EFFECTS OF DIFFERENT AMENDMENTS (ORGANIC MATTER AND HYDROGEL) ON THE ACTUAL EVAPOTRANSPIRATION AND CROP COEFFICIENT OF TURF GRASS UNDER FIELD CONDITIONS†

GLADYS L. BANDENAY[1], ARIANNA RENAU-PRUÑONOSA[2*], IGNACIO MORELL[3]
AND MARÍA V. ESTELLER[4]

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

ABSTRACT

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 crop coefficient (K_c). The water soil availability can be increased using hydrogel and organic matter amendments, theirs 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

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† Effets de différents amandments (matière organique et hydrogel) sur l'évaporation réelle et le coefficient de culture du gazon de gazon dans les conditions du terrain

* Correspondence to: Prof. Arianna Renau-Pruñonosa. Universitat Jaume I – IUPA. Sos Baynat S/N Campus Borriol Castello de la Plana 12071. Spain. Tel.: 0034964307381. E-mail: arenau@uji.es

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.

KEY WORDS: Lysimeters, crop coefficient (K_c), evapotranspiration ($ET_{a,}$), organic matter, hydrogel, Mediterranean climate

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 (ET_a) ainsi que celle du coefficient d'agriculture (K_c). L'objectif de cette étude était de déterminer la ET_a et le K_c 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 (ET_0) a été déterminée à partir de données météorologiques (équation FAO-Penman-Monteith). L'ET_a a été calculée à partir de l'équilibre d'eau, et le K_c a été obtenu en divisant la ET_a par la ET_0. Le K_c 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 K_c (0.92-1.16), similaires à celle d'un lysimètre modifiée par matière organique (0.99-1.17). Les valeurs maximum et minimum du K_c 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 facilita l'évapotranspiration). Finalement, l'hydrogel facilite ainsi la maintenance de la qualité du gazon.

MOTS CLÉS: Lysimètre, coefficient d'agriculture (K_c), évapotranspiration (ET_a), matière organique, climat méditerranéen

INTRODUCTION

Evapotranspiration is the combination of two separate processes whereby water is lost from the soil: evaporation and transpiration. Evaporation consists in 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 (Allen, 1998). Evapotranspiration can be measured in experimental lysimeters (actual evapotranspiration, ET_a) or estimated from meteorological data (reference evapotranspiration, ET_0).

The ET_a 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 ET_a 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, ET_0 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; Allen *et al.*, 1998).

Under standard conditions (well-watered conditions) the ET_a of a crop can be related to the ET_0 through the crop coefficient, K_c (ASCE 1990; Zhang *et al.*, 2010; Marin *et al.* 2016). The K_c 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 K_c shows daily variation and, to minimize complexity, is expressed as the average over a period, either monthly, yearly, by stage of crop development, or season (Allen *et al.*, 1998).

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 ET_a varies according to the variety of grass. ET_a from cool season and warm season grasses ranges from 3 to 8 mm/day and from 2 to 6 mm/day, respectively (Augustin, 2000; Huang, 2006; Xinmin *et al.*, 2007, Wherley *et al.*, 2015, Colmer and Barton, 2017). When the water availability drops, the grass responds to the shortage by activating biological mechanisms that result in lower water consumption. As reported by McCann and Huang (2008), the *Agrostis stolonifera-L-93* variety generally suffers a sharp decline in the rate of ET_a in low water stress conditions, and, as indicated by Xu and Huang (2000), Liu and Huang (2001) and Da Costa and Huang (2006a, b), also suffers from biological changes that are triggered to reduce water consumption. Numerous studies have reported different values of K_c for the same grass variety, reflecting the influence of the growing area. For example, the K_c value of the Bermuda grass (*Cynodon dactylon*) variety ranges is between 0.17 and 0.99 in south eastern USA (Wherley *et al*., 2015). *Kentucky bluegrass* has K_c values is between 0.80 and 1.40 in Beijing, and K_c of *Tall fescue* is 0.5 and 0.8 in Colorado, and ranges from 0.84 to 1.49 in Beijing (Erwin and Koski, 1998; Fu *et al*., 2004; Xinmin *et al*., 2007).

For this study, carried out under Mediterranean climatic conditions, an experimental golf green comprised by four sand based lysimeters was built. The actual water requirement (ET_a) of a maintained *Agrostis stolonifera-L-93* creeping turf grass was determined under both total water availability and water stress conditions. Since the sand based lysimeters were amended with organic matter (OM) and hydrogel, an evaluation of the effect of these amendments on the ET_a and K_c could be made.

