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Evaluation of the crop coefficients for tomato crop grown in a Mediterranean climate

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Abstract. Effective improvement in crop coefficient (K_c) estimates is particularly important for mid-season K_c values, because mid-season K_c refers to the peak K_c values and relies on the period of growing season that is usually the most relevant for irrigation and the most sensitive to water stress, thus when accurate scheduling should be applied. The relationship between crop coefficient and growing parameters (temperature) was investigated for tomato (cv. Dracula) on the basis of experimental data obtained from the experimental station of Bari University and CNR-Bari "E. Pantenelli", located in Policoro (Southern Italy). A strong relationship was observed between crop coefficient and temperature suggesting good potential for use of a growing degree days approach for estimating crop evapotranspiration. The overall results for tomato grown under semi-arid conditions, indicates that the initial K_c can be neglected and that the K_c and crop evapotranspiration (ET_{c_model}) can be modelled through the three-stage growing cycle and linear relationship between K_c and cumulative growing degree days. Furthermore, this work has confirmed that peak K_c estimation can be improved by applying the corrections for relative humidity, wind speed and plant height as suggested in FAO 56.

Keywords. Crop coefficient – Crop evapotranspiration – Mediterranean – Tomato (cv. Dracula) – Management – Irrigation – Growing degree days.

Évaluation des coefficients culturaux pour une culture de tomates sous climat méditerranéen

Résumé. *L'amélioration du coefficient cultural est importante, surtout pour le K_c mi-saison, car il se réfère aux valeurs de pointe de K_c et à une phase de la saison de croissance qui est généralement la plus importante pour l'irrigation et la plus sensible au stress hydrique, où l'on devrait pratiquer un pilotage d'irrigation approprié. On a étudié la relation entre le coefficient cultural et les paramètres de croissance (température) pour la tomate (cv. Dracula) en se basant sur les données expérimentales obtenues à partir de la station expérimentale de l'Université de Bari et du CNR-Bari "E. Pantenelli", situé à Policoro (Sud de l'Italie). Pour la tomate il a été observé une forte relation entre le coefficient cultural et la température permettant d'utiliser l'approche de degrés-jours pour estimer l'évapotranspiration des cultures. L'ensemble des résultats obtenus pour la tomate cultivée en conditions semi-arides a indiqué que le K_c initial devrait être négligé et que le K_c et l'évapotranspiration culturale ($ETc_{\_model}$) peuvent être modélisés à travers le cycle de croissance à trois stades et la relation linéaire entre K_c et les degrés-jours cumulés (DJ). En outre, ce travail a montré que l'estimation de K_c de pointe peut être améliorée à travers la correction pour l'humidité relative, la vitesse du vent et la hauteur de la plante ainsi qu'il est suggéré par le bulletin FAO 56.*

Mots-clés. *Coefficient cultural – Évapotranspiration culturale – Méditerranée – Tomate (cv. Dracula) – Gestion – Irrigation – Degrés-jours.*

I – Introduction

The challenge for researchers today is to develop economically viable irrigation scheduling methodology, that is simple to implement and easy to understand from the farmer and project management standpoints. Improvements in breeding techniques, irrigation and crop management have changed crop development and growth, irrigation management, evapotranspiration, and hence crop coefficients (Amayreh and Al-Abed, 2005; Hanson and

May, 2006; Todorović, 2006). The main purpose of the experiment was to test the variability of the crop evapotranspiration for tomato crop measured and estimated under specific climatic and management conditions. Finally, the data were used to compare K_c values with the most recent update of the FAO Irrigation and Drainage Paper 56.

