Correlation Analysis Procedures for Canopy Spectral Reflectance Data of Seashore *Paspalum* under Traffic Stress

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ABSTRACT. Traffic stresses often cause a decline in turfgrass quality. Analysis of spectral reflectance is valuable for assessing turfgrass canopy status. The objectives of this study were to determine correlations of narrow band canopy reflectance and selected reflectance indices with canopy temperature and turf quality for seashore paspalum exposed to wear and wear plus soil compaction traffic stresses, and to evaluate the effects of the first derivative of reflectance and degree of data smoothing (spectral manipulations) on such correlations. ‘Sea Isle 1’ seashore paspalum (*Paspalum vaginatum* Swartz) was established on a simulated sports field during 1999 and used for this study. Compared to original reflectance, the first derivative of reflectance increased the correlation coefficient (r) of certain wavelengths with canopy temperature and turf quality under both traffic stresses. Among 217 wavelengths tested between 400 and 1100 nm, the peak correlations of the first derivative of reflectance occurred at 661 nm and 664 nm for both canopy temperature and turf quality under wear stress, respectively, while the highest correlations were found at 667 nm and 820 to 869 nm for both variables under wear plus soil compaction. Collectively, the first derivative of reflectance at 667 nm was the optimum position to determine correlation with canopy temperature ($r > 0.62$) and turf quality ($r < -0.72$) under both traffic stresses. All correlations were not sensitive to degrees of smoothing of reflectance from 400 to 1100 nm. A ratio of R936/R661 (IR/R, Infrared/red) and R693/759 (stress index) had the strongest correlations with canopy temperature for wear ($r = -0.63$) and wear plus soil compaction ($r = 0.66$), respectively; and a ratio of R693/R759 had the strongest correlation with turf quality for both wear ($r = -0.89$) and wear plus soil compaction ($r = -0.82$). The results suggested that the first derivative of reflectance could be used to estimate any single wavelength simultaneously correlated with multiple turf canopy variables such as turf quality and canopy temperature, and that the stress index (R693/R759) was also a good indicator of canopy stress status.

Canopy spectral reflectance provides an important method for plant canopy study under different environmental conditions. Multispectral analysis has been widely used for determining canopy responses to environmental stresses, primarily by measuring variations of canopy reflectance from visible or/and near infrared wavelengths (Carter et al., 1996; Cure et al., 1989; Huang et al., 1998; Penuelas et al., 1997a; Trenholm et al., 1999a). The changes in canopy reflectance at a single wavelength, a defined wavelength band, or various indices have been used to identify a correlation with canopy variables such as pigment content, photochemical activity, green biomass, and water content (Gamon and Surfus, 1999; Lorenzen and Jensen, 1988; Rollin and Milton, 1998). The most commonly used indices are the normalized difference vegetation index (NDVI), leaf area index, stress index and water content index, with different versions of each of these reported in the literature.

Multispectral data are often collected in the field using natural illumination, which may include noise caused by sun angle, cloud cover, or canopy parameters, although a reference scan is used. To eliminate background effects, reflectance data can be appropriately transformed and manipulated before they are used to describe relationships between reflectance and canopy variables. The techniques of derivative analysis of reflectance data have been applied to multispectral research since the derived data are relatively insensitive to variations of illumination (Tsai and Philpot, 1998), and also could estimate a range of canopy

structures (Danson et al., 1992; Malthus and Madeira, 1993). Rollin and Milton (1998) reported that strong correlations existed between the first derivative of reflectance and chlorophyll content, fresh and dry biomass, and canopy water content. Spectral derivative approaches were also found to be highly correlated to photosynthetic pigment content at both the canopy and the leaf level (Blackburn, 1998).

In addition to using derivative analysis of reflectance, reflectance data are commonly smoothed, which is a major process for removal of random noise from spectra and reduction of fluctuating data. The degree of smoothing may cause a peak correlation to shift from one position of a wavelength to another between canopy biophysical variables and reflectance. Rollin and Milton (1998) reported that the wavelength of the peak correlation between the first derivative of reflectance and percent canopy water content were sensitive to degree of smoothing across the 1150 nm, a water absorption band. Since spectral smoothing is a factor affecting correlation of the first derivative of reflectance and canopy variables, the selected degree of spectral smoothing should be considered for a particular study by using the derived reflectance to identify any important wavelengths.