The addition of OM and hydrogel amendments is a common practice since it increases efficiency in water and agrochemicals use (Aamlid *et al*., 2009; Ullah *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 growing (Akhter *et al*., 2004; Abedi-Koupai *et al*., 2008; Ullah *et al*., 2015).

MATERIALS AND METHODS

Description of the experimental green

Four lysimeters were built, each with a surface of approximately 40 m^2 and a volume of 11 m^3. 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 it was mixed with the first 10 cm of the sandy substrate. The lysimeters are amended as follows: P-1 is amended with both: 20% OM (peat) and 145 g/m^2 hydrogel, P-2 is amended with 20% OM (constructed according to USGA requirements), and P-3 is amended with 145 g/m^2 hydrogel (TerraCottem®). P-4 is sand only.

Each lysimeter has an independent irrigation system. Each irrigation system comprises eight diffusers (Model 6406-ADV Nelson Turf®) equipped with 15 cm body type nozzles (7370 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. 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 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 if irrigation water could be saved in comparison to 2010.

The lysimeters are equipped with three moisture sensors installed vertically (DECAGON). Two sensors are 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 the 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 minutes.

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 ET_0 from the FAO-Penman-Monteith equation (Smith *et al*., 1992; Allen *et al*., 1998).

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 in the golf course.

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

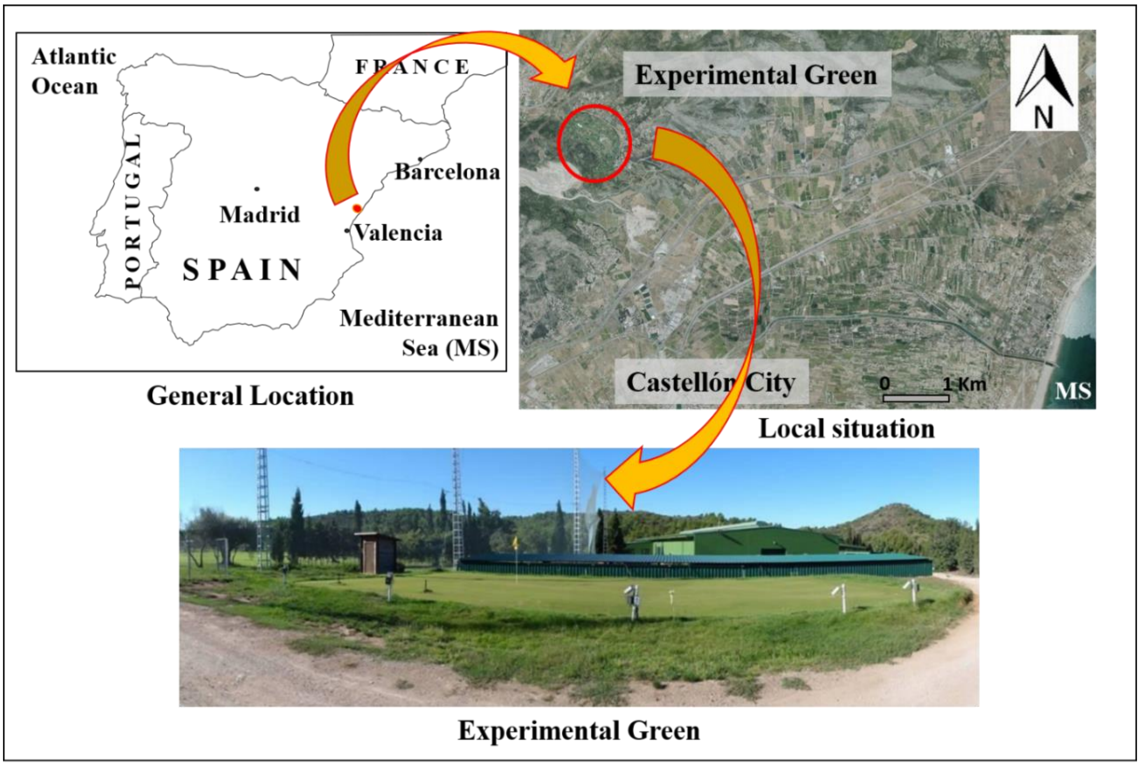

Figure 1. Location of the field study site

Climatic characteristics of the area

The experimental green is located a few kilometres from the Mediterranean coast in Spain (Figure 1). The area is characterised 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 ºC, with peak point temperatures close to 30 ºC. On the other hand, the average temperatures for the winter months were between 8 and 10 ºC, with minimum temperatures of 2 - 3 ºC. 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 rainy month was September 2009 with a rainfall of 360 mm, followed by November 2011 with 182 mm (Figure 2).

