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Spectral Reflectance of Tall Fescue (*Festuca Arundinacea* Schreb.) Under Different Irrigation and Nitrogen Conditions

Lisa Caturegli[A*], Nicola Grossi[A], Matteo Saltari[B], Monica Gaetani[A], Simone Magni[A], Aimila Eleni Nikolopoulou[C], Enrico Bonari[D] and Marco Volterrani[A]

[A] *Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto 80, 56124 Pisa, Italy*
[B] *Marche Polytechnic University, Piazza Roma 22, 60121 Ancona, Italy*
[C] *Department of Crop Science, Agricultural University of Athens, Iera Odos 75, 11855, Athens, Greece*
[D] *Sant'Anna School of Advanced Studies, Piazza Martiri della Libertà 33, 56127 Pisa, Italy*

Abstract

The issue of water and climate change is present in many countries. Drought stress is one of the main abiotic stresses influencing turfgrass growth and quality. Tall fescue is the most suitable cool-season turfgrass for the Mediterranean region. This species has a better heat tolerance than perennial ryegrass and Kentucky bluegrass. The analysis of radiation reflected by turfgrass can supply precious information on drought stress and nutritional status. In this study a Linear Gradient Irrigation System (LGIS) was adopted on a *Festuca arundinacea* turf with 9 water replenishment levels and 2 nitrogen conditions, to evaluate the proximity sensed spectral reflectance. ET_0 was estimated using the Hargreaves and Samani method. The following parameters were determined: turf quality, drought tolerance, pest problems, temperature of the surface, clippings weight and relative nitrogen content, turf growth and soil moisture. Spectral reflectance data were acquired using a LICOR 1800 spectroradiometer. Pearson correlation coefficients were studied among all parameters and vegetation indices. Nitrogen fertilization influenced significantly turf quality, clippings weight, nitrogen content and turf growth. Water replenishment influenced significantly all parameters except nitrogen content. Among all parameters the highest correlation coefficient was registered relating drought tolerance with turf quality (r = 0.88) and with surface temperature (r = - 0.88). Among vegetation indices results showed that Water Index (WI) and Normalized Difference Water Index (NDWI), are the most suitable to discriminate between different levels of water replenishment. Comparing WI with NDWI, the correlation coefficients were higher for Water Index in all the parameters, in particular the highest WI value was registered for drought tolerance (r = 0.91). This preliminary research demonstrates that spectral remote sensing can be a useful diagnostic tool to detect water stress in turfgrasses.

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Key words: Cool-Season Turfgrass; Drought Tolerance; LGIS; NDVI; NDWI; Replenishment; WI.

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[*] Corresponding author. Tel.: +39 3332057100 *E-mail address*: lisa.caturegli@gmail.com

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1. Introduction

The issue of climate change and the sustainable use of resources is at the heart of international topics and discussions. Also in the management and maintenance of tufgrasses the current trend is heading towards an optimization of inputs, such as irrigation and fertilization. Drought stress is one of the main abiotic stresses influencing turfgrass growth and quality. Under Italian climatic conditions rainfall does not supply a sufficient amount of water, especially in the areas of south-central Italy. Therefore, irrigation management is of paramount importance for maintaining turf quality during dry periods. In the Mediterranean area tall fescue is the most suitable cool-season turfgrass (Damiani et al., 2004; Grossi et al., 2004; Volterrani and Magni, 2004). This species can grow at temperatures ranging from 0 to 35 °C (OGTR, 2008) and has a better ability to avoid drought stress than perennial ryegrass or Kentucky bluegrass (Huang and Gao, 1999; 2000; Carrow, 1996; Qian et al., 1997). When turf is under water stress, a light fertilization may improve the overall quality, vice versa an excessive intake of fertilizer may worsen the situation (Carrow et al., 2001) and produce detrimental effects on turf.

