QUANTIFICATION OF EVAPORATION FROM BARE SOILS IN A CHANGING CLIMATE

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Abstract: The purpose of this study was to predict the rate of changes in evaporation from bare soils in a Mediterranean environment of Turkey in response to climate change.

Climate change data projected with a regional climate model developed in Japan (hereafter RCM) were used. In order to calculate the rates of reference evapotranspiration and soil evaporation, the necessary daily RCM data were obtained for the periods of 1994 to 2003 and 2070 to 2079. Potential evaporation rate from bare soils was calculated using the Penman-Monteith equation with a surface resistance of zero. Simulation of actual soil evaporation rate was carried out using Aydin model (described in detail by Aydin et al., Ecol. Modelling, 182: 91-105, 2005) combined with Aydin and Uygur approach (Proceedings of 18th International Soil Meeting-ISM, Şanlıurfa-Turkey, ISBN 975-96629-3-0, Volume 1: 477-480, 2006).

Potential evaporation from a reference crop and potential evaporation from bare soils are projected to increase mean annually by 8.0 and 7.3% (equivalent to 92 and 69 mm increases), respectively, in the Mediterranean region in response to an elevated evaporative demand of the atmosphere by the 2070s. On the contrary, actual evaporation from bare soils is projected to reduce by 16.5% (equivalent to 50 mm decrease) due to decreased rainfall, and consequently, decreased soil wetness in the future.

During the wet period of November to May when actual evaporation is close to potential one, the fields should be kept cropped to increase beneficial use of soil water by crops, consequently to prevent water loss through evaporation from soils. Alternatively, adoption of such agronomic practices as retention of crop residues or formation of a natural layer of mulch on the soil surface when evaporation rate is most rapid may play a significant role in the magnitude of reduction in soil water loss. Summer fallow is not practiced under the current climatic conditions of the study area but may be adopted in the case of a decrease in rainfall by 46% projected by RCM.

INTRODUCTION

Recently, global climate change has been of great interest due to its unprecedented magnitude and rate of potential impacts on health and well-being of the world. The globally averaged surface temperature is projected to increase over the period of 1990 to 2100 (IPCC, 2001). Precipitation is not likely to increase in (semi)-arid regions where the effects of climate change on soil water balance may become a major concern as the increased temperature stimulates the evaporative demand of the atmosphere. In such regions, evaporation from the soil surface constitutes a large fraction of the total water loss not only from bare soils but also from cropped fields.

The evaporation from bare soils depends not only on the atmospheric conditions but also on soil properties. Many simple models are available which give a reasonable prediction of evaporation from bare soils.

Aydin et al. (2005) validated a simplified model for estimating actual soil evaporation using soil water potential measured at the top surface layer. They concluded that the model was potentially valuable, but the objective measurement of soil water potential near the surface of the profile was difficult especially for drier upper layer. In order to overcome such difficulties, a simple model for predicting soil water potential at the top surface layer was described by Aydin and Uygur (2006). On the other hand, a regional climate model (RCM) has been developed in Japan to evaluate sufficiently climate change on a regional scale (Sato et al., in press).

The purpose of this research was to predict the rate of changes in evaporation from bare soils in response to climate change projections by RCM.

MATERIALS AND METHODS

Models

A simple model validated by Aydin *et al.* (2005) (hereafter called Aydin model) was applied to estimate actual soil evaporation using soil water potential at the top surface layer:

$$E_a = \frac{\text{Log}\,|\Psi| - \text{Log}\,|\Psi_{ad}|}{\text{Log}\,|\Psi_{tp}| - \text{Log}\,|\Psi_{ad}|} E_p \qquad (1)$$

where E_a and E_p are actual and potential evaporation rates (mm d^{-1}), respectively; Ψ_{tp} is the absolute values of soil water potential (matric potential) at which actual evaporation starts to drop below potential one; Ψ_{ad} is the absolute values of soil water potential at air-dryness; Ψ is the absolute value of soil water potential determined between the range of Ψ_{tp} and Ψ_{ad}. The values of all Ψ are in cm of water.