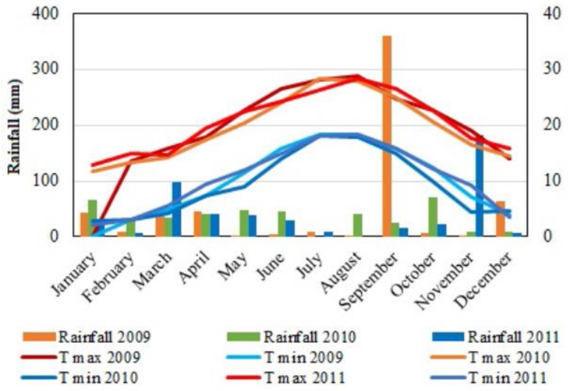

Figure 2. Temperatures and rainfall (2009-2010). Data from the meteorological station of experimental site

Reference evapotranspiration (ET_0)

ET_0 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 ET_0 (Smith *et al*., 1992; Allen *et al*., 1998):

$$ET_o = \frac{0,408\Delta(Rn - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0,34U_2)} \tag{1}$$

From Eq. 1, ET_0 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. ET_0 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 (U_2), the saturation vapour pressure (e_s), the actual vapour pressure (e_a), the slope of the vapour pressure curve versus temperature (Δ), and the psychrometric constant (γ).

Determination of actual evapotranspiration (ET_a*) using the water balance*

$ET_{\mathbf{a}}$ can be calculated using the water balance (Eq. 2) between two dates on which substrate moisture values were approximately the same; thus, the variation in moisture storage was zero ($\Delta V = 0$). Under this premise ET_a is the difference between the input water (rainfall and irrigation) and the output water (drainage). This condition was used for determining ET_a in 2009, since no moisture sensors were installed that year.

$$\text{Input (rainfall + irrigation)} = \text{Output (drainage} + ET_a) + \Delta V \qquad (2)$$

In 2010 and 2011 data from the moisture sensors were used to determine ΔV and ET_a could be calculated in 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 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.

RESULTS AND DISCUSSION

Effect of amendments under total water availability

Effect of the OM amendment

To test the effect of OM on the water balance, the values of $ET_\mathbf{a}$ for P-2 (amended with OM) and P-4 (100% sand) are compared. Figure 3 shows that the $ET_\mathbf{a}$ values for the two lysimeters are similar; in fact, for a few months (March, April, May and July. 2010), ETa in the P-2 is lower than the not amended lysimeter, while in other months (June, August, September and October 2010) it is up to 23% higher. The highest values of ET_a were reached in June-August 2010: 2.76-12.2 mm/day in P-2 and 3.06-10.3 mm/day in P-4. These values are similar to those obtained by Green *et al*. (1990) and Bowman and Macaulay (1991): 7.7-12.7 mm/day and 4.57-13.0 mm/day, respectively. Research carried out in Norway by Aamlid *et al*. (2016) showed that, under daily irrigation conditions, they obtained ET_a values of 5-10 mm/day, 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*. (2004), Waltz *et al*. (2003) and McCoy *et al*. (2007) already showed in previous research.

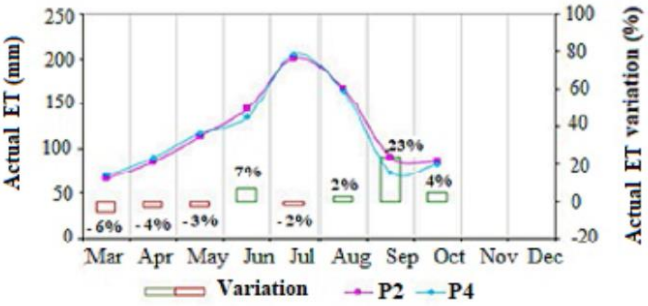

Figure 3. ET$_a$ values for P-2 (OM) and P-4 (100% sand), to show the effect of OM for 2010. ET$_a$ variation: difference between the ET$_a$ value of P2 and the ET$_a$ value of P4

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 4A (P-1 compared with P-2, amended with OM) and 4B (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 high 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 *Kc* value generated by transpiration. Mohawesh and Durner (2019) and Narjary *et al*. (2012) suggested that soil amendments, as hydrogel, improved soil water retentivity, across the whole moisture range saturation (from total water availability to water stress condition), and, also, improved the water availability of the sandy soils for a larger period (nearly 22 days). The ET$_a$ values achieved at P-1 and P-3 (P-1: 3.71-13.18 mm/day; P-3: 3.34-15.16 mm/day) exceed the maximum values of Green *et al*. (1990) (12.7 mm/day) and Bowman and Macaulay (1991) (13.0 mm/day).

