Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi 24 (Özel Sayı):24-40, 2019
(*Mustafa Kemal University Journal of Agricultural Sciences* 24 (Special Issue):24-40, 2019)
e-ISSN: 2667-7733
http://dergipark.org.tr/mkutbd

1st Int. Congress on Biosystems Engineering (ICOBEN 2019) ARAŞTIRMA MAKALESİ/RESEARCH ARTICLE

Irrigation scheduling based on Crop Water Stress Index (CWSI) for cool and warm-season turf grass under subsurface-drip irrigation method

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MAKALE BİLGİSİ / ARTICLE INFO

Makale tarihçesi / Article history:
Geliş tarihi /Received:09.10.2019
Kabul tarihi/Accepted:16.12.2019

Keywords:
Landscape irrigation, evapotranspiration, canopy temperature, water use efficiency, crop coefficient.

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Ö Z E T / A B S T R A C T

Aims: This study was conducted to determine irrigation scheduling based on the Crop Water Stress Index (CWSI) of cool (CS) and warm-season (WS) turfgrass species under subsurface-drip irrigation method.

Methods and Results: The field experiment was carried out during the summer period of 2018 in the Agricultural Production and Research Centre (TURAM) of Silivri municipality, Istanbul-Turkey. Specific objectives were to measure actual evapotranspiration (ETc) values for both turfgrass types, to compare their responses to different water levels, to determine CWSI values for both turfgrass species under different irrigation scheduling and opportunity of using CWSI in irrigation timing, to compare ETc with reference to evapotranspiration (ETo) calculated with five different methods and to determine crop coefficient curve (kc) for experimental conditions, and to focus on the crop growing and irrigation management parameters under subsurface-drip irrigation method. Three irrigation strategies [I1:30%, I2:50%, and I3:70%) were tested in a split-plot randomized complete block design with three replications. These strategies corresponded, respectively, to 30%, 50% and 70% of total available soil moisture depletion at 0-30 cm of the effective root zone and returning soil moisture back to field capacity. The results indicated that colour, quality, fresh yield, dry matter yield, irrigation water use efficiency, water use efficiency, vegetation height and mowing were significantly different in terms of irrigation strategies for both species. The most appropriate irrigation strategies were I2:50% for CS and I3:70% for WS turfgrass which corresponded to a CWSI of 0.47 and 0.45, respectively.

Conclusions: The amount of applied irrigation water in WS turfgrass was 53% less than in CS turfgrass. Actual evapotranspiration was 26% lower for WS than for CS turfgrass.

Significance and Impact of the Study: These results obtained from the experiments will help choosing of turf type and irrigation scheduling to save water in urban areas.

Atıf / Citation: Oncel CS, Todorovic M, Orta AH (2019) Irrigation scheduling based on Crop Water Stress Index (CWSI) for cool and warm-season turf grass under subsurface-drip irrigation method. *MKU. Tar. Bil. Derg.* 24 (Özel Sayı) :24-40

INTRODUCTION

Irrigation scheduling methods are generally based on measurement of soil water content or meteorological parameters for modelling or computing evapotranspiration. In addition, methods based on crop monitoring have become widely used, including porometers, pressure chambers, etc. In general, these approaches rely on direct contact with the crop;

however, methods based on remote sensing, such as infrared thermometers (IRTs), have become the preferred methods for detecting crop water stress. This remote sensing through measurement of a crop's surface temperature can be accomplished with no damage. The correlation between surface temperature and water stress is based on the assumption that, as the crop goes under water stress, the stomata close, transpiration decreases and leaf temperature increases. In practice, leaf/canopy temperature obtained by hand-held IRTs could be used in the Crop Water Stress Index (CWSI) method, defined by Idso et al., (1981). The idea of CWSI is first to determine minimum water stress (lower baseline) under well irrigated conditions, maximum water stress (upper baseline) under rain-field conditions and then periodically monitor leaf/canopy temperature between the minimum and maximum stress conditions with respect to water deficit. Technically, lower baseline has been based on empirical linear relationships between canopy-air temperature difference (Tc-Ta) and vapour pressure deficit (VPD); however, upper baseline depends on the (Tc-Ta). Ta and VPD have been obtained in several ways, including use of a psychrometer to get dry and wet bulb temperatures, or use of other temperature and humidity measuring devices and accompanying software built into an infrared thermometer and data logging system.

Many studies have reported on determination of CWSI for different turfgrasses. For example, (Jalali-Farahani et al., 1994) reported that crop water stress index (CWSI) values of Bermuda grass should be 0.16 to start irrigation to maintain quality in Tucson, AZ. Similar CWSI value of Bermuda grass, 0.15, was found by Bijanzadeh et al. (2013) for maintaining quality of turfgrass in Shiraz Iran. Also, (Emekli et al., 2007) suggested that, for good quality, the CWSI value should be 0.10 to start irrigation for Bermuda grass in Antalya Turkey.

The main purpose of this study was to determine irrigation scheduling of warm-season and cool-season turfgrass under subsurface-drip irrigation system in the western part of Turkey. Specific objectives are the following: to measure actual ETc (crop Evapotranspiration) values for both turfgrass species, to compare cool and warm season turfgrass in the concept of actual ETc and their response to different water levels, to determine CWSI values for both turfgrass species under different irrigation scheduling and opportunity of using CWSI in irrigation timing, to focus on crop growing and irrigation management parameters under subsurface-drip irrigation method.

MATERIAL and METHODS

The field experiment was carried out during the summer period of 2018 in the Agricultural Production and Research Centre (TURAM) of Silivri municipality, Istanbul,-Turkey (41°03′N; 28°00′E; 46 m a.s.l.) (Figure 1). Disturbed and undisturbed soil samples were taken from soil layers at 30 cm depth of opened profile for determining physical properties of soil such as texture, bulk density, field capacity, wilting point, and some chemical properties. Soil samples were taken according to the specified principles in Blake, (1965) from soil layers at 30 cm depth of 60 cm soil profile, and water samples from pump and study areas were taken to determine quality by Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC) parameters. Soil and water samples were measured by Atatürk Soil And Water Agricultural Meteorology Research Institute. Infiltration rate was measured on-site using a double ring infiltrometer. Necessary meteorological parameters were measured by an automatic meteorological station located just near the experimental field and manual pluviometry in the field supported the station in terms of precipitation. The amount of water evaporated was measured by Class A pan. Ambient conditions of Class A pan represented Case B as described in the FAO 56 (Allen et al., 2006).

Figure 1. View of the study area

Experimental Background

The experiment was designed in Split-Plots (SP) in a Randomized Complete Block Design (RCBD) with three replications. Main treatments were two different species: Cool-Season (CS) turfgrass (10% *Poa pratensis*, 25% *Festuca rubra* var. *rubra*, 30% *Lolium perenne*, 35% Festuca arundinacea) and Warm-Season (WS) (*Cynodon dactylon* L. Pers.) turfgrasses. Sub-treatments were three different irrigation strategies as a threshold (I1:30%, I2:50%, and I3:70%). These thresholds corresponded, respectively, to 30%, 50% and 70% of total available soil moisture depletion at 0-30 cm of the effective root zone and returning soil moisture back to field capacity (Figure 2). Each plot was 4 m^2 and there was a gap of 2 m within blocks and plots in order to avoid the side effects of seepage (Figure 3). Five laterals were installed and each lateral had 6 emitters, that is to say, 30 emitters are per plot. The plots were irrigated at nearly 10-15 cm depth by self-regulated in-line emitters with flow rates of 2.3 litres per hour at an operating pressure of more than 1 bar; emitter and lateral spacing were determined by previous researchers as 0.40 m according to emitter discharge and soil infiltration rate . to wet all plot area (Figure 4). Moreover, nearly 30 minute intervals were applied into the irrigation duration to let water infiltrate into the soil and to avoid possible deep percolation at 30-60 cm depth; this application is known as surge irrigation.

