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Crop coefficient changes with reference evapotranspiration for highly canopy-atmosphere coupled crops

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ABSTRACT: Good irrigation practices lead to higher yields and incomes for producers but also raise the demand for water use. Despite of the great advancement of technologies for water supply, irrigation management remains inadequate in most areas. The lack of basic information on crop water needs is one of the causes for inadequate water use and irrigation management. The approach normally used to quantify the consumptive use of water by irrigated crops is the crop coefficient-reference evapotranspiration (Kc ETo) procedure. In this procedure, reference evapotranspiration (ETo) is computed for a grass or alfalfa reference crop and is then multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc). The ETo represents the non-stressed ET based on weather data. We selected three experiments with different crops in terms of physiology and planting arrangements to discuss the crop coefficient paradigm and its relation with reference evapotranspiration for highly canopy-atmosphere coupled crops.We found the Kc decreasing as ETo increased as a consequence of high plant atmosphere coupling, which limits the amount of water the plant could supply to the atmosphere. This finding my imply that irrigation might be reduced under these conditions

KEYWORDS: Kc, decouplingfactor, irrigation

O coeficiente de cultura varia com a evapotranspiração de referência para culturas altamente acopladas com a atmosfera

RESUMO: As boas práticas em irrigação podem conduzir a elevação da produtividade e aumento da renda dos produtores, mas também elevam a demanda por água dos mananciais. Apesar do grande avanço das tecnologias, o manejo da irrigação é ainda inadequado na maioria das áreas. A falta de informações básicas sobre as necessidades hídricas das culturas é uma das causas dessa deficiência no manejo da irrigação. Uma das abordagens mais usadas para quantificar o uso consultivo de água para culturas é através da abordagem do coeficiente de cultura. Nesta abordagem, a evapotranspiração de referência (ETo) é dada pela evapotranspiração de um gramado ou da alfafa e então multiplicada por um coeficiente empírico (Kc) para estimar a evapotranspiração da cultura (ETc). A ETo, neste caso, representa o consumo hídrico sem limitação por deficiência hídrica baseada apenas em dados meteorológicos. Neste trabalho, selecionou-se dados de três experimentos para discutir o paradigma da abordagem do coeficiente de cultura e sua relação com a ETo para culturas altamente acopladas com a atmosfera. Observou-se para os três casos que o Kc decresceu com o aumento do ETo com uma consequência do alto acoplamento com a atmosfera, que possivelmente limita o transporte de água das plantas para a atmosfera. Este fato pode representar a redução do volume de água utilizado para a irrigação pode ser reduzido.

PALAVRAS-CHAVE: Kc, fator de desacoplamento, irrigação

INTRODUCTION

Good irrigation practices lead to higher yields and incomes for producers but usually raise the demand for water use. Despite of the great advancement of technologies for water supply, irrigation management remains inadequate in most areas. The lack of basic information on crop water needs is one of the causes for inadequate water use and irrigation management.

A very used approach to quantify the consumptive use of water by irrigated crops is the crop coefficient-reference evapotranspiration (Kc ETo) procedure. This approach also makes it possible to consider the independent contributions of the soil evaporation and crop transpiration by splitting Kc into two separate coefficients as follows: Ke, a soil evaporation coefficient; and Kcb, a crop transpiration coefficient (referred to as the basal crop transpiration coefficient) (Allen et al., 1998). In this procedure, reference evapotranspiration (ETo) is computed for a reference crop and is then multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc).

This approach has been universally adopted as a procedure for scheduling and quantifying the water amount to be applied in the field and it has been supported by data along years, but the same data frequently shows the need of systematic improvement.

In this paper, we used data from different crops (citrus orchard, coffee and sugarcane plantations) in terms of physiology and planting arrangements to discuss the crop coefficient paradigm, and to show how this approach might be improved if the transpiration coupling to the atmosphere would be considered. To do so, we were based on our previous published studies showing canopy-atmosphere decoupling influencing the crop transpiration responses to weather under high evaporative demand (Marin et al., 2005; Marin &Angelocci, 2011, Nassif et al., 2014), which could be explained by the decoupling factor (Ω) approach proposed by McNaughton & Jarvis (1983).

