims are too tall relative to crop the wind is shielded and the radiative energy balance is modified due to reflection of solar radiation by the inner wall of the rim toward the crop.

Indirect ET measurements

Because of the lysimeters limitations, researchers have then investigated indirect methods of measurement combining accuracy, convenience, and lack of soil disturbance. Two types of methods have been examined more thoroughly:

- Micrometeorological methods;
- Soil water balance method.

Micrometeorological methods

The three micrometeorological methods that have been investigated extensively for technical applications are the Eddy covariance technique, the Bowen ratio procedure and the aerodynamic method (in its complete and simplified forms) . They will be presented in detail below.

Eddy covariance technique

The transport of scalar (vapour, heat, CO_2) and vectorial amounts (i.e. momentum) in the low atmosphere in contact with the canopies is mostly governed by air turbulence (Stull, 1988).

When certain assumptions are valid, theory predicts that fluxes from the surface can be measured correlating the vertical wind fluctuations from the mean (w') with the fluctuations from the mean in concentration of the transported admixture. So that for latent heat we can write the following covariance of vertical wind speed (m s^{-1}) and vapour density (q' in g m^{-3}):

$$\lambda E = \lambda \overline{w'q'} \tag{1}$$

By making measurements of the instantaneous fluctuations of vertical wind speed w' and of humidity q' at sufficient frequency to obtain the contribution from all the significant sizes of eddy and summing their product over a hourly time scale (from 15 min to 1 hour), the Eq. (1) gives directly the ET. A representative fetch is required; fetch to height ratios of 100 are usually considered adequate but longer fetches are desirable (Wieringa, 1993). The distribution of eddy size contributing to vertical transport creates a range of frequencies important to eddy correlation measurements.

To measure directly ET by this method, vertical wind fluctuations have to be measured and acquired contemporary to the vapour density. The first one can be measured by sonic anemometer, the second one by fast response hygrometer, both have to be acquired at a typical frequency of 10-20 Hz. The commercial fast hygrometers can be severely damaged if moistened so they can be installed only during the day period, which makes difficult to use this instrument continuously for period longer than few days. Furthermore, errors in eddy covariance method can be due not only to possible deviations from the theoretical assumptions but also to problems of the sensors configuration and meteorological characteristics (Foken and Wichura, 1996).

A problem to be known are is due to the geometrical configuration of the sensors. A distortion of the flow can be caused by the sensor arrangement of the anemometer itself and other sensors. The spatial separation between the sonic anemometer and the hygrometer can cause lack of covariance between the wind speed and the humidity fluctuations. In fact, the typical distance between the measuring path of the vertical wind fluctuation and the hygrometer is 30-40 cm, this spacing act like a lower-pass filtering process on the measured signals and must be corrected (Foken and Wichura, 1996).

To avoid some of the above probes linked to the humidity fluctuations measurements, λE can be obtained indirectly as residue of the energy budget

$$R_n - G = H + \lambda ET \tag{2}$$

where R_n (W m^{-2}), net radiation and G (W m^{-2}), soil heat flux, are directly measurable by net-radiometers and soil heat flux plates, H is the sensible heat flux, that by followinf the eddy covariance technique can bes expressed by:

$$H = \rho c_p \overline{w'T'} \tag{3}$$

where c_p (J kg^{-1} C^{-1}) and (kg m^{-3}) are the specific heat and density of air. The wind speed and temperature fluctuations are measured by means of sonic anemometer and fast response thermometer respectively.

Despite problems linked to the correct management of the sensors and data remain, this method has very good performances both at hourly and daily scale, also in semi-arid environments (see Rana and Katerji, 1996 for an application in south Italy).

Anyway, the use of eddy covariance for latent or sensible heat flux is still a useful tool only at research level, also if recent development of robust sensors could permit in the next future its practical application in arid regions.

Bowen ratio procedure

The Bowen ratio method involves estimating the energy needed for ET represented by the latent heat flux, using the energy balance equation (1). This method has been extensively described in the literature for very different crops (Slatyer and McIlory, 1961; more recently Zhao *et al.*, 1996; Rana and Katerji, 1996). The $H/\lambda ET$ ratio is determined from the differences in both dry and wet-bulb temperature (ΔT_d and ΔT_w) between two levels above the canopy. Thus, H is expressed by the following formula:

$$H = -(R_n - G)\frac{\gamma}{\Delta + \gamma}\frac{\Delta T_a}{\Delta T_w} \quad (4)$$

where γ is the psychrometric constant (Pa °C^{-1}), Δ (Pa °C^{-1}) is the sSlope of the saturation vapour pressure curve at wet-bulb temperature (T_w).

