Int. Agrophysics, 2005, 19, 159-164

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Comparison between experimental and estimated crop evapotranspiration in Romania

Cr. Paltineanu

Research Institute for Fruit Growing, 0312 Pitesti-Maracineni, Romania

Received July 5, 2004; accepted August 31, 2004

A b s t r a c t. The purpose of this paper is to compare experimental crop evapotranspiration ($ET_{c\text{-}exp}$) obtained under irrigation conditions in fields versus estimated values of crop evapotranspiration ($ET_{c\text{-}est}$) based on the Penman-Monteith reference evapotranspiration (PM-ET_o) and using the method developed by Allen *et al*. (1998), for various crops as well as for different soil and climate conditions in Romania. Crop coefficients (K_c) for some representative crops like: barley, wheat, maize, sunflower, sugarbeet, soybean, tomato, potato, alfalfa, peach, apricot, table grapes were calculated for the same period of time. ET_c was calculated using the above K_c multiplied by the mean values of PM-ET_o for the experimental period. The $ET_{c\text{-}exp}$ data were taken from the Romanian literature reported in Romania. The locations where the experiments took place were widely spread, covering large areas within the lowlands of this country (southern, eastern and western parts). Then, $ET_{c\text{-}est}$ data were correlated and compared with $ET_{c\text{-}exp}$ data for the above crops using common statistical procedures. A highly significant correlation between the estimated ET_c and experimental ET_c data was obtained for most of the crops. However, ET_c estimated by Allen's method was slightly lower than real ET_c for previously reported crops tested in this area. This could be attributed to inaccurate measurements of deep drainage and runoff in some of the experiments rather than to the deficiency of Allen's method. This paper confirms in Romania, with fairly good results, the method developed by Allen *et al.* (1998), in estimating K_c, and implicitly ET_c, for any region or watershed. The findings of this paper could also contribute to better water management in regions similar in climate with the Romanian territories discussed in this paper with many high water consumers.

K e y w o r d s: reference evapotranspiration, crop coefficients, irrigation application

INTRODUCTION

In Romania, Grumeza *et al*. (1989) and Paltineanu *et al*. (2000a; 2000b) among others, developed irrigation techniques and research methodologies, or reported crop coefficients (K_c) based on the Thornthwaite, class A pan evaporation or Penman-Monteith (PM) formula for various crops, climate and soil conditions. Much effort has been made recently to find a standard reference evapotranspiration (ET_o) method. Therefore, Jensen *et al*. (1990), Allen *et al.* (1998) and others recommended the Penman-Monteith evapotranspiration (PM-ET_o) as a standard method. Allen *et al*. (1998) developed an estimating procedure to calculate K_c and ET_c using the PM-ET_o method.

The purpose of this paper is to compare experimental crop evapotranspiration ($ET_{c\text{-}exp}$) obtained under optimum irrigation conditions in fields with estimated values of crop evapotranspiration ($ET_{c\text{-}est}$) based on PM-ET_o and using the method developed by Allen *et al*. (1998), for various crops as well as for different soil and climate conditions in Romania.

MATERIALS AND METHODS

The study area is located in the irrigable regions of Romania, within the lower plains and plateaus of this country, particularly in its southern, eastern and western parts. For these locations, PM-ET_o was calculated for the duration of the experiments using the combined equation (Monteith, 1965; CROPWAT program-Smith, 1992; Allen *et al.,* 1998) that utilizes monthly data of mean temperature, sunshine duration, air humidity and wind speed at 2 m above ground level:

$$\text{PM-}ET_o\ (\text{mm day}^{-1}) = (0.408\Delta\ (R_n\text{-}G)+900\gamma\ U_2(e_a\text{-}e_d)/(T_m+273))/(\Delta + \gamma(1+0.34U_2)) \quad (1)$$

where: R_n is the net radiation at the grass surface (MJ m^{-2} day^{-1}); G is the calorific soil flux (MJ m^{-2} day^{-1}); Δ is the slope of water vapor pressure curve (kPa °C^{-1}); γ is the psychrometric constant (kPa °C^{-1}); U_2 (m s^{-1}) is the wind

Corresponding author's e-mail: cristian_paltineanu@yahoo.com

speed at 2 m above ground level; (e_a-e_d) is the water vapor pressure deficit (kPa) and T_m (°C) is the mean air temperature. Other formulas described in Doorendos and Pruitt (1977) and Jensen *et al*. (1990) were also used to compute the other indicators needed in this relationship.

