Evaluation of lawn color and chlorophyll concentration using hyperspectral index

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Abstract: A study was carried out at a subtropical zone of southern west China to test if hyperspectral methods could be used to measure turf canopy chlorophyll concentration, and to analyse correlation between green normalized difference vegetation index (GNDVI) values. Turf chlorophyll concentration, canopy hyperspectral reflectance, and visual rating were measured. The results showed that canopy hyperspectral reflectance value was more sensitive to the turfgrass chlorophyll concentration difference than visual rating both among turfgrass species. Visual rating value and hyperspectral index were both highly correlated with canopy chlorophyll concentration. Regression analysis indicated a strong linear correlation between GNDV and visual rating value. Hyperspectral technique can provide an improved method to evaluate turfgrass chlorophyll concentration and to quantify turfgrass color.

1. Introduction

Color is one of the important contents of turfgrass evaluation. There are several techniques to measure turf color, such as visual rating, visual color comparison using standardized color palette, chlorophyll analysis in laboratory, and reflectance measurements using spectral technology (Gitelson et al, 1994; Birth et al, 1968; Bell et al, 2004). Traditionally, turfgrass color was judged visually. This method is widely used in the evaluation of lawn quality of different lawns. Experienced evaluators are more likely to provide expert advice on visual quality of turfgrass stands. Although visual rating provides quick data acquisition without specialized equipment, it is very subjective and biased, depending on experience of the evaluator. As a result, there are often inconsistencies among evaluators and even assessments of the same lawns. Furthermore, for the same evaluator, visual lawn evaluation may vary by time.

Chlorophyll concentration has close relationship with turfgrass color and could be used to quantify turfgrass color (Trenholm et al, 1999; Thorogoodt et al, 1993). Previous researches have found that leaf reflectance of visible light wavelengths (400–700 nm) is highly correlated with leaf pigments concentration, particularly chlorophyll Chlorophyll absorption increased in this range because of the relatively low reflectivity in the visible range (Karcher et al, 2003; Landschoot et al, 2000). Generally speaking, the higher the chlorophyll concentration, the darker the turfgrass color. Vegetation index,
such as normalized difference vegetation index (NDVI), is often used to assess turf color (Pinar et al, 1996). NDVI is defined as the near-infrared (NIR) minus visible reflectance divided by NIR plus visible reflectance. Higher NDVI values are related to higher turfgrass density and greenness, while lower values indicate sparse or stressed turf [Richardson et al., 2001, Xiong et al., 2007]. Currently, the majority of research on spectral reflectance has been conducted on crops or dense forest areas, however, there is limited information on the spectral response of turfgrass, especially on turfgrass color evaluation [Nelson et al., 1984, Trenholmet et al., 1999, Zhanget al, 2007]. The objective of this research was to determine whether hyperspectral vegetation indices can be used to describe turf color quantitatively in comparison with visual rating and laboratory method by analysing chlorophyll.

2. Materials and methods
This study was undertaken in the Turf Experiment Station of Yunnan Agricultural University (25°01’ N, 103 °11’ E, altitude 1931m) in a 900–1000 mm rainfall zone. The climate is characterized by subtropical zone with year temperature averages 14.7° C. Soil is a red soil with organic matter 1.74% and pH 6.7. There were 5 turfgrass cultivars included in this experiment, namely tall fescue, perennial ryegrass and creeping bentgrass. The experiment was a randomized block design with each individual turfgrass replicated three times. Plot size was 2×3 m with 0.5 m buffers. The turf is irrigated when necessary to maintain a healthy state.

A fibre optic spectrometer was used to measure reflectance spectra over 450-800 nm wavelength at approximately 0.5 nm intervals near solar noon under clear sky condition. Downward facing detector was mounted at 0.3 m above the turf canopy with a 1° field of view. Three readings were taken on each plot. The spectrometer was calibrated using a barium sulphate Lambertian surface every 15 to 20 minutes. Visual rating was given on 1–9 scale (9 = best quality, 1 = worst quality) immediately after spectral reflectance measurement. Three evaluators were employed.

Fresh leaf sample was taken at each location of reflectance measurement and bulked into one sample in each plot. The leaf samples were placed in a sealed plastic bag and kept cool until they were brought back to the laboratory for chlorophyll concentration measurement. Chlorophyll was extracted using mixture of acetone and ethanol (95% v/v) as a solvent for 24 hours in the dark at 25°C. The concentrations of chlorophyll (Chl a and b mg/g fresh plant material) were measured using spectrophotometer and calculated (Yang, 2002), as follows:

\[ \text{Chl } a (\text{mg/L}) = 12.7A_{663} - 2.69A_{645} \]
\[ \text{Chl } b (\text{mg/L}) = 22.9A_{645} - 4.68A_{663} \]
\[ \text{Chl } a + b (\text{mg/L}) = \text{Chl } a + \text{Chl } b \]

The optimum wavelengths for GNDVI and NDVI were pre-determined between 510-560 nm for green band, 640-680 nm for red band, and 700-800 nm for near-infrared band. A series of NDVI and GNDVI was calculated with all possible combinations of selected wavelengths at step of 0.5 nm. Each set of NDVI or GNDVI was then regressed using linear, or power models against visual rating or chlorophyll concentration. The best fit model with the highest coefficients of determination was chosen as the optimum model, and the associated wavelengths were selected as the optimum wavelengths for NDVI and GNDVI.

