Nitrogen Deficiencies in Creeping Bentgrass can be Identified Through Remote Sensing

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Turfgrass managers continually monitor their fertilization and irrigation programs to ensure optimal appearance while minimizing losses to the environment and maximizing profit. Characterizing the spatial variability of nutrient and moisture status across a golf course or large sports facility requires careful observation and collection of many soil and tissue samples. Optical remote sensing techniques have been shown to be valuable tools in identifying stressed plants quickly and reliably through the use of various vegetative indices derived from reflectance data collected from the crop canopy. Extensive research has been conducted investigating vegetative indices as they relate to the nutritional and moisture status of various agricultural crops with intriguing results. Currently, most of the research has investigated the ability of vegetative indices to identify plants responding to a variety of biotic and abiotic stresses. The use of remotely sensed data may prove to be a valuable tool in the modification of traditional irrigation and fertility programs to reduce inputs and improve environmental quality.

The objectives of this research were to: 1) Evaluate various indices reported in the literature as tools for identifying moisture and nutrient stressed turf, 2) Develop new indices to be used in detection of moisture and nutrient deficiencies, and 3) Determine differences in spectral response of Creeping Bentgrass, Kentucky Bluegrass, and Perennial Ryegrass.

This work was conducted at the Iowa State University Horticulture Research Station, Gilbert, Iowa, on a ‘Penncross’ creeping bentgrass putting green (USGA, 1993). Plots were 1.52 m × 1.52 m and arranged in a randomized complete block design with four replications per treatment. Nitrogen fertilizer treatments were applied with a backpack sprayer at 0, 12.2, and 24.4 kg·ha-1 every 15 d (14 total) as urea in solution. Spray volume was 122.5 mL·m-2 and pressure was 207 kPa. In addition to N, all plots received uniform phosphorous (P) at 2.44 kg·ha-1 as phosphoric acid and potassium (K) at 5.0 kg·ha-1 as potassium chloride. Treatments were applied from March 25, 2002 to October 8, 2002. Plots were mowed four times each week at a height of 3.8 mm and clippings were removed. Irrigation was applied when the soil surface was dry to the touch to prevent drought stress.

Turf evaluation of quality was made on a twice monthly basis, coinciding with collection of remotely sensed data. Quality was ranked on a scale of 1 to 9; with 9 = best, 6 = lowest acceptable and 1 = worst. Optical remote sensing data was collected twice monthly using an OceanOptics SD1000 spectrometer mounted on a self contained cart equipped with a hood to block out ambient sunlight and halogen bulbs to provide a consistent source of illumination on the turf. This system was designed to eliminate the problems typically associated with differences due to shade, which is a common occurrence on many turfgrass areas. The spectrometer was calibrated to measure reflectance from 450-1050 nm with a resolution 1.0 nm.

The following growth and stress indices were evaluated for their relationship to plant chlorophyll content, turfgrass quality, and nutrient concentration:

1. Normalized Difference Vegetation Index (NDVI) computed as $R_{800} - R_{600}/R_{800} + R_{600}$
2. Infrared/Red (IR/R) computed as R_{780}/R_{600}
3. Far Red/Infrared (FR/IR) computed as R_{695}/R_{760}
4. AREA computed as total area under each reflectance curve from 450 to 1050 nm
5. Nitrogen Stress Index (NSI) computed as the total area under the reflectance curve from 450 to 1050 nm divided by (R_{695}/R_{760}) or [(AREA) / (FR/IR)]

Tissue was harvested once a month following collection of remotely sensed optical data and analyzed for plant nutrient content using standard Total Kejhdahl Nitrogen and Inductively Coupled Argon Plasma Spectroscopy plant analysis procedures.

Regression analysis was used to test linear relationships between vegetative indices and tissue nutrient concentrations. The general linear models (GLM) procedure and the Fisher’s least significant difference (LSD) option of Statistical Analysis Software (SAS) were used to determine differences in tissue nutrient concentration. A correlation procedure was used to investigate relationships between the vegetative indices and tissue chlorophyll content, turfgrass quality, and biomass production.

Results

In general, plots that receive low rates of N are characterized by increased reflectance in the visible region of the spectrum (450 to 700 nm) and decreased reflectance in the far red and near-IR regions of the spectrum (700 to 1050 nm) when compared to plots receiving adequate N fertilization. Treatment effects on tissue N concentration as a result of N treatments were observed at all sampling dates (data not shown). The tissue N concentration ranged from 22.3 g/kg in plots receiving no N to 45 g/kg in plots receiving N at a rate of 24.4 kg·ha-1. Regression analysis of the NSI, NDVI, IR/R, and FR/IR against N concentration resulted in significant linear regressions (r2 = 0.34 to 0.86) for all sampling dates in 2002 (Table 2). The AREA index produced significant regression coefficients at four of the five sampling dates (r2 = 0.44 to 0.61) (Table 1). We found correlations between turfgrass quality and biomass production for all indices throughout the study (Table 2). Chlorophyll content was correlated with all vegetative indices with the exception of AREA (June 25) and NDVI (September 2) (Table 2). Correlation coefficients were stronger between NSI and quality, chlorophyll content, and biomass than for any other vegetative index on both dates with the exception of chlorophyll content on June 25 (Table 2). Treatments did not have an effect on P, K, or micronutrient concentrations in the turfgrass tissue (data not shown).

