Measuring crop evapotranspiration over hilly areas

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1 Introduction

Agricultural production systems around the Mediterranean basin rely mostly on rainfed agriculture in hilly watersheds, although some irrigation is sustained downstream of water reservoirs. With climate change and increasing demand for water, most commonly cultivated species, particularly cereals, are exposed to high risks of water shortages during the growing season. Under such threats, managing agricultural activities, for optimum water use, requires a good assessment of crop actual evapotranspiration (ET), a major term of both land surface energy and water balances. In practice, ET could be obtained either from direct measurements or through estimations by models using weather and soil moisture data. The eddy covariance technique (EC), based on high-frequency measurements of fluctuations of wind speed and air temperature/humidity, is a direct method used to determine the convective fluxes between land surface and atmosphere in terms of sensible heat flux and latent heat flux which is equivalent to ET. However, characterizing evapotranspiration over crop fields in a hilly terrain requires accounting for relief influences. First, solar and net radiations are larger over south-facing slopes (Raupach and Finnigan 1997; Holst et al. 2005). Second, soil water content increases when coming closer to the valley bottom (Hugo et al. 2013). Third, boundary layer conditions are typified by specific regimes in terms of thermal stratification, airflow, wind speed and wind vertical profile (Raupach and Finnigan 1997). Such constraints are not considered in operational models used for ET estimation, including the widely adopted Penman-Monteith (ETo) or FAO-56 method (Allen et al. 1998).

The main objective of this study was to assess the variability of ET during the period of active growth for wheat in a hilly watershed of northern Tunisia, using flux measurement stations. Experimental data were compared to ET estimations based on reference evapotranspiration (ETo) and crop coefficients.

2 Materials and Methods

The experiment was conducted in three wheat fields, located within the hilly area of Cap-Bon -Tunisia. Two flux measurement stations were installed in sloping parcels (A, B) on opposite rims and the third in a flat area (C) within a watershed. In situ monitoring of sensible heat and water vapor fluxes, net radiation and weather factors covered the months of active growth for wheat (January–April 2013). During the experiment, micro-meteorological instability combined with instrumental dysfunctions reduced the volume of complete data sets. With many missing data in the obtained time series, we had to use the gap-filling method

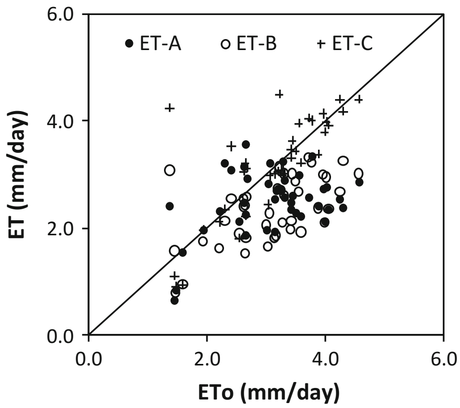

Fig. 1 Daily ET values of wheat estimated in sloping (A, B) and flat (C) fields versus ETo during the mid-season (March 01–April 15, 2013)

based on the LE/Rn ratio to derive daily ET values from hourly records, following the technique proposed by Roupsard et al. (2006). Reference evapotranspiration (ETo) was determined from meteorological measurements, according to the Penman-Monteith equation (Allen et al. 1998).

3 Results and Discussion

Daily ET measurements obtained in the different sites were compared to corresponding ETo values. Figure 1 shows an important scatter of ET data, reflecting important variations in precipitations and climate demand conditions during the growing season. Strikingly, most of ET points are found below the line 1:1, while empirically ET/ETo ratio, or crop coefficient, of the wheat crop is supposed to be around 1.15 during periods of full vegetation (Allen et al. 1998). Several authors reported on cases of underestimation of ET by the EC method, arguing that EC overestimates the available energy and underestimates the convective energy (Twine et al. 2000; Evett et al. 2012a, b). The results of Fig. 1 also indicate that differences between ETo and ET are more obvious for sloping sites (A, B) than for horizontal terrain (C). Field configurations could be associated to the effect of slope and aspect, inducing in the case of upslope winds a low evapotranspiration (stomata closure and increasing of the aerodynamic resistance), and in the case of down slope winds high evapotranspiration (Rana et al. 2007).

On the overall, ET or water consumptive use by the wheat crop reported in Fig. 1 is frequently higher on the flat terrain (C) than on sloping fields (A and B). This means that relief has an effect on ET, regardless of the possible systematic underestimations inherent to EC measurements.

During the life cycle of the crop, ET increases following vegetation growth and in response to increasing ETo. Calculation of mean values over the main growth stages of wheat shows smaller ET averages in the sloping fields (A, B) compared to flat conditions (C) (Table 1). ET was at a minimum of 1.6 for sloping fields and 1.8 for flat area (C) at early stages of crop development in winter (17/01–28/02) and maximums of 2.3 and 3.2 mm/day during the period of maximum vegetation (01/03–15/04). ETo increased during the same period from 1.9 to 3.1 mm/day. Under adequate water supply, the ratio ET/ETo, representing empirically the crop coefficient Kc, is considered to reach its maximum at full crop growth. ET/ETo ratios during the mid-season stage (March 1–April 15) were 0.81, 0.74 and 1.03, respectively, for field A, B and C (Table 1), well below the commonly used value of 1.15, proposed by the FAO-56 paper (Allen et al. 1998).

The differences are basically in the range of 10–30%. These results suggest that it is necessary to take into account topography in order to have accurate ET estimates when using the Penman-Monteith model outside standard conditions.

Table 1 Daily averages of ET (mm/d) for the wheat crop and ratios of ET/ETo (FAO Penman-Monteith), showing the range of evapotranspiration reduction in sloping terrain

Period	Development (17/01–28/02)		Mid-season (01/03–15/04)	
	ET (mm/d)	ET/ETo	ET (mm/d)	ET/ETo
Reference ETo	1.9	1.0	3.1	1.0
Sloping site (A)	1.6	0.84	2.5	0.81
Sloping site (B)	1.6	0.84	2.3	0.74
Flat area (C)	1.8	0.94	3.2	1.03
FAO method	1.7	0.90	3.7	1.15

4 Conclusion

Used in a comparative study of evapotranspiration over changing topography, Eddy Covariance method showed very good performances in semi-arid environments, despite some problems linked to sensors and missing data. Measurements demonstrated substantial reduction in water consumption for wheat grown on sloping fields. For daily ETo variations between 2.0 and 4.0 mm/day, ET of actively growing wheat was in the range of 1.6–3.2 mm/day, well below estimations based on ETo according to FAO method. Reductions of 10–30%, were associated to effects of slope and aspect of terrain, suggesting that the EC method is appropriate for testing land surface water and energy balance models. Also, correction factors, taking into account topography, should be used in hilly areas for more accurate estimations of ET.

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