The soil water level was monitored daily in the middle block by using a soil moisture profile probe (PR2/6, Delta company, UK) with a soil moisture meter (HH2, Delta company, UK) for 0.10, 0.20, 0.30, 0.40, and 0.60 m depths during the whole growing season (May-August). The soil water level was measured at nearly 9.00 a.m. daily and, when necessary, the plots were irrigated individually with their replications. Previous researchers (Bezirgan, 2018;Ayanoglu, 2018) calibrated PR2/6 profile probe by using the gravimetric method as described in Blake, (1965) (Figure 5). The amount of soil water in the 0.30 m top layer was used to initiate irrigation. Evapotranspiration for a 10-day period was calculated based on results of only the PR2/6 by applying the water balance method to the upper 0.60 m soil layer (Heerman, 1985). Thanks to this approach, possible deep percolation could be monitored at 30-60 cm for trustable calculation of actual crop evapotranspiration.

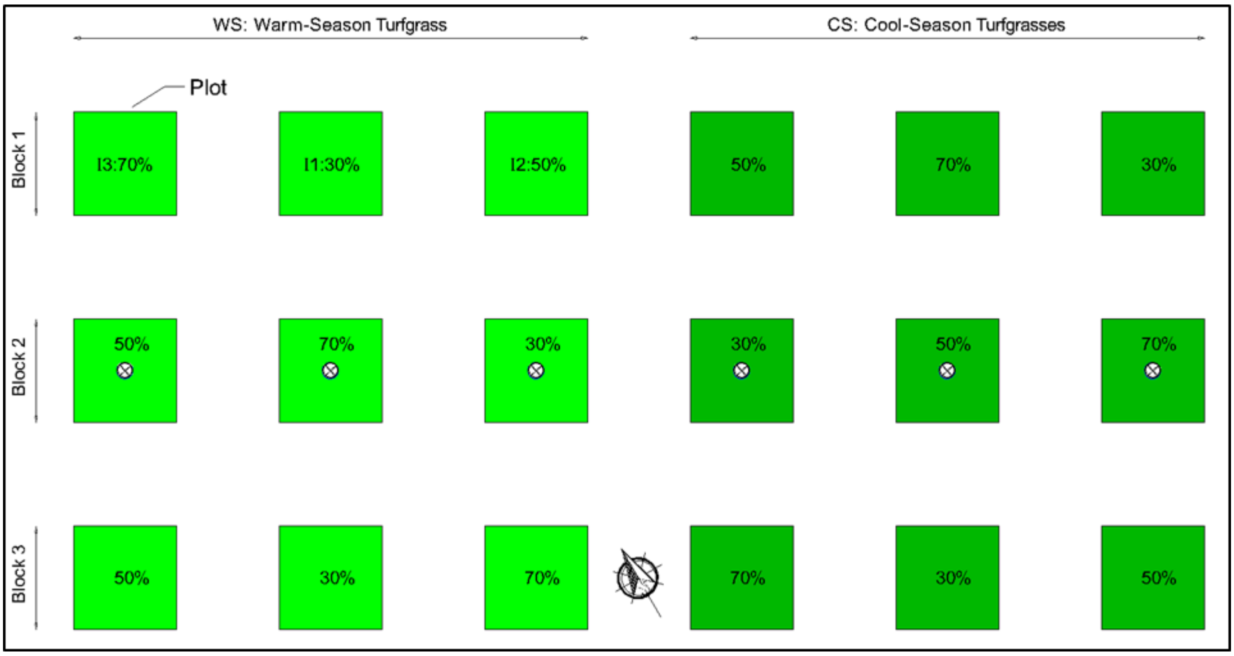

Figure 2. Experimental Design

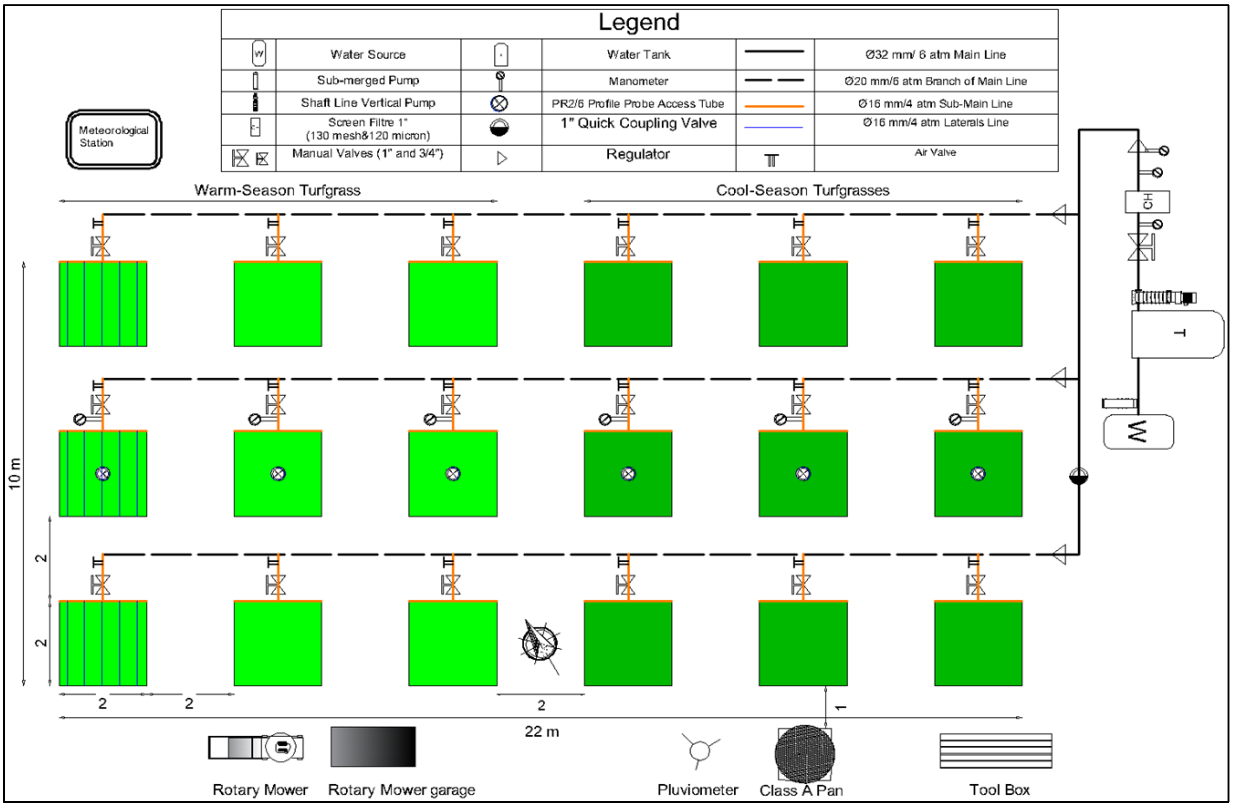

Figure 3. Layout of Experimental Field

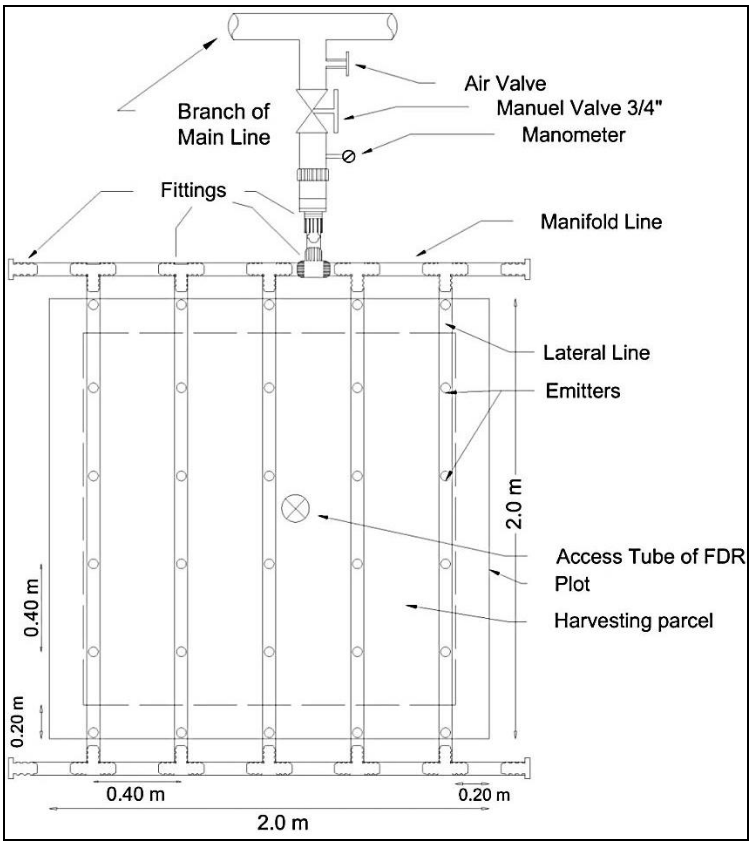

Figure 4. Details of a Plot

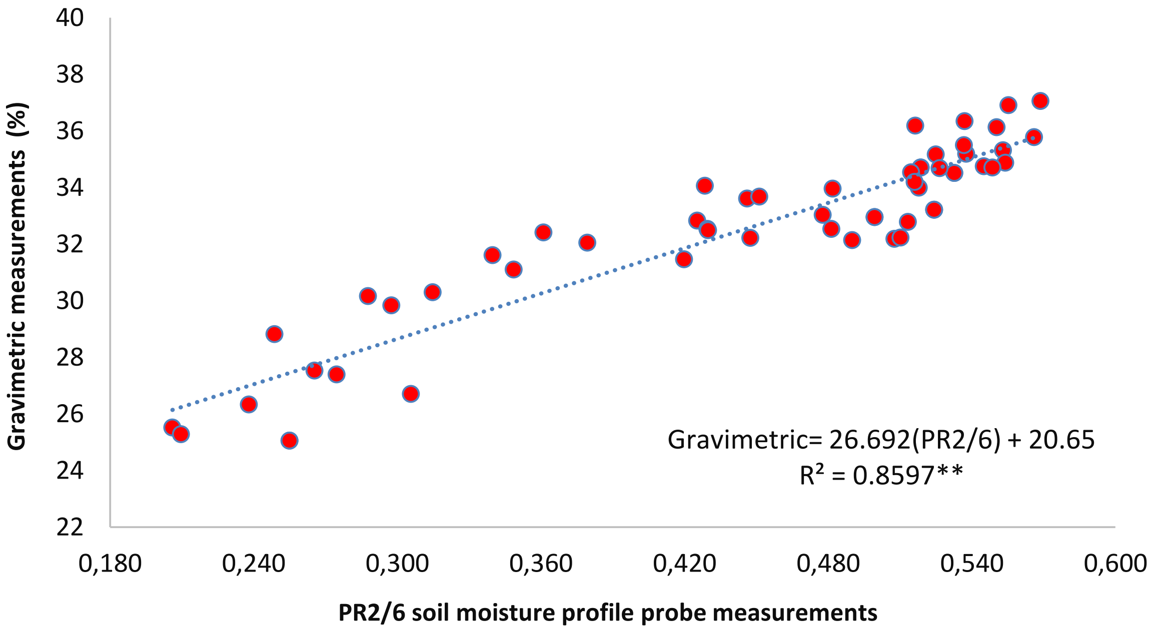

Figure 5. Calibration curve of PR2/6 Soil Moisture probe and its equation (Bezirgan, 2018; Ayanoglu, 2018)

Determination of Yield Characteristics, Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE)

The warm-season turfgrass and cool-season turfgrass were mowed according the suggestion of one-third (⅓) of canopy height (Kopec & Umeda, 2015) by rotary mower when they reached approximately 9-11 cm and 14-16 cm height, respectively, leaving nearly 5-6 cm vegetation height on the ground for both species after mowing (Figure 6).

After the mowing process, samples from each plot were taken and weighed as fast as possible by digital scale to find fresh yield before taking Dry Matter Yield samples. Results were expressed in $g\,m^{-2}$(Brede & Duich, 1984; Avcıoglu, 1997).

The most desirable turfgrass may be the species, varieties, cultivars that grow slowly while being always green, reducing environmental requirements such as irrigation, fertilizers, maintenance, etc. and tending to decrease dry matter yield. Possible correlation between dry matter yield and irrigation requirement of turfgrass was investigated. After mowing the grasses, approximately 500 g samples from each plot were collected and stored in paper bags. These were placed in a greenhouse to remove excess water from foliage and then dried at 78°C for 24 hours in a blight chamber, after which they were weighed by sensitive scale (Figure 7). Results were expressed by percentage (Brede & Duich, 1984; Avcıoglu, 1997). Percentage (%) values were transformed to angle or aspect (arcsin$\sqrt{\%}$) by using specially prepared tables for that conversion in order to apply the variance analysis and make interpretation statistically (Yurtsever, 1984); these values which were normally distributed after transformation.

Quality parameters of density, frequency, coverage and weed activity were observed for each plot and were evaluated periodically with a 1 to 9 scale (1: poor, 6: acceptable, 9: excellent)(Brede & Duich, 1984);(Avcıoglu, 1997).

