Effects of different amendments (organic matter and hydrogel) on the actual evapotranspiration and crop coefficient of turf grass under field conditions*

Gladys L. Bandenay1 | Arianna Renau-Pruñonosa2 | Ignacio Morell3 | María V. Esteller4

1Universidad de Ingeniería y Tecnología. UTEC, Barranco, Lima, Peru
2Department of Botany and Geology, University of Valencia, Burjassot, Valencia, Spain
3Research Institute of Pesticides and Water (IUPA), Jaume I University, Castelló, Spain
4Instituto Interamericano de Tecnología y Ciencias del Agua (IITCA), Universidad Autónoma del Estado de México, San Cayetano Morelos, Toluca, Mexico

Abstract
The irrigation schedule in arid areas has to be efficient in order to reduce losses due to evaporation and deep infiltration. Irrigation optimization poses the need to establish with precision the value of actual evapotranspiration (ET$_a$), and the crop coefficient ($K_c$). The water soil availability can be increased using hydrogel and organic matter amendments, and their effects could vary ET$_a$ and $K_c$. The aim of this study was to determine the ET$_a$ and $K_c$ of an experimental site with lysimeters on the Spanish Mediterranean coast cropped with a turf grass variety, Agrostis stolonifera -L-93, under field conditions, and amended with hydrogel and organic matter.

Reference evapotranspiration (ET$_0$) was determined from meteorological data (FAO-Penman-Monteith equation). ET$_a$ was calculated from the water balance, and $K_c$ was obtained by dividing ET$_a$ by ET$_0$. $K_c$ was calculated and compared on a yearly, monthly and daily basis. In summer, the differences between amendments become manifest: Unamended lysimeter (100% sand) had $K_c$ values (0.92-1.16), similar to organic matter amended lysimeter (0.99-1.17). Maximum and minimum $K_c$ values for the hydrogel amended lysimeters (1.04-1.52) were higher than those from the other because of the ability of this compound to retain water, which facilitated evapotranspiration. Finally, hydrogel helped to maintain the turf grass quality.

Keywords
crop coefficient ($K_c$), evapotranspiration (ET$_a$), hydrogel, lysimeters, Mediterranean climate, organic matter

* Effets de différents amendements (matière organique et hydrogel) sur l’évaporation réelle et le coefficient de culture du gazon dans les conditions du terrain.
Résumé
La planification de l’irrigation dans des zones arides doit être efficace afin de réduire les pertes par évaporation et infiltration profonde. L’optimisation de l’irrigation nécessite définir avec précision la valeur réelle d’évapotranspiration (ETa) ainsi que celle du coefficient d’agriculture (Kc). L’objectif de cette étude était de déterminer la ETa et le Kc d’une pelouse expérimentale cultivée sur la côte méditerranéenne avec une variété de gazon, Agrostis stolonifera-L-93, en conditions naturelles et modifié avec de l’hydrogel et de la matière organique. L’évapotranspiration de référence (ET0) a été déterminée à partir de données météorologiques (équation FAO-Penman–Monteith). L’ETa a été calculée à partir de l’équilibre d’eau, et le Kc a été obtenu en divisant la ETa par la ET0. Le Kc a été calculé et comparé quotidiennement, mensuellement et annuellement. En été de façon significative et les différences entre les modifications deviennent alors évidentes: un lysimètre non modifiée (100% sable) avait des valeurs de Kc (0.92–1.16), similaires à celle d’un lysimètre modifiée par matière organique (0.99–1.17). Les valeurs maximum et minimum du Kc sur les lysimètres modifiées par hydrogel (1.04–1.52) étaient plus grandes que celles des autres en raison de la capacité du composé à retenir l’eau en surface (ce qui facilite l’évapotranspiration). Finalement, l’hydrogel facilite ainsi la maintenance de la qualité du gazon.

MOTS CLÉS
lysimètre, coefficient d'agriculture (Kc), évapotranspiration (ETa), matière organique, climat méditerranéen

1 | INTRODUCTION

Evapotranspiration is the combination of two separate processes whereby water is lost from the soil: evaporation and transpiration. Evaporation consists of the vaporization of water due to solar radiation, temperature, wind and other meteorological factors, and transpiration consists of the vaporization of liquid water contained in plant tissues and its removal to the atmosphere. Since both processes occur simultaneously and there is no easy way of distinguishing between them, they are compiled in a single term: evapotranspiration. Evapotranspiration can be measured with experimental lysimeters (actual evapotranspiration, ETa) or estimated from meteorological data (reference evapotranspiration, ET0).