Crop coefficients (K_c) for the following crops: barley, wheat, maize, sunflower, sugarbeet, soybean, tomato, potato, alfalfa, peach, apricot, table grapes for both mid-season ($K_{c\ mid}$) and final plant stage ($K_{c\ end}$) were calculated for the same period according to the formulae given by Allen *et al*. (1998):

$$K_{c\ mid} = K_{c\ mid}' + (0.04\,(U_2 - 2) - 0.004\,(RH_{min} - 45))\,(h/3)^{0.3} \qquad (2)$$

where: $K_{c\ mid}$' was tabulated in Allen *et al*. (1998) and was given for the conditions where the relative air humidity (RH_{min}) = 45% and the wind speed at 2 m agl (U_2) = 2 m s^{-1}; h denominated the average crop height. $K_{c\ end}$ was similarly estimated with the same formula by replacing $K_{c\ mid}$' with $K_{c\ end}$', also tabulated, and K_c initial ($K_{c\ ini}$) was taken from the same table (Allen *et al*., 1998). The procedure was similar to that presented by Doorenbos and Pruitt (1977). Crop coefficients for each 10-day period in the growing season were then plotted versus time for all the months of interest. ET_c was calculated using the above K_c multiplied by the mean values of PM-ET_o for the experimental period. These ET_c values estimated by the method developed by Allen *et al*. (1998) were expressed further as $ET_{c\text{-}est}$.

Experimental data on $ET_{c\text{-}exp}$ were used for: barley, wheat, maize, sunflower, sugar beet, soybean, potato, alfalfa, peach, apricot, table grapes. Here, $ET_{c\text{-}exp}$ was determined using the water balance equation in the field. The same method was used in these experiments for every crop. It consisted in measuring soil moisture content periodically, either gravimetrically or by use of neutron moisture meter, as a function of location and author. Run-off and deep drainage were estimated depending on the magnitude of the rainfall events. The sprinkler irrigation method was mostly applied in these experiments.

These $ET_{c\text{-}exp}$ data was taken from the Romanian literature reported in this country: Grumeza *et al*. (1970, 1979, 1989), Ionescu and Tomulet (1968), Ionescu (1976), Renea (1983), Enciu and Ploaie (1983), Iancu and Ionescu (1981), Iancu *et al*. (1998), Paltineanu *et al*. (2000 a, b). The locations where the experiments took place were widely spread, covering large areas within the lowlands of this country, of southern, eastern and western parts: Baneasa-Bucharest, Draganesti-Vlasca, Baneasa-Giurgiu, Berceni, Cateasca, Filaret, Videle, Maglavit, Bailesti, Caracal, Dor Marunt, Marculesti, Braila, Cosmesti-Tecuci, Podu Iloaiei, Suceava, Oradea, Arad, Timisoara, Cluj-Napoca, Gogosu-Slatina, Braila Island, Malu Mare-Craiova and Pitesti.

Then, $ET_{c\text{-}est}$ data were correlated and compared with $ET_{c\text{-}exp}$ data for the crops mentioned using common statistical procedures.

RESULTS AND DISCUSSION

Geographical distribution of annual Penman-Monteith evapotranspiration

Annual values of the geographical distribution of PM-ET_o are shown in Fig. 1. The lowest values, generally <500 mm, are located within the Carpathians peaks. The 700 mm PM-ET_o isoline actually represents the lower limit of the highlands and, implicitly, the highest limit of the plains and low plateaus. Annually, PM-ET_o values lower than 750 mm are generally met in the Moldovei Plateau and in the northern part of The Danube Plain, while values lower than 775 mm characterize the Tisei Plain, respectively. The southern part of the Danube Plain shows again the highest PM-ET_o values, up to 800 mm annually.

