Sensor-based Technology for Assessing Drought Stress in Two Warm-Season Turfgrasses

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난지형 잔디의 건조 스트레스를 측정하기 위한 센서 기술 연구

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ABSTRACT

This study was designed to determine what sensor-based technologies might reliably and accurately predict irrigation scheduling needs of warm-season turfgrass. 'Floratam' St. Augustinegrass[*Stenotaphrum secundatum*(Walt.) Kuntze] and 'Sea Isle I' seashore paspalum(*Paspalum vaginatum* Swartz) were established in tubs in the Envirotron Turfgrass Research Laboratory in Gainesville, FL in the spring of 2002. Each grass was subjected to repeated dry-down cycles where irrigation was withheld. Sensor-based data were collected and these evaluations were used to determine if irrigation scheduling could be determined based on plant response during dry-down. Results indicated that reflectance indices($P \leq 0.001$) and soil moisture($P \leq 0.0001$) throughout the dry-down cycle can predict the need for irrigation scheduling as turf quality declined below acceptable levels.

Key words: drought stress, multi-spectral reflectance, soil moisture, warm-season turfgrass

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INTRODUCTION

Water is one of the greatest limiting factors influencing turfgrass growth. In recent years there has been increasing interest in deficit irrigation, or providing water at less than the evapotranspiration(ET) rate over the growing season. With demand on urban water resources often exceeding available supplies, it has become important to understand and quantify the responses of turf to deficit irrigation and to gain better understanding of relative drought tolerance.

Drought is defined as a condition caused by a prolonged period of dry weather which results in plant damage and water supply shortages(Kneebone et al., 1992). Turfgrass response to water stress varies and drought is a major limiting factor in turfgrass management(White et al., 1993). Drought suppresses turfgrass growth and causes deterioration of turf quality. The use of cultivars and species with superior drought resistance is one way in which water use can be reduced while maintaining good quality and growth of turfgrass(White et al., 1992). For this reason, drought resistance has been investigated among many turfgrass species and cultivars(Carrow, 1996), including seashore paspalum(Huang et al., 1997).

Seashore paspalum is found in sandy coastal environments in tropical and subtropical regions of North and South America, and has excellent tolerance to salinity(Duncan, 1994), and ranked high in drought resistance(Huang et al., 1997). Structural features of this species such as leaf morphology and root system contribute to its drought resistance(Huang et al., 1997). Sifers and Beard(1999) assessed drought resistance of selected genotypes within St. Augustinegrass, centipedegrass[*Eremochloa ophiuroides*(Munro) Hack.], seashore paspalum, and buffalograss(*Buchloe dactyloides*(Nutt.)). Most of the genotypes of St. Augustinegrass and seashore paspalum had outstanding drought tolerance and were capable of remaining green through 158 days of drought stress periods. However, there was a significant drought stress reaction such as early color loss and dormancy in some drought tolerant species such as buffalograss.

Light from the sun is either reflected from, absorbed by, or transmitted through the leaf. By measuring the quantity of radiation at various wavelengths, the condition of a plant can be defined(Carter, 1994). Carter(1991) investigated the effect of water content on spectral reflectance in leaves of six diverse species including broadleaved and pine trees(*Pinus taeda*) and cane grass(*Arundinaria tecta*) using a scanning radiometer(IRIS, Geophysical Environmental Research). As leaf water content decreased, reflectance from leaf surfaces tended to increase through most of the 400-

2500 nm spectrum. However, canopy measurement using multispectral radiometry(MSR) showed decreasing reflectance in the near infrared region(NIR) due to decreased leaf area caused by drought(Knipling, 1970).

Carter(1996) compared plant stress detection by narrow-band reflectance and images with thermal infrared images. Reflectance at 694 nm was a good indicator of stress and the 690 to 700 nm band was superior to thermal imagery for the early and pre-visual detection of stress in loblolly pine(*Pinus taeda* L.) and slash pine(*Pinus elliottii* Engelm.). A strong relationship between stress and reflectance values throughout the visible range has been associated with turf growth and health status(Trenholm et al., 1999a) and turf response to both fertilization and stress(Trenholm et al., 2001).

