Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 10 (1): 67-73, 2011
ISSN 1682-3974 / DOI: 10.3923/ajps.2011.67.73

Spectral Reflectance Response of Three Turfgrasses to Leaf Dehydration

M.R. Suplick-Ploense, S.F. Alshammary and Y.L. Qian
Department of Horticulture and Landscape Architecture, Colorado State University,
Fort Collins, CO 80523-1173, USA

Abstract: Spectral reflectance assessment of turfgrass canopies is likely to enhance our ability to refine irrigation management technology. Reliable spectral detection of water stress is dependent upon knowledge of wavelengths most sensitive to leaf water content. The purposes of this study were (1) to determine wavelengths at which turfgrass canopy reflectance is most sensitive to progressive dehydration in the visible and near infrared portions of the spectrum and (2) to investigate whether different turfgrasses exhibit spectrally unique canopy reflectance responses to progressive dehydration. Two consecutive studies were conducted using established field plots of hybrid bluegrass (*Poa pratensis* L. x *Poa arachnifera* Torr.) (HBG), Kentucky bluegrass (*Poa pratensis* L.) (KBG) and perennial ryegrass (*Lolium perenne* L.) (PRG). Field plots were brought to field capacity, irrigation was then withheld and spectral reflectance and Leaf Water Content (LWC) measured as dehydration progressed. In study I, turfgrass canopy spectral reflectance within 616-696 nm in HBG, 658-688 nm in KBG and 630-688 in PRG were well correlated to LWC with maximum coefficients of determination (R^2) occurring at 664, 672 and 664 nm for HBG, KBG and PRG, respectively. In study II significant coefficients of determination ranged from 642-694, 594-698 and 638-678 nm with maximum r^2 occurring at 668, 672 and 660 nm for HBG, KBG and PRG, respectively. Within the near infrared range only KBG exhibited correlation between canopy reflectance and decreasing leaf water content. Within 734-878 nm range, three species exhibited different degree of reflectance change between fully turgid and wilted turf; indicating the rank of canopy reflectance sensitivity to dehydration was KBG>PRG>HBG, the reverse order of their drought resistance ranking.

Key words: Hybrid bluegrass, kentucky bluegrass, perennial ryegrass, spectral reflectance, leaf dehydration

INTRODUCTION

Use of multispectral radiometry as a tool in detecting initial onset and progression of biotic and abiotic turfgrass stresses prior to appearance of visible symptoms is receiving increased attention. Early detection of stress could reduce the application of costly or environmentally sensitive corrective inputs and maintain visual turfgrass quality. Strong relationships between many plant health indicators with spectral reflectance have been well proven in several agronomic crops and forest canopies (Bell *et al*., 2002; Carter and Miller, 1994; Cibula and Carter, 1992; Hoque and Hutzler, 1992; Hutto *et al*., 2006; Jiang and Carrow, 2007, 2005; McHugh *et al*., 2008; Penuelas *et al*., 1997; Poss *et al*., 2006; Tarpley *et al*., 2000; White and Raine, 2007). At present, limited information is available on the use of spectral imaging as a tool in the evaluation of turfgrass stand health. Initial research has demonstrated strong correlations between changes in spectral reflectance at specific and narrow wavelengths and visual observations of disease, drought and soil compaction in several turfgrass species (Bell *et al*., 2002; Fenstermaker-Shaulis *et al*., 1997; Green *et al*, 1998; Richardson and Everitt, 1987; Trenholm *et al*., 1999a, b). However, high-resolution continuous multispectral reflectance response curves for turfgrass species in response to directly quantified stress agents are not presently available due to the instrumentation limitations of these previous studies.

