ACTUAL EVAPOTRANSPIRATION ESTIMATION FOR CEREALS CROPPED IN COMPLEX TERRAINS IN MEDITERRANEAN ENVIRONMENTS

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Abstract
In this paper we present an operational model to estimate the actual evapotranspiration (*ET*) of crops cultivated on hilly terrains. This model is based on a Penman-Monteith type equation where canopy resistance is calculated in function of climatic variables. The estimation of *ET* is made by using meteorological variables simulated on sloped sites as inputs, by using the values measured at a reference site on plane linked to the topographic characteristics of the site. This model was validated at daily scales at four sites cultivated with wheat and oats, offering a wide range of slope and orientation values. The proposed model allows to verify the different steps for calculating the fluxes, to identify the eventual sources of error and to make the needed corrections. For this reasons, the proposed model seems to be particularly useful in practice.

Keywords: Daily Evapotranspiration, microclimate, topography, wheat, oat.

Introduction
The actual evapotranspiration (*ET*) of a cropped surface on hilly terrain, at plot scale, is driven by local microclimate as well as influenced by topographic characteristics such as slope, orientation and altitude of site (i.a. Rana *et al.*, 2007). The solutions proposed to estimate *ET*, and energy fluxes in general, on sloped site are difficult to apply for practical purposes, i.e. they are not operational, because of the number of needed input variables and the complex calculation required. A simple "operational" model is here presented to estimate the daily *ET* of a crop cultivated on slope, at plot scale. The model presented uses variables measurable at a reference site on plane and simple calculation procedures. The approach has the following characteristics: (i) *ET* modelling is based on a Penman-Monteith (PM) type equation (Monteith, 1965) where canopy resistance is simulated by following an approach already illustrated by Katerji and Perrier (1983); (ii) the estimation of *ET* is made by using the meteorological variables simulated on sloped site as input; (iii) these variables are simulated by using simple relationships linking the meteorological variables measured at a reference site on plane to the topographic characteristics of the site (slope, orientation, altitude). The validation tests were performed in south Italy on wheat and oats crops, grown on sites having contrasted topographic conditions.

Material and methods
The proposed *ET* estimation is based on the PM equation originally formulated for crops cultivated on plane sites (Monteith 1965), where the aerodynamic resistance r_a was calculated between the top of the crop and a reference point z sited in the boundary layer above the canopy, following Perrier (1975a; 1975b). By following Katerji and Perrier (1983) the canopy resistance was linearly related to climatic resistance r^* (s m^{-1}) (Monteith, 1965; Rana *et al.*, 2011) and r_a. Thus the hourly latent heat flux can be written as:

$$\lambda E = \frac{1+\frac{\gamma}{\gamma+\Delta}\frac{r^*}{r_a}}{1+\frac{\gamma}{\gamma+\Delta}\left(a\frac{r^*}{r_a}+b\right)}\cdot\frac{\Delta}{\Delta+\gamma}A \qquad (1)$$

To determine *ET* it is necessary to carry out the following steps: (i) to measure the following meteorological variables: available energy, wind speed, air temperature and humidity – these measurements are usually carried out on surfaces on plane site; (ii) to calibrate the model by determining coefficients "*a*" and "*b*". These two parameters translate the response of the canopy resistance r_c to the climate and they are specific for each crop species (see the review by Katerji and Rana, 2008). Available energy (A in W m^{-2}) in slope was calculated from global radiation estimated from direct and diffuse radiations as indicated in Rana *et al.*, (2007). The wind speed for calculating r_a on slope was calculated following Taylor and Lee (1984) as:

$$u = u_{ref}\left(1+\Delta Sh\cdot\frac{\Delta z}{h}\right) \qquad (2)$$

where u_{ref} (m s^{-1}) is the wind speed at the reference point on plane, Δz (m) is the difference between the mean height of the cell i and the reference point (usually the bottom of the catchment), h (m) is the maximum height of the hill and ΔSh is a sinusoidal function taking into account the shape of the hill. The temperature difference between the reference site (T_{ref}) and the site on slope depends on the air temperature measured at the reference site on plane and on the difference in altitude Δz between the reference and the experimental sloped sites (T_s), so:

$$T_s = T_{ref} + \Delta z\cdot\Gamma \qquad (3)$$

where Γ is the temperature lapse rate equal to 0.01 K m^{-1}.
Summarizing, *ET* was estimated by eq. (1). In this case the available energy, the wind speed, the air temperature and the air humidity at four sloped sites were directly measured using the equipment installed in the site on plane (all the details of the calculation can be found in Rana *et al.*, 2011).
Two trials were carried out to test the model in a small catchment of Volturino (Foggia), southern Italy, which experiences Mediterranean climate. The whole catchment area was 40 ha. Side slopes ranged from 1° to 12° and the maximum height was 410 m. The soil was classified as silt