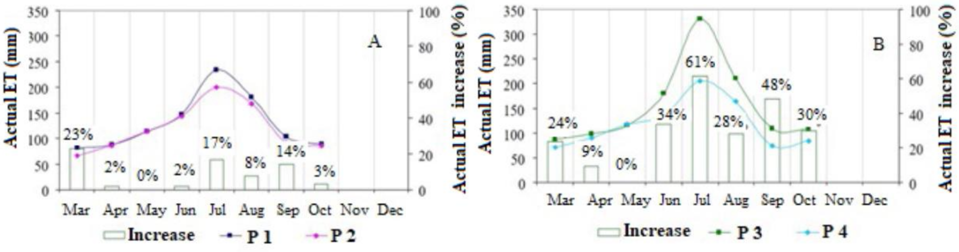

Figure 4. A) ET$_a$ values for P-1 (hydrogel and OM) and P-2 (OM). ET$_a$ increase: percentage by which the ET$_a$ value of P4 increased with respect to P2. B) ET$_a$ values for P-3 (hydrogel) and P-4 (100% sand), to show the effect of the hydrogel for 2010. ET$_a$ increase: percentage by which

the ET_a value of P3 increased with respect to P4.

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 March 1st, 2010 and December 31st, 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 clear influence of agronomic activities and the FAO-Penman-Monteith equation underestimates the water requirement. Qian *et al*. (1996) and Lecina y Martínez-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 the all lysimeters. Irrigation was increased when tracer tests were made in December 2010 and the 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).

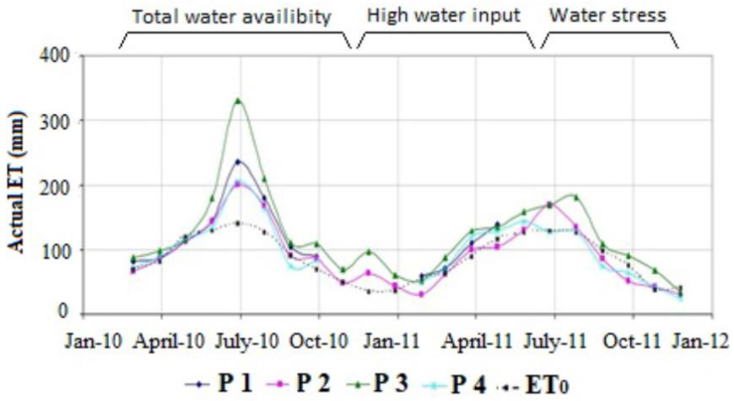

Figure 5. Monthly ET_a and ET_0 values for the period from March 1st, 2010 until December 31st, 2011 for P-1 (hydrogel and OM), P-2 (OM), P-3 (hydrogel) and P-4 (100% sand)

Effect of amendments under slight water stress condition

A slight water stress was imposed in the period from June to December 2011 to determine if 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 is no data for P-1); however, each lysimeter reacted differently to water deficit, depending on the amendment. Gómez-Armayones *et al*. (2017) 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.

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 ET_a of P-2 that in the P-4. For example, in July 2011, a decrease of 13% in storage in P2 (Figure 6A) caused the ET_a to decrease 16% (Figure 6B), while in P-4, a 5% decrease in storage in P-4 (Figure 6C) caused a decrease of 38% in the ET_a (Figure 6D). In August 2011, the ratios were lower, but the OM still prevented a decrease in ET_a and plant heat stress. In September, when the decrease in soil moisture was similar in both lysimeters, the ET_a 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 ET_a 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 3-5 mm/day, and in the P-2 , for these stress conditions, ET_a presented values between 1.1 and 5.4 mm/day. In 2011, the difference in the behaviour of the substrates (edaphic factor) was not very evident as the standard condition of the FAO (total water availability) was kept in all lysimeters (2010). When the sand was amended with OM, the decline of ET_a was minimized only under conditions of water deficit, and grass stress caused by high temperatures was reduced.