Analysis of spectral reflectance is valuable for evaluations of turfgrass canopy characteristics (Trenholm et al., 1999a). A healthy turfgrass canopy usually is dark green, dense, and exhibits good uniformity of vegetation structure. Environmental or traffic stresses may cause changes in canopy characteristics, which can be determined by spectral reflectance. Therefore, the spectral reflectance data could be incorporated with visual observation or other instrumental estimations of turf canopy nature, which would aid in assessing how turfgrass research and management opera-

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tions influence the turf. To date, only a few studies have addressed the application of spectral reflectance to turfgrass environmental situations (Fenstermaker-Shaulis et al., 1997; Huang et al., 1998, Trenholm et al., 1999b). These studies used selected visible to near-infrared red wavelength bands with intervals of 10 to 50 nm or more, but more information of correlations between reflectance or the derivative of reflectance with turf canopy variables may arise by using narrow wavelength bands (1 to 3 nm intervals) in the range of visible to near-infrared red region since more detailed wavelengths are added to the analysis.

Turfgrass traffic stresses include primarily wear stress alone and the combination of wear plus soil compaction, resulting in direct injury to the shoot and increasing the degree of soil compaction, respectively (Carrow et al., 2001). Both stresses may occur simultaneously and cause decreased turf quality, reduced shoot density, and may potentially increase canopy temperature in hot weather. However, relationships of canopy reflectance at narrow band wavelengths in the visible and near infrared regions as well as various reflectance indices with temperature and turf quality have not been investigated following both wear and wear plus soil compaction. Trenholm et al. (1999a) reported a number of significant correlations between broad band wavelength and spectral indices versus turf quality, shoot density, and degree of turf injury from wear, but wear plus soil compaction treatment was not included, nor were derivative analysis or data smoothing processes practiced. Since traffic stress can increase background noise, the derivative of reflectance and data smoothing processes may be useful for interpretation of high spectral resolution reflectance data on turf canopy variables.

Seashore paspalum (*Paspalum vaginatum* Swartz) is an environmentally compatible warm-season turfgrass that has become adapted to a wide range of environmental conditions (Duncan, 1999). Therefore, the objectives of this study were a) to determine correlations of narrow band canopy reflectance and selected reflectance indices with canopy temperature and turf quality for seashore paspalum exposed to wear and wear plus soil compaction traffic stresses; and b) to evaluate the effect of the first derivative of reflectance and degree of data smoothing on such correlations.

Materials and Methods

PLANT MATERIALS. The experiment was conducted at The University of Georgia Experiment Station in Griffin, Ga. 'Sea Isle 1' seashore paspalum was established on a simulated sports field during 1999. The soil profile was an Appling sandy clay loam (clayey, kaolinitic, thermic Typic Kanhapludult) capped with a 10-cm mixture of 90% sand and 10% peat. Grasses were maintained at a 1.7-cm mowing height, and the field received a total of 80 kg·ha⁻¹N during the 2001 growing season. Irrigation was ≈2.5 cm weekly. Fertilization applied to the site in terms of N in kg·ha⁻¹ in 2001 was 5.8 N on 13 April (12N–24P–14K); 16 N on 30 April and May 18 (34N–0P–0K); 6.6 N on 23 May (Milorganite, 6.75N–2.65P–0.46K, Milwaukee Metropolitan Sewerage District, Milwaukee, Wis.); 9.8 N on 25 May, 1 June, and 10 July (GreenEdge, 10N–0P–18K, GreenTechnologies, Inc., Gainesville, Fla.); 7.3 N on 25 July (15N–0P–15K).

TRAFFIC STRESSES. A wear device (WD) (Shearman et al., 2001) and a studded roller device (wear plus soil compaction, WSC) (Carrow et al., 2001) that imposed wear and simultaneous wear and soil compaction were used. The wear device had rubber covered, smooth rollers and applied 0.90 kg·cm⁻² force.

It was designed to impose wear stress with minimal pressure to cause soil compaction. The studded roller device used football shoe-studs (12.7-mm-diameter, 20-mm-long, one stub/40 cm²) that could impose WSC and apply a static roller pressure of 0.49 kg·cm⁻² to the grass and a static pressure of 1027 kg·cm⁻² on the ends of each stud in contact with ground. The machines were run at 40 passes for WD stress by the wear device and 20 passes for WSC by the studded roller to create approximately the same degree of shoot injury. The application of the first pass was in forward motion and the next pass was in the reverse mode to maintain uniform traffic injury.