As the precipitation in Romania is unevenly distributed in time and space, and during summer the reference evapotranspiration generally exceeds precipitation (Clima RSR, 1966), irrigation is a widespread practice, particularly in locations where PM-ET_o > 750 mm annually. The places mentioned above are mostly located in this area.

Comparison between estimated evapotranspiration ($ET_{c\text{-}est}$) and experimental evapotranspiration ($ET_{c\text{-}exp}$)

$ET_{c\text{-}est}$ - $ET_{c\text{-}exp}$ correlation

The crops discussed here have specific features with regard to the $ET_{c\text{-}exp}$ magnitude that is different from crop to crop, month to month, and region to region as well. Winter cereals, *eg* wheat and barley, have a relatively high $ET_{c\text{-}exp}$ during spring, compared to other crops sown in April-May, such as corn or sugar beet, because they are well developed now and have important leaf area indexes (LAI). In mid-season, the crops possessing a high LAI value, like maize, alfalfa, sugar beet, soybean, *etc*., present a high $ET_{c\text{-}exp}$. Towards autumn, $ET_{c\text{-}exp}$ decreases abruptly with time, except for alfalfa, due to the rapid plant maturation and senescence.

For the crops investigated here, $ET_{c\text{-}est}$ and $ET_{c\text{-}exp}$ were compared and correlated. There was a linear correlation between these two indicators. The regression equations of these two parameters were highly significant for maize, wheat, alfalfa, sunflower, sugar beet, soybean, potato, apple and all crops together, distinctly significant for peach, and not significant for barley and table grapes, probably due to more errors in water measurement in the field (Figs 2 and 3).

For the crops presented, the coefficient of determination (R^2) varied between 0.51 (for potato) and 0.96 (for apple).

However, most of the crops, *eg* maize (0.85), alfalfa (0.73), sunflower (0.78), sugar beet (0.86), soybean (0.84), peach (0.91) and apple (0.96), revealed a strong correlation between the $ET_{c\text{-}est}$ and $ET_{c\text{-}exp}$, whereas a few crops, *eg* potato (0.51) and wheat (0.66), showed a weaker

