Athletic Field Paint Color Differentially Alters Light Spectral Quality and Bermudagrass Photosynthesis

William Casey Reynolds, Grady L. Miller,* and Thomas W. Rufty

ABSTRACT

Painting of athletic fields is widespread throughout the world and can often cause declines in turfgrass health. Visible light and photosynthesis share the same wavelengths (400–700 nm), and it was hypothesized that alterations in visible light to produce specific colors would lead to reductions in photosynthetically active radiation (PAR) and total canopy photosynthesis (TCP). Lab experiments using a spectroradiometer and LICOR 1800-12 integrating sphere examined the impacts of 10 colors of athletic field paint on PAR as well as wavelengths within PAR. These colors were then applied weekly for 5 wk to ‘Tifway’ bermudagrass [Cynodon dactylon (L.) Pers. × Cynodon transvaalensis Burtt Davy], and TCP was measured using a gas exchange system 24 h after each application. Spectroradiometry analyses revealed the significant effects of paint color ($P \leq 0.001$) on reflection, transmission, and absorption of PAR. Lighter colors including white, yellow, orange, and red reflected 47 to 92% of PAR while darker colors including green, black, and dark blue absorbed 87 to 95% of PAR. Accompanying gas exchange measurements revealed that TCP was most negatively correlated with absorption of PAR ($r = -0.959, P \leq 0.001$) and that darker colors negatively impact TCP more than lighter colors. The results clearly indicate that damage to turfgrasses with long-term painting will be difficult to avoid, and this is particularly true with darker colors of paint.

PAINTING OF TURFGRASS ATHLETIC FIELDS is a common practice throughout the world. It is widely recognized that repeated paint applications degrade turfgrass quality. The underlying basis for decline in quality and therefore the question of whether it can be avoided has yet to be resolved. It is conceivable that the negative impact of paint on turfgrass quality can be traced to properties of the pigments used to produce each paint color. The wavelength range for visible light overlaps with photosynthetically active radiation (PAR), between 400 and 700 nm, and alterations in visible light to produce specific colors could have negative effects on PAR and the associated rate of turfgrass photosynthesis. This cause and effect relationship was implied in a recent study where red and white paint were applied to perennial ryegrass (Lolium perenne L.) (Reynolds et al., 2012). Applications of red paint absorbed 51% of PAR and reduced total canopy photosynthesis (TCP) up to 75% while applications of white paint reflected 95% PAR and reduced TCP by only 20 to 45%.

Commonly used colors of athletic field paint influence light across the entire visible spectrum. Paint colors are produced using varying pigment sources that selectively reflect, transmit, and absorb specific wavelengths of light (Fig. 1). For example, red Fe$_2$O$_3$, a commonly used pigment in red paint, produces a red color by reflecting approximately 20 to 30% more visible light in the 600 to 700 nm range than in the remaining visible
wavelengths (Endrib, 1998). Because different colors would impact different spectral bands in the 400 to 700 nm range, it is likely that the degree of effects on TCP could differ greatly.

In addition to differences in pigments based on color, all pigments are designed to be opaque such that the painted surface, in this case the turfgrass leaf, is hidden. As a result, not only are various wavelengths of light altered in painted turfgrass canopies, but the total amount of visible light hitting the leaf surface may be greatly reduced due to absorption by paint pigments. Therefore, there is the potential for painting to disrupt the light reactions of photosynthesis and regulation of stomatal opening, which may affect the supply of C for the dark reactions (Taiz and Zeiger, 2010; Shimazaki et al., 2007).

In the experiments described in this manuscript, previous research (Reynolds et al., 2012) is extended by evaluating changes in PAR and photosynthesis over a range of 10 paint colors. Lab experiments were performed to analyze how different paint colors altered reflection, transmission, and absorption of PAR at specific broad- and narrowband wavelengths. Subsequent growth-chamber experiments evaluated the extent that the alterations in PAR affected TCP of Tifway hybrid bermudagrass. The results provide a basis for understanding declines in turfgrass quality associated with repeated applications of various colors of athletic field paint.