MATERIALS AND METHODS

Experiment 1: citrus orchard

The experiment was carried out in a orchard at the experimental area of the "Luiz de Queiroz" College of Agriculture (ESALQ)at University of São Paulo (USP), Piracicaba, São Paulo State, Brazil (latitude 22°42'S; longitude 47°30'W; 546 m a.m.s.l.) from January 1998 to August 2000, with details described by Marin &Angelocci(2011).

The mean values of r_s were used to compute the decoupling factor (Ω) for a hipostomatous leaf, which was defined by the following equation as described by McNaughton and Jarvis (1983). Conceptually, the extreme values of Ω mean are: a) $\Omega \rightarrow 1$ as $r_s/r_a \rightarrow 0$ implying that the net radiation is the only contributor to the evapotranspiration process and that vegetation is completely decoupled from the atmospheric conditions; b) $\Omega \rightarrow 0$ as $r_s/r_a \rightarrow \infty$ indicating complete coupling of vegetation with atmospheric vapor pressure deficit and wind speed.

The daily ETc was calculated, and the data was averaged over 15 min, recorded at 10 s intervals and stored by a datalogger (CR7; Campbell Scientific, Inc.) using the Aerodynamic method.

Experiment 2: Coffee plantation

The study was carried out in ESALQ-USP from August to October, 2002, as fully described in Marin et al (2005). The overall crop evapotranspiration (ETc) was determined by the surface energy balance using the Bowen ratio (β) method, based on vertical differences of air temperature (ΔT) and vapor pressure (Δe)by measuring them 1.5 m and 3.5 m above the ground. The reliability of the method was tested by rules proposed by Perez et al. (1999). These two variables were measured with an aspirated copper-constantan thermocouple psychrometer (Marin *et al*., 2001) mounted 1.5 m and 3.5 m above the ground.

Experiment 3: Sugarcane plantation

This experiment was carried out in Piracicaba ESALQ-USP from October of 2012 to April of 2015. The experimental plot had 2.3 ha of plant cane cultivar RB867515 irrigated by a center-pivot. The spacing at planting was 1.4 m between plants and nearly 15 buds per meter were used during planting. The overall crop evapotranspiration (ETc) was determined by the surface energy balance using the Bowen ratio (β) method, as in the experiment 2 and fully described by Nassif et al. (2014).

RESULTS AND DISCUSSION

Along the citrus whole experiment (Experiment 1),ETo was systematically higher thanETc, with averages ofETo=4.4 mm d^{-1} andETc=2.8 mm d^{-1}in the wet summer season (SS) andETo=2.8 mm $d^{-1}$and ETc=0.90 mm d^{-1}in the winter season. During SS ETc followed ETorelatively closer than it was along the WS, in which ETc was almost flat below 1 mm d^{-1} despiteETo ranged from 1 to 4 mm d^{-1}.During the SS, ETo ranged from 3 to 7 mm d^{-1}, butETc did not exceed 4 mm d^{-1} (Figure 2a), but rather ETc tended to reach a ceiling value when ETo surpassed 4 mm d^{-1}.Average Kc values ranged from 0.6 to 0.17 for the whole experiment time (Fig 2B) which were related with the slope of the linear equations of Fig.2A. Fig. 2B shows the Kc downward trend as ETo increases for both seasons, which might be a consequence of stabilization of ETc in days with ETo high atmospheric. It is interesting to see that even during the WS, when the atmospheric demand is relatively lower than SS, the same trend was observed (Fig 2B).

The winter Kc values for citrus were also lower than those observed by Alves et al. (2007) under the same climate and soil conditions. These Kc values were still slightly lower than those observed by Alves et al. (2007) but were within a similar range reported by others. The Kcb value was 0.41 ± 0.08 for the wet period and 0.28 ± 0.07 for the dry period, and these Kcb values were comparable to previously reported values. The variety, root-stock, plant age and management practices are responsible for differences in the Kc and Kcb values, but the differences in micrometeorological conditions might have an important role, especially regarding the atmospheric water demand. The same behavior was observed in the coffee and sugarcane.