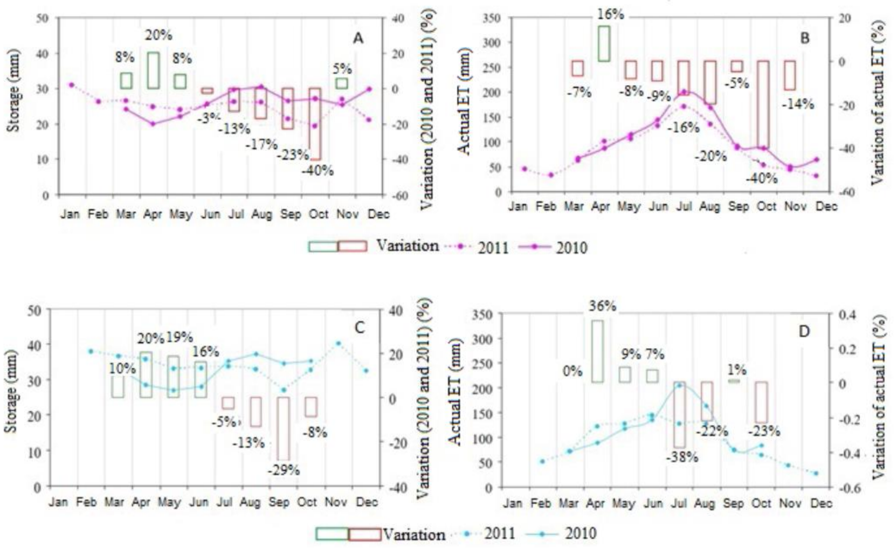

Figure 6. A) Values of the average monthly water storage for P-2 (OM), B) values of ET_a for P-2 (OM), C) values of the average monthly water storage for P-4 (100% sand), and D) values of ET_a for P-4 (100% sand), for 2010 and 2011. ET_a variation: difference between the 2010 ET_a value and the 2011 ET_a value

When the 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.

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 ET_a in Figure 7. It is shown that P-3, despite of having a greater decrease in storage in the summer of 2011 (Figure 8) than P-4 (Figure 6C), has an ET_a 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 (Narjary *et al.*, 2012).

It appears that the distribution of water within the substrate, which in turn determines the availability to the grass, is more important than the amount of water stored; this is especially important in the summer months when the grass is facing heat stress.

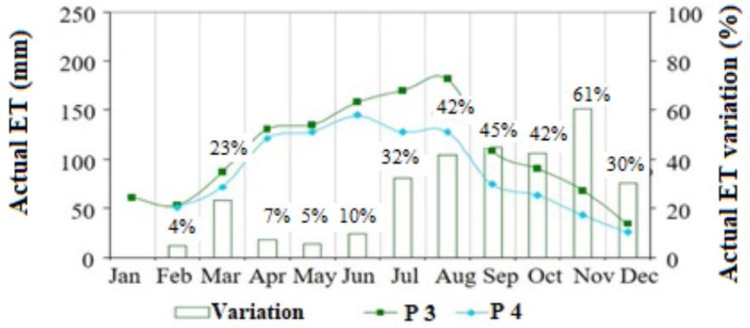

Figure 7. ET_a values for P-3 (hydrogel) and P-4 (100% sand) in 2011 to highlight the effect of the hydrogel amendment. ET_a variation: difference between the ET_a value of P3 and the ET_a value of P4

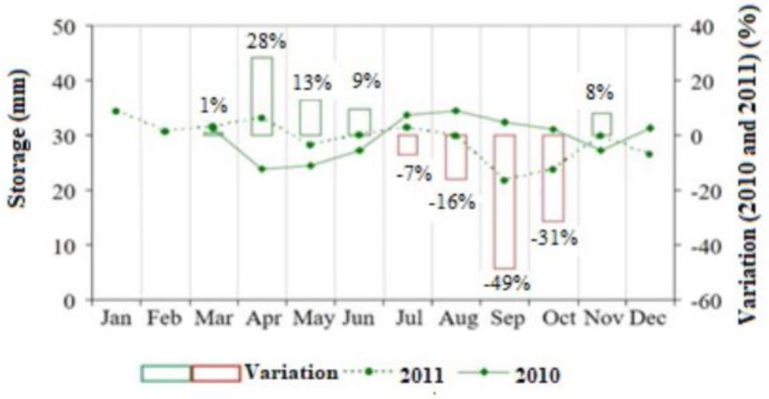

Figure 8. Comparison of the average monthly storage in P-3 (hydrogel) during 2010 and 2011.Storage variation: difference between the 2010 storage value and the 2011 storage value

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 the water availability decreased, as occurred in this 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.