Each plot was evaluated periodically for colour of the crop within a 1 to 9 scale (1: yellow, 9: bottle green) (Brede & Duich, 1984; Avcıoglu, 1997) .

Water use efficiency (WUE) and irrigation water use efficiency (IWUE), which are fundamental criteria for comparing irrigation methods or evaluating any irrigation scheduling, can be expressed as a unit water utilization rate. Water use efficiency (WUE) is defined as grain yield (Y, gm^{-2}) divided by water use (ET_c ; Crop Evapotranspiration, mm) during the growing season (Aydinsakir et al., 2013) while irrigation water use efficiency (IWUE) is defined as the ratio of fresh yield of irrigated turfgrass (Y, gm^{-2}) and the amount of irrigation water (I, mm) applied throughout the season (Zhang & Owesis, 1999).

Data were analyzed with a Split-Plot with three replications in a Randomized Complete Block Model using software package "Jump 5.0.1". Treatment means such as Colour (Cr) and Quality (Qy), Vegetation Height and Mowing (VHM), Fresh Yield (FY) and Dry Matter Yield (DMY), Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE) were compared using "LSmean student's t" test at P=0.05 if they were significant in the analysis of variance ($P<0.05${*} or $P<0.01${**}). Measurement and observations such as reliability of Non-water-stress-baseline (NWSB) equation was analysed by t-test methodology at P=0.01{**} or P=0.05{*}.

Figure 6. A mowing process for Warm-Season turfgrass and Cool-season turfgrass from left to right

Figure 7. Dry Matter Yield application

Crop Water Stress Index (CWSI)

CWSI was calculated according to (Idso et al. 1981) using canopy temperature (Tc). This was determined using a hand-held IRT (Model 574 precision, Fluke Corporation, Washington, USA) with a 3° field view and equipped with an 8–14 µm spectral band-pass filter. Air temperature and vapour pressure deficit (VPD; kPa) were taken daily from an automatic meteorological station. The IRT was operated with emissivity adjustment set at 0.98. The IRT data collection was initiated on 1st July (DOY 182) and ended on 15th August (DOY 227) in the growing period for each plot. The canopy temperature for each plot was measured per hour of solar noon time (11:00 a.m. to 02:00 p.m.) at four cardinal directions (North, East, South, and West) under clear sky conditions (Figure 8, Figure 9). The lower baseline (Non-stress) was determined based on the well-irrigated plots (I1:30%) for both species. Without supplying water regularly to turfgrass under the hottest conditions of summer, they can't survive. For this reason, there is no treatment in this study that is a non-irrigated plot; however, two small plots were established separately on 30th June for both species for determining the upper baseline (fully stressed) (Figure 10). Their dimensions are 50 cm x 50 cm at nearly 15 cm depth. They were measured daily per hour of extended time (10.00 a.m. to 04.00 p.m.) and measurements of upper baseline were finished on 9th July (DOY 190). At the end, two figures were prepared for both species for the calculation of Crop Water Stress Index (CWSI) values.