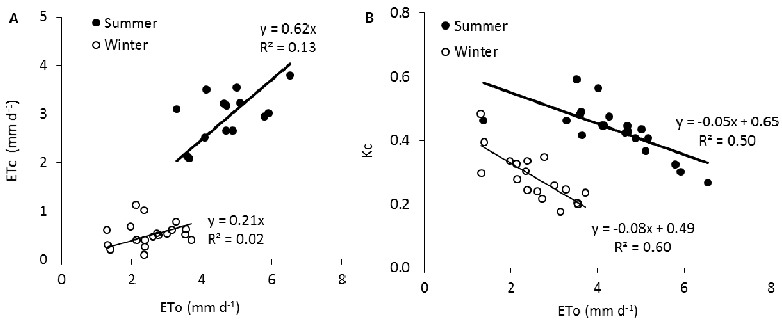

Figure 1. Relationship between acid lime evapotranspiration (ETc, A) and crop coefficient (Kc, B) with the reference evapotranspiration (ETo) in two seasons.

Coffee measurement in Experiment 2 showed similar values of ETcin relation to ETo, with average ETc=3.1 mm d^{-1} and average ETo=3.2 mm d^{-1}. At the time of year when measurements occurred, coffee plants were usually recovering their physiologic activity and preparing for the coming flowering phase, which is usually induced after a certain period beneath cold and dry weather.

The mean value of Kc obtained was 0.99, ranging from 0.6 to 1.9 (Figure 2b). The value of Kc is essentially composed of two terms: the basal coefficient (Kcb), which represents the plant transpiration, and the evaporative coefficient (Kce), which represents the bare soil evaporation (Allen et al., 1998). Although Kce was originally defined for bare soil, in orchards it can be defined in terms of the interrow water loss, including weed transpiration. The average value of Kce obtained was 0.24. In Hawaii, Gutiérrez and Meinzer (1994b) found an mean Kc value of 0.66 for Coffeaarabica, var. Catuaí, with LAI ranging from 1.4 to 7.5. One of the causes for low values of Kc observed at Hawaii seems to be the differences in the micrometeorological conditions compared with the Brazilian plantation, especially with respect to atmospheric water demand.

The relation between ETc and ETo for coffee plantation whose ratio, given by the slope of the straight line forced to pass by the origin (Fig. 4a), represents the Kc values, indicatesmean value of Kc around 1.0 and there was no clear stabilization trend for high ETo values (Fig. 2a) as observed in Experiment 1 (Fig 2), but there was as well a downward trend of Kc values as ETo increased (Fig. 2b).

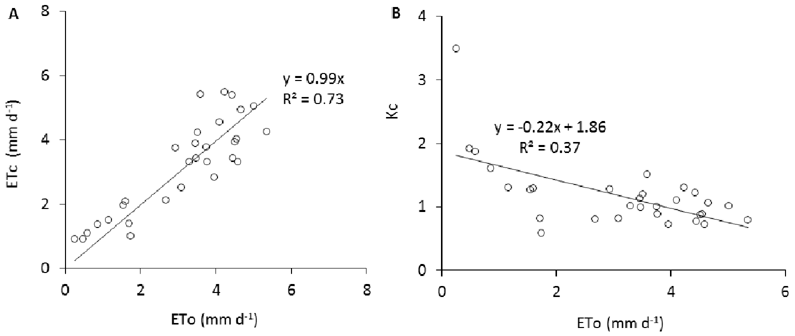

Figure 2. Relationship betweencoffee evapotranspiration (ETc) and reference (ETo) evapotranspiration (A), and relationship between crop transpiration (T) and ETo (B).

