Multi-Spectral Reflectance of Warm-Season Turfgrasses as Influenced by Deficit Irrigation

Joon-Hee Lee[1]*, Laurie. E. Trenholm[2] and J. Bryan Unruh[2]

[1]*Hampyung Dynasty Country Club of Daeju Group, Hampyung 525-812, Korea*

[2]*Dep. of Environmental Horticulture, Univ. of Florida, 1549 Fifield Hall, Gainesville, FL 32611*

난지형 잔디의 가뭄 스트레스 상태로 인한 멀티스팩트럴 반사광 연구

이준희[1]* · Laurie E. Trenholm[2] · J. Bryan Unruh[2]

[1]함평 다이너스티 C.C., [2]플로리다 대학교 환경원예학과

ABSTRACT

Remote sensing using multispectral radiometry may be a useful tool to detect drought stress in turf. The objective of this research was to investigate the correlation between drought stress and multispectral reflectance (MSR) from the turf canopy. St. Augustinegrass (*Stenotaphrum secundatum*[Walt.] Kuntze.) cultivars 'Floratam' and 'Palmetto', 'SeaIsle 1' seashore paspalum (*Paspalum vaginatum* Swartz.), 'Empire' zoysiagrass (*Zoysia japonica* Steud.), and 'Pensacola' bahiagrass (*Paspalum notatum*Flugge) were established in lysimeters in the University of Florida Envirotron greenhouse facility in Gainesville. Irrigation was applied at 100%, 80%, 60%, or 40% of evapotranspiration (ET). Weekly evaluations included: a) shoot quality, leaf rolling, leaf firing b) soil moisture, chlorophyll content index; c) photosynthesis and d) multispectral reflectance. All the measurements were correlated with MSR data. Drought stress affected the infrared spectral region more than the visible spectral region. Reflectance sensitivity to water content of leaves was higher in the infrared spectral region than in the visible spectral region. Grasses irrigated at 100% and 80% of ET had no differences in normalized difference vegetation indices (NDVI), leaf area index (LAI), and stress indices. Grasses irrigated at 60% and 40% of ET had differences in NDVI, LAI, and stress indices. All measured wavelengths except 710nm were highly correlated ($P < 0.0001$) with turf visual quality, leaf firing, leaf rolling, soil moisture, chlorophyll content index, and photosynthesis. MSR could detect drought stress from the turf canopy.

Key words: drought stress, multi-spectral reflectance, deficit irrigation, evapotranspiration

*Corresponding author. Tel : 061-320-7755

E-mail : jle3576@gmail.com

Received : Feb. 12, 2008, Revised : Apr. 6, 2008, Accepted : Jun. 8, 2008

INTRODUCTION

The use of remote sensing technology is a powerful tool that can utilize in the development of turfgrass management practices to reduce water use (Kenna, 1995). Such remote sensing technology can provide detailed data of turfgrass response to change in irrigation management even in micro scale. Satellite system such as a balloon can read reflectance from turfgrass canopy. Satellite system can send these information to the main irrigation controlling system. The main system can analyze the data and send signals to the individual sprinkler head. This system will be one of irrigation management practices in the near future. The author wants to provide the base line for this irrigation management system from this experiment.

Mutispectral reflectometry is one of sensor-based technologies to investigate physiological responses under stress conditions. 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 (Knipling, 1970). A plant leaf typically has a low reflectance in the visible spectral range because chlorophylls strongly absorb the wavelengths in visible regions and has relatively high reflectance in the near infrared because of internal leaf scattering. Thus, when disease and physiological stresses directly affect the reflectance properties of individual leaves, the initial changes often occur in the visible spectral region rather than in the infrared region because chlorophylls are sensitive to physiological disturbance (Knipling, 1970).

