Golfdom's PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

TURFGRASS TRENDS

REMOTE SENSING

System Pinpoints Stressed Turfgrass

By Jason Kruse

Turfgrass managers spend a significant amount of time monitoring their turfgrass fertility and irrigation programs to ensure the most efficient use of their resources while minimizing potential environmental impacts.

Characterizing the spatial variability of nutrients across a golf course or large sports facility requires careful observation and periodic collection of soil and tissue samples. Remote sensing techniques have been shown to be valuable tools in quickly and reliably identifying stressed plants through the use of various vegetative indices. Research has shown that remote sensing data can be related to turf chlorophyll content, turf injury and quality (Trenholm et al., 1999). As a result, there has been an increased interest in using remote-sensing tools as a non-destructive tool for determining the nutrient status of plants due to the potential time savings that could result when compared to traditional sampling methods.

Handheld chlorophyll meters have been used to rapidly assess plant nitrogen status in agronomic crops (Piekielek and Fox, 1992; Schepers et al., 1996; Wood et al., 1992) by measuring optical density at two wavelengths and converting to a value that has been positively correlated with chlorophyll and nitrogen. While handheld chlorophyll meters are an attractive option for monitoring turfgrass health, they are limited in the amount of spectral information collected from the turfgrass canopy.

An alternative to chlorophyll meters is to measure light reflected from the turfgrass canopy with a multispectral radiometer that is capable of measurements at numerous wavelengths along the electromagnetic spectrum, thus increasing the amount of information that might be gathered and interpreted from the canopy.

Research in turfgrass science often involves using controllable variable (factors) to explain or predict other variable (responses). For instance, we may be interested in the influence of nitrogen (N) concentration on the biomass production of a particular turfgrass. When these factors are few in number, not highly collinear and have a well-understood relationship to the responses, then multiple linear regression (MLR) can be a good way to turn data into information (Tobias, 1997). Partial least-squares (PLS) is a method developed for constructing predictive models when there are a large number of highly collinear factors (Tobias, 1997).

The research was conducted during a two-year field experiment at the Iowa State University Horticulture research station in Gilbert, Iowa, on a creeping bentgrass (*Agrostis stolonifera L.*, Penncross) putting green constructed according to United States Golf Association specifications to determine the correlation between nitrogen concentration of plant tissue and remotely sensed multispectral scanner data. Plots were 5 feet by 5 feet in size and arranged in a randomized, complete-block design with four replications per treatment.

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TABLE 1

Effect of fertilizer nitrogen (N) on canopy N concentration, biomass production, chlorophyll concentration and visual quality ratings for creeping bentgrass in Gilbert, Iowa, in 2002-03.

N Rate	Nitrogen Concentration (g kg-1)	Biomass (g m2 d-1)	Chlorophyll Concentration (_g g-1)	Quality
lb 1000 ft-2 15 d-1	2002			
0.0	30.30	1.82	991.6	4.55
0.25	33.96	2.82	112.93	6.25
0.50	38.57	4.26	1211.5	7.2
LSD0.05	3.96	0.81	96.45	0.81
	2003			
0.0	35.05	1.40	1096.90	4.69
0.25	39.41	2.15	1124.14	6.59
0.50	43.32	3.04	1205.23	8.47
LSD0.05	3.49	0.85	54.14	0.54

QUICK TIP

On a dry weight basis, leaf clippings may contain 2 to 6 percent nitrogen, 0.1 to 1 percent phosphorus and 1 to 3 percent potassium. If the clippings are recycled to the soil, they act as a slow-release fertilizer. Turfgrasses grown on fine-textured soils, where leaching of nutrients from the soil is limited, can benefit from recycling of clippings. Annual nitrogen needs can often be reduced by 10 to 35 percent after two years of recycling. Turfgrasses grown on coarse-textured soils can also benefit from recycling clippings, but leaching losses of the mobile nutrients (N and K) from the soil can occur. If clippings are removed, additional fertilizer will be needed to compensate for the loss of these nutrients.