This method has been the basis of two measurement systems: an analogical one developed by Australian reserchers (McIlroy, 1971), and a digital one known as BEARN (Bilan d'Energie Automatique Regional Numérique), which was developed at INRA (Perrier *et al.*, 1976). The major improvement brought about by the latter system is the periodical inversion of the measurement levels T_d and T_w to increase the precision of ΔT_h measurement, which is of utmost important for this method. The ET values obtained by using BEARN were compared with the ET values given by a sensitive weighing lysimeter placed under similar conditions in many sites of the Mediterranean region. The results, for the cumulated values displays differences between 10% and 4% for a large range of crops type (Fuchs and Tanner, 1970; Sinclair *et al.*, 1975; Revheim and Jordan, 1976; Katerji 1977, Rana and Katerji, 1996).

The aerodynamic method

If we assume that a flux density can be related to the gradient of the concentration in the atmospheric surface layer (ASL), the latent heat flux by the aerodynamic technique can be determined directly by means of the scaling factors u^* and q^*, with q specific air humidity

$$\lambda E = -\lambda \rho u^* q^* \quad (5)$$

the friction velocity u* is derived from the wind profile measurement:

$$u^* = \frac{ku}{\ln\left(\frac{z-d}{z_0}\right) - \Psi_m} \quad (6)$$

where k=0.41 is the von Karman constant, d (m) is the zero plane displacement height, z_0 (m) is the roughness length of the surface and Ψ_m is the stability correction function for momentum transport. Analogously, q^* is determined similarly from the humidity profile measurements.

The calculation of stability functions is made by iterative processes (e.g. Pieri and Fuchs, 1990). The major difficult with this technique is the correct measurement of the vapour pressure at different heights above the crop. For this reason λE can be derived indirectly by the energy balance (1) if the sensible heat flux is determined by the flux-gradient relation:

$$H = -\rho c_p u^* T^* \quad (7)$$

where T^* is deduced by the air temperature profile:

$$T^* = \frac{k(T - T_0)}{\ln\frac{z-d}{z_0} - \Psi_h} \quad (8)$$

where T_0 is the temperature extrapolated at $z=d+z_0$ and $_h$ is the correction function for the heat transport.

Under this form, the main advantage of the aerodynamic technique consists in avoiding humidity measurements. Nevertheless, the accuracy depends on the number of measurement levels of wind speed and temperature profiles.

This method, in its simplified form (Itier, 1980), involves determining flux H from wind speed and air temperature measurements at two levels above the canopy. In this case, the flux H is then written:

$$H = f(\Delta u, \Delta T) \quad (9)$$

Function *f* depends on ΔT and/or on $\Delta u/\Delta T$ through different coefficients depending on the stability of the atmosphere above the crop.

Unlike the Bowen ratio method, the simplified aerodynamic method (from which the SAMER system, Système Automatique de Mesure de l'Evapotranspiration Réelle, has been derived) does not require measuring the wet-bulb temperature T_w. However, its use is limited in case of excessive surface roughness: canopy height should not exceed 1.5 m (Rana and Katerji, 1996).

Advantages and limitations of the micrometeorological methods

Unlike the lysimeter, the BEARN, SAMER and eddy covariance systems are light and not bound to the experimental field. These systems provide a more representative measurement of the whole field, because the equipment does not disturb the environment, and because the vertical gradients of temperature (dry or wet) and wind speed result from an integration of the fluxes over a large surface area than that of the lysimeter. Finally, the precision of the ET values obtained with these systems is compatible with the studies of plant canopy response to instantaneous water supply.

Nevertheless, these systems have several limitations. Precision and reliability of results depend on strict technical monitoring, thus implying the presence of a competent technician in charge of operating the system. Because of these limitations, the systems cannot be generalized for field use. Their use is indispensable, however, in research laboratories to obtain reference values and to validate the estimates obtained with other procedures.

The soil water balance method

The ET of a crop can be determined by calculating the soil water balance: the amount of water entering, leaving, or remaining in the soil volume determined within a given time interval. If lateral water flow is disregarded, the various terms of water balance are related by the following equation:

$$ET = P - \Delta Q \pm R - D \quad (10)$$

where ΔQ is the variation in soil water storage within a given time interval (usually 3-5 days) and near the crop root zone, *P* is the cumulated rainfall within the same time interval, $\pm R$ is the lateral water supply or loss due to surface runoff, *D* is the upward and downward water movement at depth *Z*, expressed positively for drainage, and negatively for upward water movement. The latter movement can be attributed to two processes: capillary flow caused by physical diffusion, or water suction by the root deep in the soil.