Normalized difference vegetation index (NDVI) can be defined as the near-infrared regions (NIR) minus visible red spectral regions divided by NIR plus visible red spectral regions. Vegetation indices such as NDVI and leaf area index (LAI) have been developed to a single numerical index by multi-band observations (Tucker et al., 1979; Perry and Lautenschlager, 1984). The index is typically a sum, difference, ration or radiance observations from two or more wavelength intervals. High absorption of incident sunlight in the visible red ranges(600-700nm) and strong reflectance in the near-infrared ranges (750-1350nm) of the electromagnetic spectrum is differentiated from that of soil and water. Thus, vegetation indices from two wavelengths of visible red region and NIR have highly correlated with the plant stand parameters (Wiegand et al., 1991). Asrar et al. (1984) found that NDVI correlated well (r^2=0.97) with absorbed photosynthetically active radiation in wheat (*Triticum aestivum* L.).

Carter (1993) measured leaf spectral reflectances to determine if reflectance responses might differ according to various plant stress such as competition, herbicide, pathogen, ozone, and dehydration. He found that visible reflectance was most sensitive to stress in the 535-640nm and 685-700nm wavelength regions. Carter and Miller (1994) developed the ratio of 695:760nm as particularly sensitive to herbicide or biological stress in various species. Trenholm et al. (1999) investigated ifdata obtained by MSR could be correlated with qualitative data such as visual quality and density in turfgrass. They found that the ratio of 706:813nm was greater r^2values than the ratio of 706:760nm when correlation coefficient of reflectance at wavelengths vs. turf quality, density, shoot tissue injure, and shoot growth by wear stress was estimated. The results showed that reflectance at 661 nm, as well as growth indices normalized difference vegetation index (NDVI) computed as (R_{935} - R_{661}) / (R_{935} + R_{661}), leaf area index (LAI) computed as R_{935} / R_{661}, and two stress indices computed as R_{706} / R_{760} and R_{706} / R_{813} were highly correlated with qualitative data.

Lee at al. (2005) examined if MSR could investigate physiological responses of warm season turfgrasses by drought stress. They found that spectral reflectance throughout the visible wavelengths and all indices were highly correlated with turf quality, RWC, soil moisture, and chlorophyll content index. Accordingly, MSR can be a reliable method for assessing physiological conditions and quantifying turf quality, density and uniformity.

The objectives for this research were: 1) To investigate the correlation between drought stress and multispectral reflectance (MSR) from the turf canopy, and 2) To assess differences in multispectral reflectance of warm-season turfgrasses due to deficit irrigation.

MATERIALS AND METHODS

Plant Materials

Two repeated studies were conducted consecutively in a greenhouse at the University of Florida Envirotron Turfgrass Research Laboratory in Gainesville. Study 1 was conducted from 31 October, 2002 to 16 April, 2003 and study 2 was conducted from 28 October, 2003 to 30 March, 2004. St. Augustinegrass cultivars Floratam and Palmetto, SeaIsle 1 seashore paspalum, Empire zoysiagrass, and Pensacola bahiagrass were established in 46-cm-deep and 15-cm diameter PVC lysimeters. Grasseswere established on an Arredondo fine sand soil [loamy, siliceous, hyperthermic, grossarenic paleudult] overlying 5 cm of gravel. Grasses were transplanted 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 7cm and irrigation was provided as needed during establishment. Average greenhouse temperatures were 31/27°C day and night, respectively. When grasses were uniformly established, deficit irrigation treatments began and data were obtained over the duration of the dry-down cycles.

Deficit Irrigation Treatments

Irrigation was applied once a week at 100%, 80%, 60%, or 40% of evapotranspiration (ET) as measured gravimetrically. Actual ET rate of grasses was determined by measuring the lysimeters receiving100% ET. This was calculated by the following formula:

$$ET = W_{max} - W_{min}$$

$$W_{needed} = \text{deficit irrigation level} \times ET_{control}$$

$$W_{max} = W_{min} + W_{needed}$$

W_{min} and W_{max} are lysimeter weights before and after water is applied. W_{needed} represents water amount applied for lysimeters. $ET_{control}$ represents the mean of 100% irrigation levels of ET.