Sugarcane ETc was usually higher than the ETo along of the three years of measurements, with average ETc=3.43 mm d^{-1} and average ETo=4.05 mm d^{-1} (Fig. 5). 2014 was one of the driest and hottest years of the climatic registers in the region and the very high ETc data observed might be related to this, with maximum values reaching 7.9 mm day^{-1} (Fig. 5). On average, ETc was nearly 16% higher the ETo (Fig. 6a), and Kc showed a decreasing trend from 1.4 (for values of ETo less than 2 mm day^{-1}) to 1.0 for ETo higher than 6 mm day^{-1}. In the sugarcane field, the mean Kc for the whole experiment was 1.21, ranging from 0,5 to 2.52. The Kc for plant cane (first year of Experiment 3) was 1.04; and for the first ratoon (second year of experiment 3) it reach 1.31 in average, while in the second ratoon season it decreased again to 1.23 (Fig. 4). This year average might be biased by the period of the year was taken, as it varied from year to year. Anyway these data reasonably agreed with FAO suggested values for sugarcane (Allen et al., 1998). Figure3b shows Kc decreasing with ETo, as a consequence of the highly coupled plant-atmosphere conditions, asalready observed by Nassif et al.(2014) but this relationship seems to be less marked than ones observed for citrus (Fig. 1b) and coffee (Fig. 2b).

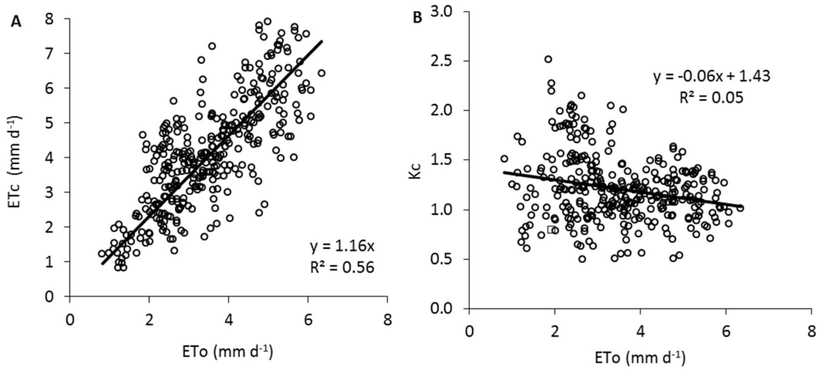

Figure 3.(A) Relationship between sugarcane evapotranspiration (ETc) and reference (ETo) evapotranspiration, and (B) relationship between crop coefficient (Kc) and ETo.

Results from Angelocci et al. (2004), Marin et al. (2005) and Nassif et al. (2014) shows the response of leaf conductance (gs) to weather variables having a quadratic relationship in which gs decreases when the atmosphere demands high transpiration rates.Based on values of vapor pressure deficits, solar radiation and air temperature, it is possible to see gsincreasing up to weather conditions equivalent to ETo less than 4.5 mm d^{-1}, and decreasing thereafter for higher ETo values. Despite the high variability of gs, these relations corroborates the hypothesis that trees control the transpiration as the ETo increases, supporting the proposition for the use of different Kcb values for discrete ETo ranges. In function of this and the results of the experiments, Table 1 shows proposed values for Kc and Kcb in different ETo ranges for the three crops. For all of them, Kc (or Kcb) values decreased as the ETo increased, which may represent an interesting way to improve the water management in orchards under localized irrigation (for coffee and citrus for instance) and an important way to save water for extensive irrigated sugarcane plantations.

Table 1. Values of Kc (and/orKcb) for three ranges of ETofor citrus orchards, coffee and sugarcane plantations, under the experimental conditions.The standard deviation is found in the brackets.

	Coffee		Sugarcane	Acid lime (summer)		Acid lime (winter)	
ETo range	Kc	Kcb	Kc	Kc	Kcb	Kc	Kcb
< 2 mm d^{-1}	1.57 [0.84]	1.27 [0.48]	1.26 [0.46]	0.74 [0.14]	0.53 [0.11]	0.39 [0.16]	0.46 [0.09]
2 - 4 mm d^{-1}	1.03 [0.23]	0.87 [0.18]	1.15 [0.27]	0.71 [0.12]	0.45 [0.03]	0.31 [0.15]	0.35 [0.06]
> 4 mm d^{-1}	0.94 [0.20]	0.67 [0.08]	1.10 [0.20]	0.68 [0.10]	0.37 [0.06]	0.22 [0.05]	0.24 [0.03]