The ETa can be determined from the water balance and depends on the type of crop, the characteristics of the substrate, soil moisture, agronomic activities and climatic conditions (intensity and frequency of rainfall, temperature, solar radiation, wind speed and relative humidity) (Shearman and Beard, 1973; Xinmin et al., 2007; Wherley et al., 2015; Amgain et al., 2018). In addition, as pointed out by Biran et al. (1981) and Kneebone and Pepper (1984), we must account for the fact that the ETa increases when water is available. Aronson et al. (1987) and Blankenship (2011) noted that evapotranspiration was governed mainly by meteorological factors when there was enough moisture in the soil, but that it declined after a critical level of moisture was reached.

On the other hand, ET0 is estimated from meteorological data (precipitation, solar radiation, maximum and minimum temperature, wind speed and relative humidity) using the FAO-Penman–Monteith equation (Smith et al., 1992;)

Under standard conditions (well-watered conditions) the ETa of a crop can be related to the ET0 through the crop coefficient, Kc (ASCE, 1990; Zhang et al., 2010; Marin et al., 2016). The Kc refers to the characteristics that distinguish the studied crop from a reference crop under standard (well-watered) conditions. It varies with the nature of the crop, its height and stage of development, the supporting substrate and the climatic characteristics of the area. The Kc shows daily variation and, to minimize complexity,
expressed as the average over a period, either monthly, yearly, by stage of crop development or season.

The installation and maintenance of golf courses constitute a demanding agricultural activity involving the intensive cultivation of large areas of grass that require significant quantities of water for irrigation (Rodriguez Diaz et al., 2007). The use of different grass according to weather conditions seeks to increase the efficiency of irrigation, and ETa varies according to the variety of grass. ETa from cool- and warm-season grasses ranges from 3 to 8 mm day⁻¹ and from 2 to 6 mm day⁻¹, respectively (Augustin, 2000; Huang, 2006; Xinmin et al., 2007; Wherley et al., 2015; Colmer and Barton, 2017). When water availability drops, the grass responds to the shortage by activating biological mechanisms that result in lower water consumption. Numerous studies have reported different values of Kc for the same grass variety, reflecting the influence of the growing area. For example, the Kc value of the Bermuda grass (Cynodon dactylon) variety ranges is between 0.17 and 0.99 in south-eastern USA (Wherley et al., 2004; Abedi-Koupai et al., 2015; Martin del Campo et al., 2019). Hydrogels are hydrophilic polymers that absorb water, improve soil porosity, aeration, infiltration, nutrient transport and release, and water absorption that promote plant growth (Akhter et al., 2004; Abedi-Koupai et al., 2008; Ullah et al., 2015).

2 | MATERIALS AND METHODS

2.1 | Description of the experimental green

Four lysimeters were built, each with a surface of approximately 40 m² and a volume of 11 m³. The substrate is composed of a 26–40 cm sandy base (substrate categorized by the United States Golf Association (USGA) as siliceous sand), overlaying a 10-cm gravel layer containing drainage pipes (7.5 cm diameter) that collect water and drain them toward the exit. At the exit, recipients collect drainage water for control purposes. Water drainage samples were collected daily.

Each lysimeter is coated on the bottom and sides with a geomembrane that independently collects and channels all infiltrated water toward the drainage exit.

The addition of the OM and hydrogel in the lysimeters was carried out on the already deposited sand, and was mixed with the first 10 cm of the sandy substrate. The lysimeters were amended as follows: P-1 amended with both: 20% OM (peat) and 145 g m⁻² hydrogel, P-2 amended with 20% OM (constructed according to USGA requirements) and P-3 amended with 145 g m⁻² hydrogel (TerraCottem⁴). P-4 is sand only.

Each lysimeter has an independent irrigation system. Each irrigation system comprises eight diffusers (Model 6,406-ADV Nelson Turf⁴) equipped with 15 cm body type nozzles (7,370 Multiarc). Each system is controlled by an electric pump and a counter. Although irrigation is programmed, the flow is not always the same and depends on different factors, such as water pressure in the main pipes and water availability. Flow rates in lysimeters vary between 23.4 and 39.0 mm h⁻¹. The determination of the water that falls within each lysimeter was made assuming that the irrigation is uniform. Irrigation during the investigation was scheduled according to rainfall and the objectives pursued: (i) total water availability: the condition of total water availability was maintained through most of 2010; (ii) tracer tests: tests that involved high water inputs were carried out from December 2010 to May 2011; and (iii) water stress: a slight water stress was imposed in the period from June to December 2011 to determine whether irrigation water could be saved in comparison to 2010.

The lysimeters were equipped with three moisture sensors installed vertically (DECAGON). Two sensors were the 10HS type that measures the volumetric moisture at depths of 12 and 24 cm, respectively, while the other one is the 5TE type, installed at a depth of about 18 cm, which also measures electrical conductivity and temperature. They were all calibrated for the substrate in...
which they were installed and were set up to record data every 2 min.

A meteorological station (Weather Rain Bird Smart), installed next to the green, provided hourly precipitation, solar radiation, maximum and minimum temperature, wind speed and relative humidity data. We used the data from this station to calculate the ET₀ from the FAO-Penman–Monteith equation (Smith et al., 1992).