Measurements

Evaluations included turf quality, leaf rolling, leaf firing, volumetric soil moisture content, chlorophyll content index (CCI), canopy photosynthesis (PS), and multispectral reflectance (MSR). Turf quality was assessed weekly during the dry-down using a 1 to 9 scale based on shoot color, density, uniformity, and drought symptoms, where 1 indicates no live grass and complete wilting, 5 indicates the beginning of drought stress, 6 indicates a minimum acceptable quality without drought stress, and 9 indicates optimum quality. Leaf rolling and leaf firing were assessed daily using a 1 to 9 scale, where 1 equaled no live grass and 9 equaled no leaf rolling or leaf firing.

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

Chlorophyll content index of leaves (CCI) was randomly measured from two locations within each pot with a FieldScout CM1000™ chlorophyll meter (Spectrum Technology, Inc.). This chlorophyll meter senses light at wavelengths of 700 nm and

840 nm and develops an index to estimate the quantity of chlorophyll in leaves.

Canopy photosynthesis was measured once a week with the LI-COR 6200 portable photosynthesis system. The net exchange of CO_2between canopy and the atmosphere in the chamber was monitored and measured the reducing rate at the CO_2concentration in the air changes over 30 seconds interval. Each lysimeter was put under high intensity discharge (HID) lamp during photosynthesis measurement to have consistent light intensity. The range of photosynthetic photon flux density (PPFD) was between 1200 and 1800 umol/m^2/sec. All readings were taken from 1200 to 1500 h EST under conditions of minimal cloud cover. Photosynthesis loss was calculated as the difference between 100% and 40% ET is divided by 100% of ET rate.

Spectral reflectance readings were taken concurrently with qualitative ratings 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:

1. Normalized difference vegetation index (NDVI) computed as $(R_{930} - R_{660}) / (R_{930} + R_{660})$.
2. NDVI II computed as $(R_{810} - R_{660}) / (R_{810} + R_{660})$.
3. IR/R (LAI) growth index computed as R_{930} / R_{660}.
4. Stress 1 index computed as R_{710}/ R_{760}.
5. Stress 2 index computed as R_{710} / R_{810}.

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

The two studies were compared for differences with analysis of variance at the 0.05 probability level (PROC ANOVA) and data from each study were analyzed with general linear regression (PROC GLM) or correlation models (PROC CORR) (SAS Institute,1987). Means were separated using the LSD test ($P < 0.05$). Regression analysis was used to test correlations among visual measurements, RWC, soil moisture content, CCI, and multispectral reflectance data.

RESULTS

Visual Measurements vs. Reflectance

As visual turfgrass quality was regressed against spectral reflectance at each wavelength and indices, the indices NDVI, NDVI II, Stress 1, and Stress 2 explained the variability in the model, with r^2 values ranging from 0.25 to 0.69 (Table 1 and 2). Reflectance at all wavelengths didn't provide a good fit for the quality model in either study, although turf visual quality models were highly significant for all wavelengths except 710nm, growth indices and stress indices. Wavelengh at 710 indicated the "blue shift", occurring between visible and NIR regions, which is related with leaf chlorophyll concentration (Carter et al., 1996; Trenholm et al., 1999). NDVI II had higher correlation coefficient than NDVI during both studies because the response to reflectance at 810nm was higher than at 930nm in Study 1 an 2. Highest r^2 values (0.47-0.69) were obtained from NDVI II and Stress 1 in Study 1 and from NDVI, NDVI II, and Stress 1 in Study 2. r^2 values were higher in both studies in Stress 1 than in Stress 2 (Table 1 and 2).However, Trenholm et al. (1999) found that correlation coefficient was greater for Stress 2 than for Stress 1 in wear stress study. This result is inconsistent with drought stress study. It may show that drought stress is higher related with Stress 1 than Stress 2.

In leaf firing, highest r^2 values (0.40-0.64) were obtained from NDVI II and Stress 1 in Study 1 and from NDVI, NDVI II, and Stress 1 in Study 2. r^2values were higher in both studies in Stress 1 than in Stress 2 (Table 1 and 2). Reflectance at all wavelengths didn't provide a good fit for the leaf firing model in either study, although all wavelengths except 710nm, growth indices and stress indices showed high probability levels. NDVI II had higher correlation coefficient than NDVI during both studies as previously explained.