DATA COLLECTION. Turf quality, canopy temperature, and canopy reflectance were collected one day after traffic treatments to record initial turfgrass responses to stresses, and measurements were then made weekly following stress treatments. Turf quality was rated visually based on color, shoot density and uniformity, where 0 = brown, dead turf and 9 = optimum color, density and uniformity. Turf density rating was based on shoot density, where 1 was no grass and 9 was uniformly dense grass. Percent canopy coverage was rated as grass cover above ground, where 100% = full coverage and 0% = no grass. Canopy temperature was measured using an infrared thermometer (Everest Interscience Inc., Tustin, Calif.), and ΔT ($T_{\text{stressed}} - T_{\text{control}}$) was used for analysis of various correlations. T_{control} was the canopy temperature of the grass not subjected to traffic stresses. Canopy spectral reflectance measurements were collected with a Unispec Spectral Analysis System (PP systems, Haverhill, Mass.), which measured reflectance between 400 nm and 1100 nm at 3-nm intervals. Reflectance foreoptics are bifurcated fiberoptics and the reflectance measurements were made with ambient light as an illumination source. The instrument shutter was first closed to establish a dark current correction and then opened and a white standard reference was scanned. Canopy reflectance was measured at the same position immediately after the standard reference was scanned. Canopy reflectance was calculated by comparing the sample reflectance to a standard reference scan. The fiberoptics probe was held 20 cm directly above ground and measured ≈400 cm² for each scan and an average reflectance was calculated. All reflectance readings were taken between 1300 and 1400 HR on sunny days after canopy temperature determinations.

SPECTRAL INDICES, DATA SMOOTHING AND THE FIRST DERIVATIVE CALCULATION. Correlations of each narrow band reflectance from 400 to 1100 nm with canopy temperature and turf quality and correlations of the first derivative of reflectance with canopy temperature and turf quality were determined after traffic stress treatments.

The processes of smoothing canopy spectral data were performed by using a cubic convolution over 5 and 9 points and a simplified least squares equation described by (Savitzky and Golay, 1964). The equation provides simultaneously smoothing and differentiating of data, and the procedure smoothes data with minimal effect on spectral details. Smoothing over 5 and 9 points provides ≈2 and 3 times improvement of the signal-to-noise ratio, respectively. The first derivative of reflectance was then calculated from the smoothed reflectance using a 17-point polynomial least squares equation (Rollin and Milton, 1998; Savitzky and Golay, 1964).

The following specific reflectance indices were used to evaluate correlations of canopy original reflectance with canopy temperature and turf quality. The wavelengths were modified from previous studies as noted, based on the closest bands of the Unispec instrument used in this study.

Table 1. Turf quality (TQ), density and percent canopy coverage (PCC) as affected by wear stress (WD) and wear plus soil compaction (WSC) at 7 and 14 d after treatment (DAT).

DAT	Traffic	TQ	Density	PCC
7	WD	6.7 a ^z	6.6 a	81 a
	WSC	6.4 b	6.1 b	72 b
14	WD	7.6 a	7.5 a	90 a
	WSC	7.4 a	7.2 b	84 b

^zMeans followed by the same letters within a column at a given day after treatment were not significantly different based on LSD ($P < 0.05$).

NORMALIZED DIFFERENCE VEGETATION INDEX (THREE VERSIONS): $(R750 - R705)/(R750 + R705)$; $(R900 - R680)/(R900 + R680)$; and $(R935 - R661)/(R935 + R661)$ (modified from Gamon and Surfus, 1999; Penuelas, et al., 1997b; Trenholm et al., 1999a).

STRESS INDEX (THREE VERSIONS): $R695/R420$, $R695/R760$; $R706/R813$ (modified from Carter, 1994; Trenholm et al., 1999a).

LEAF AREA INDEX (IR/R) (TWO VERSIONS): $R850/R620$; $R935/R661$ (modified from Cure et al., 1989; Trenholm et al., 1999a).

WATER BAND INDEX (TWO VERSIONS): $R900/R970$, $(R700 - R1100)/R700$ (modified from Penuelas et al., 1997a; Rollin and Milton, 1998).