Apart from the irrigation rates, which were modified to meet the requirements of each lysimeter, the experimental site was treated in the same way (watering, mowing, fertilizing, phytosanitary treatment, pricked and verticutting) as the other greens on the golf course.

Data were collected from these lysimeters for 3 years (2009–2011).

2.2 | Climatic characteristics of the area

The experimental green is located a few kilometres from the Mediterranean coast in Spain (Figure 1). The area is characterized by a mild and humid Mediterranean climate. According to the meteorological data obtained from the meteorological station of the experimental green, the average temperatures in the warmer months during the study period were about 23 °C, with peak point temperatures close to 30 °C. On the other hand, the average temperatures for the winter months were between 8 and 10 °C, with minimum temperatures of 2–3 °C. During the period from 2009 to 2011, the months with the lowest rainfall were July 2010 and August 2011, with no rainfall. In contrast, the rainiest month was September 2009 with a rainfall of 360 mm, followed by November 2011 with 182 mm (Figure 2).

2.3 | Reference evapotranspiration (ET₀)

ET₀ is usually estimated from meteorological data, which were obtained from the installed meteorological station. The FAO-Penman–Monteith equation is the most widely accepted method for calculating ET₀ (Smith et al., 1992):

\[
ET₀ = \frac{0.408 \Delta (Rn - G) + 900 \left(\frac{U_2(e_s - e_a)}{T_{273} + 273}\right)}{\Delta + \gamma (1 + 0.34U_2)}
\]  

(1)

**FIGURE 1** Location of the field study site
From Equation (1), ET₀ is calculated for an area planted with a hypothetical reference crop that has an assumed height of 12 cm, a fixed surface resistance of 70 s m⁻¹ and an albedo of 0.23. ET₀ depends on the net radiation (Rₙ), the heat flux on the ground (G), the air temperature measured 2 m from the ground (T), the average wind speed (U₂), the saturation vapour pressure (eₛ), the actual vapour pressure (eₐ), the slope of the vapour pressure curve versus temperature (Δ), and the psychrometric constant (γ).

2.4 | Determination of actual evapotranspiration (ETₐ) using the water balance

ETₐ can be calculated using the water balance (Equation (2)) between two dates on which substrate moisture values were approximately the same; thus, the variation in moisture storage was zero (ΔV = 0). Under this premise ETₐ is the difference between the input water (rainfall and irrigation) and the output water (drainage). This condition was used for determining ETₐ in 2009, since no moisture sensors were installed that year.

\[
\text{Input (rainfall + irrigation)} = \text{Output (drainage + ETₐ)} + \Delta V
\]

In 2010 and 2011 data from the moisture sensors were used to determine ΔV and ETₐ could be calculated on a daily and monthly basis.

The condition of total water availability was maintained through most of 2010. Tracer tests that involved high water inputs were carried out from December 2010 to May 2011. When tracer tests were performed, a restriction on irrigation was set in the second half of 2011 (June to December) in order to maintain the soil moisture at lower levels than those from June to December 2010.

3 | RESULTS AND DISCUSSION

3.1 | Effect of amendments under total water availability

3.1.1 | Effect of the OM amendment

To test the effect of OM on the water balance, the values of ETₐ for P-2 (amended with OM) and P-4 (100% sand) are compared. Figure 3 shows that the ETₐ values for the two lysimeters are similar; in fact, for a few months (March, April, May and July 2010), ETₐ in P-2 is lower than in the not amended lysimeter, while in other months (June, August, September and October 2010) it is up to 23% higher. The highest values of ETₐ were reached in June–August 2010: 2.76–12.2 mm day⁻¹ in P-2 and 3.06–10.3 mm day⁻¹ in P-4. These values are similar to those obtained by Green et al. (1990) and Bowman and Macaulay (1991): 7.7–12.7 and 4.57–13.0 mm day⁻¹, respectively. Research carried out in Norway by Aamlid et al. (2016) showed that, under daily irrigation conditions, they obtained ETₐ values of 5–10 mm day⁻¹, lower...
than P-2, probably due to climatic conditions. To achieve these results, they installed mini lysimeters on a green with *Agrostis stolonifera* -L-93.

Under this condition of total availability of water, the edaphic factor (in this case, the presence of OM) is barely relevant and the presence of OM does not show its water retention capacity, as Bigelow *et al.* (2000), Waltz *et al.* (2003) and McCoy *et al.* (2007) already showed in previous research.