Perhaps most promising is the potential use of spectral reflectance data as a turfgrass water conservation management tool, however, reliable detection of impending water stress is dependent upon knowledge of wavelengths most sensitive to leaf water content. A variety of plant stress, including dehydration, are known to increase reflectance of green vegetation in the visible portion of the spectrum (400-700 nm) due to decreased

Corresponding Author: Y.L. Qian, Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, CO 80523-1173, USA

chlorophyll content and in the near infrared region (700-1100 nm) to changes in cell structure (Datt, 1998; Gausman and Allen, 1973; Lichtenthaler, 1987; Schepers *et al*., 1996; Sinclair *et al*., 1973). Carter (1991) reported increased reflectance in the 535-640 nm and 685-700 nm wavelength ranges to be most consistent and particularly sensitive to leaf dehydration in switchcane (*Arundinaria tecta* [Walt.] Muhl). Also, Jiang and Carrow (2005) indicated that correlations of canopy reflectance versus turf quality and leaf firing varied with turfgrass species and cultivars. They also reported that the photosynthetic regions specifically from 664 to 687 nm were relatively important in determining turf quality and leaf firing in selected bermudagrass, tall fescue, zoysiagrass and St. Augustinegrass under drought stress.

Reflectance response to leaf dehydration in the near infrared region was found to be consistent only when water stress had developed sufficiently to cause severe leaf dehydration resulting in alterations in cell structure. The wavelength at which turfgrass canopy reflectance is most sensitive to water stress and whether variability in wavelength sensitivity exists between species, generally remains uninvestigated and undefined.

Therefore, the purpose of this study was to (i) determine the wavelengths at which turfgrass canopy reflectance is most sensitive to progressive dehydration across the visible and near infrared portions of the spectrum and (ii) investigate whether different turfgrass species exhibit spectrally unique canopy reflectance responses to progressive dehydration.

MATERIALS AND METHODS

This investigation consisted of two studies conducted consecutively using fully established field plots of hybrid bluegrass (*Poa pratensis* L. x *Poa arachnifera* Torr.) (HBG), Kentucky bluegrass (*Poa pratensis* L.) (KBG) and perennial ryegrass (*Lolium perenne* L.) (PRG) at the Colorado State University Horticultural Research Center at Fort Collins, CO. Plots measuring 6 by 6 m were arranged in a randomized complete block design with three replications. Plots were mowed 2 to 3 times weekly to maintain a height of 6.4 cm and were fertilized to provide a total of 149 kg N ha^{-1} (as urea, 46-0-0) annually. The experimental area contained semi-circle popup spray heads at the corners providing uniform irrigation. Plots were irrigated to replace 100% Kimberly-Penman-estimated-ET prior to initiation of each study (Allen *et al*., 1989) where after irrigation was withheld to induce dehydration.

During each evaluation, leaf water content was measured by collecting leaf clippings from the experimental areas. After fresh weight determination, clippings were dried in a forced air oven at 70°C to determine clipping dry weight. Leaf water content was then calculated. Concurrent with leaf water content determination, turf canopy spectral reflectance from 400 to 1100 nm at 2 nm resolutions was measured with a LI-COR spectral radiometer model LI1800 (LI-COR, Lincoln, NE) equipped with a LI1800-06 Telescope Receptor. The telescope receptor was mounted on a tripod at a height of approximately 0.9 m from the turfgrass canopy measuring canopy reflectance from an approximately 0.1 m circular area. Reflectance readings were taken during each evaluation between 1100 to 1300 h MST under conditions of no or minimal cloud cover and three scans averaged during each measurement.

At each 2 nm wavelength from 400-700 nm, in both Studies I and II, leaf water content was regressed against canopy reflectance and tested for significant linear relationships. Reflectance differences at each 2 nm wavelength from 400-1100 nm between non-stressed and dehydrated turf were calculated as:

Reflectance difference (%) = [Canopy reflectance of dehydrated turf − Canopy reflectance of non stressed turf/Canopy reflectance of dehydrated turf] ×100

The calculated reflectance differences were then subjected to ANOVA test to determine species effects. Species means were separated by protected LSD.

RESULTS AND DISCUSSION

Changes in turfgrass canopy spectral reflectance within the red region of the visible range (400-700 nm) were well correlated to decreasing leaf water content in a manner typical of reflectance response to plant stress; as canopy dehydration progressed reflectance was increased. In study 1 significant coefficients of determination (R^2) for linear regressions of leaf water content with canopy reflectance ranged from 616-696 nm in HBG, 658-688 nm in KBG and 630-688 in PRG (Fig. 1). Maximum R^2 in Study 1 occurred at 664, 672 and 664 nm for HBG, KBG and PRG, respectively. In Study 2 significant coefficients of determination ranged from 642-694, 594-698 and 638-678 nm, with maximum R^2 occurring at 668, 672 and 660 for HBG, KBG and PRG, respectively (Fig. 1).