Figure 8. IRTs measurement under a clear sky at four cardinal directions in a plot for sub-treatment (I2:50%) of cool-season turfgrass while determining the NWSB.

Figure 9. IRTs measurement under a clear sky at four cardinal directions in a plot for sub-treatment (I2:50%) of warm-season turfgrass while determining the NWSB.

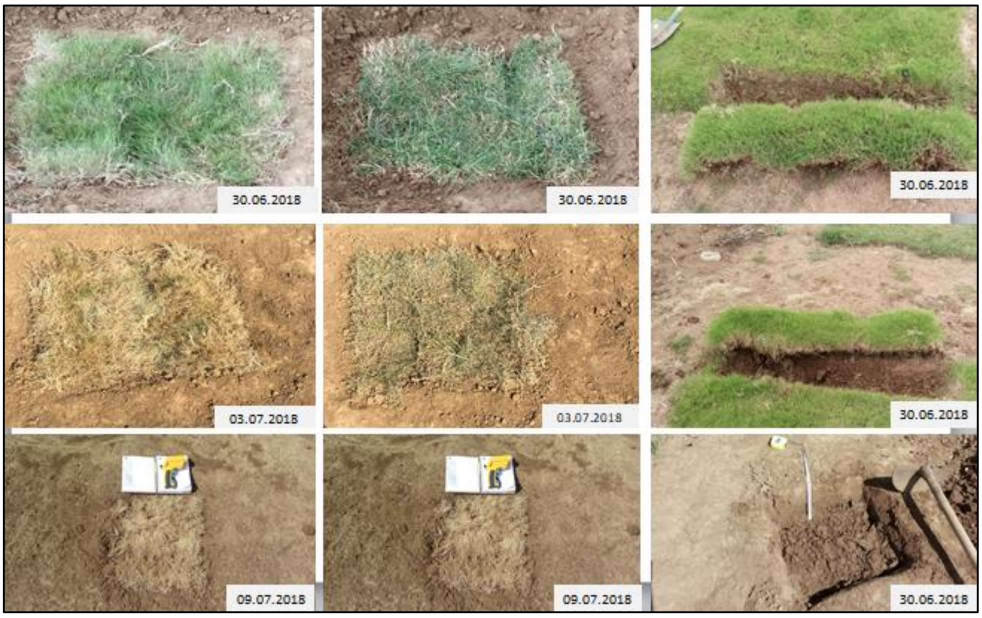

Figure 10. IRTs measurement for determining the WSB of Warm-season and Cool-season turfgrass from left to right respectively under a clear sky and soil preparation of Warm-season turfgrass

RESULTS and DISCUSSION

Soil, Water and Study Area

The soil of the experimental field at 0-30 and 30-60 cm depth was Clay-Loam (CL) [mid-heavy]. The soil of the area was a deep profile, no shallow underground water table in 1 m depth, and available soil moisture at 30 cm effective root zone of turfgrass was 41.03 mm. Saturation was nearly a half percentage and bulk density was 1.64 g cm^{-1}. The electrical conductivity (EC) of irrigation water was 555.7 μScm^{-1} and the sodium absorption rate was 1.72, which was classified as C2S1 according to US Salinity Laboratory (US Salinity Laboratory Staff, 1954). The slope varied between 2%-7% from east to west.

Amount of Applied Irrigation Water, Evapotranspiration (ETc), Yield Characteristics, Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE), Crop Water Stress Index (CWSI)

At the end of the study, it was very clear for both turfgrass species that maximum evapotranspiration (ETc) in the growing period had occurred in the I1:30% treatment because of enough water application; on the other hand ETc was minimum in the I3:70% treatment because of water stress (Table 1). In other words, much water created much consumption.

Colour (Cr) and Quality (Qy), Vegetation Height and Mowing (VHM), Fresh Yield (FY) and Dry Matter Yield (DMY), Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE), and Crop Water Stress Index (CWSI) could be taken into consideration to decide the proper irrigation scheduling for turfgrass (Table 2). Concerning CS turfgrass, the highest water consumption and the most frequent mowing were obtained by CS-I1:30% treatment. In addition, CS-I1:30% showed the darkest green colour, the densest texture, higher resistance to broad-leaf weeds, and the highest FY and DMY. However, the IWUE and the WUE were inefficient. Contrarily, the CS-I2:50% treatment required less water consumption and irrigation water. In case of landscape areas, although CS-I1:30% treatment will provide a good visual quality, it will cost in terms of fuel and labour, which is not the case of CS-I2:50% treatment that can provide good quality with less cost. Concerning the WS turfgrass, the different irrigation levels or sub-treatments did not affect significantly the quality parameters as in the case of CS turfgrass. The WS-I3:70% treatment which had less number and quantity of irrigation provided good visual appearance, with more WUE and IWUE. In the case of cool-season turfgrass, the CS-I2:50% treatment was irrigated 15 times, which is 309.9 mm, and leads to an actual ETc of 550.6 mm during the growing period (Figure 11). However, in the case of warm-season turfgrass, the WS-I3:70% treatment was irrigated seven times, 143.0 mm, and resulted in 404.9 mm of actual ETc (Figure 12).

Non-Water-Stress baselines with their equations based on treatments (CSI1:30% and WSI1:30%) and Maximum stress baselines of Cool-season and Warm-season turfgrass based on little plots are given in Figure 13 and Figure 14, respectively. The CWSI values were calculated for the period of 01.07.2018 (DOY: 182)-15.08.2018 (DOY: 227) based on those figures for both species with their sub-treatments. The means of CWSI values were calculated according to the peak CWSI values for all treatments and the results are given in Figure 15. During the measurement period, CWSI values showed a variation within 0.17 and 0.75. In other words, WS-I1:30% treatment resulted in the smallest value; in spite of that, CS-I3:70% treatment resulted in the greatest value throughout the period. When separately evaluated, CWSI values for Cool-Season (CS) turfgrass species ranged from 0.21 to 0.75, and corresponding values for Warm season turfgrass (WS) species were 0.17 and 0.45. The CWSI result of CS-I2:50% treatment is given in Figure 16 and WS-I3:70% treatment in Figure 17. Arrows in the figures indicate only the timing of irrigation application at the CWSI values which peaked before irrigation application.

Table 1. Total number of irrigations, total amount of irrigation water, rainfall, seasonal evapotranspiration for treatments

Treatment	Sub-Treatments	Number of irrigation	Irrigation water applied (mm)	Rainfall (mm)	Seasonal evapotranspiration (mm)
CS	I1:30%	24	345.9	186.2	635.9
	I2:50%	15	309.9		550.6
	I3:70%	10	245.3		462.0
WS	I1:30%	22	302.2		543.1
	I2:50%	13	266.4		492.3
	I3:70%	7	143.0		404.9