### 3.1.2 Effect of the hydrogel amendment

Over the same period, ET$_a$ values of the lysimeters amended with hydrogel, P-1 and P-3, are greater than those for the not amended lysimeters, as shown in Figure 4(A) (P-1 compared with P-2, amended with OM) and 4(B) (P-3 compared with P-4, which is 100% sand). The moderate increase of 23% in the ET$_a$ of P-1 (OM and hydrogel), and the large increase of 61% for P-3 (hydrogel) may be explained by the ability of the hydrogel to retain water, which facilitated evaporation, and/or a high $K_c$ value generated by transpiration. Mohawesh and Durner (2019) suggested that soil amendments such as hydrogel improved soil water retentivity across the whole moisture saturation range (from total water availability to water stress conditions) and, also, improved the water availability of the sandy soils for a longer period (almost 22 days). The ET$_a$ values achieved in P-1 and P-3 (P-1: 3.71–13.18 mm day$^{-1}$; P-3: 3.34–15.16 mm day$^{-1}$) exceed...
the maximum values of Green et al. (1990) (12.7 mm day\(^{-1}\)) and Bowman and Macaulay (1991) (13.0 mm day\(^{-1}\)).

It is noteworthy that the increase in water storage under existing conditions of water availability may become more damaging to the grass than a lack of water, especially in summer. Surface water absorbs heat from the sun and transfers it to the root zone, such that the temperatures may be several degrees above the ambient temperature, causing damage to the roots (Dernoeden, 2006).

Monthly variations of \(ET_a\) and \(ET_0\) between 1 March 2010 and 31 December 2011 for all lysimeters are presented in Figure 5. All the curves follow the same trend: the highest values are reached in the months from June to August and the lowest in the months from November to February.

It is important to point out that \(ET_a\) values were greater than \(ET_0\) between July and August 2010 (total availability water) in all lysimeters, and especially noticeable in the hydrogel treated P-1 and P-3. Detailed analysis indicated that, in these months, the water requirements \((ET_a)\) of P-1 and P-3 are greater than \(ET_0\) (Figure 5), because of the extra water needed when air temperatures approach 30 °C. There is a a clear influence of agronomic activities and the FAO-Penman–Monteith equation underestimates the water requirement. Qian et al. (1996) and Lecina and Martinez-Cob (2000) reached the same conclusion from studies of other grass varieties that had high values of evapotranspiration.

From March to June and September to November 2010 (Figure 5), when the temperature dropped, \(ET_0\) provided a reasonable reflection of the water requirement in all the lysimeters. Irrigation was increased when tracer tests were done in December 2010 and moisture in the substrates was high. Excess moisture resulted in an increase in \(ET_a\) in December in P-2 and P-3 (no data for P-4 and P-1), which shows that the level of moisture in the substrate also influenced the value of \(ET_a\), as mentioned by Biran et al. (1981) and Kneebone and Pepper (1984).

### 3.2 Effect of amendments under slight water stress condition

A slight water stress was imposed in the period from June to December 2011 to determine whether irrigation water could be saved in comparison to 2010. The result was a low-quality turf and a decline in the \(ET_a\) in P-2 (with OM) and P-4 (sand) (there are no data for P-1); however, each lysimeter reacted differently to water deficit, depending on the amendment. Gómez-Armayones et al. (2018) showed that adverse effects of deficit irrigation on turfgrass quality are more evident when turf is subject to environmental and/or management stresses such as long intervals between irrigation, short mowing heights or high temperatures.

**Figure 5** Monthly \(ET_a\) and \(ET_0\) values for the period from 1 March 2010 until 31 December 2011 for P-1 (hydrogel and OM), P-2 (OM), P-3 (hydrogel) and P-4 (100% sand)
3.2.1  |  Effect of the OM amendment

Evapotranspiration in P-2 (OM) and P-4 (100% sand) are compared in Figure 6. Given the water restriction from July to December 2011, the effect of the OM was manifested in a lower decrease in ETa of P-2 than in P-4. For example, in July 2011, a decrease of 13% in storage in P-2 (Figure 6(A)) caused the ETa to decrease 16% (Figure 6(B)), while in P-4, a 5% decrease in storage in P-4 (Figure 6(C)) caused a decrease of 38% in the ETa (Figure 6(D)). In August 2011, the ratios were lower, but the OM still prevented a decrease in ETa and plant heat stress. In September, when the decrease in soil moisture was similar in both lysimeters, the ETa for P-2 was still greater than that for P-4. The effect of OM was very low in October as the moisture was too low in P-2 (40% less than in 2010); the ETa was therefore lower in P-2 than in P-4, for which the humidity was only 8%, less than in the previous year. The values obtained by Aamlid et al. (2016) under non-irrigation conditions (one single irrigation at the beginning of the period) varied between 3 and 5 mm day⁻¹, and in the P-2, for these stress conditions, ETa presented values between 1.1 and 5.4 mm day⁻¹. In 2011, the difference in the behaviour of the substrates (edaphic factor) was not very evident as the standard conditions of the FAO (total water availability) were kept in all lysimeters (2010). When the sand was amended with OM, the decline of ETa was minimized only under conditions of water deficit, and grass stress caused by high temperatures was reduced.