Trenholm et al.(1999b) investigated weather data by MSR could be correlated with qualitative data such as visual quality, density, and uniformity in turfgrass. The results showed that reflectance at 661 nm, as well as the growth indices normalized difference vegetation index(NDVI) computed as$(R_{930} - R_{660})/(R_{930} + R_{660})$, leaf area index(LAI) computed as R_{930} / R_{660}, and two stress indices computed as R_{710} / R_{760} and R_{710} / R_{810} were highly correlated with qualitative data. Therefore, spectral reflectance was determined to be a reliable method for quantifying turf quality, density, and uniformity. The objectives for this research were: 1) to assess differences in drought tolerance between 'Floratam' St. Augustinegrass and 'Sea Isle 1' seashore paspalum, and 2) to evaluate the potential of sensor-based technologies to detect drought stress in these two turfgrass species.

MATERIALS AND METHODS

Two studies were conducted consecutively on 'Floratam' St. Augustinegrass and 'Sea Isle I' seashore paspalum in a greenhouse at the University of Florida Envirotron Turfgrass Research Laboratory in Gainesville. Study 1 was conducted from 19 April to 7 May 2002 and study 2 from 29 May to 8 July 2002. Grasses were established on an Arredondo fine sand soil(loamy, siliceous, hyperthermic, grossarenic paleudult) overlying 5 cm of gravel in 43 cm diameter and 35 cm deep plastic tubs. Grasses were transplanted in each tub from established sod that was washed free of soil before planting. A stock solution fertilizer containing essential macro- and micronutrients was applied to supply 2.5g m^{-2} of nitrogen biweekly. Grasses were mowed with hand-held shears once a week at 5cm and irrigation was provided as needed during establishment. Average greenhouse temperatures were 31/27°C day and night, respectively. When grasses were uniformly established, irrigation was withheld and data were obtained over the duration of the dry-down cycles.

Volumetric soil moisture content(SMC, %) was randomly measured from two locations within each pot on a daily basis with a FieldScout 300 TDR(Spectrum Technology, Inc.). Average volumetric water content was measured to a depth of 20 cm.

Spectral reflectance readings were taken concurrently with qualitative ratings on a daily basis using a hand-held Cropscan multispectral radiometer(MSR 16, Cropscan Inc., Rochester, MN) fitted with wavelength filters to measure reflectance at 450, 550, 660, 694, 710, 760, 810, and 930 nm. In addition, the growth and stress indices were calculated:

Normalized difference vegetation index(NDVI) computed as$(R_{930} - R_{660})/(R_{930} + R_{660})$.

IR/R(LAI) growth index computed as R_{930}/R_{660}.

Stress 1 index computed as R_{710}/R_{760}.

Stress 2 index computed as R_{710}/R_{810}.

MSR Readings were taken from 1100 to 1300 h EST under conditions of minimal cloud cover.

Experimental design was completely randomized with 8 replications. Two studies were compared for differences with analysis of variance(PROC ANOVA) and data from each study were analyzed with general linear regression(PROC GLM) or correlation models(PROC CORR)(SAS Institute). Means were separated using the LSD test($P < 0.05$). Regression analysis was used to test correlations between soil moisture and MSR data.

RESULTS AND DISCUSSION

Data are presented as an average of both studies. Where differences between grasses were found, data are presented separately by species. Spectral reflectance at wavelengths 660 and 694, NDVI, LAI, and all stress indices were highly correlated with soil moisture(Table 1).

'Floratam' had the lowest reflectance at 13.8% and 14.3% soil moisture levels at 660 nm and 694 nm, respectively(Figs. 1a and 1b). 'Floratam' showed the highest growth indices NDVI and LAI at 13.9% and 12.9% soil moisture levels, respectively(Figs. 1c and 1d). 'Floratam' also had the lowest stress at 15.6% and 16.8% in Stress 1 and Stress 2, respectively(Figs. 1e and 1f). When soil moisture was above or below the optimal level, reflectance and stress levels increased indicating less than optimal plant function. 'Sea Isle I' required higher soil moisture levels for optimal conditions compared to 'Floratam'. The lowest reflectance occurred at 16.1% of soil moisture at 660 nm and 694 nm(Fig. 1a and 1b). At 21% soil moisture levels, 'Sea Isle I' produced optimal responses for growth index LAI(Fig. 1d). Stress indices indicated that stress levels were lowest when soil moisture was at 19.4% and 21.1% for stress 1 and 2, respectively(Figs. 1e and 1f). With these results, 'Sea Isle I' required lower soil moisture content to maintain minimum acceptable quality and higher soil moisture content to have the optimum quality than 'Floratam'.