The analysis of radiation reflected by plants can supply precious information on species quality and color (Bremer et al., 2011; Darvishsefat et., 2011), LAI (Finke, 1992; Lee, 2008), chlorophyll content (Munden et al., 1994), biomass (Resop et al., 2011), drought stress (Jiang and Carrow, 2007; Foschi et al., 2009) and nutritional status (Bell et al., 2004; Bausch and Khosla, 2010). Reflectance can be gathered via remote sensing as a diagnostic tool for detecting variations in all these parameters. In previous research, vegetation indices, calculated by combining band of the reflectance spectrum, were correlated with numerous turfgrass canopy parameters. Trenholm et al. (1999), Jiang and Carrow (2007), reported on the utilization of normalized difference vegetation index (NDVI) and other spectral reflectance-based plant stress indices for assessing turfgrass performance, while Bell et al. (2004) provided a recent review of optical sensing in turfgrass systems. NDVI was useful for detecting growth differences between species (Caturegli et al., 2014a). Furthermore, there are several hyperspectral indices proposed in the literature that quantify chlorophyll concentration (Zarco Tejada et al., 2004) allowing remote detection methods to identify and map vegetation stress through the influence of chlorophyll content variation. The most used chlorophyll indices are SIPI (Structure Intensive Pigment Index), MCARI (Modified Chlorophyll Absorption in Reflectance Index), SR (Simple Ratio) (Foschi et al., 2009; Agati et al., 2013) and the most responsive for detecting leaf nutritional status are Vegetation Index (VI=NIR/Red; NIR=Near InfraRed; Red=Reflectance (R) in the red region), Red edge position and Red edge. Furthermore, Water Index (WI = R_{900}/R_{970}) has been reported to be a robust index of canopy water content (Peñuelas et al., 1997). Another vegetation index to detect water features is normalized difference water index (NDWI), designed to maximize reflectance of water by using green wavelengths, minimize the low reflectance of NIR by water features, and take advantage of the high reflectance of NIR by vegetation and soil features (McFeeters, 1996; Xu H., 2006; Caturegli et al., 2014b).

In this study we evaluated the proximity sensed turfgrass spectral reflectance of *Festuca arundinacea* under different water and nitrogen conditions through the application of some of the most common vegetation indices. The aim was to use proximity sensing as a diagnostic tool to better manage the available resources on turfgrasses and, on a broader view, a potential large scale management and control of irrigation via satellite remotely sensed data.

2. Methods

The experimental trial was carried out in S. Piero a Grado, Pisa (43° 39′ N 10° 21′ E, 5 m a.s.l.) from September 2011 to July 2012 on a stand of *Festuca arundinacea* cv 'Grande', established on a soil characterized by the following physical-chemical properties: 91% sand, 5% silt, 4% clay, pH 6.5, 1.3 g kg^{-1} of organic matter; EC 0.46 dS m^{-1}, water availability 3.45 % w/w. Seeding took place on 19 September 2011, 43 g m^{-2} seeding rates. Pre-seeding fertilization was carried out with 5 g m^{-2} of N (urea), 5 g m^{-2} of P_2O_5 from perphosphate and 10 g m^{-2} of K_2O from potassium sulphate. From November to April broadcast fertilization was carried out for a total of 6.0 g m^{-2} of N (urea). A turf height of 4.5 cm was held. Irrigation was applied as necessary to maintain a healthy turfgrass. On June 5, Linear Gradient Irrigation System (LGIS) was installed (Hanks et al., 1976; Robins, 2010; Qian and Engelke, 1999). The central line of LGIS was composed by a row of 13 sprinklers (NaanDan Jain, mod. 5022-U) with a 7.5 m range. A spacing between sprinklers of 2.5 m was adopted. A strip 1 m wide centered on central line was left unmowed, to avoid damages to the sprinkler junctions (Fig. 1).