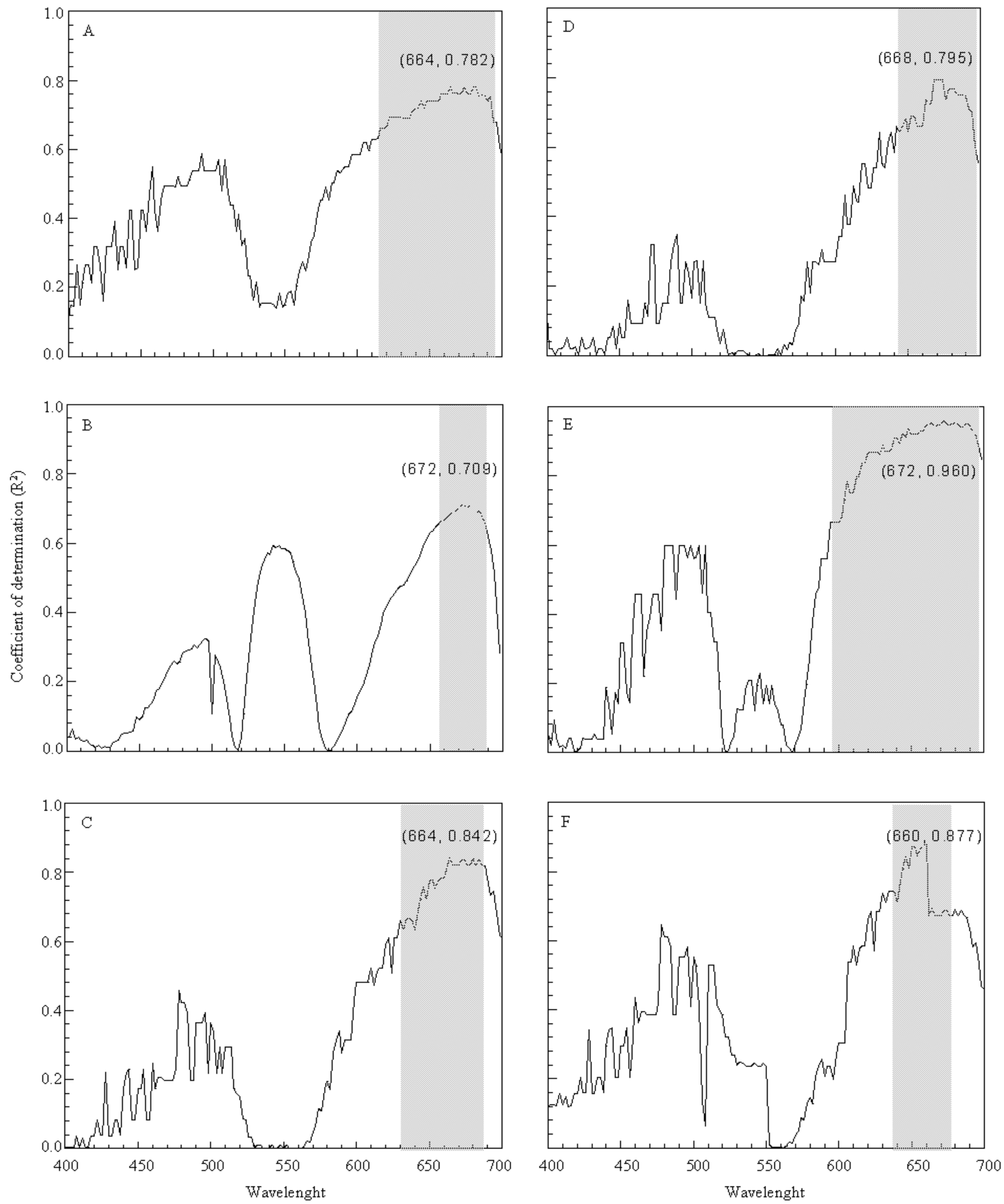

Fig. 1: Coefficient of determination (R^2) vs. wavelength for simple linear relationships of turfgrass canopy reflectance with leaf water content within the visible wavelength range (400-700 nm) in study I (A, B, C) and Study II (D, E, F) for hybrid bluegrass, (A, D), Kentucky bluegrass (B, E) and perennial ryegrass (C, F). Wavelengths at which best-fit relationships were identified and corresponding R^2 are indicated in parentheses. Shaded regions under the curve denote significant correlations at the 0.05 probability level