Daily potential evaporation from bare soils (E_p=kg m^{-2} d^{-1}≈mm d^{-1}) can be calculated using the Penman-Monteith equation (Allen et al., 1994) with a surface resistance of zero (Brisson et al., 1998; Wallace et al. 1999):

$$E_p = \frac{\Delta(R_n - G_s) + 86.4\rho c_p \delta / r_a}{\lambda(\Delta + \gamma)} \qquad (2)$$

where Δ is the slope of saturated vapor pressure-temperature curve (kPa $^{o}C^{-1}$), R_n is the net radiation (MJ m^{-2} d^{-1}), G_s is the soil heat flux (MJ m^{-2} d^{-1}), ρ is the air density (kg m^{-3}), c_p is the specific heat of air (kJ kg^{-1} $^{o}C^{-1}$=1.013), δ is the vapor pressure deficit of the air (kPa), r_a is the aerodynamic resistance (s m^{-1}), λ is the latent heat of vaporization (MJ kg^{-1}), γ is the psychrometric constant (kPa $^{o}C^{-1}$), and 86.4 is the factor for conversion from kJ s^{-1} to MJ d^{-1}.

Assuming that the water potential at dry soil surface is at equilibrium with the atmosphere, Ψ_{ad} (cm of water) can be derived from the Kelvin equation (Brown and Oosterhuis, 1992; Kirby and Ringrose-Voase, 2000; Aydin et al., 2005):

$$\Psi_{ad} = \frac{R_g T}{mg} \ln H_r \qquad (3)$$

where T is the absolute temperature (K), g is the acceleration due to gravity (981 cm s^{-2}), m is the molecular weight of water (0.01802 kg mol^{-1}), H_r is the relative humidity of the air (fraction), and R_g is the universal gas constant (8.3143x10^4 kg cm^2 s^{-2} mol^{-1} K^{-1}).

Since the objective measurement of soil water potential near the surface of the profile is difficult especially for drier upper layer (Aydin et al., 2005), a simple model for predicting soil water potential (Ψ =cm of water) at the top surface layer was described by Aydin and Uygur (2006):

$$\Psi = -[(1/\alpha)\ (10\sum E_{ps})^3 / 2(\theta_{fc}-\theta_{ad})\ (D_{av}\ t/\pi)^{1/2}] \qquad (4)$$

where α is a soil specific parameter (cm) related to flow path tortuosity in the soil; $\sum E_{ps}$ is cumulative potential soil evaporation (cm); θ_{fc} and θ_{ad} are volumetric water content (cm^3 cm^{-3}) at field capacity and air-dryness, respectively; D_{av} is average hydraulic diffusivity (cm^2 day^{-1}) which should be determined experimentally; t is time (day); π is the pi (3.1416).

Location and climate change projections

Study site, Adana (36°59′N, 35°18′E) is located in the Cukurova region, a southern Mediterranean environment of Turkey. The climate of the region is subhumid-semiarid Mediterranean with mild rainy winters and hot dry summers.

The historical data for the study location were obtained from DMI (Turkish State Meteorological Service) for the period 1994-2003 (basedata). Climate change data projected with a regional climate model developed in Japan (hereafter RCM) were used (Sato et al., in press). In order to calculate reference evapotranspiration (*ET*r) and soil evaporation, the necessary daily RCM data were obtained for the periods 1994-2003 and 2070-2079.

Experimental studies and calculations

In order to evaluate the performance of the model described by Aydin and Uygur (2006), a pot-experiment was carried out in a chamber using soil psychrometers installed at depth of 1 cm below the soil surface and connected to Eight Channel Water Potential System (WESCOR Inc.). Details of the pot-experiment were reported by Aydin and Uygur (2006).