EXPERIMENTAL DESIGN. Data for this study came from a project investigating seashore paspalum responses to selected traffic and light conditions (Jiang et al., 2002). The experiment included two consecutive trials from 9 July to 30 July and from 20 Aug. to 10 Sept. 2001 with different plots for studies 1 and 2, respectively. For the current experiment, plots were in a completely randomized design with three traffic treatments and three replicates of each treatment. The three traffic treatments were none, wear, and wear plus soil compaction. Data were collected at 1, 7, 14, and 21 d after treatment (DAT) in both study 1 and 2 and were combined for the

evaluation of various correlation coefficients (r) between canopy reflectance and canopy temperature, and between reflectance and turf quality. The nontraffic control was not subjected to correlation analyses since little variation in canopy characteristics occurred over time for that treatment in contrast to the traffic treatments. The total observations for each treatment were 24 (3 replications by 4 dates by 2 studies). Correlation coefficients were derived using correlation SAS code (SAS Institute, 1987) (SAS Institute Inc., Cary, N.C). The assumption of homogeneous variance was checked by residual plots and found to be satisfied.

Results and Discussion

TURF QUALITY, DENSITY, AND PERCENT CANOPY COVERAGE. Turf quality, shoot density and percent canopy coverage were generally more affected under wear plus soil compaction than under wear stress (Table 1). Greater reductions in shoot density and percent canopy coverage were observed in the wear plus soil compaction treatment than in the wear treatment at 7 and 14 DAT. Turf quality and shoot density have been found to correlate with canopy reflectance at 661 and 813 nm, $R935/R662$, and $R706/R813$ under wear stress (Trenholm et al., 1999a). These results indicate that differences between the degree of the reduced shoot density and canopy coverage under wear versus wear plus soil compaction may be factors that could influence variations in canopy reflectance.

CANOPY REFLECTANCE, THE FIRST DERIVATIVE OF REFLECTANCE, AND CANOPY TEMPERATURE. In the range of 400 to 1100 nm, the first derivative of reflectance (with reflectance smoothed over 5 points) was better correlated with canopy temperature than original reflectance and increased the significance level of correlations under both traffic stresses (Figs. 1 and 2). The peak values of r were -0.51 ($P < 0.05$) and 0.67 ($P < 0.001$) under wear stress

Fig. 1. Correlation coefficient (r) between canopy temperature (ΔT) ($T_{\text{stressed}} - T_{\text{control}}$) and canopy reflectance using the original data (A) and the first derivative of reflectance (B) under wear stress.

Fig. 2. Correlation coefficient (r) between canopy temperature (ΔT) ($T_{\text{stressed}} - T_{\text{control}}$) and canopy reflectance using the original data (A) and the first derivative of reflectance (B) under wear plus soil compaction.

Fig. 3. Correlation coefficient (r) between turf quality and canopy reflectance using the original data (A) and the first derivative of reflectance (B) under wear stress.

and were 0.53 ($P < 0.01$) and 0.70 ($P < 0.001$) under wear plus soil compaction for original reflectance and the first derivative of reflectance data, respectively.

Under wear stress, the strongest correlations between the first derivative of reflectance and temperature occurred at 661 and 664 nm, while the strongest correlations were at 667 and 820 to 869 nm for wear plus soil compaction, but no correlations at $P < 0.001$ were observed with original reflectance data for either treatment. The first derivative of reflectance at 939 to 952 nm was correlated with temperature under both stresses at $P < 0.01$, but not at $P < 0.001$.

Cure et al. (1989) found that canopy temperature was correlated with canopy reflectance at 620 nm and 850 nm in soybean (*Glycine max* L.) under drought stress. In our study, wear stress mainly affected turfgrass above ground but the wear plus soil compaction operation reduced shoot density and exposed more soil. The first derivative of reflectance appeared to suppress canopy background noise that may arise from exposed soil and enhanced correlations. This was particularly apparent for the wear plus soil compaction treatment where the greatest improvements in correlation with temperature were found. The results indicated the first derivative of reflectance was an effective tool to identify wavelengths most correlated to turf canopy temperature under specific traffic stresses, and that different traffic regimes resulted in variations in the significance of r .