In leaf rolling, highest r^2 values (0.52-0.60) were obtained from NDVI, NDVI II, and Stress 1 in Study 2. In Study 1, all wavelengths, growth indices, stress indices had an r^2 value < 0.40. In visual measurements, correlation values and r^2 values were comparatively lower for leaf rolling than for visual quality and leaf firing (Table 1 and 2).

Sensor-based Measurements vs. Reflectance

In correlations between soil moisture content and reflectance, Study 1 showed that all wavelengths, growth indices, and stress indices didn't provide a good fit for the correlation with soil moisture, although all wavelengths, growth indices and stress indices showed high probability levels. In Study 2, only NDVI and NDVI II had an r^2 value > 0.40. NDVI II had higher correlation coefficient than NDVI during both studies. Stress 1 had higher r^2 value than Stress 2 in both studies (Table 1 and 2).

As photosynthesis was regressed against spectral reflectance at each wavelength and indices, Growth indices and stress indices only showed explained the variability in the model, with r^2 values ranging from 0.20 to 0.46 (Table 1 and 2). Reflectance at all wavelengths didn't provide a good fit for the photosynthesis model in either study, although photosynthesis was highly significant for all wavelengths, growth indices and stress indices. NDVI II and Stress 1 had higher correlation coefficient than NDVI and Stress 2, respectively in both studies.

Chlorophyll content index had higher correlation coefficient in Study 2 than in Study 1.

In Study 1, the highest r^2 value (0.43) was obtained from only NDVI II. In Study 2, the highest r2 values (0.56-0.61) were obtained from NDVI, NDVI II, and Stress 1 (Table 1 and 2).

Multi-Spectral Reflectance

At the termination of Study 1, reflectance at wavelengths 660 and 694 could distinguish 40% ET treated turf from the other ET treated turf. Reflectance at wavelengths 760 and 810 could distinguish 60% and 40% ET treated turf from 100% and 80% ET treated turf. Growth indices LAI could distinguish 100% ET treated turf from 80% ET treated turf. NDVI and stress indices could distinguish 80% ET treated turf from 60% ET treated turf. However, there were no statistically differences between 100% and 80% ET treated turf as same as turfgrass had no significant difference between 100% and 80% ET in visual quality (Table 3).

At the termination of Study 2, reflectance at wavelengths 660 and 710 could distinguish 40% ET treated turf from the other ET treated turf. Reflectance at wavelengths 760, 810, 930, and LAI could distinguish 60% and 40% ET treated turf from 100% and 80% ET treated turf. NDVI and stress indices could distinguish 80% ET treated turf from 60% ET treated turf. However, there were no statistically differences between 100% and 80% ET treated turf as Study 1 (Table 3).

Prediction Model

In visual spectral regions, each reflectance wasincreased as ET treatments were decreased. SeaIsle 1 had lower reflectance than the other grasses. Floratam had higher reflectance than the other grasses in these spectral regions (Fig. 1). SeaIsle 1 showed significant drop down in leaf area index (LAI) compared to the other grasses as ET treatments decreased in Study 1 and 2 (Fig. 1).Empire had the highest LAI at 76.3% and 80% of ET in Study 1 and 2, respectively. Pensacola had the highest LAI at 77.5% and 82.6% of ET in Study 1 and 2, respectively. SeaIsle 1, Palmetto, and Empire had higher NDVI than Pensacola and Floratam. Interestingly, Palmetto and

Pensacola showed the highest NDVI value at 81.5% and 76.7% of ET, respectively (Fig. 1). In Study 1, Stress 1 showed that SeaIsle 1, Empire, and Palmetto had the lowest stress at 84.3%, 81.8%, and 80.2% of ET, respectively.Stress 2 showed that Empire, and Palmetto had the lowest stress at 82.3%, 82.8%, and 77.9% of ET, respectively. In Study 2, Stress 1 showed that SeaIsle 1, Empire, and Palmetto had the lowest stress at 82.8%, 90.4%, and 92.2% of ET, respectively. Stress 2 showed that SeaIsle 1, Empire, and Palmetto had the lowest stress at 80.8%, 87.5%, and 96.2% of ET, respectively (Fig. 2).

