REMOTE SENSING OF DROUGHT AND SALINITY STRESSED TURFGRASS

BY

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A dissertation submitted to the Graduate School in partial fulfillment of the requirements for the degree Doctor of Philosophy

Major Subject: Agronomy

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"Remote Sensing of Drought and Salinity Stressed Turfgrass" a dissertation prepared by Yoshiaki Ikemura in partial fulfillment of the requirements for the degree, Doctor of Philosophy, has been approved and accepted by the following:

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DEDICATION

This dissertation is dedicated to all the graduate students who take a look on this book for writing their dissertation or thesis.
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The ability to detect early signs of stress in turfgrass stands using a rapid, inexpensive, and nondestructive method would be a valuable management tool. Studies were conducted to determine if digital image analysis and spectroradiometric readings obtained from drought- and salinity-stressed turfgrasses accurately reflected the varying degrees of stress and correlated strongly with visual ratings, relative water content (RWC) and leaf osmolality, standard methods for measuring stress in plants.

Greenhouse drought and salinity experiments were conducted on hybrid bluegrass \([\textit{Poa arachnifera} \textit{(Torr.) x pratensis} \textit{(L.)}] \text{ cv. Reveille}\) and bermudagrass \([\textit{Cynodon dactylon} \textit{(L.)}] \text{ cv. Princess 77}\). Increasing drought and salinity stress led to decreased RWC, increased leaf osmolality, and decreased visual ratings for both species. Percent green cover and hue values obtained from digital image analysis, and
Normalized Difference Vegetation Index (NDVI), calculated from spectroradiometric readings, were moderately to highly correlated with visual ratings, RWC, and leaf osmolality.

Similarly, in a field validation study conducted on hybrid bluegrass, spectral reflectance ratios were moderately to highly correlated with visual ratings. In addition, percent green cover obtained from digital image analysis was strongly correlated with most of the spectral ratios, particularly the ratio of fluorescence peaks ($r = -0.88$ to $-0.99$), modified triangular vegetation index (MTVI) ($r = 0.82$ to $0.98$), and NDVI ($r = 0.84$ to $0.99$), suggesting that spectral reflectance and digital image analysis are equally effective at detecting changes in color brought on by stress.

The two methods differed in their ability to distinguish between drought and salinity stress. Hue values obtained from digital image analysis responded differently to increasing drought stress than to increasing salinity stress. Whereas the onset of drought stress was reflected by increased hue values followed by a decrease in values as drought stress increased, there was no increase in hue values at the onset of salinity stress. Thus, changes in hue could be a key to distinguish drought and salinity stress.

Both digital image analysis and spectroradiometry effectively detected drought and salinity stress and may have applications in turfgrass management as rapid and quantitative methods to determine drought and salinity stress in turf.
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<th>Description</th>
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<tbody>
<tr>
<td>D1</td>
<td>First drought experiment</td>
</tr>
<tr>
<td>D2</td>
<td>Second drought experiment</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity</td>
</tr>
<tr>
<td>ETo</td>
<td>Reference Evapotranspiration</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
</tr>
<tr>
<td>GIS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GPS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>IR</td>
<td>Irrigation amounts</td>
</tr>
<tr>
<td>Kc</td>
<td>Crop factor</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf area index</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>NIR</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>rpm</td>
<td>Revolutions per minute</td>
</tr>
<tr>
<td>RWC</td>
<td>Relative water content</td>
</tr>
<tr>
<td>S1</td>
<td>First salinity experiment</td>
</tr>
<tr>
<td>S2</td>
<td>Second salinity experiment</td>
</tr>
<tr>
<td>SAR</td>
<td>Sodium Adsorption Ratio</td>
</tr>
</tbody>
</table>
TDS ................................................................. Total dissolved solids
\( \theta \) ............................................................... Soil moisture content
\( \psi_w \) ........................................................... Leaf water potential
Due to limited annual rainfall and high temperatures in the arid southwestern United States, frequent and abundant irrigation is necessary to sustain agricultural production and urban landscapes, including turfgrass areas. In addition, human population growth and urban development are sources of increasing stress on water supplies which range, depending on precipitation, from almost adequate to scarce. Consequently, irrigation water conservation strategies have been implemented by many municipalities to minimize water used for urban landscapes. These strategies include selecting plants that are suited to arid climatic conditions, restricting or eliminating the use of potable water for irrigation purposes, and installing and using irrigation scheduling technologies (Albuquerque Bernalillo County Water Utility Authority [ABCWUA], 2007). These scheduling technologies are aimed at determining the minimum irrigation requirements of turfgrasses in order to avoid over-irrigation (Carrow et al., 2002).