Table 2. Determination of Yield Characteristics and IWUE&WUE

Determination of Yield Characteristics	Sub-Treatments	Main Treatments		
		CS	WS	Mean
Colour (Cr)	I1:30%	8.98a	6.03c	7.50a
	I2:50%	7.85b	6.03c	6.94b
	I3:70%	5.98cd	5.90d	5.84c
	Mean	7.60a	5.99b	6.79
Quality (Qy)	I1:30%	8.30b	9.00a	8.65 a
	I2:50%	7.10c	9.00a	8.05b
	I3:70%	6.03d	8.96 a	7.49c
	Mean	7.14b	8.98 a	8.06
Vegetation height(VHM)	I1:30%	15.60 a	10.90d	13.25 a
	I2:50%	14.00b	10.97d	12.48b
	I3:70%	12.97c	9.90e	11.43c
	Mean	14.19a	10.59b	12.39
Fresh Yield (FY)	I1:30%	488.33 d	1200.00 a	844.17 a
	I2:50%	461.00 e	1161.00b	811.00 b
	I3:70%	428.00 f	1043.67c	735.83 c
	Mean	459.11b	1134.89 a	797.00
Dry Matter Yield (DMY)	I1:30%	34.8c	41.3 a	38.0 a
	I2:50%	27.6e	36.7b	32.1 b
	I3:70%	22.5f	31.4 d	26.9 c
	Mean	28.3b	36.4 a	32.3
Irrigation Water Use Efficiency (IWUE)	I1:30%	1.41e	3.97c	2.69d
	I2:50%	1.48ed	4.35b	2.92b
	I3:70%	1.74d	7.46 a	4.60 a
	Mean	1.54b	5.26 a	3.40
Water Use Efficiency (WUE)	I1:30%	0.77 f	2.21 c	1.49 c
	I2:50%	0.84 e	2.36 b	1.60 b
	I3:70%	0.93 d	2.57 a	1.75 a
	Mean	0.84 b	1.75 a	1.61
LSD P=0.05 t=2.22814	Levels not connected by the same letter are significantly different.			

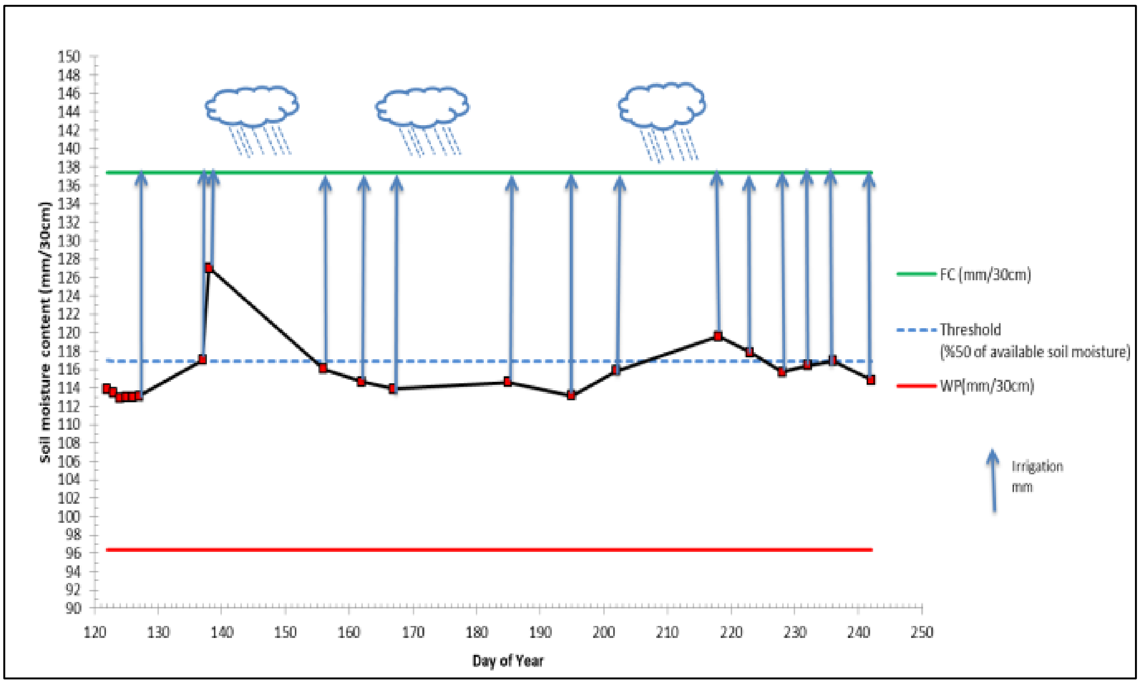

Figure 11. Soil moisture level at 0-30cm depth before irrigation application for CS-I2:50%.

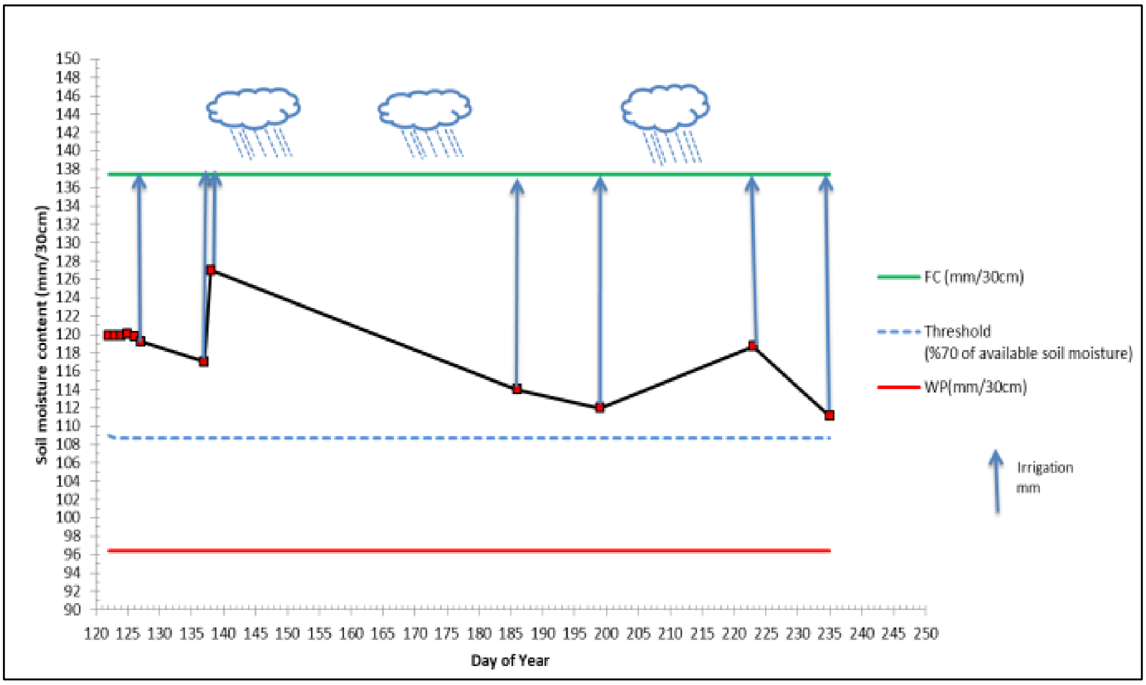

Figure 12. Soil moisture level at 0-30cm depth before irrigation application for WS-I3:70%.

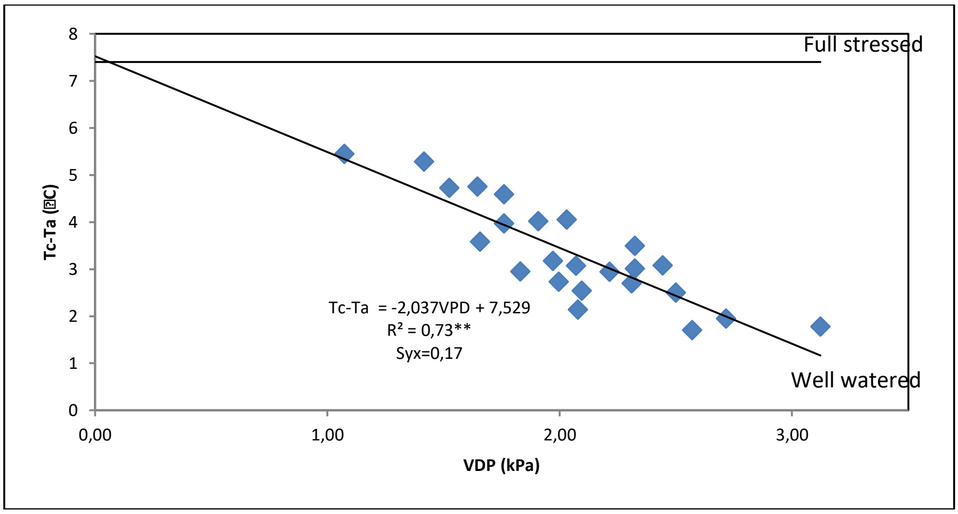

Figure 13. Graphical depiction of the non-water-stressed baseline equation and MAX baseline for CS-I1:30%.