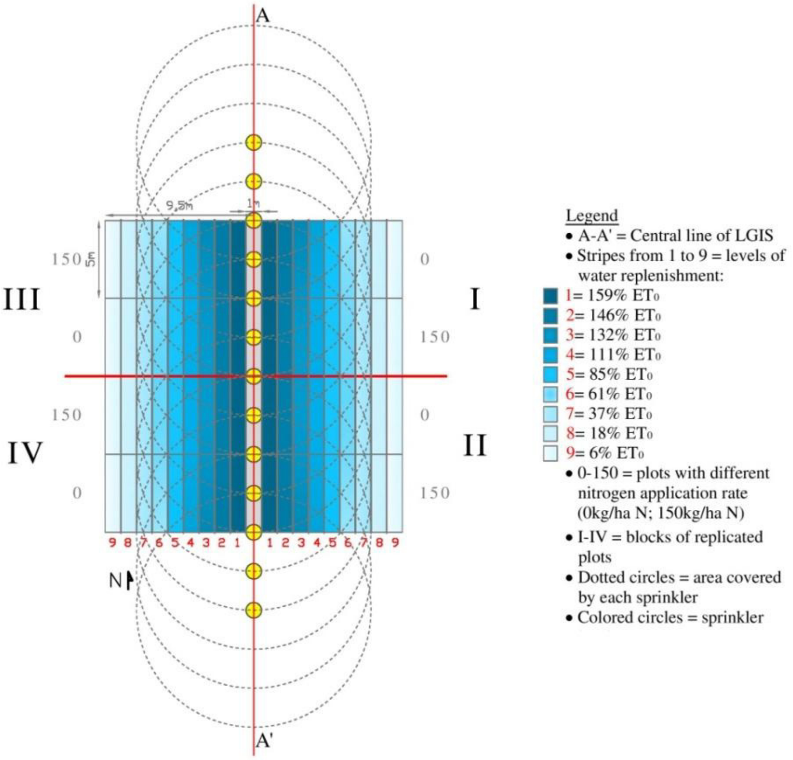

Fig. 1 Layout of the experimental area

On June 6, in order to measure the amount of water distributed by LGIS, 36 pluviometers were arranged in 4 lines of 9 each, spaced one meter on the lines, perpendicularly to the central line of LGIS, and placed in each main plot. The daily irrigation as a function of the distance from the central line of LGIS was calculated and the reference ET_0 was estimated on a daily time scale from the available meteorological data (T_{max} and T_{min}) using the Hargreaves and Samani method (1) (Hargreaves and Samani, 1982; 1985):

$$ET_O = 0.0023(T_{med} + 17.8)(T_{max}-T_{min})^{0.5}R_a \quad (1)$$

where:

T_{max} is maximum temperature [°C];
T_{min} is minimum temperature[°C];
T_{med} is mean temperature [°C];
R_a is the extraterrestrial radiation [mm day^{-1}], calculated as a function of latitude and time of year (Ra = 16.8 mm day^{-1} during the period of the trial in San Piero a Grado, Pisa).

From June 5 to June 20, cumulative ET_0 was estimated (83.2 mm) and mean daily ET_0 was calculated (5.2 mm). The irrigation run time was calculated according to this daily ET_0. The irrigation of the experimental area with LGIS was started on June 25. Up to this date, the trial area was uniformly irrigated with sprinklers (NaanDan Jain mod. Super10) spaced 7.5 m with a 7.5 m range. This irrigation system was switched off on June 24.

Considering that during the trial period (June 25 - July 17) on the study area there were no rainfall, we had a replenishment of 100% where the amount of water provided with the irrigation was equivalent to ET_0. Comparing this value to the data of the cumulative irrigation, 9 levels of replenishment were calculated (Tab. 1).

Table 1 Daily irrigation (mm) during the LGIS period (June 25 - July 17), and levels of water replenishment as function of the distance from the central pipe.

