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Determination of Crop Water Stress Index for Irrigation Scheduling of Turfgrass (*Cynodon dactylon* L. Pers.) under Drought Conditions

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Abstract

The crop water stress index (CWSI) is a valuable tool for monitoring and quantifying water stress as well as for irrigation scheduling. A field experiment was conducted during spring and summer 2012 at Research Station of College of Agriculture and Natural Resources of Darab, Shiraz University, Iran, to determine CWSI of turfgrass for irrigation scheduling. Four levels of water regimes including well watered [Irrigation according to 100% field capacity (FC)], mild drought stress (75% FC), severe drought (50% FC), and most severe drought (25% FC) stress were arranged in a randomized complete block design with four replicateions. The highest monthly average value of CWSI for all treatments was reached in August and decreased in September slightly. In all treatments the CWSI values showed an increasing trend from June (0.097 in well watered treatment) to August (0.684 under most severe drought) as a result of higher vapor pressure deficit values and negatively increase in Tc-Ta differential. Also, significant differences were observed between mean CWSI values of well watered and mild drought, with severe drought and most severe drought treatments. The color grading number for mild drought treatment in turfgrass decreased sharply from 8 to 4 at the start of the experiment in July, and remained constant (3) for August and September. The amounts of irrigation water more than 75% FC did not affect visual quality of turfgrass, which appeared to be sufficient to fulfill an acceptable turfgrass quality. A negative relationship was found between CWSI with water applied and color quality under different irrigation regimes. It appeared that under arid and semi-arid conditions, such as southern Iran, where the amount of water is a major limiting factor, the amount of applied water could be lowered to 75% FC without any loss in visual quality of turfgrass with the seasonal CWSI being kept about 0.15.

Keywords: Semi arid conditions; Turfgrass; Visual color quality; Water stress

Introduction

The efficient use of water in grass-covered areas is becoming an important issue due to increasing irrigation water requirements, especially in warm and semi-arid climates (Emekli*et al.* 2007; Emam and Bijanzadeh 2012). In arid and semi-arid conditions, such as southern Iran, where the amount of water is a major limiting factor, lowering the amount of applied irrigation water, without loss in visual quality of tutfgrass is worthy for irrigation scheduling especially under limited water resources (Emekli *et al.* 2007).

Irrigation on grass-covered areas is aimed essentially to sustain turf quality and performance by maintaining a favorable soil water level and this goal can be achieved with a suitable irrigation regime in drought condition (Kneebone *et al.* 1992; Bijanzadeh and Emam 2012). When a plant closes its stomata following water stress, stomatal conductivity, heat flux, transpiration and the cooling effects of evaporation decrease and the canopy temperature increase (Stokcle and Dugas1992). This is the basis for the use of canopy temperature to determine plant water status (Jackson1982).

The canopy temperature (Tc) has provided an efficient method for rapid and non-destructive monitoring of whole plant response to water stress (Idso *et al.* 1981; Jackson *et al.* 1981). It is also argued that changes in Tc, under stress and non-stress conditions, provides clues for crop water status and yield performance during drought seasons. The crop water stress index (CWSI), derived from canopy±air temperature differences (Tc-Ta) versus the air vapor pressure deficit (AVPD), was found to be a promising tool for quantifying crop water stress (Idso and Reginato 1982; Jackson, 1982; Alderfasi and Nielsen 2001).

CWSI calculation is based on three main environmental variables: plant canopy temperature (Tc), air temperature (Ta) and atmospheric vapor pressure deficiency. All these three variables have much influence on water used by plants (Braunworth1989). An infrared thermometer measures the surface temperature of a crop canopy without making direct physical contact (Jackson *et al.* 1981). Al-Faraj *et al.* (2001) reported that the canopy-air temperature differential (Tc-Ta) was increased with a decrease in soil water content in turfgrass. Furthermore, Jalali-Farahani *et al.* (1993) concluded that the changes in CWSI values depended on the applied irrigation level.