For field conditions, potential evaporation from a reference crop (ET_r) was computed with the Penman-Monteith equation for vegetated surface (Allen *et al.*, 1994; Desborough *et al.*, 1996). Daily potential evaporation from bare soils (E_p) was calculated using the Penman-Monteith equation with a surface resistance of zero. In calculations, albedo of bare soil was assumed to be 0.15 (Van Dam *et al.*, 1997; Ács, 2003). We used 60.0 cm of water as Ψ_{tp} in Eqn (1) for the clay soil as suggested by Aydin *et al.* (2005). For validation, actual soil evaporation was measured under field conditions with three replicated micro-lysimeters installed in the experimental plot according to Aydin et al. (2005). In this study, α for the experimental soil was taken as 1.0 cm in the calculations of soil water potential by Eqn (4). θ_{fc} was measured as 0.35 ($cm^3\ cm^{-3}$), θ_{ad} and D_{av} were assumed to be 0.05 ($cm^3\ cm^{-3}$) and 95 ($cm^2\ day^{-1}$), respectively, for clay soils.

RESULTS AND DISCUSSION

A comparison of measured and simulated soil water potential (as suction values) is shown in Figure 1. It can be seen that the simulated and the measured suction values compare reasonably well for a wide range. However, apart from errors in measurements, the systematic errors in the model parameters used should be considered. For example, in a nonlinear system, some average value for diffusivity can be used. This must be a weighted average for many purposes since water movement in the region of highest diffusivity often predominates. However, in a drying system, a single and constant "weighted mean diffusivity" is itself an oversimplification. For a more realistic treatment, the diffusivity values for different ranges of water content must be determined experimentally. The other reasons of considerable differences between estimated and measured values could be the complexity of water regime of the clay soil. It is a fact that the estimation of water potential of swelling soils is trickier to interpret as compared with non-swelling soils. In spite of this fact, trajectory of the estimated and measured soil water potential values (Fig. 1) is in agreement with the literature (Hillel, 1980, see: Fig. 8.2).

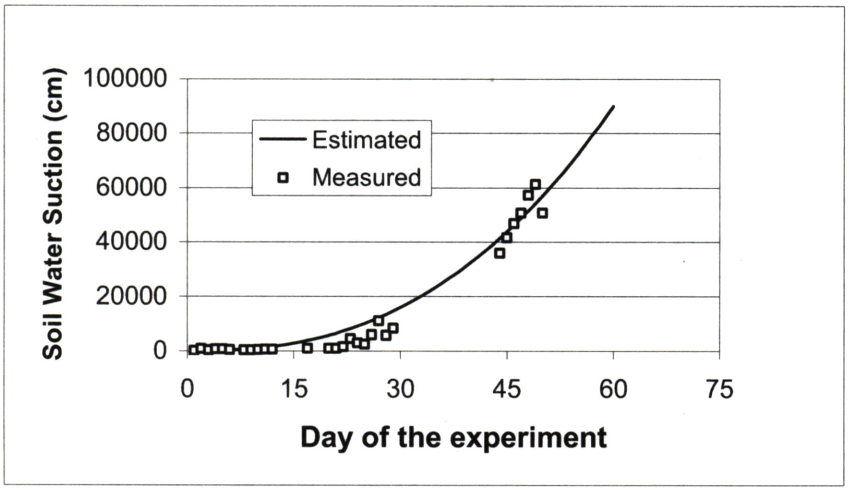

Figure 1. Comparison of estimated and measured soil water-suction at the depth of 1 cm.

A comparison of measured and simulated soil evaporation is given in Figure 2. The scatter of data is high, although there are some deviations. The models tested in this study appear to be applicable for a wide range of soils if soil specific parameters are used.