When water availability decreased, as occurred in the second half of 2011, the evapotranspiration rate was higher from the OM-amended lysimeter than from the 100% sandy lysimeter, which indicates that the retention capacity of OM was significantly lower than that of the hydrogel.

3.2.2  |  Effect of the hydrogel amendment

Hydrogel-amended P-3 is compared with not amended P-4 (100% sand) to determine the influence of hydrogel on ETa in Figure 7. It is shown that P-3, despite having a greater decrease in storage in the summer of 2011 (Figure 8) than P-4 (Figure 6(C)), has an ETa about 40% higher than P-4 from July to September, indicating that the hydrogel provided water to the roots that could be used by the plant.

It appears that the distribution of water within the substrate, which in turn determines the availability to the

![Graphs showing water storage and evapotranspiration](image-url)
grass, is more important than the amount of water stored; this is especially important in the summer months when the grass faces heat stress.

Monthly variations of ET$_a$ and ET$_0$ in the summer of 2011 (Figure 5), when the levels of humidity in the lysimeters were lower than in 2010, show values of ET$_a$ still deviated from ET$_0$ in P-2 and P-3 but with a smaller gap; there was no difference, however, between the values for P-4. Also, when water availability decreased, as occurred in the second half of 2011, the ET$_a$ was lower for P-2 (with OM) than for P-3 (hydrogel), which indicates that the retention capacity of OM was significantly lower than that of the hydrogel. Values in P-1 could not be calculated because sensors were broken.

### 3.3 ET$_0$, ET$_a$, and $K_c$ from the annual water balance

To calculate ET$_a$ when $\Delta V = 0$ (variation in moisture storage was zero), we identified periods of time when the
moisture profiles showed that the condition of total water availability was met (well-watered condition). These events corresponded to a first interval from 30 March to 22 September 2009, a second interval between 4 March and 12 October 2010, and a third interval from 12 March to 21 November 2011. For these three intervals, daily values of ET₀ were calculated from weather station data using the FAO-Penman–Monteith equation. ETₐ was calculated from water balance from the irrigation, drainage and daily precipitation data. The ETₐ and crop coefficient, \( K_c = \frac{ET_a}{ET_0} \), are presented in Table I.

Table I shows that values of \( K_c \) in 2009 are smaller than those calculated for 2010 and 2011. It should be noted that the agronomic conditions in 2010 and 2011 were like the standard conditions of the FAO, but those in 2009 were very far from the standard, reducing the transpiration of the turf. This may be due to agronomic practices in 2009, the year in which the planting and establishment of the lawn took place (Martin del Campo et al., 2019).

Under the standard conditions maintained in 2010 and 2011, ETₐ is 10–50% bigger than ET₀ depending on the amendment: the hydrogel-amended P-1 and P-3 had the highest values of \( K_c \) every year. The high values of \( K_c \) of P-1 and P-3 do not indicate higher water requirements; rather, evapotranspiration of the water retained by the hydrogel was increased since drainage was minimized, and storage showed less variation. Evaporation increases when the water is maintained in the first few centimetres of the profile; further, when there is water available for the roots, transpiration is facilitated, and is responsible for maintaining the temperature in the leaves and reducing heat stress (Throssell et al., 1987; Carrow, 1996; Liu and Huang, 2001; McCann and Huang, 2008).

The results show that, in 2010, the amount of water needed to maintain an acceptable quality of grass in P-2 (OM) and P-4 (100% sand) was between 16 and 17% higher than that determined by the weather station (ET₀), resulting in a \( K_c \) value of 1.17–1.16; the values of \( K_c \) for P-2 and P-4 in 2009 and 2011—2 years of low-quality grass—were 0.99 and 0.92, and 1.04 and 1.11, respectively. Aamlid et al. (2016) determined a \( K_c \) of 2.39 on the first day after irrigation and 0.79 a subsequent day (mean following day) on an experimental green constructed similar to P-2. Labranche (2005) for mimo grass and substrate obtained a \( K_c \) of 0.85. The range of values of \( K_c \) between 0.8 and 1.09 obtained by Aronson et al. (1987) is low compared to those obtained in P-2 and P-4. The reason for this difference may be the lower water consumption of Poa, Festuca and Lolium varieties studied by Aronson et al. (1987) against the variety Agrostis stolonifera-L-93, that presents a greater capacity of transpiration as a resource to protect its photosynthetic metabolism from stress due to high temperatures (Liu and Huang, 2001). Maximum and minimum \( K_c \) values for the hydrogel-amended lysimeters (P-1 and P-3) were higher (P-1: 1.04–1.52) than those from P-2 and P-4 because of the ability of this compound to retain water, which facilitated evapotranspiration.