Much research has been done to evaluate the application of CWSI in irrigation scheduling for different crop plants such as tall fescue [(*Festuca arundinacea* Schreb.), Al-faraj*et al.* (2001)], watermelon [(*Citrullus lanatus*), Orta and Erdem 2003] and wheat [(*Triticum aestivum* L.), Bijanzadeh and Emam 2012].

Turfgrass managers, in arid and semi- arid regions are particularly interested in studies concerning the management and conservation of water since a large amount of water is required to irrigate the recreational and sporting facilities covered with grass. The lack of studies regarding the irrigation scheduling of turfgrass based on evaluation of CWSI in semi-arid regions, encouraged the authors to conduct the present study. Main objective of this research was to develop a baseline equation, which could be used to calculate CWSI for monitoring water status and irrigation scheduling of turfgrass under water shortage conditions.

Materials and Methods

A field experiment was conducted during June to September 2012 at the Research Station of College of Agriculture and Natural Resources of Darab (28°29´ N, 54°55´ E and 1180 m above mean sea level), Shiraz University, Iran, to determine the crop water stress index of turfgrass. Ten-day averages of some meteorological data measured daily in the study area during June to September 2012 are given in Table 1. The research area has semi-arid climate with hot and dry summers and cool and rainy winters. The soil was a loam (fine, loamy, carbonatic, hyperthermic, typic Torriorthents) with pH of 7.61 and 0.19 percent organic matter. Some soil properties are given in Table 2. Rainfall during the period of experiment was negligible (about 1mm).

Table 1. Ten-day means of climatic data measured daily at experimental site

Month	Temperature(°C)	Mean evaporation (mm)	Relative humidity (%)	Wind speed (m/s)
June				
1-10	39.1	10.9	28.1	2.2
11-20	39.3	11.6	27.2	2.1
21-30	39.5	11.1	28.1	2.5
July				
1-10	40.1	12.1	29.1	2.0
11-20	40.3	12.3	29.3	1.5
21-31	41.2	12.8	29.1	1.3
August				
1-10	42.3	13.9	27.4	1.6
11-20	43.1	14.1	27.1	1.5
21-31	43.6	14.9	27.0	1.2
September				
1-10	39.2	13.1	26.1	2.0
11-20	38.1	13.0	26.3	2.3
21-30	37.2	12.7	26.8	2.1

Table 2. Soil physicochemical characteristics of the experimental site

Characteristics	
Soil texture	Loamy
Sand (%)	38.44
Silt (%)	39.28
Clay (%)	22.28
Soil pH	7.61
Phosphorus (mg kg^{-1})	21
Potassium (mg kg^{-1})	180
Total nitrogen (%)	0.028
OC (%)	0.19
Electrical conductivity (dS m^{-1})	0.69

Four levels of water regime including well watered [Irrigation according to 100% field capacity (FC)], mild drought stress (75% FC), severe drought (50% FC), and most severe drought (25% FC) stress were arranged in a randomized complete block design with four replications. Irrigation interval was two days for all treatments. There was also, a non-irrigated plot to determine the upper baseline required for determination of CWSI. The size of the assigned plots was 3m×5m and each plot was surrounded with a 20 cm high earth berm, with a 1m wide buffer space between the plots.

Turfgrass (*Cynodon dactylon* L. Pers.) seeds were sown on March12th, 2011, so the research area was established and covered with grass at the beginning of the experiment. The turfgrass was mowed at 7 cm above ground when it was 10–12 cm tall (Ritchie *et al.* 2002). The mowing intervals ranged from 10 to 20 days depending on climatic conditions and growth phase. Before planting, the plots were fertilized with 5kg/m^2 sheep manure.

The soil water status was monitored in each plot by gravimetric method at 30 cm depth down to 120 cm in each 30 cm depth interval between 8:00 and 11:00 AM. The amount of water supplied to each plot was measured by time-volume technique according to Grimes *et al.* (1987).

An infrared thermometer (Kyoritsu Electronic Instrument, Model 5500, Japan) was used to measure the canopy temperature (3, 6 and 9 days after each irrigation) from 2nd June to 30th September 2012. To ensure collection of accurate data, the infrared thermometer was held with a horizontal angle of 45° during measurements. Temperature measurement was done when there was no cloud between 13:00 and 14:00 PM. According to Idso *et al.* (1981), midday canopy temperature is the best indicator to detect the crop water stress. The measurements were carried out from four directions (east, west, north and south) in each experimental plot.