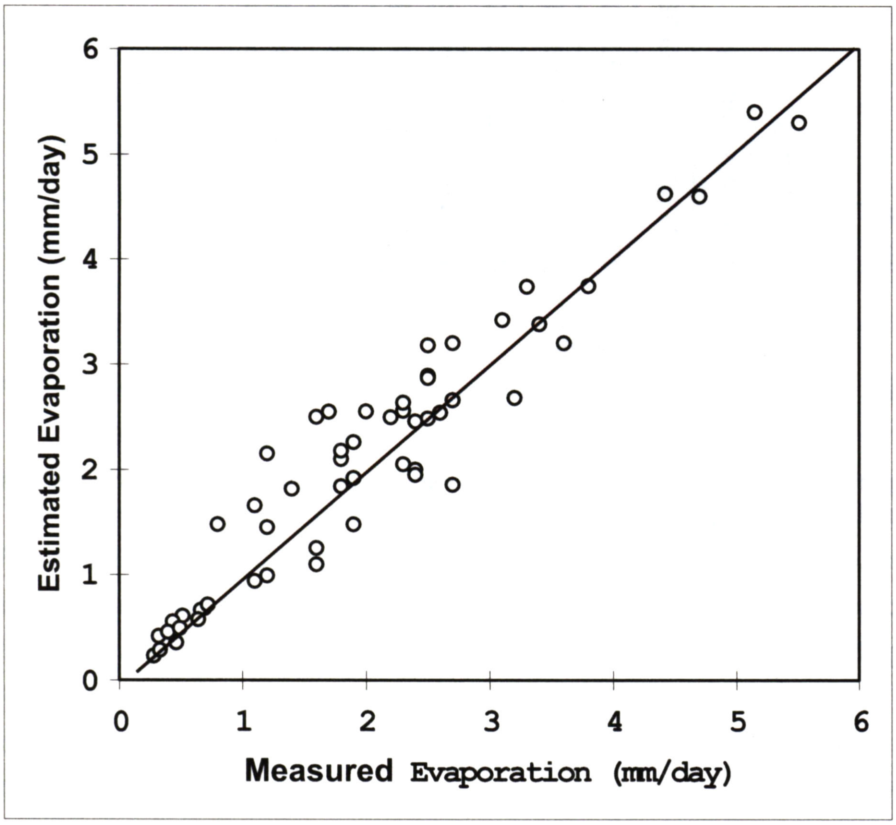

Figure 2. Estimated soil evaporation versus measured one.

A comparison of mean monthly potential evapotranspiration from reference crop (*ET*r) for the present (1994-2003) and the future (2070-2079) in Adana is depicted in Figure 3. *ET*r values were higher for the future than for the present in response to an elevated evaporative demand of the atmosphere by the 2070s.

Monthly variations of potential soil evaporation (*E*p) for the periods of 10 years from 1994 and from 2070 in Adana are given in Figure 4. *E*p values show a similar trend for *ET*r. The evaporation from bare soils depends not only on the atmospheric conditions but also on soil properties. *E*p values were lower during the winter months because of the lesser atmospheric demand for both present and future. Similarly, a comparison of monthly actual soil evaporation (*E*a) estimated by Aydin model from the RCM data for Adana in the present and the future is shown in Figure 5. In general, *E*a rates were very low in the summer season and high in the spring months because of rainfall pattern and presumably soil wetness. It is very well known that evaporation occurs in two distinct phases. During the first stage, surface resistance is zero, and the evaporation from the soil proceeds at the potential rate. During the falling rate stage, with a dry layer at the surface, the evaporation rate is reduced (Ritchie, 1972).