| I (mm) | R (mm) | D (mm) | ETₐ (mm) | ET₀ (mm) | K_c |
|--------|--------|--------|----------|----------|-----|
| 30 March–22 September 2009 |
| P-1 | 739 | 165 | 144 | 760 | 692 | 1.09 |
| P-2 | 735 | 165 | 209 | 691 | 692 | 0.99 |
| P-3 | 693 | 165 | 135 | 723 | 692 | 1.04 |
| P-4 | 798 | 165 | 326 | 638 | 692 | 0.92 |
| 4 March–12 October 2010 |
| P-1 | 919 | 279 | 211 | 987 | 783 | 1.26 |
| P-2 | 1 200 | 279 | 565 | 916 | 783 | 1.17 |
| P-3 | 1 260 | 279 | 347 | 1 190 | 783 | 1.52 |
| P-4 | 1 070 | 279 | 446 | 906 | 783 | 1.16 |
| 12 March–21 November 2011 |
| P-1 | 837 | 386 | 222 | 1 000 | 833 | 1.20 |
| P-2 | 1 010 | 386 | 530 | 866 | 833 | 1.04 |
| P-3 | 1 180 | 386 | 452 | 1 120 | 833 | 1.33 |
| P-4 | 1 160 | 386 | 623 | 926 | 833 | 1.11 |

Table I ET₀, ETₐ and \( K_c \) values for the water conditions \( \Delta V = 0 \) (P-1: hydrogel + OM, P-2: OM, P-3: hydrogel, P-4:100% sand; I: irrigation, R: rainfall, D: drainage)
3.4 | ET\textsubscript{0}, ET\textsubscript{a} and \( K_c \) from the daily water balance

If moisture sensors are available, the variations in water storage between any two given times can be calculated, and the daily ET\textsubscript{a} can be obtained from the water balance equation. Monthly ET\textsubscript{a} data are the result of the sum of the daily ET\textsubscript{a} values when enough storage data are available. For months with complete data, monthly ET\textsubscript{a} was extrapolated.

Figure 9 shows that ET\textsubscript{a} and ET\textsubscript{0} (daily data) follow the same trend but with a slight lag because of the interval chosen for the calculation. It also shows that, although the monthly \( K_c \) value was greater than 1 (\( K_c = 1.08 \)), the values of ET\textsubscript{a} did not always outperform ET\textsubscript{0}, but were sometimes above or below this value, indicating that the FAO-Penman-Monteith equation may over- or underestimate ET\textsubscript{a} in certain circumstances.

4 | CONCLUSIONS

The results obtained in this research allow verification of the effect of the amendments with hydrogel and OM on the values of ET\textsubscript{a} and \( K_c \).

The maximum and minimum \( K_c \) values for lysimeters with hydrogel were higher than other lysimeters due to the ability of this compound to retain water. The water retention effect of the hydrogel generates a greater availability of water for the root system. Its effect is particularly noticeable in conditions of low humidity and high evapotranspiration (summer).

Thus it is important to note that the addition of hydrogel can be a good measure for optimizing the use of water without impairing the quality of the grass.

It is possible to observe, in all lysimeters, that when there is total availability of water (well-watered conditions) ET\textsubscript{a} is greater than or equal to ET\textsubscript{0} and therefore \( K_c \) is higher than 1.

The monthly variation of \( K_c \) shows that the ET\textsubscript{0} calculated from meteorological parameters seems to be a reliable measure of the annual water requirement. However, while adequate in rainy periods, it is inadequate for months with dry situations because of the high water requirement of the L-93 turf grass variety during summer, especially when the temperature exceeds 29 °C, above which the grass suffers heat stress. In such situations, the water requirement is 37% more than that calculated by replacing the ET\textsubscript{0}.

To maintain the L-93 variety in optimal condition, the \( K_c \) must be higher than or equal to 1.2, because the grass is of poor quality when the \( K_c \) values are kept between 0.9 and 1.1.

ACKNOWLEDGEMENT

We wish to acknowledge the staff and direction from the Club de Campo del Mediterraneo golf course for their kind support.

ORCID

Arianna Renau-Pruñonosa © https://orcid.org/0000-0003-0862-2923
Maria V. Esteller © https://orcid.org/0000-0002-5832-8741
REFERENCES

Aamlid, T.S., J.Knox, J.W., Riley, H., Kvalbein, A. and Pettersen, T. (2016) Crop coefficients, growth rates and quality of cool-season Turfgrasses. Journal of Agronomy Crop Science, 202, 69–80. https://doi.org/10.1111/jac.12130

Aamlid, T.S., Larsbo, M. and Jarvis, N. (2009) Effects of surfactant use and peat amendment on leaching of fungicides and nitrate from golf greens. Biologia, 64(3), 419–423. https://doi.org/10.2478/s11756-009-0094-7

Abedi-Koupai, J., Sohrab, F. and Swarbrick, G. (2008) Evaluation of hydrogel application on soil water retention characteristics. Journal of Plant Nutrition, 31(2), 317–331. https://doi.org/10.1080/01904160701853928