Restricting potable water can have negative consequences on the plant, unless properly monitored. Plants can become drought stressed, particularly if the turf plant is not suited to arid conditions, or if irrigation is applied improperly and much of the water does not reach the rootzone (Carrow, 2004). Furthermore, by limiting water, salts that build up in the soil over time are not leached out by additional irrigation water, which can lead to salt stress in the turf plant.
Another solution to the restricting or banning of potable water for landscape irrigation purposes has been to use reclaimed or reused water as an alternate source of irrigation water. Reclaimed water, defined as water which has been treated at a sewage plant after having undergone at least one cycle of (human) use (Harivandi, 2004), is frequently high in salts, and is often the cause of salt build-up and subsequent salinity stress in turfgrass.

For these reasons, drought and salinity are typical problems faced by turfgrass managers in semi-arid and arid climates. In order to mitigate the effects of drought and salt stress on turf, plants need to be monitored frequently for early signs of stress, at which point steps can be taken to correct the problem. Current methods used to monitor turf for signs of stress are visual examination and rating of turf stands, or analyzing soil samples.

Remote sensing technologies

The use of remote sensing technology has been suggested by researchers as a potential tool to quantitatively and objectively monitor turf areas and to detect stress. Early work in the 1980s and 1990s measured leaf surface temperature of plants in the 10.5 to 12.5 μm waveband by means of an infrared thermometer to quantify drought stress level (Idso et al., 1981; Everest, 1984). Throssell et al. (1987) and Jalali-Farahani et al. (1993) suggested the use of a Crop Water Stress Index calculated from remotely measured leaf surface temperatures for irrigation scheduling of cool
and warm season turfgrasses.

Spectroradiometry

More recently, multi-spectrum radiometry and calculated reflectance ratios from visible wavelengths (400-700 nm) and from the near-infrared region (700-2500 nm) have been used to determine plant stress responses (Carter, 1993). The plant leaf has a low reflectance of incident energy in the visible range due to chlorophyll absorption, a relatively high reflectance in the near-infrared (NIR) range (700-1300 nm) due to internal leaf scattering and no absorption, and a relatively low reflectance in the infrared range beyond 1300 nm due to strong absorption by water (Knipling, 1970). Most studies have used a Normalized Difference Vegetation Index (NDVI), which is calculated from the reflectance at two wavelengths in the red (R) range (600-700 nm) and in the NIR range, to determine plant coverage and/or measure stresses using the following formula:

\[ \text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})} \]  

(1)

Knipling (1970) showed that in healthy plants reflectance in the R range is low due to chlorophyll absorption, and reflectance in the NIR range is high due to internal leaf scattering. However, stressed plants exhibit reduced chlorophyll content as well as a breakdown of cell walls (Knipling, 1970). These internal changes in cell structures result in a lower NDVI for stressed plants compared to healthy plants.

Spectral reflectance has been measured extensively on several turfgrasses to
evaluate stand quality (Bell et al., 2002; Trenholm et al., 1999a), tissue nitrogen content (Bell et al., 2004), moisture stress (Fenstermaker-Shaulis et al., 1997; Fitz-Rodriguez and Choi, 2002; Hutto et al., 2006. Jiang and Carrow, 2005; Lee and Bermer, 2006; Park et al., 2005; Ploense, M.R., 2002), salinity stress (Ikemura, 2004), disease stress (Rinehart et al., 2001; Green et al., 1998; Raikes and Burpee, 1998), phosphorus deficiency (Kruse et al., 2005), wear stress (Trenholm et al., 1999b), and stress from soil compaction (Guertal and Shaw, 2004). In all of these studies, except when disease stress or soil compaction was evaluated, NDVI correlated well with various plant parameters. In addition to NDVI, the leaf area index (LAI) is also commonly used in spectroradiometry research (Huang et al., 1998; Jiang et al., 2004; Trenholm et al., 1999a; 1999b). LAI is defined as the amount of leaf area in a canopy per unit ground area (Asner et al., 2003). LAI is calculated using the following formula:

$$\text{LAI} = \frac{\text{NIR}}{\text{R}}$$

(2)

NDVI and LAI are calculated using the same NIR and R wavelengths and therefore LAI correlates as well with plant parameters as does NDVI. Hatfield et al. (1983) stated that NDVI is often correlated with canopy green leaf biomass, and LAI correlated with the actual leaf area that plants exhibit. Daughtry et al. (1992) observed that NDVI was highly correlated with leaf area index in corn and soybean, and LAI was associated with shoot biomass.
Digital Image Analysis