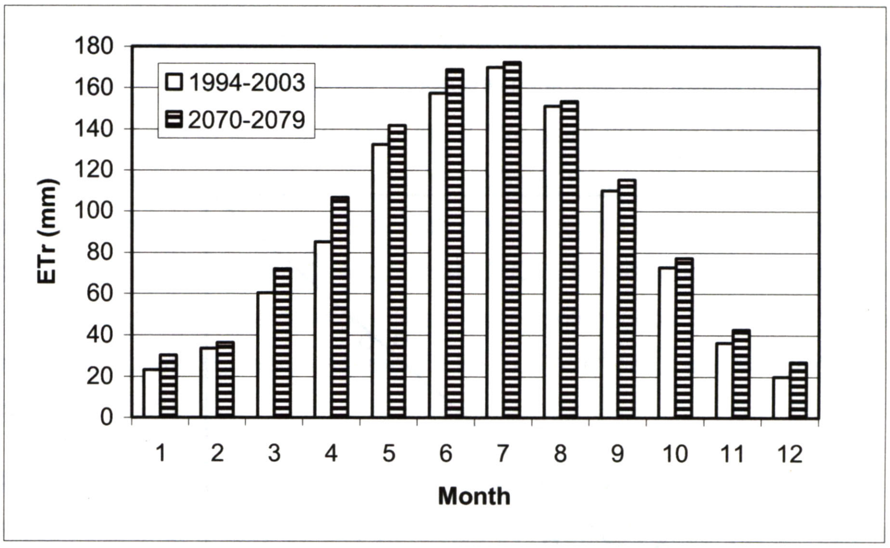

Figure 3. Comparison of mean monthly reference evapotranspiration (*ET*r) for the periods of 1994 to 2003 and 2070 to 2079.

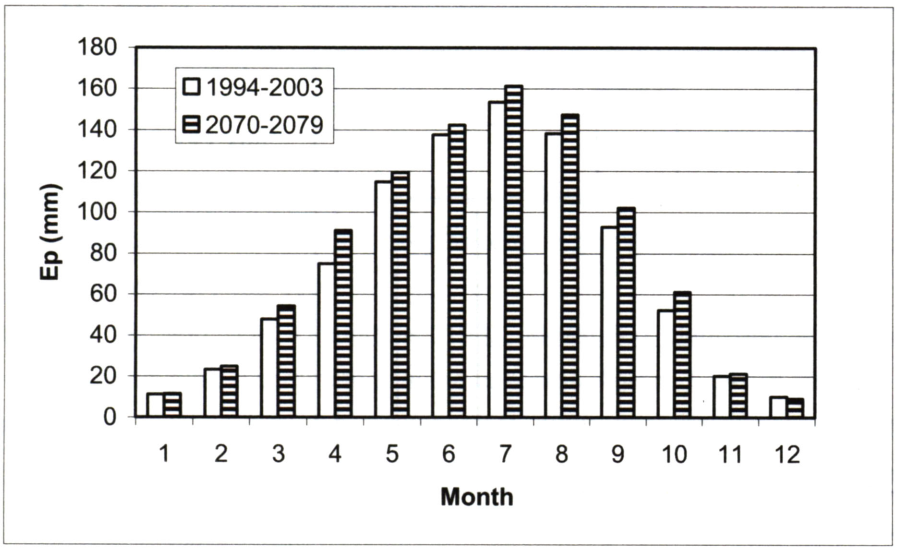

Figure 4. Comparison of mean monthly potential soil evaporation (*E*p) for the periods of 1994 to 2003 and 2070 to 2079.