CANOPY REFLECTANCE, THE FIRST DERIVATIVE OF REFLECTANCE, AND TURF QUALITY. Canopy reflectance had a broader range of significant r values with turf quality (Figs. 3 and 4), compared to canopy temperature (Figs. 1 and 2) under both traffic stresses. The first derivative of reflectance considerably increased r and was highly correlated with turf quality. The maximum values of r ($P < 0.001$) were -0.79 and 0.86 under wear stress and -0.74 and -0.80 under wear plus soil compaction for original reflectance and the first derivative of reflectance, respectively. Although significant

Fig. 4. Correlation coefficient (r) between turf quality and canopy reflectance using the original data (A) and the first derivative of reflectance (B) under wear plus soil compaction.

correlations at $P < 0.001$ were found in original reflectance with turf quality, no single wavelength with the strongest correlation was shown in both traffic stresses (Table 2). However, the first derivatives of reflectance at 444 to 484 nm, 546 to 569 nm, 667 to 671 nm, and 814 to 875 were correlated with turf quality under both traffic conditions.

Trenholm et al. (1999a) reported that turf quality was correlated with canopy reflectance at 8 selected broad wavelengths under wear stress. Our results showed that correlations could be applied to more wavelengths under wear and wear plus soil compaction, particularly by using the first derivative of reflectance and narrow band data. Reflectance in the visible range (400–700 nm) is highly correlated with chlorophyll content (Gitelson and Merzlyak, 1994) and a reliable stress indicator (Carter, 1993). The results indicated the first derivative of reflectance in this region is well correlated with turf quality, and the derivative of a near infrared region of 814 to 875 nm had the best correlation under both traffic stresses.

SMOOTHING ANALYSES OF THE FIRST DERIVATIVE OF REFLECTANCE. The first derivative of reflectance with the data smoothed over 5

Table 2. Wavelengths with peak correlation coefficients at $P < 0.001$ between reflectance and turf quality under wear stress (WD) and wear plus soil compaction (WSC).

Treatment	Wavelength (nm)	
	Original reflectance	First derivative of reflectance
WD	609–700	444–484, 549–645
	756–804	658–671, 709–765
		814–875, 936–952
WSC	411, 418, 441	437–487, 546–569
	457–513	667–677, 746, 788–878
	569–710	936–949

Table 3. Peak correlation coefficients following smoothing degree of the first derivative of reflectance under wear stress (WD) and wear plus soil compaction (WSC).

Treatment	Variable	Smoothing			
		5-point		9-point	
		Band (nm)	<i>r</i>	Band (nm)	<i>r</i>
WD	Canopy temperature	664	0.67***	664	0.68***
	Turf quality	664	-0.88***	664	-0.88***
WSC	Canopy temperature	846	0.70***	849	0.70***
	Turf quality	833	-0.81***	833	-0.81***

***Indicates correlations are significant at $P < 0.001$.

or 9 points were compared from 400 to 1100 nm, in terms of peak correlations with canopy temperature and turf quality (Table 3). The wavelength position with peak correlation was generally not affected by smoothing degree, nor was the r . Under wear stress treatment, the peak correlations occurred at 664 nm for both canopy temperature and turf quality by smoothing over 5 and 9 points. Under wear plus soil compaction, wavelength positions with peak correlations for canopy temperature slightly changed smoothing over 5 points (846 nm) and 9 points (849 nm). The strongest correlation at 833 nm for turf quality was not affected by smoothing, and smoothing over 9 points was essentially the same ($r = -0.81$) as smoothing over 5 points ($r = -0.81$). Also, the smoothing process generally did not change the wavelength regions that had significant correlations between the first derivative of reflectance with canopy temperature and turf quality in both traffic stresses (data not shown). The results indicated that smoothing procedures did not appreciably affect correlations of the first derivative of reflectance with canopy temperature and turf quality under traffic stresses. Rollin and Milton (1998) reported that the smoothing degree should be carefully selected when identifying particular wavelengths corresponding to multiple canopy variables.