Akker, J., Mahmoo, K., Malik, K.A., Ahmad, M. and Iqbal, M.M. (2004) Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. Plant, Soil and Environment, 50, 463–469. https://doi.org/10.17221/4059-PSE

American Society of Civil Engineers (ASCE). 1990. Evapotranspiration and irrigation water requirements: a manual prepared by the committee on irrigation water requirements, New York. ISBN: 0872627632

Amgain, N.R., Harris, D.K., Thapa, S.B., Martin, D.L., Wu, Y. and Moss, J.Q. (2018) Evapotranspiration rates of turf bermudagrasses under nonlimiting soil moisture conditions in Oklahoma. Crop Science, 58, 1409–1415. https://doi.org/10.2135/cropsci2017.08.0493

Aronson, L.J., Gold, A.J., Hull, R.J. and Cisar, J.L. (1987) Evapotranspiration of cool-season turfgrasses in the humid northeast. Agronomy Journal, 79, 901–905. https://doi.org/10.2134/agronj1987.00021962007900050029x

Augustin, B. (2000) Water requirements of Florida turfgrasses. Gainesville, Florida, USA: University of Florida, IFAS, Coop. Ext. Pub. EP-024. UF/IFAS.

Bigelow, C.A., Bowman, D.C. and Cassel, D.K. (2000) Sand-based rootzone modification with inorganic soil amendments and sphagnum peat moss. USGA Green Section Record, 38, 7–13.

Biran, I., Bravo, B., Bushkin-Harav, I. and Rawitz, E. (1981) Water consumption and growth rate of 11 turfgrasses as affected by mowing height, irrigation frequency, and soil moisture. Agronomy Journal, 73, 85–90. https://doi.org/10.2134/agronj1981.00021962007300010020x

Blankenship, T.M. (2011) Water use characteristics of ten newly established cool-season turfgrass species. Corvallis, Oregon, USA: MSc Thesis. Oregon State University.

Bowman, D. and Macaulay, L. (1991) Comparative evapotranspiration rates of tall fescue cultivars. HortScience, 26(2), 122–123.

Carrow, R.N. (1996) Summer decline of bentgrass greens. Golf Course Management, 64, 51–56.

Colmer, T.D. and Barton, L. (2017) A review of warm-season turfgrass evapotranspiration, responses to deficit irrigation, and drought resistance. Crop Sci., 57, 98–110. https://doi.org/10.2135/cropsci2016.10.0911

DaCosta, M. and Huang, B. (2006a) Minimum water requirements for creeping, colonial and velvet bentgrasses under fairway conditions. Crop Science, 46, 81–89. https://doi.org/10.2135/cropsci2005.0118

DaCosta, M. and Huang, B. (2006b) Deficit irrigation effects on water use characteristics of bentgrass species. Crop Science, 46, 1779–1786. https://doi.org/10.2135/cropsci2006.01-0043

Dernoeden PH. 2006. Understanding wet wilt. Shedding some light on an unfamiliar subject. USGA Green Section Record, Mar-Apr 06.

Ervin, E. and Koski, A. (1998) Drought avoidance aspects and crop coefficients of Kentucky bluegrass and tall fescue turfs in the semiarid west. Crop Science, 38, 788–795. https://doi.org/10.2135/cropsci1998.0011183X003800030028x

Fu, J., Fry, J. and Huang, B. (2004) Minimum water requirements of four turfgrasses in the transition zone. Horticultural Science, 39(7), 1740–1744. https://doi.org/10.21273/HORTSCI.39.7.1740

Gómez-Armayones, C., Kvalbein, A., Aamlid, T.S. and Knox, J.W. (2018) Assessing evidence on the agronomic and environmental impacts of turfgrass irrigation management. Journal of Agronomy and Crop Science, 204(4), 333–346. https://doi.org/10.1111/jac.12265

Green, R., Beard, J. and Casnoff, D. (1990) Leaf blade stomatal characterizations and evapotranspiration rates of 12 cool-season perennial grasses. HortScience, 25(7), 760–761. https://doi.org/10.21273/HORTSCI.25.7.760

Huang B. 2006. Turfgrass water use and conservation strategies. Council for Agricultural Science and Technology (CAST). Water Quality and Quantity Issues for Turfgrasses in Urban Landscapes. USA: Las vegas.

Kneebone, W.R. and Pepper, I.L. (1984) Luxury water use by bermudagrass turf. Agronomy Journal, 76, 999–1002. https://doi.org/10.2134/ agronj1984.00021962007600050031x

Labranche AJ. 2005. Creeping bentgrass, Kentucky Bluegrass and tall fescue responses to plant growth stimulants under deficit irrigation. MSc Thesis. Virginia Polytechnic Institute and State University. Blacksburg, Virginia, USA.

Lecina, S. and Martinez-Cob, A. (2000) Evaluación lisimétrica de la evapotranspiración de referencia semiarida calculada con el método FAO Penman-Monteith. Huelva, España: XVIII Congreso Nacional de Riegos.