Unlike the direct and micrometeorological methods, the soil water balance procedure provides neither variations nor daily values of ET. Indirect measurement of ET involves determining the four terms on the right side of Eq. (10). Only *P* (rainfall) and ΔQ (e.g. neutron probe, TDR technique) can be easily measured, whereas *R* and *D* are difficult to determine.

The surface runoff *R* can usually be disregarded. However, this approximation is impossible under certain adverse conditions (sloped land, strong rainfall). In this case, the runoff must be measured with appropriate instruments.

To estimate capillary upward movement or drainage, one must make continuous tensiometric measurements representative of the field plot under study. These measurements indicate the intensity and direction of the hydraulic charge gradients associated with water flow. It is then theoretically possible to calculate the upward water movement or the drainage, if the hydraulic soil conductivity and its variation with water content are known. To overcome the difficulties in determining *D* and *R*, investigators usually determine ET from the following equation:

$$ET = P - \Delta Q \quad (11)$$

Compared to Eq. (10), Eq. (11) is based on the assumption that deep water flows and the surface runoff are zero. While neglecting the surface runoff is perfectly justified under many circumstances as mentioned previously, many authors suggested that the amounts pf water likely to flow upward or downward between the root zone and the sub-soil may be a major component of the water balance (Robins et al., 1954; Wilcox, 1960; Van Bavel *et al.*, 1968).

Katerji *et al.* (1984) have provided some information about the importance of deep flows. These authors determined deep flows by associating rainfall records and measurements of the water storage variation in the 0-170 cm soil zone (using a neutron probe) with the permanent observation of ET (using the BEARN system). In this case, deep flow becomes the only unknown (assuming runoff to be zero) of Eq. (10). The results obtained on two crops (alfalfa and wheat) during four years with varying precipitation, showed that deep flows occurred at various periods of time, whether in dry or in humid years, and that these flows represented a non negligible fraction of the water balance. The rainy years represented an overall balance between the water drained and the water moving upward, whereas the significant upward movement of water in deep soil layers (170cm) during the dry years could account for 30% of the ET measured during the crops life cycle. After the exceptional drought of 1976, the wheat harvest on deep soil was similar to that recorded in rainy years as a result of upward water movement, thus indicating the major impact of these flows (Katerji, 1977). So, by considering that water flows in deep soil do not contribute significantly to adequate crop water supply, Eq. (11) underestimates ET during a dry period especially in deep soil.

ESTIMATING ET

ET can be estimated by means of more or less complex models: the accuracy of ET estimation is proportional to the degree of empiricism in the used model or sub-models. So, for simplicity, we can categorise the ET estimation into thwo groups of methods:

1) Methods based on analytical modelling of evapotranspiration;
2) Methods in which actual crop ET is deducted from the evapotranspiration of a reference surface.

ET analytical models

One-dimensional equations based on aerodynamic theory and energy balance, for this reason called combination models (Penman, 1948; Monteith, 1965; 1973), have proved very useful in the actual crop ET estimation, because they take into account both the canopy properties and meteorological conditions. The most widely used form of the combination equation, called Penman-Monteith equation, can be expressed under the form:

$$\lambda E = \frac{\Delta A + \rho c_p VPD / r_a}{\Delta + \gamma \left(1 + r_c / r_a\right)} \qquad (12)$$

where $A=R_n-G$ is the available energy (W m^{-2}), VPD is the vapour pressare deficit (kPa), Δ is the slope of the saturation pressure deficit versus temperature function (kPa C^{-1}), λ is the psychrometric constant (kPa C^{-1}).

In Eq. (12) we can distinguish 2 resistances:

- r_a (s m^{-1}) is the aerodynamic resistance
- r_c (s m^{-1}) is the bulk canopy resistance.

Indeed, the first one (r_a) is the aerial boundary layer resistance and describes the role of the interface between canopy and atmosphere in the water vapour transfer; the second one (r_c) is the resistance that the canopy opposes to the diffusion of water vapour from inner leaves toward the atmosphere and it is influenced by biological, climatological and agronomical variables. This model is applied to the whole plant community as if it were a single “big leaf” located at the height of virtual momentum absorption (Thom, 1975).