Distance from the central pipe (m)	Daily irrigation (mm)	Water replenishment (%)
1	8.2	159
2	7.5	146
3	6.8	132
4	5.7	111
5	4.4	85
6	3.1	61
7	1.9	37
8	0.9	18
9	0.3	6

The irrigation was carried out every day, between 7:30 and 9:30 a.m. (period of the day when winds effect is usually negligible). The experimental design was a split-plot with 4 replications. The main treatment consisted in 2 levels of nitrogen fertilization: 0 and 150 kg N ha^{-1} and was carried out on June 20 (ammonium sulphate 21-0-0). The secondary treatment consisted in 9 levels of water replenishment: from 159 to 6% (according to the reference evapotranspiration ET_0). The main plots were 47.5 m^2 (9.5 x 5 m), while the subplots were 5 m^2 (1 x 5 m).

2.1 Biometric parameters

On July 17 the following parameters were determined:

- turf quality: (1 = poor; 9 = excellent) visual assessment (Morris and Shearman, 2006).
- drought tolerance: (1 = completely stressed; 9 = no stress) visual assessment (Morris and Shearman, 2006).
- pest problems: pests include disease, insects and weeds (1 = 100% injury; 9 = no injury), visual assessment (Morris and Shearman, 2006).
- surface temperature: an infrared thermometer (Testo mod. 825-T2) was placed 0.8 m above the surface in order to collect the surface temperature.
- clippings weight (weekly) and relative nitrogen content: clippings were collected over a surface of 0.5 m^2 after a week of undisturbed growth. Fresh clippings were weighted, put in a ventilated stove at 70 °C and dried to constant weight. Dry weight data was collected and relative nitrogen content (%) was determined by Kjeldahl methods.
- turf growth (weekly): after a week of undisturbed growth, turf height was measured with rising disk (specific density = 750 g m^{-2}). The measured value minus the cutting height of July 10 (4.5 cm) gave the weekly turf growth.
- soil moisture: soil samples were collected at 15 cm depth, weighted, put in a stove at 105-110 °C and dried to constant weight. Soil moisture (%) was calculated as follow: [(fresh weight - dry weight) / fresh weight) x 100].

2.2 Spectral reflectance data

Together with the biometric parameters, on July 17 spectral reflectance data were acquired using a LICOR 1800 spectroradiometer (Li-Cor, 1992) with a fiber optic wire and LICOR 1800-06 telescope. The telescope was mounted on a purpose-built trolley at 120 cm from the ground with a vision angle of 15°. The monitored surface corresponded at ground level to approximately 2000 cm^2. Measures were taken on July 17 between 11:30 am and

1:30 pm (solar time), in complete absence of clouds. The radiation reflected by a white panel made from barium sulphate was measured in order to detect any possible variation in irradiance. Reflectance measures were carried out in the 390-1100 nm region at 5 nm intervals. The ratio between reflection from the turf and reflection from the white panel gave the value of spectral reflectance. Based on the available literature, a number of indices having good statistical relationships with several plant parameters have been selected for evaluation in the present study (Tab. 2).

Table 2 Reflectance-based vegetation indices used in this study

Vegetation Index	**Equation**	**Sensitivity**	**References**
Normalized Difference Vegetation Index (NDVI)	$NDVI=(R_{900}-R_{680})/(R_{900}+R_{680})$	Chlorophyll	Rouse *et al.* (1974)
Transformed CARI (TCARI)	$TCARI=3\ [R_{700}-R_{670})-0.2(R_{700}-R_{550})(R_{700}/R_{670})]$	Chlorophyll	Haboudane *et al.* (2002)
Structure Intensive Pigment Index (SIPI)	$SIPI=(R_{800}-R_{450})/(R_{800}+R_{650})$	Chlorophyll/ Carotenoid	Peñuelas *et al.* (1995)
Rededge	$Rededge = (R_{670}+R_{780})/2$	Nitrogen	Meer and Jong (2006)
Rededge position	The wavelength of reflectance's inflection point between 700 and 740 nm, determined by the peak value of the 1st derivative of the reflectance spectrum	Nitrogen	Cho and Skidmore (2006)
Vegetation Index (VI)	$VI=R_{775}/R_{680}$	Nitrogen	Inoue *et al.* (2008)
Water Index (WI)	$WI=R_{900}/R_{970}$	Leaf water	Peñuelas *et al.* (1997)
Normalized Difference Water Index (NDWI)	NDWI=(Green - NIR)/(Green + NIR) Green=TM_2(520 -600 nm) NIR=TM_4(760-900 nm)	Water features	McFeeters (1996)