Simultaneously, air temperature and relative humidity were recorded using thermo hygrograph (Lambrecht, Model 252, Germany) and psychrometer (Lambrecht, Model 1030, Germany) as basis for calculating vapor pressure deficit (VPD) (Monteith and Unsworth, 1990). VPD was calculated from standard psychrometer equation (Allen *et al.* 1998). Then, CWSI values were calculated using the empirical method of Idsob *et al.* (1981). The relationship between canopy-air temperature differences (T*c*-T*a*) and VPD were plotted under stressed and non- stressed conditions (Fig. 1). In this graph, the non-stressed baseline was determined from the data collected three days after irrigation in excess watered treatment between 08:00 and 17:00 hr with 30-min intervals.

The Idso's empirical non-water-stressed baseline can be expressed as follows:

$$Tc–Ta = aVPD + b \quad (1)$$

where T*c*–T*a* is the measured canopy and air temperature differences for non- stressed treatment (°C) and VPD is vapor pressure deficit (kPa) and *a* (slope) and *b* (intercept) are the linear regression coefficients of *Tc*–*Ta* on VPD. The upper baseline was determined using the average T*c*–T*a* values measured at 13:00, 14:00 and 15:00 hr before each irrigation. Using the upper and lower limit estimates, a CWSI can be defined by the following equation (Idso *et al.* 1981):

$$\mathbf{CWSI} = \frac{(Tc - Ta)m - (Tc - Ta)ll}{(Tc - Ta)ul - (Tc - Ta)ll} \quad (2)$$

where (T*c*–T*a*)*m*, (T*c*–T*a*)*ll* and (T*c*–T*a*)*ul* are the measured canopy and air temperature differences at the moment and the lower and upper limit values (°C), respectively.

Additionally, color status and visual color density were considered as criteria for turfgrass quality. The turfgrass color was evaluated based on the Munsell Color Scale, which grades colors according to the color tone of the plant tissues (Wilde and Voigt, 1977). The turfgrass color during the experiment was compared with the one given in the scale at 10 day intervals.

After comparing color grades, the color and page numbers were found out. The page numbers, color names, and color numbers as appeared in the Munsell Color Scale as well as grading score in the experiment are given in Table 3. The observed grass colors were scored in such a way that dark green color corresponded to 9 and yellow color to 1. As the scores change from 9 to 1, the corresponding colors turns from dark green to yellow color representing that the grass is dead or at dormancy. Not only the color tone but general visual status and grass density of the plots were also taken into account when the colors were evaluated to define the grading scores in the field. Finally, the collected data were analyzed using SAS (2003) software and the means were compared using LSD test at 0.05 probability level**.**

Results and Discussion

Total water applied were 1209.1 mm for well watered (100% FC), 901.7 mm for mild drought stress (75% FC), 603.6 mm for severe drought (50% FC), and 302.8 mm for most severe drought (25% FC) treatments, respectively. According to Emekli *et al.* (2007) bermudagrass in Antalya, southern Turkey, could be grown successfully when 900-1186 mm water was applied under Mediterranean conditions. Garrot and Mancino (1994) also reported that water requirements of low-maintenance bermudagrass under arid conditions between mid-April and mid-November were 930mm when irrigated every other week and this amount of water was enough under normal conditions in terms of meeting quality and color standards of turfgrass.

The upper and lower baselines required to calculate CWSI are depicted in Figure 1. The upper limit, (Tc-Ta)ul, was 12.3 °C when the air temperature at solar noon was 42°C. In a similar study, Emekli *et al.* (2007) determined that the upper limit for bermudagrass, was 40°C. The equation of lower limit was found to be (Tc-Ta)ll =-1.1279 VPD + 0.4032 (Fig. 1). Alves and Pereira, (2000) pointed out that crop type as well as local conditions could have impact on the baseline relation causing differentiation.