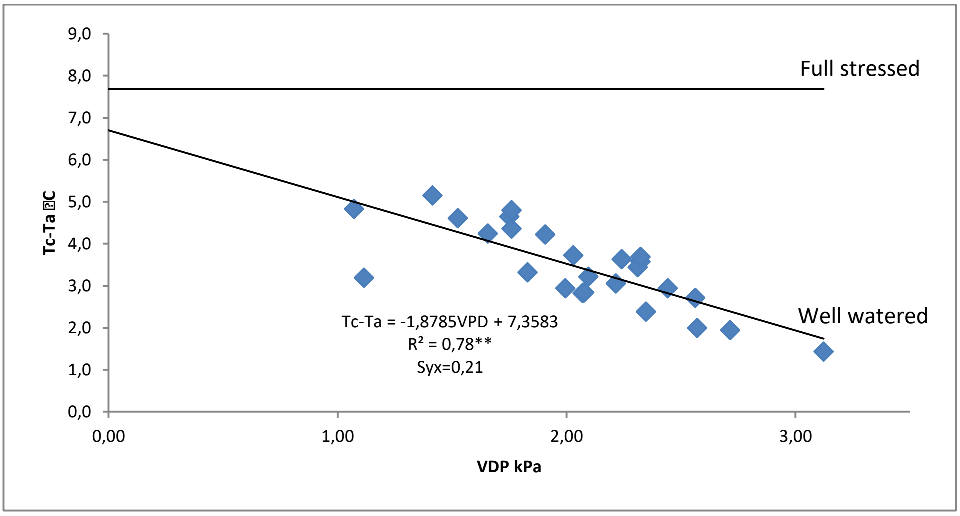

Figure 14. Graphical depiction of the non-water-stressed baseline equation and MAX baseline for WS-I1:30%.

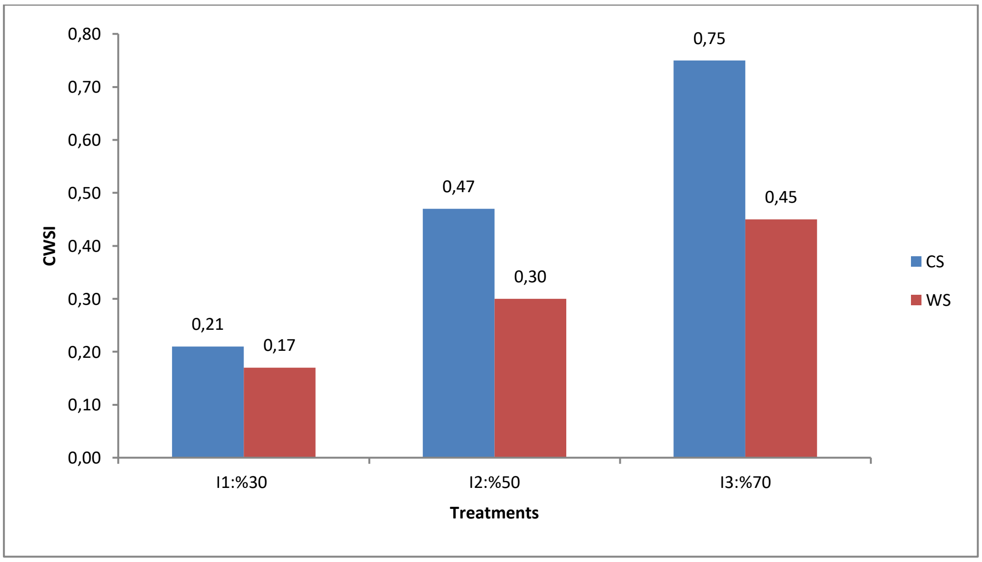

Figure 15. Average values of CWSI for all treatments during the measurement period.

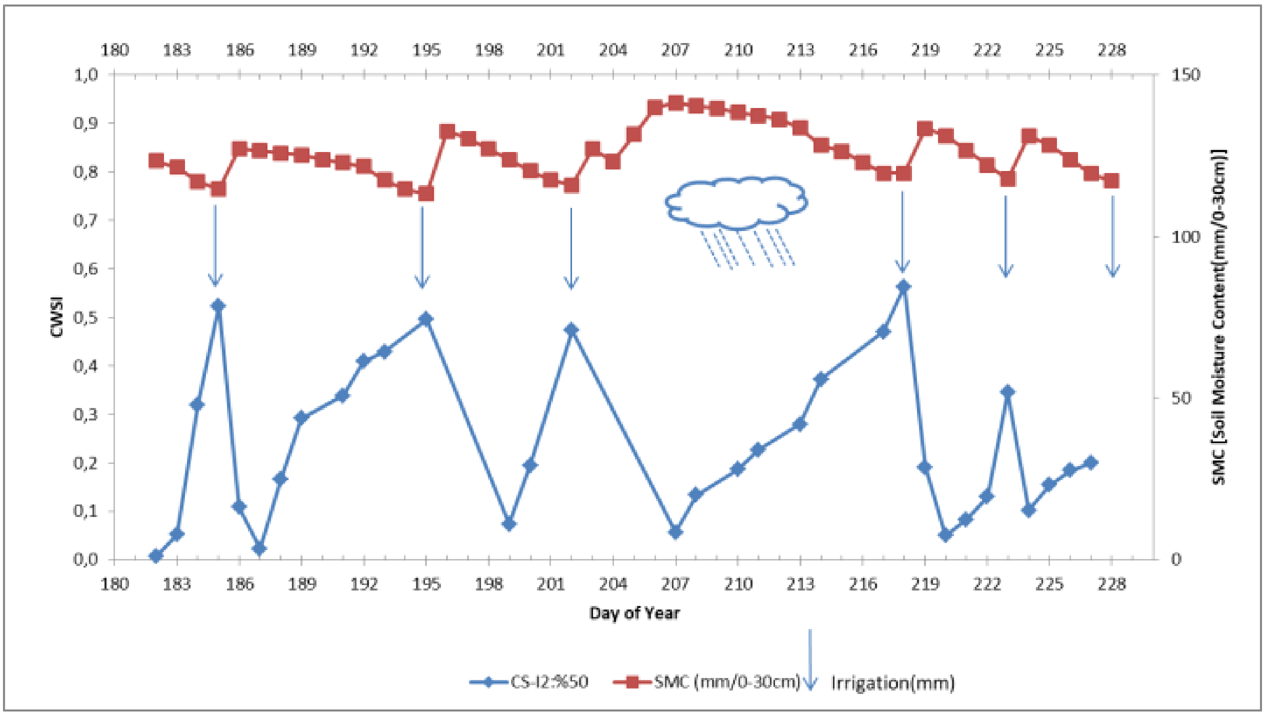

Figure 16. CWSI values of CS-I2:50% and soil moisture variation during the July and August.