In addition to spectroradiometry, digital image analysis has been used to objectively assess turf stand parameters. Richardson et al. (2001) accurately estimated percent ground cover from digital photographs, and Karcher and Richardson (2003) documented the use of digital image analysis to quantify turfgrass color. Ikemura et al. (2002) used image analysis to predict tissue nitrogen content in cool and warm season grasses. However, limited information is available on the use of digital image analysis as a standardized measurement of turf stress. Everitt et al. (1987a, 1987b) used the near-infrared region in digital images to detect drought stress in plants. Carter and Miller (1994) investigated digital photography in conjunction with optical interference filters to detect herbicide chlorosis in soybean. However, no published information is currently available on the use of standard digital imagery and subsequent image analysis to detect and quantify drought and salinity stress in turfgrass.

Turfgrasses

Two unique turfgrass varieties, bermudagrass \( [Cynodon dactylon (L.)] \) cv. Princess 77 and hybrid bluegrass \( [Poa arachnifera (Torr.) \times pratensis (L.)] \) cv. Reveille, were used in our studies. Both varieties were only recently introduced to the turf market.

Bermudagrass is the most commonly grown turfgrass in the southern U.S. and
in tropical and subtropical regions of the world (Taliaferro, 2004). Turf type
bermudagrass cultivars that have been historically used for highly maintained and
trafficked turf stands were sterile hybrids and had to be propagated from sprigs or sod
(Beard, 1973). New seeded bermudagrass varieties, such as Princess 77 and Riviera,
have been introduced to the turf market and offer turf quality equal to top performing
vegetative varieties such as Tifway and Tifgreen (Rodgers, 2003). However, very
little information is known about the performance of these new seeded bermudagrass
varieties under drought and salinity stresses. Princess 77 bermudagrass was selected
because it was the first seeded hybrid bermudagrass that combines the high density
and quality of vegetative turf type bermudagrasses with the ease of establishment
from seed (Rodgers, 2003). It is also known as the super bowl grass because it has
been used in the stadiums that hosted the four most recent Super Bowls. Princess 77
was developed by Arden Baltensperger, Professor Emeritus at New Mexico State
University, and was released in 1995 by Seeds West, Inc. Yuma, AZ. Princess 77 has
ranked high in the National Turfgrass Evaluation Trial for turf quality, turf density,
color, and leaf texture (Morris, 2002), and rivaled some of the elite vegetative cultivars
has the potential for use in home lawns, parks, athletic fields, and golf courses in areas
where bermudagrass is adapted (Rodgers and Baltensperger, 2005).
Reveille hybrid bluegrass was released by the Texas A&M University Agricultural Experimental Station in 1998 (Read et al., 1999) as a genetic cross between Texas bluegrass (*Poa arachnifera* Torr.) and Kentucky bluegrass (*Poa pratensis* L.). Reveille has been noted to withstand high temperatures and extended periods of drought due to greater drought resistance mechanisms compared to perennial ryegrass or Kentucky bluegrass (Read et al., 1999; Abraham et al., 2004; Ploense, 2002). Consequently, hybrid bluegrass could become a high quality, dark green alternative to bermudagrass in the high altitude desert Southwest that would offer color year round and provide heat tolerance and drought resistance during the summer. To date, no published studies have compared heat tolerant hybrid bluegrasses to traditional warm season grasses, such as bermudagrass.

**Research Objectives**

A series of greenhouse and field studies at New Mexico State University were conducted to determine if digital image analysis and spectroradiometry could be effectively used to detect and quantify drought and salinity stress and to compare stress responses in hybrid bluegrass and bermudagrass. To do so, we assessed whether stress response data obtained from digital image analysis and spectroradiometry could be adequately correlated with visual ratings, relative water content (RWC) and leaf osmolality measurements, three standard methods used to evaluate stress in turfgrass plants.
The objectives of the studies were:

- to assess the efficacy of digital image analysis and spectroradiometry in detecting and quantifying drought stress in hybrid bluegrass and bermudagrass grown in the greenhouse when subjected to five drought levels,
- to assess the efficacy of digital image analysis and spectroradiometry in detecting and quantifying salinity stress in hybrid bluegrass and bermudagrass grown hydroponically in five salinity solutions,
- to determine if digital image analysis and spectroradiometry could be effectively used to detect and quantify drought and salinity stress in turfgrasses under field conditions, and,
- to determine if remote sensing technology could be used to distinguish between drought and salinity stress in plants grown in field plots.
REFERENCES