CORRELATIONS OF REFLECTANCE INDICES, CANOPY TEMPERATURE AND TURF QUALITY. All reflectance indices in this study were correlated with canopy temperature for both traffic stresses except for the stress index ratio of R693/R421 under wear stress (Table 4). R936/R661, a leaf area index, had the strongest correlation ($P < 0.001$) with canopy temperature under wear stress. Stress index R693/759 showed the strongest correlation under wear plus soil compaction and other indices such as R707/814, NDVI (R749-R706)/(R749+R706) and (R901-R680)/(R901+R680) also had strong significant correlations under the same traffic treatment. The results indicated that canopy temperature under wear plus soil compaction treatment was particularly sensitive to changing NDVI and stress index. NDVI is the most widely used index and principally assesses green biomass (Gamon et al., 1995), and stress index is known for determining plant physiological status under stresses (Carter et al., 1996). Such correlations could better reflect relationships between canopy temperature and severity of wear plus soil compaction. A canopy ratio of R850/R620 was correlated with plant temperature (r from -0.64 to -0.77) in droughted soybean (Cure et al., 1989). Similar results at R849/R622 were found in wear and wear plus soil compaction for turfgrass in our study.

All indices were highly correlated to turf quality under both traffic conditions (Table 5). Significant correlations were observed at $P < 0.001$ except for the water band index of (R700-R1099)/R700 under wear plus soil compaction, which was significant at $P < 0.01$. The highest correlation was with R693/R759 for both traffic stresses; r values were -0.89 and -0.82 for wear and wear

Table 4. Correlation coefficients between various indices and canopy temperature under wear stress (WD) and wear plus soil compaction (WSC).

Indices	Correlation coefficient (<i>r</i>)	
	WD	WSC
NDVI		
(R749-R706)/(R749+R706)	-0.50*	-0.65***
(R901-R680)/(R901+R680)	-0.60**	-0.63***
(R936-R661)/(R936+R661)	-0.60**	-0.61**
Stress index		
R693/R421	0.29	0.53**
R693/R759	0.51**	0.66***
R707/R814	0.48*	0.63***
Leaf area index (IR/R)		
R849/R622	-0.59**	-0.61**
R936/R661	-0.63***	-0.61**
Water band index		
R901/R971	-0.45*	-0.60**
(R700-R1099)/R700	0.62**	0.54**

*, **, ***Indicate correlations are significant at $P < 0.05$, 0.01, and 0.001.

Table 5. Correlation coefficients between various indices and turf quality under wear stress (WD) and wear plus soil compaction (WSC).

Indices	Correlation coefficient (<i>r</i>)	
	WD	WSC
NDVI ²		
(R749-R706)/(R749+R706)	0.86***	0.81***
(R901-R680)/(R901+R680)	0.88***	0.80***
(R936-R661)/(R936+R661)	0.86***	0.79***
Stress index		
R693/R421	-0.78***	-0.80***
R693/R759	-0.89***	-0.82***
R707/R814	-0.85***	-0.79***
Leaf area index (IR/R)		
R849/R622	0.74***	0.74***
R936/R661	0.76***	0.74***
Water band index		
R901/R971	0.82***	0.63***
(R700-R1099)/R700	-0.66***	-0.58**

²Normalized difference vegetation index.

*, **, ***Indicate correlations are significant at $P < 0.05$, 0.01, and 0.001.

plus soil compaction, respectively. Carter (1994) found that a ratio of R695/R760 was a reliable indicator of plant stress status, and our study showed a very similar result for turf quality in response to traffic stress. Trenholm et al. (1999b), using broad band reflectance, reported that a NDVI (R935-R661)/(R935+R661), a stress index (R706/R813) and an IR/R (R935/R661) were highly correlated with turf quality under wear stress, and the same in-

dices of NDVI and IR/R were also useful in a study of turfgrass drought tolerance (Huang et al., 1998). The results indicated that a ratio of R693/759 could be better used for the integration of visible estimation of overall turf quality under both wear and wear plus soil compaction.

The first derivative of reflectance increased r values for both canopy temperature and turfgrass quality under two traffics, indicating an increased reliability of correlations with canopy variables by using this technique. With regard to application of the first derivative of reflectance to predict canopy variables, turf quality would be better explained than canopy temperature based on coefficient of determination (R^2), calculated by r value. The highest R^2 value was 0.77 for turf quality under traffic stresses, while it was below 0.50 for canopy temperature. The results suggested that part of the variability associated with canopy variables was not captured by reflectance and further investigations are needed.

In conclusion, the first derivative of canopy reflectance increased the significance of correlations between reflectance and canopy temperature and turf quality under two traffic stresses, particularly for canopy temperature. The use of the first derivative of reflectance would be desirable to establish single or multiple wavelengths that have the strongest correlations simultaneously with multiple canopy variables. Various reflectance indices could also be used to determine turfgrass canopy status under traffic stresses.

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