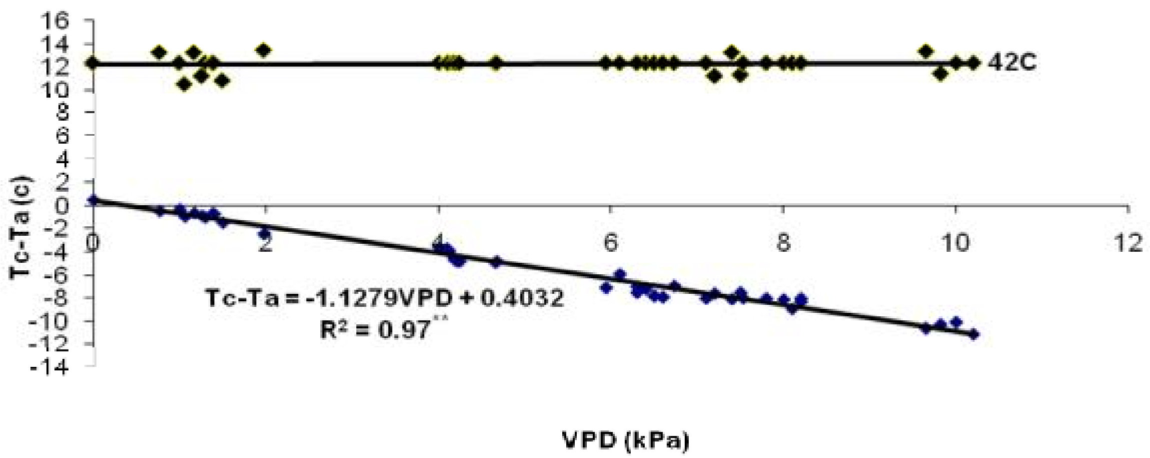

Figure 1. Stressed and non-stressed baselines for calculation of CWSI in turfgrass
VPD = vapor pressure deficit

Table3. Page numbers of Munsell Color Chart, color numbers and visual quality values (Wilde and Voigt 1977).

Page numbers of the chart	Color numbers (value/chroma)	Visual quality value	Color changing
5GY	3/4	9	Dark green
5GY	4/4	8	
5GY	4/6, 8	7	
5GY	5/4, 6, 8, 10	6	Green
5GY	6/4, 6, 8, 10	5	
5GY	7/4, 6, 8, 10	4	
2.5GY	7/4, 6, 8	3	
2.5GY	8/4, 6, 8	2	Light green
2.5Y and 5Y	All colors	1	Yellow

The highest monthly average value of CWSI for all treatments was reached in August and decreased in September slightly (Table 4). In all treatments the CWSI values showed an increasing trend from June (0.097 in well water) to August (0.684 in most severe drought) as a result of higher VPD values and negatively increase in Tc-Ta differential. As VPD increases, the transpiration also increases and when soil water is not a limiting factor, grass transpires without restriction, resulting in a smaller Tc-Ta differential (Emekli *et al.* 2007). A decrease in VPD values in August caused an increase in CWSI and the weather conditions could be the reason for lower values of CWSI in September (Table 4).

Table 4. Monthly and mean CWSI values for turfgrass as affected by drought treatments

Treatment	Month				Seasonal mean CWSI
	June	July	August	September	
			Mean	CWSI	
Well watered	0.097	0.113	0.165	0.152	0.131
Mild drought	0.012	0.181	0.234	0.207	0.156
Severe drought	0.383	0.416	0.525	0.508	0.457
Most severe drought	0.431	0.587	0.684	0.612	0.578
LSD (0.05)	0.01	0.22	0.18	0.21	0.27

The seasonal average values of CWSI for well watered, mild drought, severe drought and most severe drought treatments, were 0.131, 0.156, 0.457 and 0.578, respectively (Table 4). As a control treatment (non-irrigated crop), the seasonal average of CWSI value for non-irrigated plot was equal to 1 when the crop was dead. Significant differences were observed between mean CWSI values of well watered and mild drought, with severe drought and most severe drought treatments (Table 4).