Table 1. Correlation between reflectance values and soil moisture in 'Floratam' St. Augustinegrass and 'Sea Isle 1' Seashore paspalum in study 1 and 2.

	Floratam		Sea Isle I	
	Soil Moisture		Soil Moisture	
	R^2	P^z	R^2	P
wv450	0.34	*	0.07	NS
wv550	0.03	NS	0.01	NS
wv660	0.50	***	0.39	**
wv694	0.45	**	0.25	*
wv710	0.21	NS	0.24	NS
wv760	0.12	NS	0.35	*
wv810	0.07	NS	0.30	*
wv930	0.03	NS	0.26	*
$NDVI^y$	0.52	***	0.32	*
LAI^x	0.31	*	0.42	**
Stress1	0.64	***	0.53	***
Stress2	0.53	***	0.46	**

[z]***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively.

NS = not significant. All the data were analyzed with quadratic equation model.

[y]Normalized difference vegetation index(NDVI) =(R930 - R660) /(R930 + R660).

[x]Leaf area index(LAI) = R930 / R660. Stress 1 = R710 / R760. Stress 2 = R710 / R810.

Low reflectance in the visible spectral region occurs in a plant leaf because of strong absorption by photoreceptors such as chlorophylls, carotenoids, xanthophylls, and anthocyanins. To the contrary, a relatively high reflectance in the NIR beyond 750 nm occurs because of internal leaf scattering and lack of absorption. Disease and physiological stresses such as drought also directly affect the reflectance properties of plant leaves(Knipling, 1970).

Reflectance sensitivity analysis(Carter, 1991; Cibula and Carter, 1992) has also indicated that increased reflectance at 695 nm showed an early indication of stress as a result of the reduced light absorption by chlorophyll b(Carter, 1993; Carter and Miller, 1994). Our study indicated that reflectance at 660 and 694 nm were highly correlated with soil moisture in both grasses. From soil moisture, optimal reflectance