3. Results

3.1 Relationship between Canopy reflectance and Chlorophyll concentration
There were significant differences (P < 0.05) in canopy reflectance between 3 turfgrass species, seven tall fescue cultivars or 3 perennial ryegrass cultivars in most wavelengths of visible bands. The biggest reflectance difference occurred at 550 nm with reflectance ranged from 2.5% for tall fescue Pixie up to 8.3% for creeping bentgrass Putter (Fig. 1). At this wavelength, perennial ryegrass Bermuda grass had significantly lower reflectance (P < 0.05) compared with creeping bentgrass Putter, but significantly higher than all 3 tall fescue cultivars. Within 3 tall fescue cultivars,..
There were significant differences in chlorophyll concentration between turfgrass species. Tall fescue had the highest chlorophyll concentration, and creeping bentgrass had the lowest, whereas chlorophyll concentration of perennial ryegrass was intermediate (Table 1). Chl a+b varied from 1.87 mg/g for Putter creeping bentgrass up to 2.26 mg/g for tall fescue. Chl a concentration was more than double compared to those of Chl b. However, there were no significant differences in Chl a, Chl b, or Chl a+b either between seven tall fescue cultivars or between three perennial ryegrass cultivars.

![Graph showing reflectance of different turfgrass species](image)

**Fig. 1. Reflectance of the turfgrass in different wavelengths**

### 3.2 Visual rating value
There were significant differences in visual rating between 3 turfgrass species (P < 0.05), but no difference was observed either within 3 tall fescue cultivars. Averaged across species, tall fescue had the highest visual score, followed by perennial ryegrass, and creeping bentgrass had the lowest. However, there were no significant differences in visual rating between tall fescue and perennial ryegrass. Creeping bentgrass has significantly lower visual rating value than that of perennial ryegrass.

### Table 1. Analysis of variance for chlorophyll concentration (mg/g) and visual rating scores of different turf grasses

| Cultivars       | Chl a | Chl b | Chl a+b | Chl.D | Visual rating score |
|-----------------|-------|-------|---------|-------|--------------------|
| Tall fescue     |       |       |         |       |                    |
| Watchdog        | 1.60 a| 0.65 a| 2.25 a  | 3.34a | 7.59 a             |
| Pixie           | 1.53 ab| 0.65 a| 2.18 ab | 3.27a | 7.72 a             |
| Fire Phoenix    | 1.43 ab| 0.58 ab| 2.01 ab | 2.72 ab | 7.06 ab |
| Perennial ryegrass |       |       |         |       |                    |
| Bermudagrass    | 1.44 ab| 0.50 b | 1.94 ab | 2.48 ab | 6.00 bc |
| Creeping bentgrass |     |       |         |       |                    |
| Putter          | 1.32 b| 0.56 ab| 1.87 b  | 1.63c | 4.50 d             |

Means in the same columns followed by different letter are significantly different (P < 0.05)

### 3.3 Relationship between visual rating value, spectral vegetation indices and chlorophyll concentration
There were strong (P < 0.001) correlations between turfgrass visual rating value and their Chl a, Chl b, and Chl a+b as shown in Table 2. When regression analysis was conducted with tall fescue cultivars, similar relationships were also observed between their visual rating value and chlorophyll concentration. Chlorophyll concentration significantly affected tall fescue, perennial ryegrass, and
creeping bentgrass response measured by GNDVI. Correlation analysis indicated that GNDVI ($P < 0.01$) were strongly related with Chl a, Chl b, and Chl a+b of turfgrass.

![Fig. 2 Correlation analysis and regression equations between visual rating and chlorophyll Concentration](image)

![Fig. 3. The correlation between visual rating and estimated turfgrass color scores by GNDVI](image)

4. Discussion and conclusion

Turfgrass chlorophyll concentration varied depending on their species and cultivars. The difference of chlorophyll concentration in different turfgrass and the significant change of reflectance at some special wavelengths. Spectral reflectance technique is more sensitive to the chlorophyll concentration differences than visual rating (Gitelson et al., 2001; Bhadra et al., 2020). Results showed that there were significant differences in visual rating value between creeping bentgrass, perennial ryegrass and tall fescue. At the same site, these spectral reflectance differences mainly occurred in visible bands, especially at wavelength of near 550 nm. At this wavelength, green color is reflected from plants and seen by human eyes, however, visual rating value did not show any significant differences between different cultivars of same species.

Traditional turfgrass color evaluation methods, such as chlorophyll concentration and visual rating, are actually objective ones, and more widely used for the moment in comparison with other new approaches. However, some advantages of spectral analysis for turf color over traditional methods has been researched and recognized in recent years. Using spectral technology to quantify the color of turfgrass is more sensitive and consistent than objective visual scores, much higher than traditional
laboratory methods. Another advantage of hyperspectral technology is that the obtained data were free from researcher bias and inaccuracies before analysis[ ]. In addition, this technique may potentially be useful in indicating other turf features which has inherent relationship with turfgrass color, such as turfgrass health condition under nutrition, water or disease stress. Data obtained from this research also has the potential to be used as tools in a wide range of turf operation for both research and management. Further researches are needed to assess the utilisation of hyperspectral methods in assessing turf color responses to different turfgrass species or cultivars on larger scales and in different locations.

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