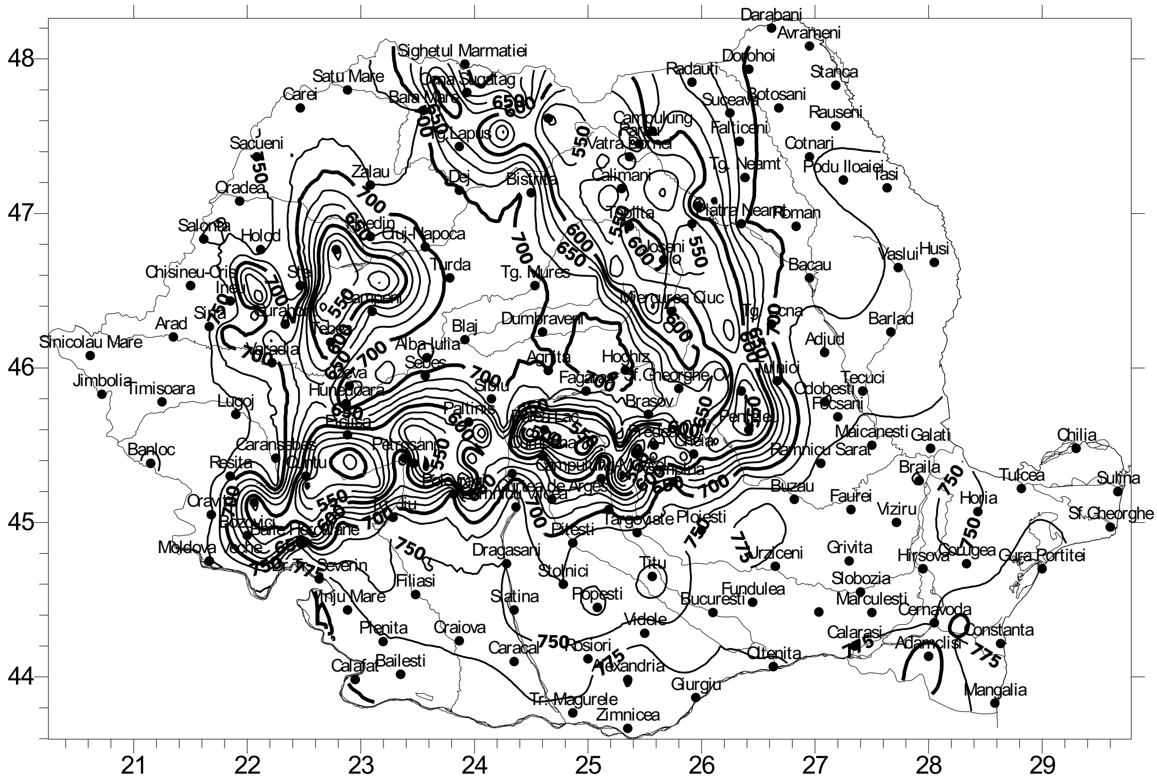

Fig. 1. PM-ET_o geographical distribution as annual values (mm) in Romania.

correlation. All the crops taken together also showed a strong correlation between $ET_{c\text{-}est}$ and $ET_{c\text{-}exp}$ highlighted by the relatively high value of R^2 (0.74), Fig. 3.

Differences, mean standard errors and ratios between the $ET_{c\text{-}exp}$ / $ET_{c\text{-}est}$

The comparison of the correlation lines depicted in Fig. 2 with the 1:1 lines of the same graphs showed that $ET_{c\text{-}est}$ was slightly lower than $ET_{c\text{-}exp}$ previously reported for the crops tested in this area. Differences were very small for ET_c values > 2 mm day^{-1}, this situation corresponding to the mid-growing season. In the above graphs there was a gap between the $ET_{c\text{-}est}$ values of 2 and 3 mm day^{-1}. This gap could probably be attributed to the specific climate conditions of the area studied during the growing season.

In order to analyze these differences more profoundly, mean standard errors (MSE) and ratios between $ET_{c\text{-}exp}$ and $ET_{c\text{-}est}$ were also computed and shown in Table 1. In this sense, even if the number of data pairs was also different (Table 1), MSE values ranged between 0.63 mm day^{-1} in the case of alfalfa and 1.29 mm day^{-1} in the case of potato. $ET_{c\text{-}exp}$ / $ET_{c\text{-}est}$ ratio itself also showed values higher than 1 for all the crops considered in this study, from 1.04 in the case of alfalfa and 1.77 in the case of maize. For all the crops studied and taken together, the mean standard error is as much as 1 mm day^{-1}.

T a b l e 1. Mean standard errors and $ET_{c\text{-}exp}$ / $ET_{c\text{-}est}$ ratios

Crop studied	MZ	WH	AL	SF	SB	SO	PO	AP-G	PE-C	GR-T	BA
Mean standard errors (mm day^{-1})	1.17	1.06	0.63	1.24	0.94	0.79	1.29	0.48	0.91	0.67	0.75
Ratio $ET_{c\text{-}exp}$/$ET_{c\text{-}est}$	1.77	1.41	1.04	1.65	1.47	1.32	1.54	1.23	1.51	1.26	1.23
Number of data	146	69	118	105	124	125	106	5	5	5	3

Symbols used here are: MZ – maize, WH – wheat, AL – alfalfa, SF – sunflower, SO – soybean, PO – potato, AP-G – apple and/or cherry with active sod groundcover, PE – peach and/or plum, no active sod groundcover, GR-T – table grapes, BA – barley; 811 cases.