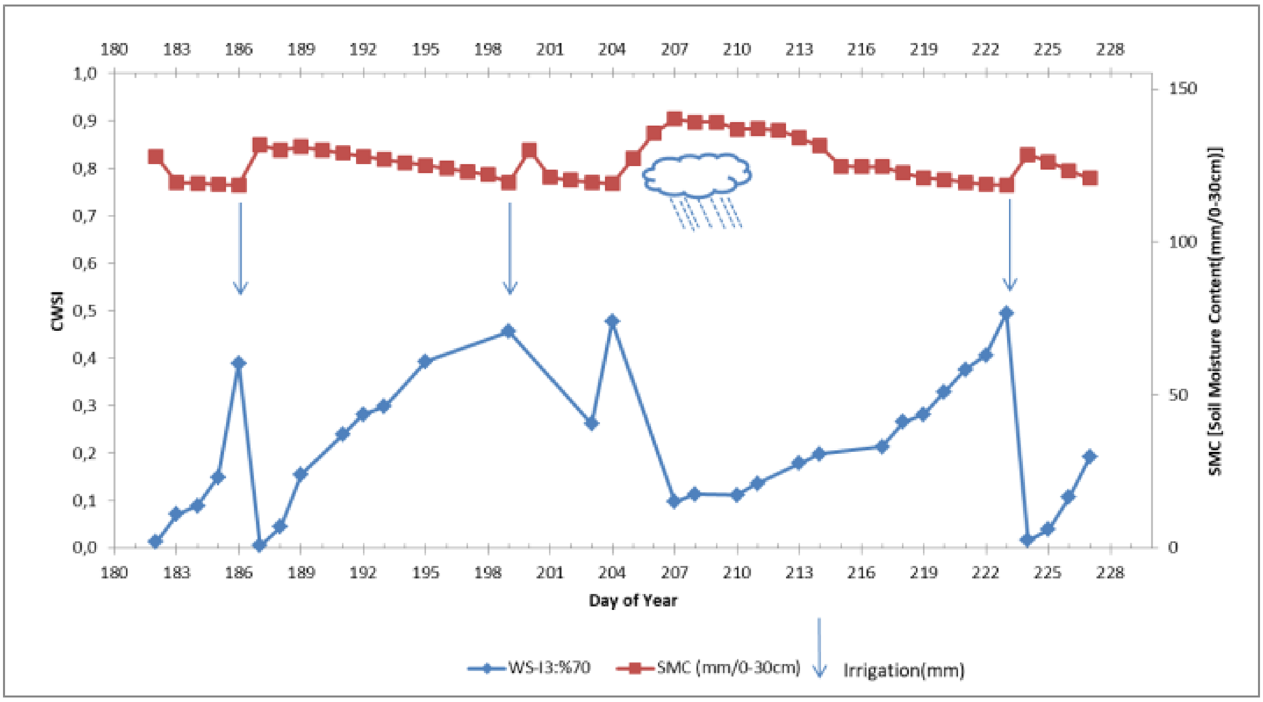

Figure 17. CWSI values of WS-I3:70% and soil moisture variation during the July and August.

Crop Coefficient (Kc)

Daily and seasonally obtained actual evapotranspiration (ETc) and reference evapotranspiration values (ETo) during the study for Cool-season turfgrass (CS) and warm-season turfgrass (WS) are given in Table 3. Reference evapotranspiration values were calculated for ten day periods by Jensen-Haise (JH), Penman FAO modification (P-FAO), Penman-Monteith FAO modification (PM-FAO), modified evaporation method Class A Pan by FAO (A-FAO), and Blaney-Criddle (BC) methodologies. The average of daily ETc values based on energy balance method were obtained from each sub-treatment for CS and WS. Crop Coefficients (kc) were calculated as the ratio of ETo and ETc for the growing period (Table 3).

Three assessments were used to determine the appropriate ETo method for the region. The first assessment was based on the sum of squares of the differences (SS) between values of the measured actual evapotranspiration and values of the reference evapotranspiration using the estimated equations. The second evaluation was Seasonal ETc Coverage Rate % (CR_{ETc}) where the closest value to 100% was chosen. Third consideration was correlation values (r) between measured evapotranspiration and calculated reference evapotranspiration (ORTA, 1994). The criteria are given in Table 4. Crop coefficient results were evaluated as the distribution of kc values lower at the beginning, higher in the middle of study and lower at nearly the end of the irrigation period, and the seasonal mean crop coefficient (kc) was also evaluated as the closest value to 1,0 as was suitable.

JH and P-FAO methods gave the lowest value of Sum of Squares difference (SS) and the other methods gave much higher SS values when comparing with the values based on JH and P-FAO methods for both species (CS and WS). If the second evaluation ($\mathrm{CR_{ETc}}$) was followed, it can be easily seen that JH and P-FAO, PM-FAO, A-FAO, BC offered closest ETc coverage relations ($\mathrm{CR_{ETc}}$) for CS while only JH and P-FAO offered the closest relationship and the other methods; PM-FAO, A-FAO, BC could offer a better estimation for WS. The third evaluation indicated that BC was the method that had the highest correlation values for both species. The lowest correlation values appeared in A-FAO and JH methods for CS and WS, respectively. On the other hand, JH and P-FAO methods gave similar results to BC for CS, but the same relation could not be said for WS. After mowing, JH and P-FAO offered a suitable distribution for kc during the growing period for both species while the other methods could not. When the last criterium was checked, JH and P-FAO offered the closest seasonal kc mean to 1.0 for CS, while all methods offered the same difference to 1.0 for WS. Firstly, JH and P-FAO offered the lowest SS for CS and secondly, their correlations were high enough that could be chosen, parallely their seasonal ETc coverage rate were enough while seasonal mean distribution kc during growing period were also disturbed well as required and the results of seasonal mean kc had also close to 1.0. Although lowest correlations appeared in JH and P-FAO for WS, their SS values were the lowest values among methods and not only SS criteria were suitable and also seasonal ETc coverage rate was also close to 100% while seasonal mean kc were closest to 1.0 and their distributions were more suitable than other methods.

JH and P-FAO were the most suitable methods to estimate reference evapotranspiration in the Marmara region for both species. In addition, kc graphs were prepared for chosen methods (JH and P-FAO) and their equations were tested statistically by t-test for reliability of the equations (Figure 18, Figure 19). Both methods found statistical significance at the $p<0.01$ and they took double asterisks for specifying. Moreover, correlations between found/measured kc and calculated kc by equation were the highest values among all methods. This supported the selected methods as being right for CS and WS.

Table 3. Measured actual evapotranspiration and calculated reference evapotranspiration values.

Main-treatments	Period	Measured Evapotranspiration (ETc) $[mm\ d^{-1}]$	Calculated reference evapotranspirations by different methods (ETo) $[mm\ d^{-1}]$				
			JH	P-FAO	PM-FAO	A-FAO	BC
CS	10.05-20.05	3.9	3.9	4.1	4.3	4.1	4.1
	20.05-31.05	3.8	3.8	3.4	4.2	3.2	3.8
	31.05-10.06	4.1	3.9	4.1	6.0	6.1	5.3
	10.06-20.06	4.7	4.3	4.0	5.7	5.6	6.1
	20.06-30.06	4.8	3.9	4.6	4.5	4.3	4.2
	30.06-10.07	4.9	4.2	4.1	5.4	6.8	6.1
	10.07-20.07	5.1	4.0	4.1	5.6	5.2	6.3
	20.07-31.07	4.6	4.1	3.9	5.2	3.5	4.8
	31.07-10.08	4.5	4.8	4.9	6.1	6.4	6.8
	10.08-20.08	5.2	4.8	5.5	6.2	6.2	7.2
	20.08-31.08	5.1	4.9	5.1	5.7	5.6	5.5
	Seasonal ETc	520.7	479.4	494.1	604.0	581.8	616.1
WS	10.05-20.05	3.6	3.9	4.1	4.3	4.1	4.1
	20.05-31.05	3.6	3.8	3.4	4.2	3.2	3.8
	31.05-10.06	3.7	3.9	4.1	6.0	6.1	5.3
	10.06-20.06	4.4	4.3	4.0	5.7	5.6	6.1
	20.06-30.06	4.2	3.9	4.6	4.5	4.3	4.2
	30.06-10.07	4.2	4.2	4.1	5.4	6.8	6.1
	10.07-20.07	4.2	4.0	4.1	5.6	5.2	6.3
	20.07-31.07	4.1	4.1	3.9	5.2	3.5	4.8
	31.07-10.08	3.7	4.8	4.9	6.1	6.4	6.8
	10.08-20.08	4.2	4.8	5.5	6.2	6.2	7.2
	20.08-31.08	4.0	4.9	5.1	5.7	5.6	5.5
	Seasonal ETc	450.9	479.4	494.1	604.0	581.8	616.1

Table 4. kc crop coefficients and crop coefficient equations for estimating reference crop evapotranspiration.