According to our results, it could be argued that the CWSI values can potentially be employed as a good indicator of crop water stress index in turfgrass. Similar results have been reported in previous studies (e.g. Irmak *et al.* 2000). Jalali-Farahani *et al.* (1993) also found that the seasonal average of CWSI values for bermudagrass, using empirical method, were 0.02, 0.16 and 0.5 in treatments including daily irrigation as well watered, mild drought and severe drought, respectively.

The color and color grading were similar for well watered and mild drought treatments during the experimental period (Table 5). Indeed, soil water content in both treatments was sufficient for turfgrass growth. The color grading score for mild drought treatment decreased sharply from 8 to 4 at the start of the experiment to July, and stayed constant (3) for August and September (Table 5). A similar trend was observed in most severe drought treatment and color grading reached to 2 in September. Apparently, the soil water content in severe and most severe drought treatments did not met the atmospheric humidity during hot summer in the area. Bonos and Murphy (1999) also found that the stress caused by hot summer days would affect visual quality of grass.

Table 5. Visual color quality values of turfgrass during the experiment as affected by drought treatments

Treatment			Visual quality values			
	Initial	June	July	August	September	Mean Seasonal
Well watered	**8**	**7**	**6**	**5**	**6**	**6.0**
Mild drought	**8**	**7**	**6**	**5**	**6**	**6.0**
Severe drought	**8**	**5**	**4**	**3**	**3**	**3.75**
Most severe drought	**8**	**4**	**3**	**2**	**2**	**2.75**
Unirrigated	**8**	**3**	**1**	**1**	**1**	**1.50**

The higher air temperature in July and August caused a decrease in color quality. In September, however, the temperature decreased and color quality started to raise again (Table 5). Also, the color grading number in the non-irrigated plot was sharply decreased (from 8 to 1) because the grass was completely perished in this treatment by the end of June and the color grading number was 1. Bastug and Buyuktas (2003) reported that the best color quality for turfgrass under the Mediterranean conditions could be attained when water was applied as much as 75% of Class A pan. In a similar study, Karcher and Richardson (2003) found that the color quality grading numbers ranged from 1 to 9 with an acceptable minimum visual quality number of 6. In the present study, an acceptable color quality (6) was sustained under well watered and mild drought conditions, however, the color quality obtained in severe and most severe drought treatments was not desirable (2.75 to 3.75) for turfgrass.

The value of CWSI was found to be negatively correlated with water supply in turfgrass (Figure 2). Linear regression showed that with decreasing water supply under stress, CWSI was increased and the slope of linear regression from 603.6 to 302.8 mm water supply was more than that of well and excess watered treatments (R^2=0.90*). Stokcle and Dugas (1992) also reported that as plants closed their stomata due to water shortage, and hence stomatal conductivity, heat flux, transpiration and the cooling effects of evaporation were decreased, the canopy temperature and CWSI were increased, compared to well watered conditions.

In the present study, turfgrass consumed more water and had more CWSI when subjected to severe drought and most severe drought stress conditions, especially under hot weather in the studied area. The relation between seasonal average CWSI and grass color quality for turfgrass is presented in Figure 3. A negative relationship was found between CWSI and color quality (R^2=0.95**). Indeed, this relation could be used as a useful tool by turfgrass managers to maintain required seasonal grass color quality based on the crop water stress index under hot summer with no rainfall conditions.