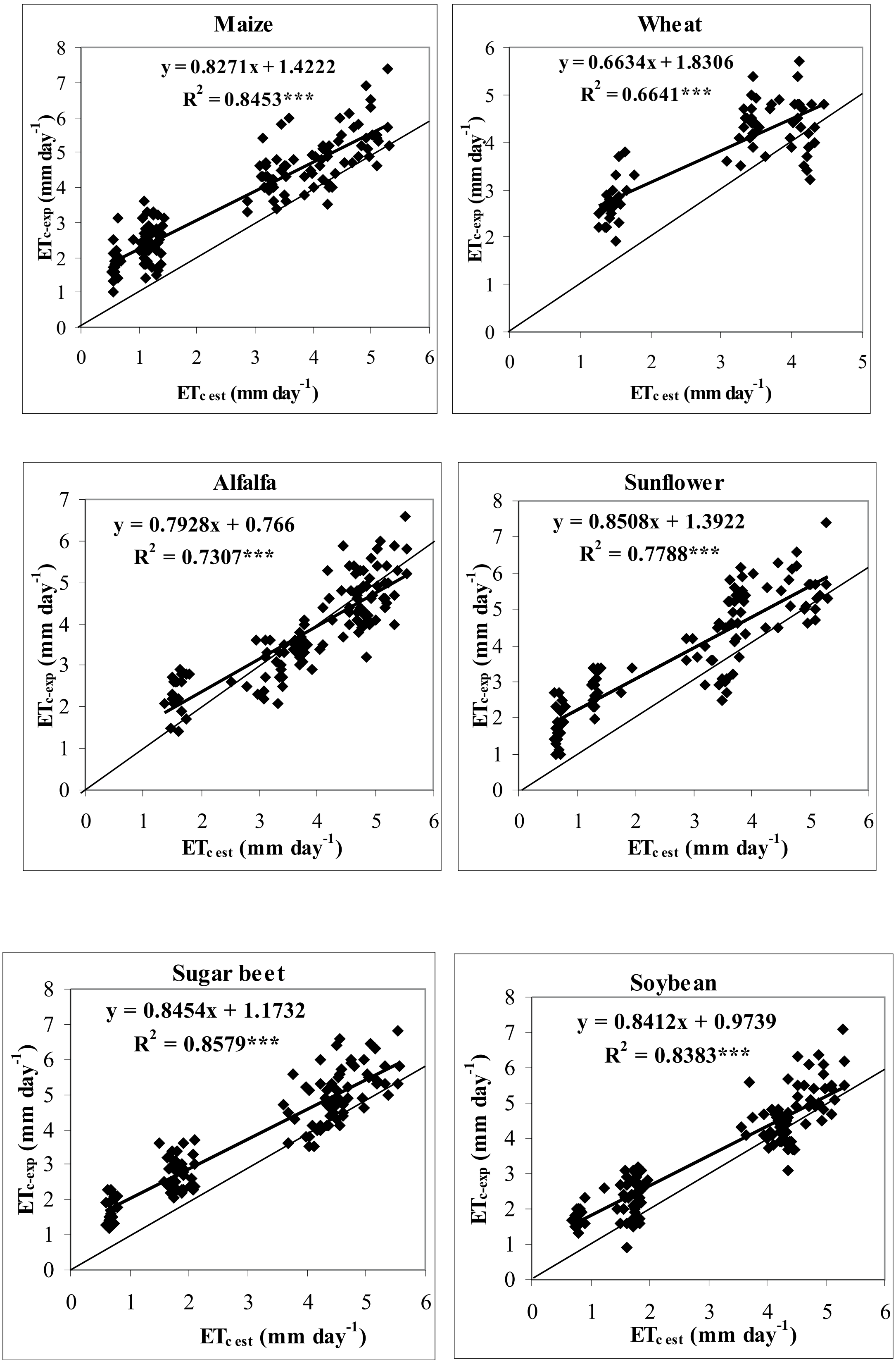

Fig. 2. Regression equations and coefficients of determination (R^2) between $ET_{c\text{-}est}$ and $ET_{c\text{-}exp}$ for: maize and wheat; alfalfa and sunflower; sugar beet and soybean. The number of stars indicates the degree of statistical significance at a level of probability P<0.01 (** distinctly significant), and P<0.001 (*** highly significant).