Main-treatments	Number of days that have started, T	kc				
		J-H	P-FAO	P-M	A-FAO	B-C
CS	10.0	1.0	0.9	0.9	0.9	0.9
	21.0	1.0	1.1	0.9	1.2	1.0
	31.0	1.0	1.0	0.7	0.7	0.8
	41.0	1.1	1.2	0.8	0.8	0.8
	51.0	1.2	1.0	1.1	1.1	1.1
	61.0	1.2	1.2	0.9	0.7	0.8
	71.0	1.3	1.2	0.9	1.0	0.8
	82.0	1.1	1.2	0.9	1.3	1.0
	92.0	0.9	0.9	0.7	0.7	0.7
	102.0	1.1	0.9	0.8	0.8	0.7
	113.0	1.0	1.0	0.9	0.9	0.9
	Seasonal Mean	1.1	1.1	0.9	0.9	0.9
	Equation	kc=-7E-05T^2+0.0089T+0.8818	kc=-7E-05T^2+0.0088T+0.8818	kc=-1E-05T^2+0.0012T+0.8511	kc=-6E-0.6T^2+9E-05T+0.9538	kc=1E-05T^2-0.0028T+0.9814
	Correlation	0.70	0.64	0.12	0.10	0.33
WS	10.0	0.9	0.9	0.8	0.9	0.9
	21.0	0.9	1.0	0.9	1.1	0.9
	31.0	1.0	0.9	0.6	0.6	0.7
	41.0	1.0	1.1	0.8	0.8	0.7
	51.0	1.1	0.9	0.9	1.0	1.0
	61.0	1.0	1.0	0.8	0.6	0.7
	71.0	1.0	1.0	0.7	0.8	0.7
	82.0	1.0	1.0	0.8	1.2	0.9
	92.0	0.8	0.8	0.6	0.6	0.5
	102.0	0.9	0.8	0.7	0.7	0.6
	113.0	0.8	0.8	0.7	0.7	0.7
	Seasonal Mean	0.9	0.9	0.8	0.8	0.8
	Equation	kc=-6E-05T^2+0.0066T+0.8557	kc=-7E-05T^2+0.0064T+0.8563	kc=-1E-05T^2-5E-05T+0.8161	kc=-7E-06T^2-0.0011T+0.9138	kc=-8E-06T^2-0.0035T+0.9326
	Correlation	0.65	0.55	0.25	0.10	0.32

Table 5. Decision criteria to choose the suitable estimation method (ETo) for the region.

Main-Treatment	Methods	Sum of Squares (SS)	Seasonal ETc Coverage Rate % (CR_{ETc})	Correlation (r)
CS	JH	3.1	92.1	0.61
	P-FAO	3.0	94.9	0.63
	PM-FAO	9.7	116.0	0.56
	A-FAO	14.9	111.7	0.49
	BC	16.0	118.3	0.68
WS	JH	2.7	106.3	0.18
	P-FAO	5.4	109.6	0.24
	PM-FAO	25.1	133.9	0.30
	A-FAO	29.2	129.0	0.26
	BC	35.3	136.6	0.41

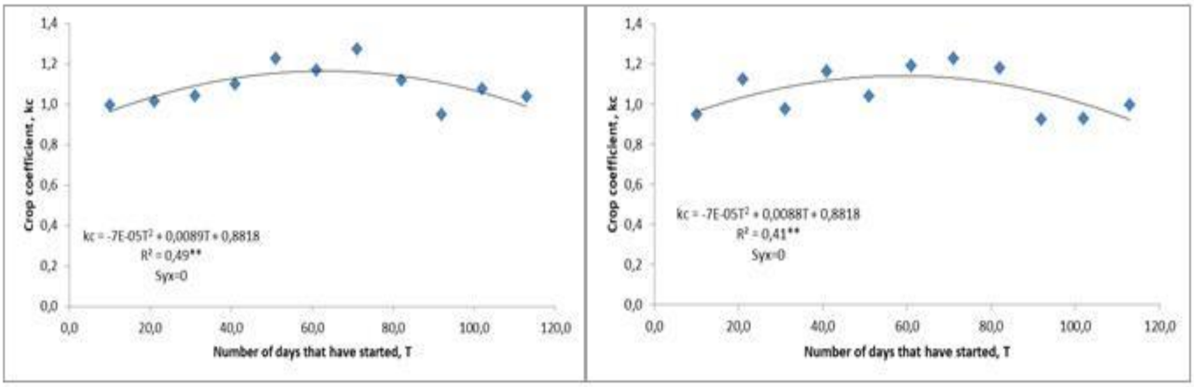

Figure 18. Crop coefficient curve (kc) of the Jensen-Haise (JH) Method and Penman FAO Modification (P-FAO) Method for Cool-Season turfgrass (CS)

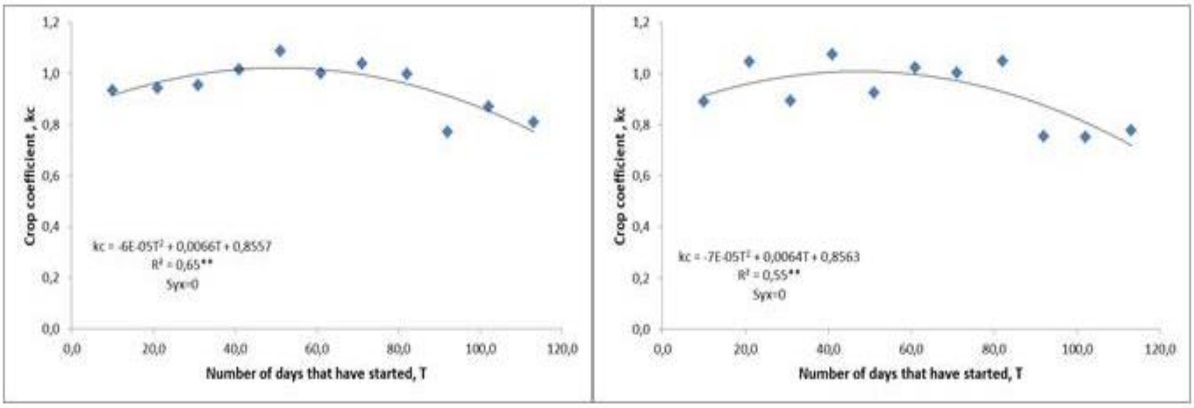

Figure 19. Crop coefficient curve (kc) of the Jensen-Haise (JH) Method and Penman FAO Modification (P-FAO) Method for Warm-Season turfgrass (WS)

CONCLUSIONS

Results from experiments suggest a recommended irrigation nearly every five days when approximately Results from experiments suggest a recommended irrigation nearly every five days when approximately 50% of the total available soil moisture at 30 cm depth is consumed (I2:50%) for cool-season turfgrass, and irrigation nearly every 14 days when approximately 70% of total available soil moisture at 30 cm depth is consumed (I3:70%) for warm-season turfgrass. The amount of applied irrigation for warm-season turfgrasses was 53% less than for cool-season turfgrasses, and 26% less in terms of ETc. At this scheduling, CWSI values of 0,47 and 0,45, could be used as a threshold to start irrigation for CS and WS, respectively. These values could also be adapted to automatic pressurized irrigation systems with an infrared thermometer, either handheld or mounted for golf courses and gardens in the municipality. The most suitable reference evapotranspiration (ETo) methods were Jensen-Haise (JH) and Penman-FAO modification (P-FAO) for both species. In addition, crop coefficient (kc) curve was prepared based on those methodologies. Thanks to kc graphs, irrigation application can be managed in detail during the growing period.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The study is summarized from MSc thesis

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