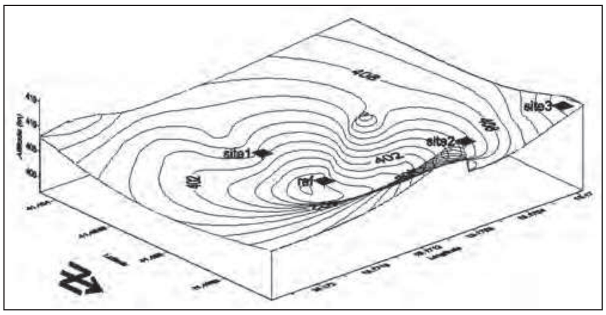

Fig. 1 - The Volturino catchment with the 4 measurement points. Reference site in plane at the bottom of the catchment; Site1 NW exposed, orientation of the plot (O) 310°, slope of 9°, 7 m is the difference in altitude from the reference; Site2 SE exposed, O 125°, slope of 6°, 12 m; Site3 SE exposed, O 120°, slope of 1°, 18 m.

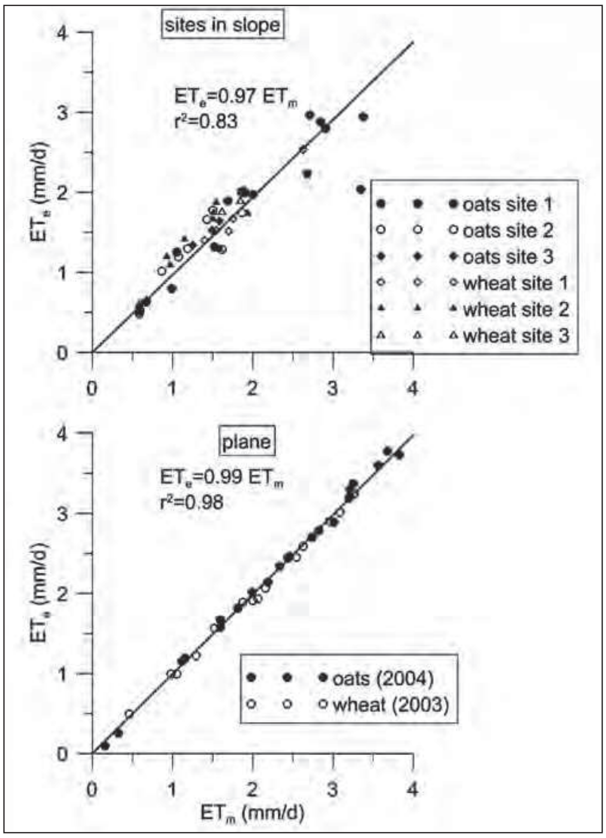

Fig. 2 - Comparison, for wheat and oat, between estimated and measured ET at daily scale, for all sloped sites, and the reference site in plane.

loam. The first trial was carried out from May to June 2003 on winter wheat (Triticum durum L., sowing date 15 November 2002) from earing up to senescence stages, with a measured green LAI ranging from 2.5 to 3.1 and a maximum height of 1 m. The second trial was carried out from end April to early June 2004 on oat crop (sowing date 3 November 2003) during the grain filling stage. In this case the green LAI was 3.2 and the height 1.3 m. The catchment is described in Figure 1. For validating the estimations, *ET* was directly measured by eddy covariance technique in the four sites (reference, 1, 2 and 3).

Results and Conclusions

The daily values of estimated and measured *ET* were calculated by the sum of hourly values, from 8:00 a.m. to 7:00 p.m. on each day, this sum is then transformed in mm day^{-1}. Figure 2 shows the comparison between estimated and measured *ET* at daily scale. In the classic models of fluxes in slope the calculation of the fluxes is often made by using iterative processes. Therefore, in general, they can be considered as “black boxes”. The user may only accept or reject the ability of the model to estimate the fluxes in slope with a given accuracy. The proposed model, having very good performances, offers to the user the possibility of verifying the different steps of computation and to identify the eventual sources of error (e.g. climatic variables simulated in function of the topographic characteristics of the plot, the modelling of the canopy resistance, the calculation of the fluxes) and to eventually make the suitable corrections.

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