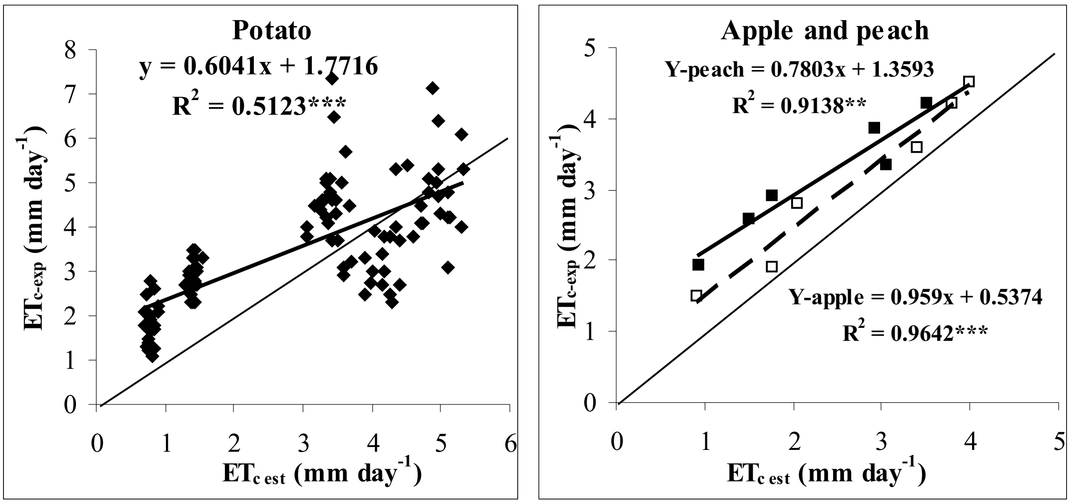

Fig. 2. Continuation. Regression equations and coefficients of determination (R^2) between $ET_{c\text{-est}}$ and $ET_{c\text{-exp}}$ for: potato and apple and peach. Explanation as on Fig. 1.

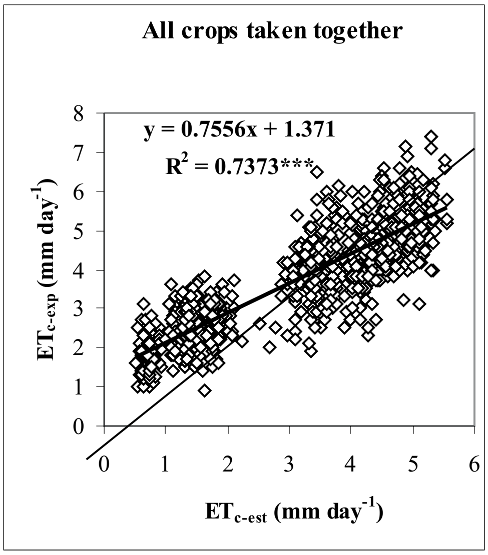

Fig. 3. Regression equations and coefficients of determination (R^2) between $ET_{c\text{-est}}$ and $ET_{c\text{-exp}}$ for all crops taken together.

Differences discussed above could be attributed to inaccurate measurements of deep drainage and runoff in the field experiments rather than to the deficiency of Allen's method. This conclusion also resulted from former studies (Paltineanu *et al*., 2000a, b).