2.3 Statistical analysis

Statistical analysis were carried out with a COSTAT 6.400 software (CoHort Software, Monterey, CA, USA). All biometric and vegetation index data were analyzed by two-ways ANOVA, and a all pairwise Fisher's Least Significant Difference (LSD) test at the probability level of 0.05. The association between biometric parameters and the latter with vegetation indices were studied. Pearson's correlation coefficient (r) was calculated among all the biometric parameters (turf quality, drought tolerance, surface temperature, clippings weight, nitrogen content, turf growth, soil moisture) and between the biometric parameters and the vegetation indices calculated in our research.

3. Results and discussion

Throughout the trial period no weeds or turf diseases occurred on turf. The analysis of the data regarding the interaction between the main and secondary treatment did not show any statistically significant differences for any parameters. Therefore, the average effects of nitrogen fertilization and water replenishment will be discussed.

3.1 Nitrogen fertilization

Nitrogen fertilization influenced significantly the following biometric parameters: turf quality, clippings weight, nitrogen content and turf growth. Turfgrass quality was influenced by nitrogen fertilization, even if it doesn't achieve a sufficient value (Tab. 3). Nitrogen fertilization produces significantly higher clippings weight, relative nitrogen content and turf growth. Drought turfgrass tolerance, surface temperature and soil moisture were not influenced by nitrogen fertilization.

Table 3 Turf quality, clippings weight and relative nitrogen content, turf growth. Nitrogen fertilization (mean effect).

Nitrogen fertilization (kg ha^{-1})	Turf quality (1-9)	Clippings weight (g m^{-2})	Nitrogen content (%)	Turf growth (cm)
0	4.2	4.7	2.5	0.8
150	5.4	13.3	3.9	1.5
LSD (0.05)	*0.5*	*5.4*	*0.6*	*0.3*

Significant different means were separated using Fisher's Least Significant Difference (LSD) at the P probability level of 0.05.

3.2 Water replenishment

Water replenishment influenced significantly all biometric parameters measured except nitrogen content (mean 3.3%). The higher turf quality was visually observed in 159 and 146% of replenishment (6.4), in the areas closer to the central pipe line, although there are no significant differences up to 85% of replenishing water. The quality of the turf is lower in the areas furthest from the pipe (between 3.6 and 1.5) (Tab. 4). The same trend was also observed in the drought turfgrass tolerance. Regarding surface temperature, the highest value was recorded in the two lower replenishing water 18% and 6%, respectively with 31.2 and 32.9 °C, while the temperature progressively decreased closest to the central line. The clippings weight was significantly reduced when the replenishment was lower than 61%. Tall fescue growth has been appreciable only in the areas closer to the pipe. The highest value were recorded from 85 to 159 % of replenishing water (max 2.2 cm). As expected, the soil moisture was progressively decreasing perpendicularly to the LGIS, ranging from 7.8 to 1.4 % (Tab. 4).

Table 4. Turf quality, drought tolerance, surface temperature, clippings weight and relative nitrogen content, turf growth, soil moisture. Replenishing water (mean effect).

Replenishing Water (%)	Turf quality (1-9)	Drought tolerance (1-9)	Surface temperature (°C)	Clippings weight (g m^{-2})	Turf growth (cm)	Soil moisture (%)
159	6.4	9.0	25.8	12.5	1.8	7.8
146	6.4	9.0	25.9	13.0	2.1	6.9
132	6.3	9.0	25.8	12.2	1.9	6.2
111	6.1	9.0	26.2	10.8	2.2	6.1
85	6.1	9.0	26.1	11.7	2.1	5.1
61	5.8	7.8	27.1	8.8	1.5	3.1
37	3.6	4.0	30.0	3.4	0.8	2.3
18	1.7	1.5	31.2	5.5	0.4	1.9
6	1.5	1.1	32.9	2.2	0.1	1.4
LSD (0.05)	*0.4*	*0.8*	*0.7*	*3.5*	*0.5*	*0.7*

Significant different means were separated using Fisher's Least Significant Difference (LSD) at the P probability level of 0.05.