By prediction model, Pensacola, Empire, Floratam, Palmetto, and SeaIsle 1 showed the symptom of drought stress at 0.78, 0.84, 0.80, 0.85, and 0.84 of NDVI and at 9.74, 15.95, 11.01, 16.32, and 15.65 of LAI and at 0.46, 0.31, 0.42, 0.37, and 0.34 of Stress 1 and at 0.42, 0.28, 0.37, 0.33, and 0.34 of Stress 2, respectively (Fig. 3). Empire, Palmetto, and SeaIsle 1 had higher NDVI and LAI than Pensacola and Floratam in whole drought stress periods. Empire had the lowest stress index in Stress 1 and 2.

DISCUSSION

All growth indices, stress indices, and all wavelengths except 710 nm were significantly correlated with visual quality, leaf firing, leaf rolling, soil moisture, photosynthesis, and chlorophyll content index in both studies. The spectral ranges at 710 nm indicates the "blue shift", occurring between visible and NIR wavelengths, which is strongly related to leaf chlorophyll concentration (Carter et al., 1996; Horler et al., 1983). Stress 1 had higher r^2 values than Stress 2. Trenholm et al. (1999) found that correlation coefficient was greater for Stress 2 than for Stress 1 in wear stress study. This result is inconsistent with drought stress study. It may show that drought stress is higher related with Stress 1 than Stress 2. Overall, NIR had higher r^2 values than visiblespectral regions in this study. Carter (1991) pointed that water sensitivity was higher in near infrared spectral regions than in visible spectral regions as the absorptivity of water is much weaker in visible regions than in the infrared regions. The growth indices NDVI and NDVI II were the significant indicators for detection of drought stress.

At the termination of both studies, 100% and 80% ET treated turf didn't show any drought stress with human visual eye. 60% and 40% ET treated turf showed mild and severe drought stress, respectively. The growth indices and stress indices distinguished 40% ET treated turf from 60% ET treated turf and 60% ET treated turf from 100 and 80% ET treated turf. There was no significant difference between 100% and 80% ET treated turf. This result is coincident with visual measurement analysis.

Prediction model indicates that each grass shows different reflectance response in various ET treatments. SeaIsle 1 showed the highest drought sensitivity compared to the other warm-season grasses. Pensacola showed the lowest drought sensitivity (Fig.1). Interestingly, all the grasses except Floratam had higher NDVI or lower stress indices when slight deficit irrigation was applied. This result is coincident with Lee's study. Lee etal. (2003) found that Floratam St. Augustinegrass grown in sandy loam soil produced optimal responses for growth indices NDVI, LAI , Stress 1, and Stress 2 at slight lower soil moisture.

Carter (1991) found that leaf reflectance of *Magnolia grandiflora* L. in the NIR increased as RWC of leaves decreased.Water is absorbed at the NIR, resulting in decreased reflectance. However, this study showed that prolonged drought induced leaf wilting, which tends to expose more bare soil, stems, or stolons to the sensor. the reflectance in infrared spectral regions was decreased by these reasons. On the contrary, the reflectance in visual spectral regions was increased due to the reduction of leaf area having chlorophylls.

Lee et al. (2005) also showed that reflectance in the near NIR decreased as drought symptoms increased.Grasses showed a low reflectance in the visible region and a high reflectance in the NIR under no drought stress condition, with the opposite occurring under drought stress condition. Carter (1991)found that the sensitivity of reflectance to water content was greatest in the water absorption bands near 1,450, 1,940, and 2,500nm. Further study should be done through the observation of these wavelengths.

