A b s t r a c t. The purpose of this paper is to compare experimental crop evapotranspiration (ETc-exp) obtained under irrigation conditions in fields versus estimated values of crop evapotranspiration (ETc-est) based on the Penman-Monteith reference evapotranspiration (PM-ETo) 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 (Kc) 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. ETc was calculated using the above Kc multiplied by the mean values of PM-ETo for the experimental period. The ETc-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, ETc-est data were correlated and compared with ETc-exp data for the above crops using common statistical procedures. A highly significant correlation between the estimated ETc and experimental ETc data was obtained for most of the crops. However, ETc estimated by Allen’s method was slightly lower than real ETc 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 Kc and ETc using the PM-ETo method.

The purpose of this paper is to compare experimental crop evapotranspiration (ETc-exp) obtained under optimum irrigation conditions in fields with estimated values of crop evapotranspiration (ETc-est) based on PM-ETo 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-ETo 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:

\[
PM-ETo (\text{mm day}^{-1}) = \frac{(0.408 \Delta (R_n-G)+900 \gamma U_2(e_s-e_d))/\left(T_m+273\right))}{\left(\Delta + \gamma (1+0.34U_2)\right)}
\]

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\(^{-1}\)); \(\Delta\) is the slope of water vapor pressure curve (kPa °C\(^{-1}\)); \(\gamma\) is the psychrometric constant (kPa °C\(^{-1}\)); \(U_2\) (m s\(^{-1}\)) is the wind

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

© 2004 Institute of Agrophysics, Polish Academy of Sciences
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, sugar beet, 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):

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

\[(2)\]

where: \(K_{c\, mid}'\) was tabulated in Allen et al. (1998) and was given for the conditions where the relative air humidity \((RH_{\text{min}}) = 45\%\) and the wind speed at 2 m agl \((U_2) = 2\,\text{m s}^{-1}\); \(h\) 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-ETo for the experimental period. These \(ET_c\) values estimated by the method developed by Allen et al. (1998) were expressed further as \(ET_c\)-est.

Experimental data on \(ET_c\)-exp were used for: barley, wheat, maize, sunflower, sugar beet, soybean, potato, alfalfa, peach, apricot, table grapes. Here, \(ET_c\)-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 \(ET_c\)-exp data was taken from the Romanian literature reported in this country: Grumeza et al. (1970, 1979, 1989), Ionescu and Tomulea (1968), Ionescu (1976), Renea (1983), Enciu and Ploaie (1983), Iancu and Ionescu (1981), Iancu et al. (1998), Paltineanu et al. (2000a, b). The locations where the experiments took place were widely distributed, 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, \(ET_c\)-est data were correlated and compared with \(ET_c\)-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-ETo are shown in Fig. 1. The lowest values, generally <500 mm, are located within the Carpathians peaks. The 700 mm PM-ETo isoline actually represents the lower limit of the highlands and, implicitly, the highest limit of the plains and low plateaus. Annually, PM-ETo 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-ETo 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-ETo > 750 mm annually. The places mentioned above are mostly located in this area.

**Comparison between estimated evapotranspiration (\(ET_c\)-est) and experimental evapotranspiration (\(ET_c\)-exp)**

\(ET_c\)-est - \(ET_c\)-exp correlation

The crops discussed here have specific features with regard to the \(ET_c\)-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 \(ET_c\)-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 \(ET_c\)-exp. Towards autumn, \(ET_c\)-exp decreases abruptly with time, except for alfalfa, due to the rapid plant maturation and senescence.

For the crops investigated here, \(ET_c\)-est and \(ET_c\)-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 \(ET_c\)-est and \(ET_c\)-exp, whereas a few crops, eg potato (0.51) and wheat (0.66), showed a weaker
correlation. All the crops taken together also showed a strong correlation between ET<sub>c-est</sub> and ET<sub>c-exp</sub> highlighted by the relatively high value of R<sup>2</sup> (0.74), Fig. 3.

Differences, mean standard errors and ratios between the ET<sub>c-exp</sub>/ET<sub>c-est</sub>

The comparison of the correlation lines depicted in Fig. 2 with the 1:1 lines of the same graphs showed that ET<sub>c-est</sub> was slightly lower than ET<sub>c-exp</sub> previously reported for the crops tested in this area. Differences were very small for ET<sub>c</sub> values > 2 mm day<sup>-1</sup>, this situation corresponding to the mid-growing season. In the above graphs there was a gap between the ET<sub>c-est</sub> values of 2 and 3 mm day<sup>-1</sup>. 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<sub>c-exp</sub> and ET<sub>c-est</sub> 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<sup>-1</sup> in the case of alfalfa and 1.29 mm day<sup>-1</sup> in the case of potato. ET<sub>c-exp</sub>/ET<sub>c-est</sub> 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<sup>-1</sup>.

Table 1. Mean standard errors and ET<sub>c-exp</sub>/ET<sub>c-est</sub> ratios

<table>
<thead>
<tr>
<th>Crop studied</th>
<th>MZ</th>
<th>WH</th>
<th>AL</th>
<th>SF</th>
<th>SB</th>
<th>SO</th>
<th>PO</th>
<th>AP-G</th>
<th>PE-C</th>
<th>GR-T</th>
<th>BA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean standard errors (mm day&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1.17</td>
<td>1.06</td>
<td>0.63</td>
<td>1.24</td>
<td>0.94</td>
<td>0.79</td>
<td>1.29</td>
<td>0.48</td>
<td>0.91</td>
<td>0.67</td>
<td>0.75</td>
</tr>
<tr>
<td>Ratio</td>
<td>1.77</td>
<td>1.41</td>
<td>1.04</td>
<td>1.65</td>
<td>1.47</td>
<td>1.32</td>
<td>1.54</td>
<td>1.23</td>
<td>1.51</td>
<td>1.26</td>
<td>1.23</td>
</tr>
<tr>
<td>Number of data</td>
<td>146</td>
<td>69</td>
<td>118</td>
<td>105</td>
<td>124</td>
<td>125</td>
<td>106</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

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-est} and ET_{c-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).
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$_c$ for any region or watershed. As there were still some differences between ET$_c$-est and ET$_c$-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**


**Fig. 2.** Continuation. Regression equations and coefficients of determination (R$^2$) between ET$_c$-est and ET$_c$-exp for: potato and apple and peach. Explanation as on Fig. 1.

**Fig. 3.** Regression equations and coefficients of determination (R$^2$) between ET$_c$-est and ET$_c$-exp for all crops taken together.


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.