3.3 Correlation among turf quality, drought tolerance and all biometric parameters

Turf quality was positively correlated with drought tolerance (r = 0.88), turf growth (r = 0.73) and negatively with surface temperature (r = - 0.78) (Tab. 5). Drought tolerance was found to be negatively correlated with surface temperature (r = - 0.88) and as expected, was positively correlated with soil moisture (r = 0.74). Thus, a good drought tolerance is equivalent of a better turf quality, with lower surface temperatures.

3.4 Correlation among turf quality, drought tolerance and some vegetation indices

Comparing turf quality with all the vegetation indices, it is interesting to point that the correlation coefficients (r) with Normalized Difference Vegetation Index (NDVI), Structure Intensive Pigment Index (SIPI), Vegetation Index (VI) and Water Index (WI) were higher than 0.82. All these indices have registered higher values also with drought tolerance, that was highly correlated with NDVI (r = 0.92) and SIPI (r = 0.93). It was found that SIPI, which employs ratios of reflectance at 800, 445 and 680 nm, can be used to accurately estimate the ratio of carotenoids (*Cars*) to chlorophyll *a (Chl a)* (Daughtry et al., 2000; Blackburn, 1998). With high values of *Cars* and chlorophyll *a* turf quality is higher and therefore the drought tolerance is strightly related. WI was also highly correlated with drought tolerance (r = 0.91). Differently from what expected, with normalized difference water index (NDWI), proposed by McFeeters (1996), we observed only a good correlation with drought tolerance (r = 0.71).

Table 5 Pearson correlation coefficients (r) among turf quality, drought tolerance and a) biometric parameters; b) vegetation indices. Correlation coefficients are calculated across all entries.

a) biometric parameters

r	Turf quality	Drought tolerance	Surface temperature	Clippings weight	Nitrogen content	Turf growth	Soil moisture
Turf quality	-	0.88***	- 0.78***	0.63***	0.41**	0.73***	0.65***
Drought tolerance	0.88***	-	- 0.88***	0.50**	0.21ns	0.64***	0.74***

b) vegetation indices

r	NDVI	TCARI	SIPI	Red edge	Red edge posit.	VI	WI	NDWI
Turf quality	0.87***	0.61***	0.87***	0.07ns	0.59***	0.86***	0.82***	0.52***
Drought toler.	0.92***	0.80***	0.93***	0.27ns	0.39*	0.88***	0.91***	0.71***

* = Significant at 0.05 level; ** = Significant at 0.01 level; *** = Significant at 0.001 level; ns = Not significant

4. Conclusions

This trial has shown the ability of tall fescue to tolerate a deficit irrigation with an amount of water lower than the reference evapotranspiration (ET_0), for a summer period of 3 weeks in a sandy soil. The use of a lesser amount of water and fertilization could provide environmental and economic benefits and this method could allow a target management depending on the real turf needs, less wasteful. Through the application of vegetation indices we evaluated proximity-sensed spectral reflectance of tall fescue. These indices have highlighted high correlations with some of the biometric parameters observed, above all turf quality and drought tolerance. Results showed the best vegetation indices to estimate the water content of a turf of tall fescue, in terms of different levels of water replenishment. In particular the indices with the highest correlations with drought tolerance were Normalized Difference Vegetation Index (r = 0.92), Structure Intensive Pigment Index (r = 0.93) and Water Index (r = 0.91). This research has been useful as preliminary evaluation of spectral remote sensing as a diagnostic tool. In the future it is expected that the information obtained from proximity sensed measurements could be correlated with satellite data to afford different treatments depending on the real needs.

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