In conclusion, there were strong correlation between drought stress and spectral reflectance from the turf canopy. Thus, this research provides that multispectral reflectance can be one of methods to detect drought stress. This study also indicates that warm-season turfgrasses showed different responses in multispectral reflectance under drought stress. Further study is needed to have more information about multi-spectral reflectance response of various warm-season and cool-season turfgrasses under drought stress condition.

국문 요약

Multi-spectral radiometer (MSR)를 사용한 리모트 센싱 기술이 향 후 잔디의 건조스트레스를 감지할 수 있는 도구로 사용될 수 있다. 본 연구의 목적은 네가지 각기 다른 조건의 건조스트레스를 받은 난지형 잔디의 잎에서 반사되는 Reflectance와 토양수분, 비주얼 잔디상태, 엽록소 함량, 광합성 등을 측정하여 각 factor간의 상관관계를 조사했으며 본 연구를 통해 모든 factor가 MSR 데이터와 깊은 상관관계를 가지고 있었다. 또한 Reflectance 민감도는Visual spectral region보다 Infrared spectral region에서 더 높음을 알 수 있었다. 모든 결과를 종합해 볼 때 Multi-spectral radiometer (MSR)은 잔디의 건조상태를 미리 예측할 수 있는 도구로 사용될 수 있음을 확인할 수 있었다. 이 기술의 자료를 활용하게 된다면 향 후 MSR이 부착된 기구(Balloon)를 이용한 필드 스터디 연구로 확대될 수 있을 것이다.

주요어 : 가뭄 스트레스, Multi-sprectral reflectance, Deficit irrigation, 증발산량

REFERENCES

1. Asrar, G., M. Fuchs, E. T. Kanemasu, and J. L. Hatfield. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. J. 76:300-306.
2. Carter, G. A. 1991. Primary and secondary effects of water content on the spectral reflectance of leaves. Am. J. Botany. 78:916-924.
3. Carter, G. A. 1993. Responses of leaf spectral reflectance to plant stress. American Journal of Botany. 80(3):239-243.
4. Carter, G. A., and R. L. Miller. 1994. Early detection of plant stress by digital imaging within narrow stress-sensitive wavebands. Remote Sensing of Environment. 50:295-302.
5. Carter, G. A., W. G. Cibula, and R. L. Miller. 1996. Narrow-band reflectance imagery compared with thermal imagery for early detection of plant stress. J. Plant Physiol. 148:515-522.
6. Kenna, M P. 1995. Detecting turf stress with remote sensing. Grounds Maintenance. 10:17-20.
7. Knipling,E. B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of Environment. 1:155-159.
8. Horler, D. N. H., M. Dockray, and J. Barber. 1983. The red edge of plant leaf reflectance. Int. J. Remote Sens. 4:273-288.

9. Lee, J. H., L. E. Trenholm, and J. B. Unruh. 2003. Technology for irrigation scheduling for ST. Augustinegrass. Proc. Fla. State Hort. Soc. 116:319-321.

10. Lee, J. H., L. E. Trenholm, and J. B. Unruh. 2005. Evaluating methods of predicting irrigation needs of warm-season turfgrasses. Crop Science. Submitted.

11. Perry, C. A., and L. P. Lautenschlager. 1984. Functional equivalence of spectral vegetation indices. Remote Sensing of Environment. 14:169-182.

12. SAS Institure. 1987. SAS user's guide: Statistics. 6^{th} ed. SAS Inst., Cary, NC.

13. Tucker, C. J., J. H. Elgin, J. E. McMurtrey, and C. J. Fan. 1979. Monitoring corn and soybean crop development with hand-held radiometer spectral data. Remote Sensing of Environment. 13:461-474.

14. Trenholm, L E., R. N. Carrow, and R. R. Duncan. 1999. Relationship of multispectral radiometry data to qualitative data in turfgrass research. Crop Science. 39:763-769.

15. Wiegand, C. L., A. J. Richardson, E. E. Escobar, and A. H. Gerbermann. 1991. Vegetation indices in crop assessments. Remote Sensing of Environment. 35:105-119.