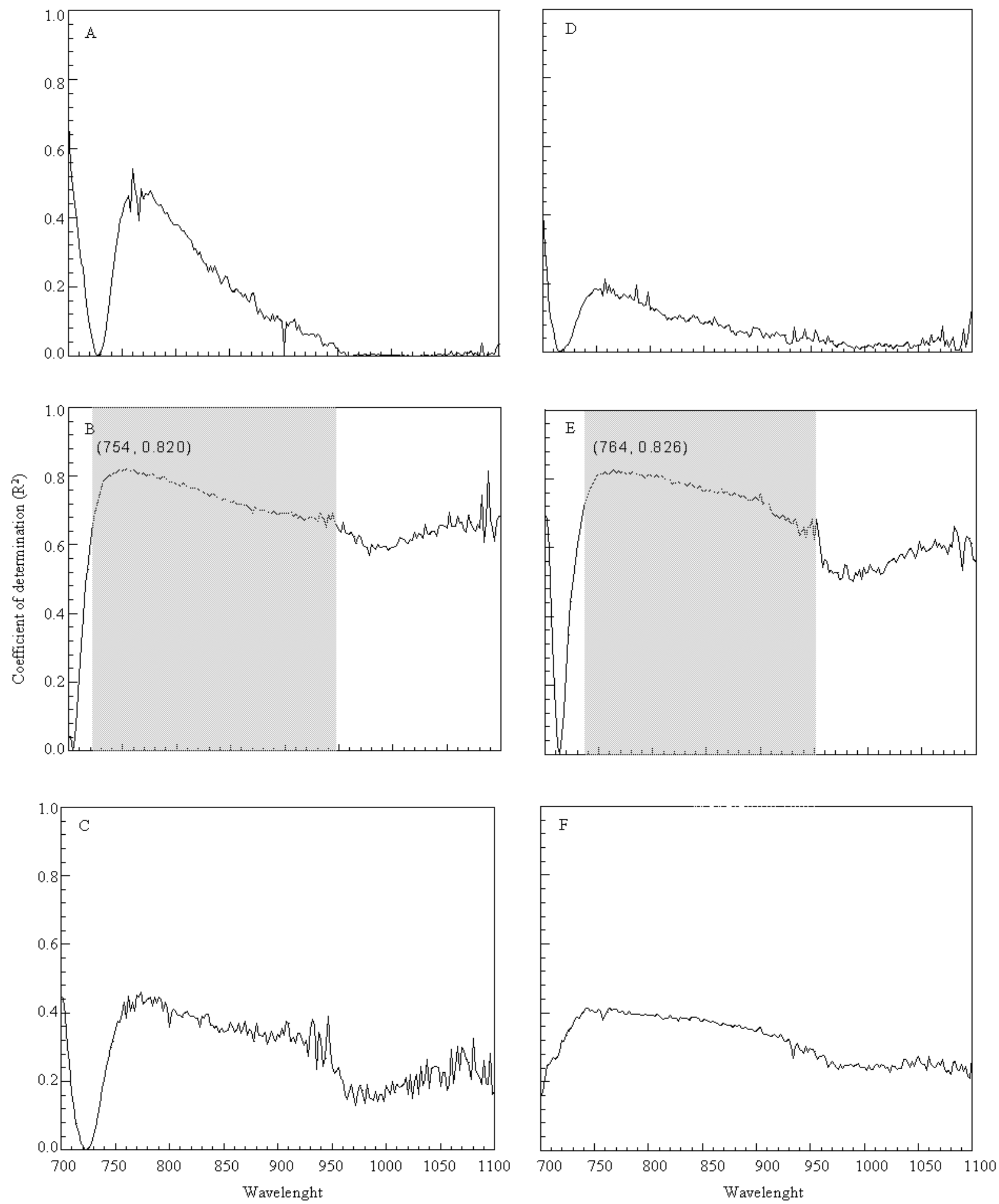

Fig. 2: Coefficient of determination (R^2) vs. wavelength for simple linear relationships of turfgrass canopy reflectance with leaf water content within the near infrared wavelength range (700-1100) in study I (A, B, C) and study II (D, E, F) for hybrid bluegrass (A, D), Kentucky bluegrass (B, E) and perennial ryegrass (C, F). Wavelengths at which best-fit relationships were identified and corresponding R^2 are indicated in parentheses. Shaded regions under the curve denote significant correlations at the 0.05 probability level

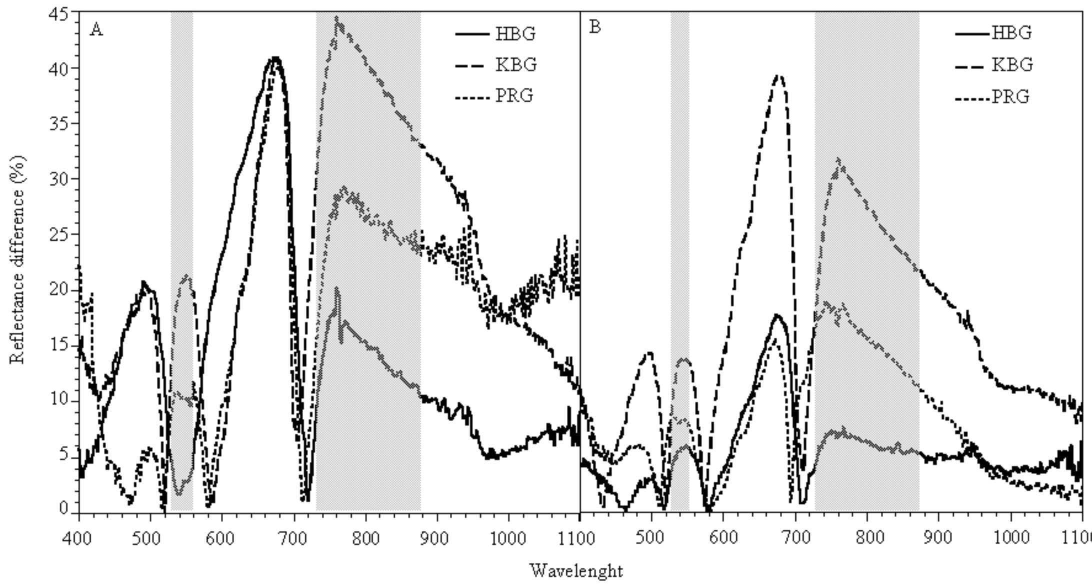

Fig. 3: Reflectance difference between fully turgid and wilted leaves vs. wavelength in Studies I (A) and II (B) for hybrid bluegrass, Kentucky bluegrass and perennial ryegrass. Shaded regions under the curve denote statistical separation of the three grasses from one another. Significant species separation ($p \leq 0.001$-0.0001) occurred between 528-560 and 736-878 nm in Study I and 524-556 and 734-874 nm in Study II

Kentucky bluegrass was the only turfgrass that exhibited the same reflectance maxima from Study I to Study II. Spectral reflectance in the visible portion of the spectrum is generally characterized to be a sole function of chlorophyll a and b, with strict absorption maxima having been identified at 420, 435, 663 and 668 *in vitro* (Hopkins, 1999). However, *in situ*, attachment of chlorophylls to a variety of proteins, as well as the presence of other plant pigments, can alter and expand the peak and range of wavelengths at which green leaves harvest light energy as these results indicate. We observed no statistically significant association between decreasing leaf water content and chlorophyll a and b near their absorption maxima at 420 and 435 nm. These results are consistent with those of Carter (1993) and Carter and Knapp (2001) in that leaf reflectance is altered by stress most reliably and consistently and therefore detected earliest, within the far-red region of the spectrum due to the high sensitivity of chlorophyll concentrations to physiological disturbances at these wavelengths.