Low values of Ωindicates the influence of wind speed and VPD on ETc and T, i.e., the crop transpiration becomes conditioned by aerodynamic conditions rather than radiation conditions, which imposed a tendency of larger crop evapotranspiration rates. As Jarvis (1985) postulated, Ω tends to be gradually lesser in tall rough crops (mainly with discontinuous ground cover) due to a reduction of aerodynamic resistances of the canopy caused by a vigorous air mixing and a high crop roughness. Interesting to note that for even such a less rough canopy crop as sugarcane, Ω low values of Ω for the three crops also points for enough air mixing for coupling the canopy to the atmosphere (Table 2).

Table 2.Average values of decoupling factor for coffee, citrus and sugarcane plantations.

Crop	Decoupling factor
Coffee	0.09
Citrus	0.11
Sugarcane	0.22

Allen et al (1998) claimed that the Kc values proposed by them must be used under standard climatic conditions, as sub-humid climate, minimum relative humidity of 45% and wind speeds averaging 2 m s^{-1} and that variations in wind speed may alter aerodynamic resistance and, hence, the crop coefficients mainly for tall crops. They also inferred that under high wind speeds and low relative humidity, Kc tends to increase. However, some aspects observed in the three experiments here analyzed were slight different from the aspects postulated by Allen et al. (1998). Firstly, we noted that Kc for coffee and citrus had a small variation as the ETo ranges up to 5.5 mm d^{-1}, which is mainly due to the role of interrow vegetation. Secondly, high wind speed and low air relative humidity affectedcrop evapotranspiration and decreased Kcb values as the ETo varied.

CONCLUSIONS

For the crops here analyzed, leaves reduced the stomatal conductance under high temperature, DPV and solar radiation, even with good soil water conditions. Strong canopy coupling to the atmosphere – due to relatively low aerodynamic resistance and moderate-to-high leaf resistance – enhancedthis response pattern in the studied crops. These characteristics caused the Kc and Kcband Kc to inversely vary in function of ETo. Based on these results, it was proposed that the Kc and Kcb recommendation for practical purposes should include their variation alsoin function of ETo.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998).Crop evapotranspiration – guidelines for computing crop water requirements.FAO: Rome. 300p. (IrrigationandDrainagepaper, n. 56).

Alves, J.,Folegatti, M.V., Parsons, L.R., Bandaranayake, W., da Silva, C.R., da Silva, T.J.., Campeche, L.F.S.., 2007. Determination of the crop coefficient for grafted “Tahiti”lime trees and soil evaporation coefficient of RhodicKandiudalf clay soil in Sao Paulo, Brazil. Irrigation Science 25, 419–428.s12355-013-0267-0

Gutierrez, M.V., Meinzer, F.C., 1994. Estimating water use and irrigation requirements of coffee in Hawaii. Journal of the American Society for Horticultural Science 119, 652–657.

Marin, F. R, L. R Angelocci, E. Z Righi, and P. C Sentelhas.2005. Evapotranspiration and irrigation requirements of a coffee plantation in Southern Brazil. Experimental Agriculture 41, no. 02: 187–197.

Marin, F. R, L. R Angelocci, M. A Coelho Filho, and N. A Villa Nova. 2001. Construction and evaluation of an aspirated thermocouple psychrometer.Scientia Agricola 58: 839–844.

Marin, F.R., L. R Angelocci, 2011. Irrigation requirements and transpiration coupling to the atmosphere of a citrus orchard in Southern Brazil. Agricultural Water Management 98, 1091–1096.

McNaughton, K.G. and Jarvis, P.G. (1983). Predicting effects of vegetation changes on transpiration and evaporation. In: T.T. Koslowski (Ed.) Water deficit and Plant Growth, 7:1-47. New York: Academic Press.

Nassif, D.S.P., Marin, F.R., Costa, L.G., 2014. Evapotranspiration and Transpiration Coupling to the Atmosphere of Sugarcane in Southern Brazil: Scaling Up from Leaf to Field. Sugar Tech 1–5. doi:10.1007/