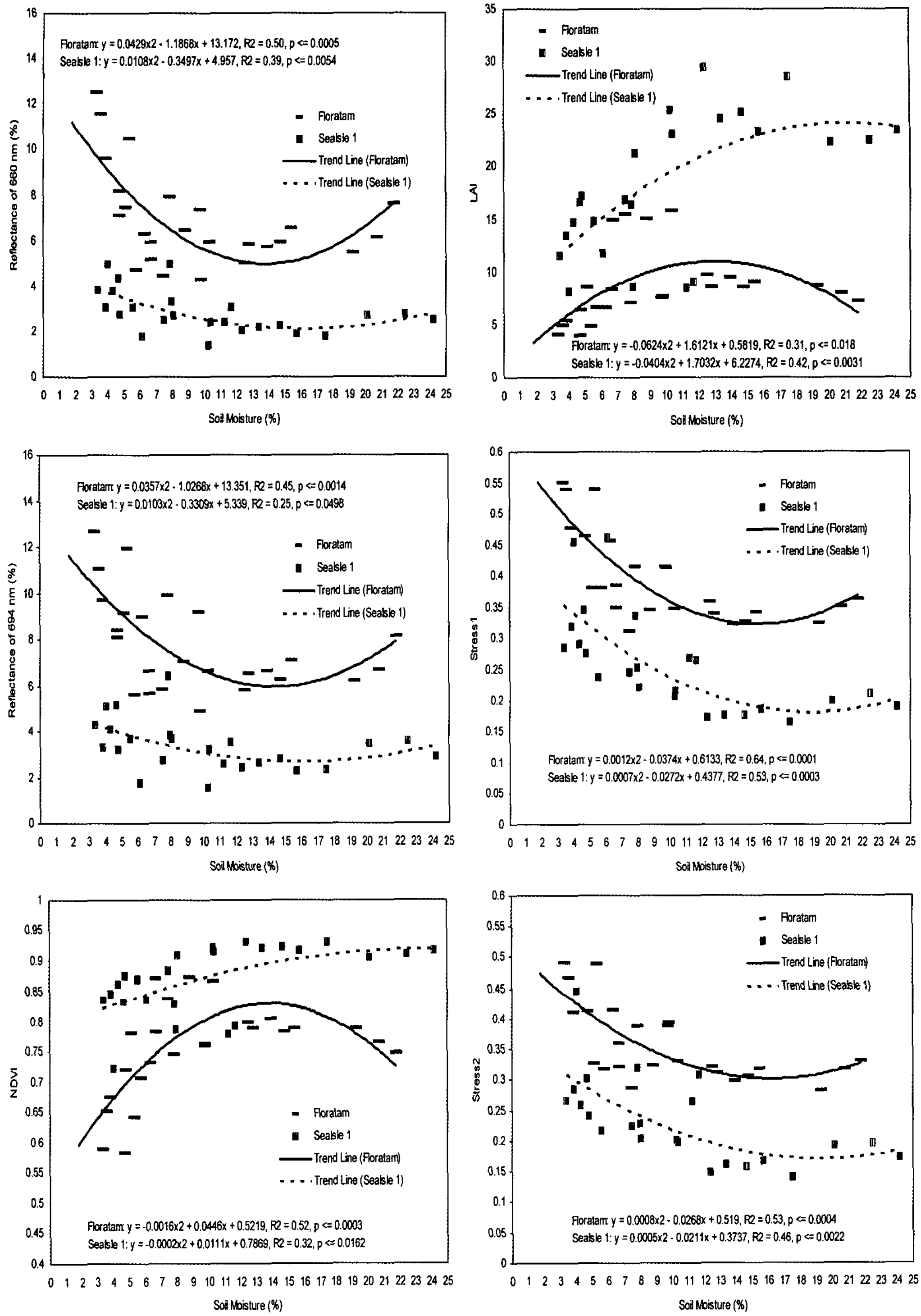

Fig. 1. Correlation between soil moisture vs. 660nm, 694nm, NDVI, LAI, Stress1, Stress2, and NDVI in study 1 and 2.

responses have been determined that can be used to detect when moisture is required.

Regression analysis could determine what levels of reflectance then correlate with various levels of quality. Data appeared to be equally obtainable and useful for either species used in the research. By regressing soil moisture and turf quality data, 'Floratam' and 'Sea Isle I' could have maintained minimum acceptable quality at low soil moisture. This implies that maintenance of turfgrass with low soil moisture can be possible.

In this study, we found the optimum SMC for 'Floratam' and 'Sea Isle I' by regression model between soil moisture and spectral reflectance. Supra-optimal soil moisture showed increased stress indices and decreased NDVI and LAI indices in both grasses. Regression model between reflectance and turf quality indicated that reflectance in the visible ranges and the stress indices increased and reflectance in the NIR, NDVI, and LAI decreased as turfgrass visual quality decreased. This result is similar to other studies(Trenholm et al., 1999b). As previously reported, NDVI and LAI ratio decreased as drought stress increased.

In conclusion, strong correlations exist among reflectance throughout visible range and SMC. This research indicates that drought stress can be detected by sensor-based technology such as multispectral reflectance(MSR) and may be used to schedule irrigation events to reduce turfgrass water use.

국문 요약

본 연구는 토양 수분함량을 즉시 파악할 수 있는 Time Domain Radiometer(TDR) 과 식물의 광합성 시 잎에서 반사되는 Reflectance를 통하여 식물의 상태를 파악할 수 있는 Multi-spectral radiometer(MSR)를 사용하여 난지형 잔디인 'Sea Isle 1' Seashore paspalum 과 'Floratam' St. Augustinegrass를 대상으로 토양수분함량과 Reflectance와의 상관관계를 파악하고자 시작하였다. 본 연구를 통해 토양 수분함량이 660, 694 wavelengths와 NDVI, LAI, stress index에서 높은 상관관계를 가지고 있음을 알 수 있었다. 이는 Sensor-based technology가 잔디의 수분요구 시점을 미리 파악할 수 있는 기술의 기초 자료로서 활용될 수 있으며 여러 다른 Sensor-based technology를 이용한 연구로 확대될 수 있을 것이다.

주요어: 건조스트레스, 난지형잔디, 토양수분, mult-spectral reflectance

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