Discussion

The successful implementation of a remote sensing model for analyzing the N status of turfgrass plants requires that the model be accurate throughout the duration of the season. One measure of this is the indexes ability to explain a majority of the variation in the model, as indicated by the regression coefficients. Our results demonstrate that NSI values generated from remotely sensed, spectral data can be used to assess turfgrass N stress in creeping bentgrass. We contend that dividing the area under the curve by FR/IR magnified the response to N concentration due to the sensitivity of FR/IR to the N in the plant tissue and produced regression coefficients that consistently explained a majority of the variability in the model throughout the season (r2 = 0.62 to 0.86).

The NDVI is sensitive to changes in turfgrass biomass and turfgrass quality, which is consistent with our findings. Previous research has established that the relationship between NDVI and various biological parameters such as biomass can be adversely affected during mid-season. This is supported by our results in which the NDVI failed to account for a majority of the variability on two of the five sampling dates (July 22 and September 22) (Table 2). By comparing NDVI to the other vegetative indices, we found that in all cases the IR/R, FR/IR, and NSI indices resulted in stronger correlations than NDVI (Table 2).

The AREA index failed to explain the variability due to N-treatments in the model as well as the other indices in this study. This was surprising to us as changes in the N rate seem to have a significant impact on the height of the reflectance curve, which in turn would affect the total area under the curve. It appears that combining the AREA with the FR/IR index that monitors changes in the “blue shift” as we have done with the NSI has succeeded in improving the reliability of the index during the mid- to late-season when proper fertilization is critical. We feel that the success of the NSI is due in part to the use of an auxiliary source of irradiance instead of ambient sunlight, which allowed us to eliminate the variability caused by constant changes in the atmosphere and the angle of incidence.

The goal of remote sensing research has been to identify characteristics of the reflectance spectrum that are sensitive to specific changes in plant stress. While it is clear that we have been able to identify the point at which plants become stressed, it has not been as easy to identify the causal agent. Development of a remote sensing tool that can accurately identify N-stressed turfgrass areas will assist turfgrass managers in reducing fertilizer inputs and improving the overall quality of their facilities. We feel that the NSI proposed here has succeeded in improving sensitivity to changes in N stress throughout the season. The NSI may prove as a valuable tool for quickly assessing the N status of creeping bentgrass greens and allowing for site-specific applications of fertilizer. Utilization of site-specific technology for fertilizer applications would help improve fertilizer-use efficiency thereby, reducing the risks of nutrient runoff and groundwater contamination. With future work, the NSI has the potential to change the way we currently approach remote sensing problems and improve the overall success.

In addition to the results discussed here, several moisture studies have been conducted investigating the use of the remote sensing equipment to evaluate the moisture status of turfgrass plants growing under fairway conditions on a golf course. Work is also being done to evaluate the influence of soil amendments on spring green-up and heat stress on the reflectance qualities of a turfgrass stand.

Table 1. The r^2 values for vegetative indices regressed against nitrogen status of ‘Penncross’ creeping bentgrass on a USGA sand based green for five sampling dates during 2002 at the Iowa State Horticulture Research Station, Gilbert, IA. (n = 12).

Vegetative Index	Sampling Date				
	28-May	25-June	22-July	21-Aug.	22-Sept.
NSI	0.76***	0.86***	0.76***	0.62**	0.80***
NDVI[z]	0.65**	0.81***	0.46*	0.66**	0.48*
IR/R[y]	0.82***	0.79***	0.34*	0.78***	0.53**
FR/IR[x]	0.77***	0.81***	0.56**	0.58**	0.78***
Area[w]	ns	0.44*	0.45*	0.61**	0.48*

ns,*,**,*** Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

[z] Normalized Difference Vegetation Index = $(R_{800} - R_{600})/(R_{800} + R_{600})$.

[y] Infrared/Red = R_{780}/R_{600}.

[x] Far Red/Infrared = R_{695}/R_{760}.

[w] Area = Area under reflectance curve calculated from 450 to 1050 nm.

[v] Nitrogen Stress Index = (AREA)/(R_{695}/R_{760}).

Table 2. Correlation coefficients for reflectance vs. visual quality, chlorophyll content and biomass of creeping bentgrass growing on a USGA sand based green at the Iowa State Horticulture Research Station, Gilbert, IA in 2002 (n = 12).

	NDVI[z]	IR/R[y]	FR/IR[x]	AREA[w]	NSI[v]
			25-June		
Quality	0.92***	0.87***	-0.95***	0.62*	0.96***
Chlorophyll content	0.63*	0.67*	-0.60*	ns	0.58*
Biomass	0.85***	0.83***	-0.89***	0.60*	0.91***
			2-September		
Quality	0.65*	0.76**	-0.75**	0.67*	0.77**
Chlorophyll content	ns	0.58*	-0.70*	0.63*	0.73**
Biomass	0.74**	0.79**	-0.81**	0.70*	0.82**

ns,*,**,*** Not significant or significant at $P<0.05$, 0.01, or 0.001, respectively.

[z] Normalized Difference Vegetation Index (NDVI) = $(R_{800} - R_{600})/(R_{800} + R_{600})$.

[y] Infrared/Red (IR/R) = R_{780}/R_{600}.

[x] Far Red/Infrared (FR/IR) = R_{695}/R_{760}.

[w] AREA = Area under reflectance curve calculated from 450 to 1050 nm.

[v] Nitrogen Stress Index (NSI) = (AREA)/(R_{695}/R_{760})