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Three N fertilizer treatments were applied at 0, 0.25 and 0.5 pounds per 1,000 square feet on a 15-day interval as urea in solution with a carbon dioxide (CO_2) sprayer. In addition to the N treatments, all plots received uniform phosphorus applied as phosphoric acid and potassium applied as potassium chloride.

Plots were mowed four times a week at a height of 0.15 inches, removing clippings after each mowing. Irrigation was applied as needed to maintain optimum turfgrass quality and prevent drought stress.

Remotely-sensed data was collected with a field-portable fiber-optic spectrometer (Model S2000, Ocean Optics Inc., Winter Park, Fla.) on a 30-day interval, corresponding with the collection of clippings.

To reduce variability because of cloud cover and solar zenith angle, the tip of the fiber was mounted inside a rectangular plastic and rubber hood that extended down to the turf canopy. Auxiliary lighting was provided by two 12-volt halogen lights to provide a uniform and consistent light source, thus minimizing the introduction of variability in the data. Radiance values were expressed as percent spectral reflectance after standardization with a white standard.

Canopy reflectance was measured on days with minimal cloud cover between 11 a.m. and 2 p.m. central standard time (CST).

Reflectance at individual wavelengths and several spectral indices was examined for comparison to PLS regression results. They included: normalized difference vegetation index (NDVI) = (R800 - R600)/(R800 + R600); IR/R = (R780/R600); Stress1 = (R706/R760); Stress2 = (R706/R813); and WL550 = R550; WL710 = R710, where Rx is the reflectance value at the x wavelength.

Nitrogen treatments resulted in a wide range of responses for N concentration, biomass production, chlorophyll concentration and turfgrass quality in creeping bentgrass plots during 2002 and 2003.

The N treatments resulted in different N concentrations that increased from 30.30 grams (g) per kilogram (kg) in the 0 pounds per 1,000 square feet every 15 days treatment to 38.57 g per kg in the 0.5 pounds per 1,000 square feet treatment during 2002 (Table 1).

Nitrogen treatments succeeded in establishing tissue concentrations that ranged from low to sufficient according to the sufficiency values reported by Jones et al. (1991). Similar results were observed during 2003. Biomass production, chlorophyll concentration and visual quality ratings also increased with increasing N rate during 2002 and 2003 (Table 1).

The 0 pounds per 1,000 square feet every 15 days N treatment resulted in visual quality that was below the minimally acceptable level of 6.0 along with the lowest chlorophyll concentration

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TABLE 2

Coefficient of determination for regressions of nitrogen concentration, biomass production, chlorophyll concentration and visual quality of creeping bentgrass regressed on normalized difference vegetation index (NDVI), infrared/red (IR/R), Stress1, Stress2, spectral reflectance at 550 nm (WL550) and spectral reflectance at 710 nm (WL710) in Gilbert, Iowa, in 2002-2003.

Calibration	NDVI†	IR/R‡	Stress1§	Stress2	WL550#	WL710††
2002						
Nitrogen concentration	0.23	0.32	0.58	0.51	NS‡‡	0.16
Biomass production	0.35	0.24	0.25	0.17	0.28	0.30
Chlorophyll content	0.32	0.26	0.29	0.29	0.20	0.19
Visual quality	0.54	0.71	0.71	0.67	0.25	0.32
2003						
Nitrogen concentration	0.63	0.48	0.63	0.68	0.16	0.39
Biomass production	0.34	0.23	0.27	0.35	NS	0.16
Chlorophyll content	0.15	0.22	0.24	0.16	0.34	0.30
Visual quality	0.40	0.45	0.54	0.44	0.43	0.38

† Normalized difference vegetation index (NDVI) = (R800 - R600)/(R800 + R600)

‡ Infrared/red (IR/R) = (R780/R600).