The degree of empiricism of the Penman-Monteith equation (and consequently its success) mainly depends on the accuracy of the estimation of the canopy resistance (Beven, 1979). Rana and Katerji (1998) demonstrated that the canopy resistance plays the major role:

- In general when the crops are submitted to water stress: which is the case in Mediterranean region;
- In the case of medium and tall crops, also when the crops are well watered. On the other hands, for short crops, such as the grass meadow, its role is weak.

Thus, the r_c modelling is the most critical point of the Penman-Monteith model to estimate actual crop ET under Mediterranean climate.

The most complete model of r_c should have the following general form (Stewart, 1988; 1989):

$$r_c = f\left(LAI, R_g, VPD, T, \text{crop water status}\right) \tag{13}$$

where R_g is global radiation, T air temperature.

The rc modelling starting from the relation (13) needs to determine the adjustment function *f a posteriori* (Stewart, 1988), for each experimental conditions and for every variables in the Eq. (13) (Stewart, 1988; 1989).

Katerji and Perrier (1983), following a dimensional analysis, proposed to model the resistance r_c by means of a relation like:

$$\frac{r_c}{r_a} = a\frac{r^*}{r_a} + b \tag{14}$$

where *a* and *b* are empirical calibration coefficients which require experimental determination. r^* (s m^{-1}) is given as:

$$r^* = \frac{\Delta + \gamma}{\Delta\gamma}\frac{\rho c_p D}{A} \tag{15}$$

This resistance, r^*, is linked to the isothermal resistance ($r_i = \rho c_p D/\gamma H$) introduced for the first time by Monteith, (1965); it can be considered as a "climatic" resistance, because it depends only on weather variables.

This model, firstly thought for well watered crops, has been adapted to crops cultivated in Mediterranean region in different water conditions, by Rana *et al.* (1997a; 1997b; 2001). This adaptation has been realised by analysing the relationship between the ratios r_c/r_a and r^*/r_a with the predawn leaf water potential, Ψ_b. This parameter represents the crop water status and it does not need to be measured instantaneously, but just once a day. The application of a such model in semi-arid environments gives quite good results. Afterwards, Rana *et al.*, (1997b; 2001) demonstrated that the calibration carried out for a given species can be generalised.

It is possible to simplify the model by using the transpirable soil water as input of the model instead of Ψ_b, but in this case the model looses its generality and must be locally calibrated (Rana *et al.*, 1997c).

ET empirical models

By these methods the water consumption of crops is estimated as a fraction of the reference evapotranspiration (ET_0):

$$ET = K_c \cdot ET_0 \tag{16}$$

where K_c is the experimentally derived crop coefficient and ET_0 is the maximum evapotranspiration; this latter can be evaluated i) on a reference crop or ii) on free water in a pan. The accuracy of a such estimation depends on:

- the chosen reference (grass meadow or free water in a standard pan);
- the used method to evaluate reference ET (measurement or modelling);
- the method used to evaluate the crop coefficient K_c.

Moreover, the data necessary for the determination of reference evapotranspiration ET_0 are usually collected in standard agrometeorological stations. These stations are usually installed to be representative of the catchment, i.e. an area of several squared kilometres in extension.

ET_0 is the water consumed by a standard crop. In order to make procedures and results comparable world-wide, a well adapted variety of clipped grass has been chosen. It must be 8 to 16 cm high, actively growing and in well watered conditions, subjected to the same weather as the crop whose water consumption is to be estimated. ET_0 can be again measured (for example by means of a weighing lysimeter) or estimated. So that, also about ET_0 the comments and observations made for actual crop ET are along valid. In the following we analysed the more and used models of ET_0.

Today the most used and suggested method to evaluate reference ET is based on the Penman-Monteith model, so that it suffers of the same problems encountered in actual crop ET estimation regarding r_c modelling.

Several authors proposed an ET_0 Penman-Monteith formula using constant value of r_c (Allen et al., 1989). This approach has been proposed in the bulletin FAO 56, for estimating the crop water requirements.

Steduto *et al.*, (1996) tested such ET_0 estimates with constant r_c in several Mediterranean regions. Their results demonstrated that this approach has not good performances in all the experimental sites.

For calculating ET_0 Rana *et al.*, (1994) and Todorovic, (1997) proposed a resistance r_c, for the grass variable following the climatic conditions. In the climatic conditions of the Mediterranean region, the estimation of ET_0 obtained by the authors are much more accurate than those obtained by following the approach proposed by Allen *et al.*, (1989).