II – Materials and methods

The measurements of the main weather parameters and crop growing data for tomato grown in 2001 were collected at the agrometeorological station in the area of Policoro (MT) along the Western Ionian Coast at about 3 km west from the sea, latitude 40° 17' N, longitude 4° 25' E. This site is located 15 m above sea level and is characterized by sub-humid climate according to the De Martonne classification (Cantore *et al*., 1987). The Policoro data included information from 356 days recorded over one study year (2001). The data sets included the irrigation dates. Measurements of daily values of maximum and minimum air temperature and relative humidity, solar radiation, wind speed, precipitation and leaf area index were used for the model calculation. The weather station was located above a grass surface at about 30 m from the lysimeter. The daily crop evapotranspiration was measured by weighing lysimeter while ET_o was estimated using Penman-Monteith equation (Allen *et al*., 1998) with input data from the meteorological station. Crop coefficients were determined as the ratio of ET_c to ET_o. The K_c values measured in this way were related to those proposed by FAO 56.

III – Results and discussion

According to FAO 56, the trends in K_c during the growing period that is divided into four crop development stages (initial, rapid development, mid-season and late season) should be present in the crop coefficient curve taking in consideration only three values for K_c: initial stage ($K_{c\ ini}$), mid-season stage ($K_{c\ mid}$), and end of the late season stage ($K_{c\ end}$). The growing season started on 10 June and finished on 10 September. The initial stage lasted for 20 days and it was fixed at $K_{c\ ini}$ = 0.4 on the basis of measured data. The rapid growth stage starts on 1 July and ends on 16 July. The mid-season stage was 35 days long with an average $K_{c\ mid}$ = 1.18 according to the FAO 56 procedure as:

$$K_{c\ mid} = K_{c\ mid\ (Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad (1)$$

where, $K_{c\ mid\ (Tab)}$ = $K_{c\ mid}$ from Table 12, page 110 in FAO 56, u_2 = mean daily wind speed at 2 m height over grass (m/s), for 1 m/s ≤ u_2 ≤ 6 m/s, RH_{min} = mean daily minimum relative humidity (%), for 20% ≤ RH_{min} ≤ 80%, and H = mean plant height (m) for 0.1 m < h < 10 m.

The late season stage started on 20 August and ended 20 days later on 10 September. The $K_{c\ end}$ = 0.7 was estimated from measured data. The 91 day growing season in Policoro was nearly two months shorter than that suggested by FAO 56 (145 days) for the tomato grown in a Mediterranean climate. This can be explained by shorter season varieties and influence of the drip irrigation methods. The starting of the growing season for Policoro was on 10 June, which was much later than suggested by FAO 56 (April/May).

Growing degree days (°D) is a measure of thermal time rather than calendar time, and it is used to estimate the lengths of growth and development stages. The basic concept of growing degree days is that plant growth and development will occur when temperatures exceed a base temperature. When the experimental data were compared with FAO examples using °D and T_{base} = 12.8°C as suggested by Battilani *et al.* (2000) no substantial difference was observed between the summed °D values at the end of the season for the experimental and FAO data. This confirms that under optimal water supply the crop development is strongly related to air temperature and other weather factors (Fig. 1). Because the tomatoes were started in plastic house and transplanted, the initial growth phase was missed and the increase of °D was nearly linear. For a tomato crop planted in April, a clear initial growing stage, lasting for about 30-40 days, was observed. Therefore, for a late-planted tomato crop growing in a hot Mediterranean environment, it is possible to describe the tomato growth and K_c development through only the rapid growth, mid-season and late season stages.

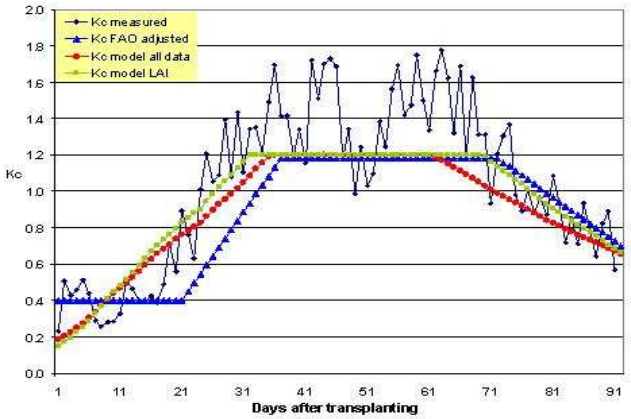

Fig. 1. The variation of K_c of tomato for the location of Policoro according to the measured lysimeter data, K_c obtained through a standard 4 stages procedure, K_c obtained by modelling using Equations 2 and 3 (K_c model LAI), and K_c obtained by modelling using Equations 4 and 5 (K_c model all data).