Within the near infrared range (700-1100 nm) only KBG exhibited correlation between canopy reflectance and decreasing leaf water content (Fig. 3). Significant coefficients of determination (R^2) for KBG ranged from 722-948 nm and 734-952 nm in Studies I and II, respectively (Fig. 2). Hybrid bluegrass and perennial ryegrass exhibited no such correlation.

The effect of slow and progressive dehydration in the near infrared region of the spectrum can be subtler and therefore more difficult to evaluate, than in the visible region (Carter, 1991). However, broad bands of great differences in species reflectance difference (between fully turgid and wilted leaves) were observed in the near infrared region, at 736-878 nm in Study I and 734-874 nm in Study II (Fig. 3). These results indicated the ranking for canopy reflectance sensitivity to dehydration was Kentucky bluegrass > perennial ryegrass > hybrid bluegrass, the reverse order of their drought resistance ranking (Beard, 2002; Sheffer *et al.*, 1987; Suplick-Ploense and Qian, 2005). Reflectance of leaves within the near infrared region is governed by the multiplicity of reflections inside the leaf, which can be altered by cell size, shape and distribution. Dehydration can alter these characteristics resulting in a change in spectral reflectance (Gausman *et al.*, 1969). These results indicate there exists sufficient difference in the leaf histology of these three grasses to influence their reflectance response to dehydration in the near infrared region and influence their drought resistance.

Small wavebands of species separation were also observed to occur within the green portion of the visible range (528-560 and 524-556 nm in Studies I and II, respectively) a pattern indicative of chlorophyll degradation and thus loss of green reflectance (Fig. 3).

Although the species separation pattern was consistent with that observed in the near infrared range, the trend of the hybrid bluegrass curve was not between Studies 1 and 2.

CONCLUSIONS

In this study we found spectral reflectance within the far-red region of the visible portion of the spectrum to be most sensitive to and highly correlated with, progressive dehydration. These wavelengths might effectively be used as an irrigation management tool in non-destructively monitoring leaf water status. Computation of reflectance difference between non-stressed and dehydrated leaves of hybrid bluegrass, Kentucky bluegrass and perennial ryegrass revealed consistent differences in their reflectance sensitivity to dehydration. This sensitivity ranking was comparable with previous reports of drought resistance among these grasses, suggesting that the magnitude of reflectance change may be used as an indicator of drought resistance. Present results also confirm that leaf histology has a strong influence on drought resistance.

REFERENCES

Allen, R.G., M.E. Jensen, J.L. Wright and R.D. Burman, 1989. Operational estimates of reference evapotranspiration. Agron. J., 81: 650-662.

Beard, J.B., 2002. Turf Management for Golf Courses. 2nd Edn., Ann Arbor Press, Chelsea, MI..

Bell, G.E., D.L. Martin, S.G. Wiese, D.D. Dobson, M.W. Smith, M.L. Stone and J.B. Solie, 2002. Vehicle-mounted optical sensing: An objective means for evaluating turf quality. Crop Sci., 42: 197-201.

Carter, G.A., 1991. Primary and secondary effects of water content on the spectral reflectance of leaves. Am. J. Bot., 78: 916-924.

Carter, G.A., 1993. Responses of leaf spectral reflectance to plant stress. Am. J. Bot., 80: 230-243.

Carter, G.A. and R.L. Miller, 1994. Early detection of plant stress by digital imaging within narrow stress-sensitive wavebands. Remote Sensing Environ., 50: 295-302.

Carter, G.A. and A.K. Knapp, 2001. Leaf optical properties in higher plants: Linking spectral characteristics to stress and chlorophyll concentration. Am. J. Bot., 88: 677-684.

Cibula, W.G. and G.A. Carter, 1992. Identification of a far red reflectance response to ectomycorrhizae in slash pine. Int. J. Remote Sensing, 13: 925-932.

Datt, B., 1998. Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a + b and total carotenoids content in eucalyptus leaves. Remote Sensing Environ., 66: 111-121.