Other simplest methods to estimate reference crop ET are based on statistical-empirical formulas (an exhaustive review of these methods can be found in Jensen *et al.* 1990). These methods can be used very easily from the practical point of view, above all in rural lands, but their empiricism may lead to very inaccurate estimations, as clearly shown by Ibrahim (1996), in arid environments.

Pan evaporation data can be used to estimate reference ET, using a simple proportional relationship:

$$ET_0 = K_p \cdot E_{pan} \qquad (17)$$

where K_p is dependent on the type of pan involved, the pan environment in relation to nearby surfaces and the climate. Doorenbos and Pruitt (1977) provided detailed guidelines for using pan data to estimate reference ET_0. In the case of pan surrounded by short green grass K_p ranges between 0.4 and 0.85. In semi-arid environments its mean value is about 0.7 (Jensen et al., 1990). The value of K_p to be adopted is strongly dependent on the upwind fetch and on the local advection.

Adaptation of the crop coefficient K_c to the water stress conditions

The crop coefficient represents an integration of the effects that distinguish the crop from the reference ET; many such K_c are reported in literature (e.g. Doorenbos and Pruitt, 1977; Allen *et al.*, 1998) usually derived from soil water balance experiments.

Crop coefficient can be improved for estimating the effects of evaporation from wet soil, but also in water stress conditions, on K_c on a daily basis (Wright, 1982). In this case the crop coefficient can be expressed by the equation:

$$K_c = K_s \cdot K_{cb} + K_e \qquad (18)$$

where K_s is a stress reduction coefficient (0÷1). It can be experimentally calculated in function of soil water storage S and depends on the amount of soil available to the plants' roots. In fact, in open soil systems, when the conditions are favourable for root system development, it is almost constant, also when soil humidity decreases considerably, because of an appreciable contribution of the non-rooted soil layer to the water balance. In closed soil systems (pots for example) K_s is variable and following the soil humidity and it begin to decrease appreciably for values of soil water reserve approximately 60 to 70% of available soil water to transpiration.

K_{CB} is the basal crop coefficient (0÷1.4) and represents the ratio of ET and ET_0 under conditions when the soil surface is dry, but where the soil water content of the root zone is adequate to sustain full plant transpiration; K_e is a soil water evaporation coefficient (0÷1.4).

The methods to estimate crop coefficients and reference ET have been recently modified by Allen *et al.* (1994a), Allen et al. (1994b) and Allen *et al.* (1996).

Crop coefficient play an essential role in practice (Pereira et al., 1999) and has been (and is still) widely use to estimate actual ET for irrigation scheduling purposes. However, it can be subject to serious criticisms, regarding the meaning and the use of crop coefficient. Besides obvious variations among different crops, empirical crop coefficients have been shown to be affected by crop development and by weather conditions (De Bruin, 1987). Furthermore, Stanghellini *et al.*, (1990) demonstrated that they should be expected to vary according to the conditions of both climate and crop stage under which they are derived. Moreover, these researchers stated that it cannot take for granted that estimates of crop water requirements based on the same crop coefficient next month, next season and, above all, another place will have the same accuracy. This inaccuracy of K_c approach can be found in the discrepancies between local calculated K_c and crop coefficients reported in literature (e.g. Rana *et al.*, 1990; Vasic *et al.*, 1996).

Recently Katerji and Rana (2006) demonstrated that the direct ET estimation approach gives much more reliable results than the K_c approach in determining the actual crop evapotranspiration of agricultural crops (both herbaceous and orchard trees), at hourly and daily scale, in Mediterranean region.

CONCLUSION

We have demonstrated here the strengths and limitations of number of methods used for measuring ET in Mediterranean region. Today, the micrometeorological methods appear as the best ones: they are as accurate as the direct method in addition to being mobile and more representative of the measured surface. In order to be fully efficient, however, these methods require strict technical monitoring during manipulation.

Nowadays, the most interesting ET estimation methods are those based on the direct estimation of this variables, instead of the indirect estimation which needs an intermediate step with the determination of the reference evapotranspiration ET_0. The using of these kind of models is today limited by the need of determining a certain number of climatic variables, to be measured above the crop. The possibility of using a direct models, with standard meteorological variable as input, can be an appropriate solution to make more simple its application in practice. This is an interesting research which merits to be investigated in the future.

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