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 March 30th to September 22nd, 2009, a second interval between March 4th and October 12th, 2010, and a third interval from March, 12th to November, 21st, 2011. For these three intervals, daily values of ET_0 were calculated from weather station data using the FAO-Penman-Monteith equation. ET_a was calculated from water balance from the irrigation, drainage, and daily precipitation data. The ET_a and crop coefficient, $K_c = ET_a/ET_0$, are presented in Table I.

Table I shows that values of K_c in year 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, ET_a is 10 to 50% bigger than ET_0 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 the 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 (Throsell *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 in P-4 (100% sand) was between 16% and 17% higher than that determined by the weather station (ET_0), 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 - two years of low quality grass, were 0.99 and 0.92, and 1.04 and 1.11, respectively. Aamlid *et al*. (2016) determinate 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 construed similar to P2. Labranche (2005) for mime 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 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 lysimeter (P1 and P4) were higher (P1: 1.09-1.26); P3: 1.04-1.52) than those from P2 and P4 because of the ability of this compound to retain water, which facilitated evapotranspiration.

Table I. ET_0, ET_a, 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**)**

March, 30 – September, 22, 2009						
	I (mm)	*R (mm)*	*D (mm)*	ET_a *(mm)*	ET_0 *(mm)*	K_c
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

March, 4 – October, 12, 2010						
	I (mm)	*R (mm)*	*D (mm)*	ET_a *(mm)*	ET_0 *(mm)*	K_c
P-1	919	279	211	987	783	1.26
P-2	1200	279	565	916	783	1.17
P-3	1260	279	347	1190	783	1.52
P-4	1070	279	446	906	783	1.16

March, 12 – November, 21, 2011						
	I (mm)	*R (mm)*	*D (mm)*	ET_a *(mm)*	ET_0 *(mm)*	K_c
P-1	837	386	222	1000	833	1.20
P-2	1010	386	530	866	833	1.04
P-3	1180	386	452	1120	833	1.33
P-4	1160	386	623	926	833	1.11

ET_0, ET_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_a can be obtained from the water balance equation. Monthly ET_a data is the result of the sum of the daily ET_a values when enough storage data is available. For months with uncomplete data, monthly ET_a was extrapolated.

Figure 9 shows that ET_a and ET_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_a did not always outperform ET_0, but were sometimes above or below this value, indicating that the FAO-Penman-Monteith equation may overestimate or underestimate ET_a in certain circumstances.

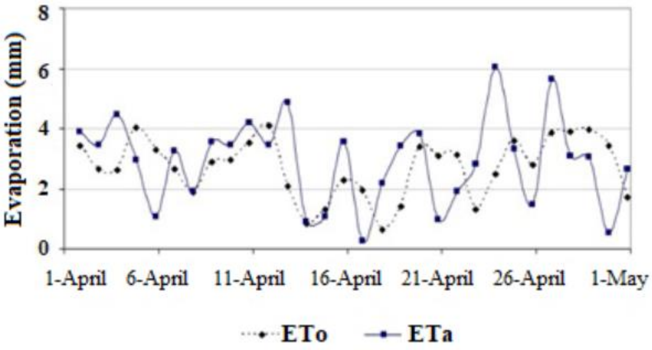

Figure 9. Daily ET_a and ET_0 values in P-1 (hydrogel and OM) for April, 2010

CONCLUSIONS

The results obtained in this research allow to verify the effect of the amendments with hydrogel and OM on the values of ET_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).

So, it is important to note that the addition of hydrogel can be a good measure to optimize 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_a is greater or equal to ET_0 and therefore K_c is higher than 1.

The monthly variation of K_c shows that the ET_0, calculated from meteorological parameters seems to be a reliable measure of the annual water requirement. However, while adequate from rainy periods, it is inadequate from month 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 $ET_{0.}$

To maintain L-93 variety in optimal conditions, the K_c must be higher or equal to 1.2, because the grass presents poor quality when the K_c values are kept between 0.9 and 1.1.

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