Fenstermaker-Shaulis, L.K., A. Leskys and D.A. Devitt, 1997. Utilization of remotely sensed data to map and evaluate turfgrass stress associated with drought. J. Turfgrass Manage., 2: 65-81.

Gausman, H.W. and W.A. Allen, 1973. Optical parameters of 30 plant species. Plant Physiol., 52: 57-62.

Gausman, H.W., W.A. Allen, V.I. Meyers and R. Cardenas, 1969. Reflectance and internal structure of cotton leave, *Gossypium hirsutum* L. Agron. J., 61: 374-376.

Green, D.E., II, L.L. Burpee and K.L. Stevenson, 1998. Canopy reflectance as a measure of disease in tall fescue. Crop Sci., 38: 1603-1613.

Hopkins, W.G., 1999. Introduction to Plant Physiology. Wiley, NY.

Hoque, E. and P.J.S. Hutzler, 1992. Spectral blue-shift of red edge monitors damage class of beech trees. Remote Sensing Environ., 39: 81-84.

Hutto, K.C., R.L. King, J.D. Byrd and D.R. Shaw, 2006. Implementation of hyperspectral radiometry in irrigation management of creeping bentgrass putting greens. Crop Sci., 46: 1564-1569.

Jiang, Y. and R.N. Carrow, 2005. Assessment of narrow-band canopy spectral reflectance and turfgrass performance under drought stress. Horticult. Sci., 40: 242-245.

Jiang, Y.W. and R.N. Carrow, 2007. Broadband spectral reflectance models of turfgrass species and cultivars to drought stress. Crop Sci., 47: 1611-1618.

Lichtenthaler, H.K., 1987. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. Methods Enzymol., 148: 350-380.

McHugh, A.D., B. Boughton, J. Eberhard, L.M. McKeering, A.R. Robson and S.R. Raine, 2008. Evaluating the relationships between plant based measurements and remotely sensed data for irrigation scheduling of cotton. National Centre for Engineering in Agriculture Publication 1001574/8, USQ, Toowoomba.

Penuelas, J., R. Isla, I. Filella and J.L. Araus, 1997. Visible and near-infrared reflectance assessment of salinity effects on barley. Crop Sci., 37: 198-202.

Poss, J.A., W.B. Russell and C.M. Grieve, 2006. Estimating yields of salt- and water-stressed forages with remote sensing in the visible and near infrared. J. Environ. Quality, 35: 1060-1071.

Richardson, A.J. and J.H. Everitt, 1987. Monitoring water stress in bufflegrass using hand-held radiometers. Int. J. Remote Sensing, 8: 1797-1806.

Schepers, J.S., T.M. Blackmer, W.W. Wilhelm and M. Resende, 1996. Transmittance and reflectance measurements of corn leaves from plants with different nitrogen and water supply. J. Plant Physiol., 148: 523-539.

Sheffer, K.M., J.H. Dunn and D.D. Minner, 1987. Summer drought response and rooting depth of three cool-season turfgrasses. HortScience, 22: 296-297.

Sinclair, T.R., M.M. Schreiber and R.M. Hoffer, 1973. Diffuse reflectance hypothesis for pathway of solar radiation through leaves. Agrono. J., 65: 276-283.

Suplick-Ploense M. and Y.L. Qian, 2005. Evapotranspiration, rooting characteristics and dehydration avoidance: Comparisons between hybrid bluegrass and kentucky bluegrass. Int. Turfgrass Res. J., 10: 891-898.

Tarpley, L. K.R. Reddy and G.F. Sassenrath-Cole, 2000. Reflectance indices with precision and accuracy in predicting cotton leaf nitrogen concentration. Crop Sci., 40: 1814-1819.

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

Trenholm, L.E., R.R. Duncan and R.N. Carrow, 1999b. Wear tolerance, shoot performance and spectral reflectance of seashore paspalum and bermudagrass. Crop Sci., 39: 1147-1152.

White, S.C. and S.R. Raine, 2007. Field trial report (2006/07). Optimising irrigation scheduling with the use of continuous real time plant monitoring sensors. National Centre for Engineering in Agriculture Publication 1001574/7/1, USQ, Toowoomba.