§ Stress1 = (R706/R760).

¶ Stress2 = (R706/R813).

WL550 = R550.

†† WL710 = R710.

‡‡ Not significant (NS)

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during both 2002 and 2003 due to increased chlorosis and low plant density (Table 1).

While the 0.25 pounds per 1,000 square feet every 15 days N treatment resulted in acceptable quality during 2002 and 2003, the 0.5 pounds per 1,000 square feet every 15 days N treatment yielded the highest quality and chlorophyll concentration characterized by a dense, dark green turf canopy (Table 1).

No relationships were observed between WL550 or WL710 and the nitrogen concentration, biomass production, chlorophyll concentration or visual quality. This contradicts the results of Shepers et al. (1996) who reported that reflectance centered on 550 nanometers (nm) and 710 nm yielded some of the best relationships with N deficiency in corn. The best relationship between IR/R, Stress1 and Stress2 vegetation indices when regressed against visual quality was observed during 2002. These results were similar to those reported by Trenholm et al. (1999b) in a study conducted on seashore paspalum and bermudagrass. In comparison, NDVI, Stress1 and Stress2 produced the strongest relationship with the N concentration in 2003, while yielding comparably weak results during 2002 (Table 2).

Similar limitations in the consistency for NDVI predictions of N concentration have been reported by Bronson et al. (2005) in cotton (*Gossypium hirsutum L.*) grown under varying N rates. The strength of a remote sensing system will be judged by its reliability throughout the growing season. Basing management decisions on NDVI would require recalibration of the model for each sampling date against a well-fertilized control to ensure reliable results. While this might be possible in turfgrass management systems, it may not always be practical.

Analysis of the reflectance (r) data by partial least squares (PLS) regression canopy reflectance data in 2002 and 2003 yielded better predictive tissue N concentration results based on maximum r2 and minimum standard error of prediction (SEP) values than were observed for the vegetation indices (Table 3).

The results for the PLS regression in 2003 indicate a slightly weaker relationship between the actual and predicted N concentration in the tissue than was observed during 2002 (r2 = 0.71 vs. 0.95) (Table 3).

This may be explained by reduced uniformity in plot quality that resulted from localized dry spots that were present in several of the plots for a limited amount of time in 2003. In comparison to the other vegetation indices evaluated in this study, PLS regression yielded a stronger relationship between the actual and predicted N concentration across all dates in 2002 and 2003, indicating the potential benefit in using it to develop models for future remote sensing systems.

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TABLE 3

Partial Least Squares (PLS) regression statistics for estimation of nitrogen concentration, chlorophyll concentration, biomass production and visual quality for creeping bentgrass in Ames, Iowa, during 2002 and 2003.

Calibration	No. of factors†	r^2	SEP‡	*N*
	2002			
Nitrogen concentration (g kg-1)	8	0.95	1.51	60
Biomass production (g m2 d-1)	5	0.56	0.80	60
Chlorophyll concentration (µg g-1)	6	0.12	66.59	60
Visual quality	3	0.76	0.71	60
	2003			
Nitrogen concentration (g kg-1)	4	0.76	2.85	48
Biomass production (g m2 d-1)	3	0.64	0.66	48
Chlorophyll concentration (µg g-1)	2	0.02	98.72	48
Visual quality	2	0.65	0.90	48

† The number of factors necessary to achieve a minimum global standard error of prediction for the final partial least-squares regression model.

‡ Standard error prediction (the average difference between the actual values and predicted values of samples not used to develop the equation).

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Much of the current technology that is readily available works quite well at identifying stressed areas in plant communities. With continued work, there may come a day when we will be able to rely on a remote sensing system to correctly identify specific nutrient deficiencies in turfgrass systems.

Until then, we can begin by using the remote-sensing systems as tools which can help pinpoint stressed areas, which can then be further investigated and diagnosed to maintain optimum turfgrass health and quality.

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