The relationship between crop coefficient (for days when LAI was measured) and cumulative °D < 480, corresponding to crop development phase before reaching the maximum K_c value, is presented through a linear equation:

$$K_c = 0.0023(°D) + 0.1712 \quad (2)$$

A similar relationship was drawn also for the late season phase taking into consideration the period when °D > 880. The K_c as a function of °D was:

$$K_c = -0.0017(°D) + 2.5109 \quad (3)$$

Due to fewer data points used in analysis, the previous analysis was extended to the whole data within two ranges, the first for °D < 480 °days and the second for °D > 880:

(i) for the rapid growth stage; $K_c = 0.0027(°D) + 0.1336$ (4)

(ii) for the late season stage; $K_c = -0.0024(°D) + 3.2834$ (5)

New K_c curves were developed on the basis of equations (2 and 3, and 4 and 5), and they are presented (Fig. 1) together with the measured K_c values and those developed through the standard adjustments procedure. The start of mid-season was defined on the basis of data estimated by Equations 2 and 4 forward, i.e. when the values coming from equations becomes greater than a pre-defined $K_{c\ mid}$ (1.18 or 1.20). The late season equations (3 and 5) were applied backward until the mid-season value was reached. The duration of mid-season was 26 days using equations 2 and 3, and 38 days in the case of applications of equations 4 and 5.

A comparison between cumulative ET_c, for $ET_{c\_model\_all\ data}$, $ET_{c\_model\_LAI}$, $ET_{c\_FAO\ adjusted}$ and $ET_{c\_measured}$ showed a good agreement during the rapid growth phase. At the end of season, the total cumulative ET_c was 439 mm from the model using all data, 420 mm from the model using data only when LAI was measured, 398 mm from the FAO adjustment procedure and 489 mm from measurements. The measured ET_c was 11, 14 and 18.6% higher than the $ET_{c\_model\_all\ data}$, $ET_{c\_model\_LAI}$ and ET_{c_FAO} respectively. Root mean square error of estimates relative to measured ET_c data were 1.4 mm/day for the $ET_{c\_model\_all\ data}$, 1.5 mm/day for $ET_{c\_\ model\_LAI}$, and 1.8 mm/day for $ET_{c\_FAO\ adjusted}$ model.

IV – Conclusions

The results of investigations on Policoro data indicate that K_c for tomato can be modelled satisfactorily either through the linear relationship between K_c and cumulative growing degree days as $K_c = a \times GDD + b$. The K_c and ET_c can be modelled through more complex approaches and equations that take into consideration specific weather growing conditions, management practices and growing characteristics of different varieties. Nowadays, with the wide extension of computing technologies, use of models is important for modern agricultural production and irrigation management.

The linear relationship between K_c and cumulative growing degree days has been tested by using both the whole data set (on a daily basis affected by extremes caused by wetting by precipitation and irrigation) and days when LAI was measured (presumable corresponding to non wetted conditions). In both cases, the parameters *a* and *b* of linear relationship do not change significantly which indicates robustness of proposed functions. Moreover, in the case of tomato grown under no-mulching management practices, the linear function parameters have remained similar with slopes between 0.0023 and 0.0027 for fast development phase and –0.0017 and –0.0024 for late season phase. The presented results and the proposed relationships should be tested at other sites and under different soil and climatic conditions.

This work has confirmed that the length of the growing season is strongly affected by air temperature especially when new crop varieties are grown. Therefore, the growing degree days (°D), as a measure of thermal time rather than calendar time, should be used in K_c modelling to estimate the lengths of growth stages (rather then a fixed number of days). Certainly, this approach could contribute to a better estimation of crop water requirements and a more accurate irrigation scheduling on both a whole season and a daily time span.

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