CONCLUSIONS

1. A highly significant correlation between the estimated ET_c and experimental ET_c data was obtained in this study for most of the crops. However, ET_c estimated by Allen's method was slightly lower than real ET_c for previously reported crops tested in this area. This could be attributed to inaccurate measurements of deep drainage and runoff in experiments formerly developed in Romania rather than to the deficiency of Allen's method.

2. This paper confirms in Romania with fairly good results the method developed by Allen *et al*. (1998) in estimating K_c, and implicitly $ET_{c\text{-est}}$ for any region or watershed. As there were still some differences between $ET_{c\text{-est}}$ and $ET_{c\text{-exp}}$, more accurately designed experiments should be organized in future research to carry out an advance in this method.

3. The findings of this paper could also contribute to better water management in regions similar in terms of climate to the Romanian territories discussed in this paper, with many high water consumers. This is supported by the fact that the method developed by Allen *et al*. (1998) was confirmed by the experimental results under the above conditions.

REFERENCES

Allen R.G., Pereira L.S., Raes D., and Smith M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, 56, Rome.

Doorenbos J. and Pruitt W.O., 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper, 24, Rome.

Enciu M. and Ploaie V., 1983. Corn irrigation in Dobrogea (in Romanian). Stațiunea de Cercetari pentru Culturi Irigate Dobrogea-Valu lui Traian-Constanta. Lucrari Stiintifice, VIII, 169-201.

Grumeza N., Alexandrescu I., and Ionescu Pr., 1979. Fruit Tree and Vineyard Irrigation Technique (in Romanian). Ceres Press, Bucharest.

Grumeza N., Alexandrescu I., and Mihalache L., 1970. Studies on irrigation regime in vineyard in south-eastern Romania (in Romanian). Analele ICIFP, Imbunatatiri Funciare, III(VII), Bucharest, 59-71.

Grumeza N., Merculiev O., and Kleps Cr., 1989. Forecast and application of irrigation in irrigation systems (in Romanian). Ceres Press, Bucharest.

Iancu M. and Ionescu Pr., 1981. Some results and trends on irrigation application in Romanian fruit trees (in Romanian). Buletin Informativ al ASAS, Bucharest, 93-106.

Iancu M., Paltineanu C., and Simota C., 1998. Investigations on crop water uptake in apple (in Romanian). Proc. Conf. ASAS, Modern concepts in Romanian horticulture, Bucharest, 3-4 June, 135-144.

Ionescu Pr., 1976. Studying the effect of peach irrigation under the specific conditions of Dobrogea (in Romanian). PhD. Thesis, ASAS, Bucharest.

Ionescu Pr. and Tomulet T., 1968. Contributions at studying the irrigation regime in apple and pear under the specific conditions of Dobrogea (in Romanian). Analele Statiunii Experimentale Dobrogea, 75-84.

Jensen M.E., Burman R.D., and Allen R.G., (Eds), 1990. Evapotranspiration and irrigation water requirements. ASCE Manual, 70, New York.

Monteith J.L., 1965. Evaporation and the environment. In: The state and movement of water in living organisms. XIX Symp. Soc. Exp. Biol., Swansea, Cambridge University Press, 205-234.

Paltineanu Cr., Chitu E., Tanasescu N., Apostol G., and Pufu M.N., 2000a. Irrigation water requirements for some fruit trees specific to the Arges-Vedea river basin, Romania. Proc. 3rd Int. Symp. Irrigation of Horticultural Crops. Lisboa, Portugal, Acta Horticulturae, 537, 1, 113-119.

Paltineanu Cr., Mihailescu I.F., and Seceleanu I., 2000b. Dobrogea, soil and climate conditions, irrigation needs and water uptake for the main agricultural crops (in Romanian). EX PONTO Press, Constanta, Romania.

Renea S., 1983. The real plant water uptake for some crops and the reference evapotranspiration determined using various methods (in Romanian). Lucrari Stiintifice, VIII, 305-317.

Smith M., 1992. CROPWAT-A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper, 46, Rome.

Clima R.S.R., 1966. Climatologic dates. II. Romanian Institute of Meteorology, Bucharest.