Liu, X. and Huang, B. (2001) Seasonal changes and cultivar difference in turf quality, photosynthesis and respiration of creeping bentgrass. Horticultural Science, 36(6), 1131–1135. https://doi.org/10.21273/hortscis.36.6.1131

Marin, F.R., Angelocci, L.R. and Nassif, D.S.P. (2016) Crop coefficient changes with reference evapotranspiration for highly canopy-atmosphere couple crops. Agricultural Water Management., 163, 139–145. https://doi.org/10.1016/j.agwat.2015.09.010

Martín del Campo, M.A., Esteller, M.V., Morell, I., Esposito, J.L., Bandenay, G. and Díaz-Delgado, C. (2019) A lysimeter study under field conditions of nitrogen and phosphorus leaching in a turf grass crop amended with peat and hydrogel. Science of the Total Environment, 648, 530541. https://doi.org/10.1016/j. scitotenv.2018.08.152

McCann, S.E. and Huang, B. (2008) Evaluation of drought tolerance and avoidance traits for six creeping bentgrass cultivars. HortScience, 43(2), 519–528. https://doi.org/10.21273/HORTSCI.43.2.519

McCoy, E.L., Kunkel, P., Prettyman, G.W. and McCoy, K.R. (2007) Root zone composition effects on putting green soil water.
Mohawesh, O. and Durner, W. (2019) Effects of bentonite, hydrogel and biochar amendments on soil hydraulic properties from saturation to oven dryness. Pedosphere, 29(5), 598–607. https://doi.org/10.1007/S10201-016-0429-0
Qian, Y.L., Fry, J.D., Wiest, S.C. and Upham, W.S. (1996) Estimating turfgrass evapotranspiration using atmometers and the penman-Monteith model. Crop Science, 36, 699–704. https://doi.org/10.2135/cropsci1996.0011183X003600030010x
Rodriguez Diaz, J.A., Knox, J.W. and Weatherhead, E.K. (2007) Competing demands for irrigation water: Golf and agriculture in Spain. Irrigation and Drainage, 56(5), 541–549. https://doi.org/10.1002/ird.317
Shearman, R.C. and Beard, J.B. (1973) Environmental and cultural preconditioning effects on the water use rate of Agrostis palustris Huds, cultivar Penncross. Crop Science, 13, 424–427. https://doi.org/10.2135/cropsci1973.0011183X001300040010x
Smith, M., Allen, R.G., Monteith, J.L., Pereira, L.S. and Pruitt, W.O. (1992) Report on the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements. Land and Water Development Division. Rome, Italy: Food and Agriculture Organization of the United Nations.
Throssell, C.S., Carrow, R.N. and Milliken, G.A. (1987) Canopy temperature based irrigation scheduling indices for Kentucky bluegrass turf. Crop Science, 27, 126–131. https://doi.org/10.2135/cropsci1987.0011183X002700010013x
Ullah, F., Othman, M.B.H., Javed, F., Ahmada, Z. and Akil, H.M. (2015) Classification, processing and application of hydrogels: A review. Materials Science and Engineering C, 57, 414–433. https://doi.org/10.1016/j.msec.2015.07.053
Waltz, F., Quisenberry, V. and McCarty, L. (2003) Physical and hydraulic properties of rootzone mixes amended with inorganics for golf putting greens. Agronomy Journal, 95, 395–404. https://doi.org/10.2134/agronj2003.3950
Wherley, B., Dukes, M.D. and Cathey, S. (2015) Consumptive water use and crop coefficients for warm-season turfgrass species in the southeastern United States. Agricultural Water Management, 156, 10–18. https://doi.org/10.1016/j.agwat.2015.03.020
Xinmin, Z., Lin, H., Xiuju, F.C. and Xinzhang, S. (2007) The most economical irrigation amount and evapotranspiration of the turfgrasses in Beijing, China. Agricultural Water Management, 89, 98–104. https://doi.org/10.1016/j.agwat.2006.11.006
Xu, Q. and Huang, B. (2000) Effects of differential air and soil temperature on carbohydrate metabolism in creeping bentgrass. Crop Science, 40, 1368–1374. https://doi.org/10.2135/cropsci2000.4051368x
Zhang, X., Kang, S. and Zang, L. (2010) Spatial variation of climatology monthly crop reference evapotranspiration and sensitivity coefficients in Shiyang river basin of Northwest China. Agricultural Water Management, 97:1506-1516, https://doi.org/10.1016/j.agwat.2010.05.004

How to cite this article: Bandenay GL, Renau-Puñonosa A, Morell I, Esteller MV. Effects of different amendments (organic matter and hydrogel) on the actual evapotranspiration and crop coefficient of turf grass under field conditions. Irrig. and Drain. 2021;70:293–305. https://doi.org/10.1002/ird.2544