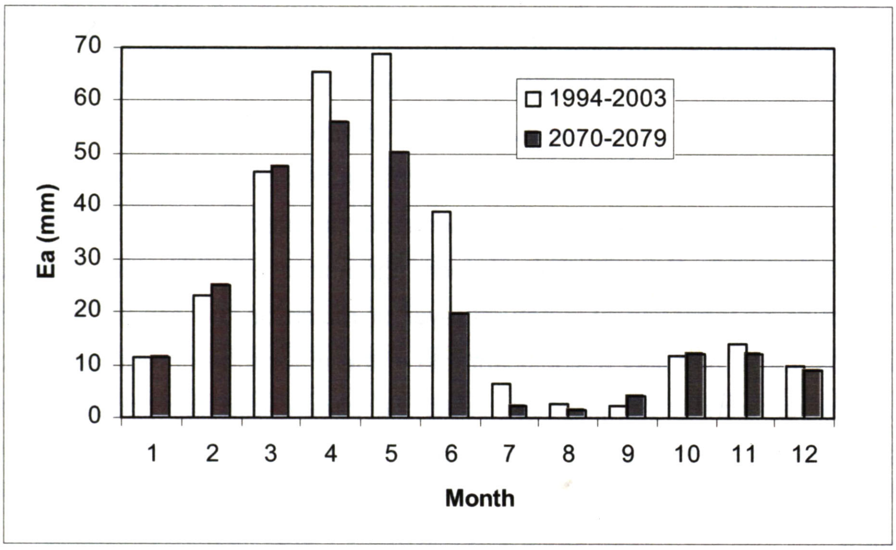

Figure 5. Comparison of mean monthly actual soil evaporation (*E*a) for the periods of 1994 to 2003 and 2070 to 2079.

Percent changes in the mean annual evaporation for present and future are compared in Figure 6. Both *ET*r and *E*p are projected to increase by 8.0 and 7.3% (equivalent to 92 and 69 mm increase) based on calculations from RCM data, respectively. This change would be caused by the predicted temperature increase (1.4 °C by the 2070s according to RCM) as well as changes in the other climatic data (not shown). Projected annual *E*a during 2070-2079 would decrease by 16.5% (equivalent to 50 mm decrease) relative to the baseline period of 1994 to 2003. In a warmer climate and under lesser precipitation, increased evaporative demand of the atmosphere favors soil dryness. Since projected mean annual precipitation during 2070-2079 compared with baseline would decrease by 306 mm according to RCM data.

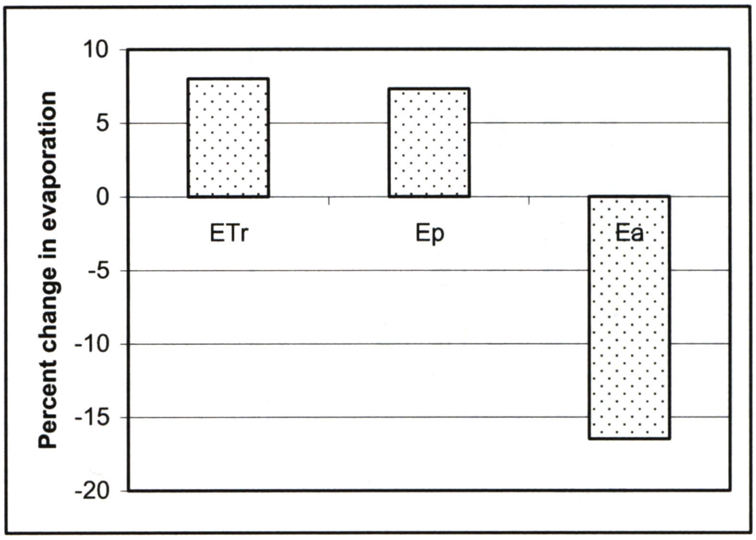

Figure 6. Percent changes in reference evapotranspiration (*ETr*), potential (*Ep*) and actual (*Ea*) soil evaporation by 2070s.

It can be concluded that potential evapotranspiration from reference crop and potential evaporation from bare soils in the Mediterranean environment will increase in the future. However, actual soil evaporation will decrease mainly due to lesser and erratic precipitation pattern, presumably soil wetness. During the wet period of November to May when actual evaporation is close to potential one (data not shown), the fields should be kept cropped to increase beneficial use of soil water by crops, consequently to prevent water loss through evaporation from soils. Alternatively, adoption of such agronomic practices that enhances retention of crop residues or formation of a natural layer of mulch on the soil surface when evaporation rate is most rapid may play a significant role in the magnitude of reduction in loss rate of soil water. Summer fallow is not practiced under the current climatic conditions of the study area but may be adopted in the case of a decrease in rainfall by 46% projected by RCM.

Acknowledgement

The research was financially supported by the Project – Impact of Climate Changes on Agricultural System in the Arid Areas (ICCAP), administered by the Research Institute for Humanity and Nature (RIHN) of Japan, and the Scientific and Technical Research Council of Turkey (TUBITAK).

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