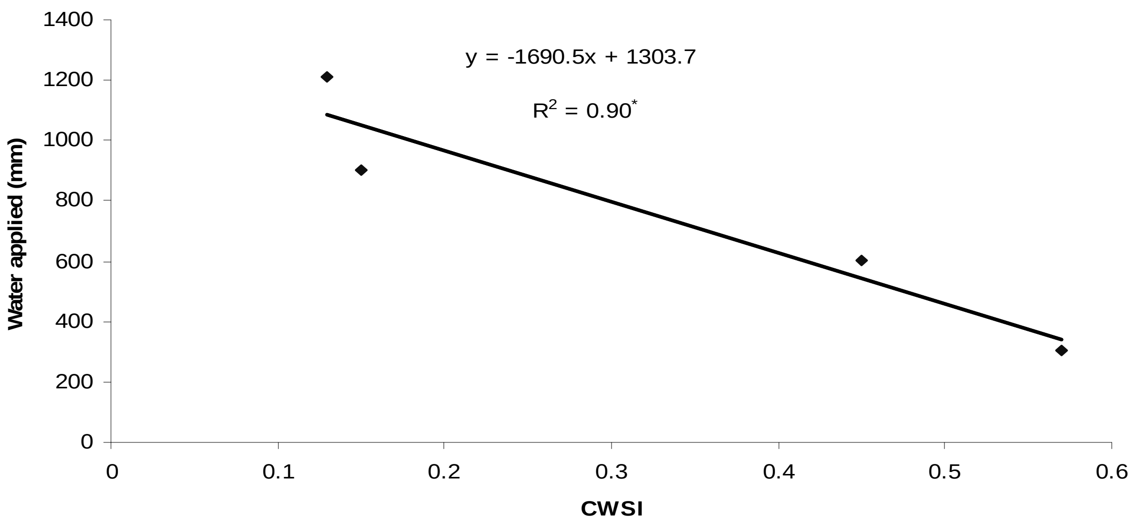

Figure 2. Relationship between CWSI and water applied in turfgrass

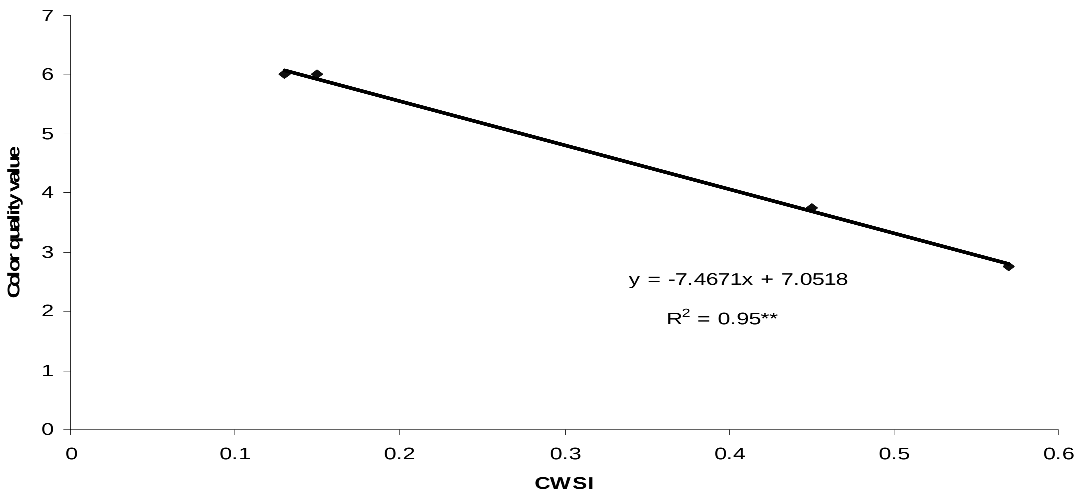

Figure 3. Relationship between CWSI and visual color quality values in turfgrass.

Conclusion

The application of canopy–air temperature difference was found to be appropriate for turfgrass water stress determination, since it is non-destructive and reliable. The CWSI could be estimated by using semi empirical approach with observations of Tc-Ta and VPD. The results showed that the best visual quality for turfgrass was obtained in well watered and mild drought treatments, however, no acceptable quality was observed in other treatments. Application of irrigation water more than 75% field capacity did not affect visual quality of turfgrass and so it appeared to be sufficient to fulfill an acceptable turfgrass quality. Under arid and semi-arid conditions, such as southern Iran, where the amount of water is a major limiting factor, lowering the amount of applied irrigation water, without loss in visual quality of grass such as 75% FC which was found in the present study is worthy of further explorations.

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VPD = vapor pressure deficit.

Figure 2. Relationship between CWSI and water applied in turfgrass.

Figure 3. Relationship between CWSI and visual color quality values in turfgrass.