**MATERIALS AND METHODS**

**Spectroradiometry**

Ten colors of Pioneer Brite Stripe Airless Paint (Pioneer Athletics) were selected for study. Pioneer Brite Stripe was chosen due to its widespread use on athletic fields as well as its ability to be diluted at various ratios ranging from 1:1 to 4:1 v/v based on the product label. It also allowed for uniform dilution across all colors, as opposed to premixed products that are not designed to be diluted. The 10 colors selected were defined using the Pantone Matching System (PMS), which is a standardized color reproduction system that assigns specific reference numbers to each color (Hunt and Pointer, 2011). Colors examined in this study were selected to include the entire visible spectrum, and their respective PMS numbers are presented in Table 1. Reflection, transmission, and absorption of PAR by each of these colors was measured using a method established by Reynolds et al. (2012) that involves uniform application of paint treatments to transparency film (3M PP2500; 3M) using a wet film applicator (Gardco 8-Path; Paul N. Gardner Company, Inc.). This device allows a small quantity of liquid to be applied to surfaces at a known wet thickness for subsequent testing. Each of the 10 colors of athletic field turf paint was diluted at a 1:1 ratio with water before application to the transparency film. To achieve similar dried thicknesses for comparison, black, dark blue, green, light blue, maroon, orange, purple, red, and yellow were each applied at a uniform wet thickness of 0.625 mm while white was applied at a wet thickness of 0.375 mm. This distinction was made due to the high amount of pigment solids present in white paint, relative to other colors, and its characteristic ability to dry thicker. The final dried thickness of each film was recorded using a digital micrometer to ensure uniformity among colors.

Reflection and transmission of PAR through each color (Fig. 1) was measured between 400 and 700 nm at 0.5 nm intervals using an integrating sphere (LICOR 1800-12; LI-COR) and spectroradiometer (Apogee Instruments). Measurements were performed on three replications of each of the 10 colors. The interior of the integrating sphere was newly pressed BaSO₄ (barium sulfate) and was used as the reflection reference as described in the manufacturer’s instructions (LICOR 1800-12). The painted side of the transparency film faced the inside of the integrating sphere for the reflection reference and sample readings. For transmission sample and reference readings, the painted side of the transparency film faced the outside of the integrating sphere. The light source used to illuminate the integrating sphere was constant, but its location within the sphere varied between reference and sample readings as well as between reflection and transmission readings. Sample absorption was calculated as sample absorption = 1 – reflection – transmission.

In addition to PAR, broad- and narrowband spectral data were collected at specific wavelengths to determine effects on light quality. Broadband wavelengths were defined as 400 to 500 nm and 600 to 700 nm, and narrowband wavelengths were defined as 410, 430, 640, and 660 ± 10 nm. These bands are often grouped by color where blue light is considered to be 400 to 500 nm and red light is considered to be 600 to 700 nm. Within these bands, chlorophyll a is known to have peak spectral absorption at 410, 430, and 660 nm while peak absorption for chlorophyll b occurs at 430 and 640 nm (Bell et al., 2000). Measurements of reflection and transmission and calculations of absorption at each of these wavelengths were determined as previously described using the integrating sphere and spectroradiometer.

**Growth Chamber Experiments**

Growth chamber experiments were conducted at the Southeastern Plant Environment Laboratory at North Carolina State University in Raleigh, NC. Sixty pots were prepared with a 50:50 v/v sand and peat substrate based on the original “Cornell Mix” (Boodley and Sheldrake, 1972). The substrate was steam sterilized, placed into 15.8-cm diameter pots, and planted with washed Tifway bermudagrass sod, which was selected due to its
Table 1. Pantone Matching System (PMS) numbers for 10 colors of athletic field turf paint.

<table>
<thead>
<tr>
<th>Color</th>
<th>PMS number</th>
<th>Pigment</th>
<th>Pigment classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>202</td>
<td>Carbon black</td>
<td>Inorganic</td>
</tr>
<tr>
<td>Dark blue</td>
<td>287</td>
<td>Phthalocyanine blue</td>
<td>Organic</td>
</tr>
<tr>
<td>Green</td>
<td>349</td>
<td>Phthalocyanine green</td>
<td>Organic</td>
</tr>
<tr>
<td>Light blue</td>
<td>278</td>
<td>Titanium dioxide and phthalocyanine blue</td>
<td>Inorganic and organic</td>
</tr>
<tr>
<td>Maroon</td>
<td>202</td>
<td>Quinacridone magenta</td>
<td>Organic</td>
</tr>
<tr>
<td>Orange</td>
<td>158</td>
<td>Pyrazolone orange</td>
<td>Organic</td>
</tr>
<tr>
<td>Purple</td>
<td>2735</td>
<td>Carbazole violet</td>
<td>Organic</td>
</tr>
<tr>
<td>Red</td>
<td>186</td>
<td>Naphthol red</td>
<td>Organic</td>
</tr>
<tr>
<td>Yellow</td>
<td>124</td>
<td>Yellow iron oxide and pyrazolone orange</td>
<td>Inorganic and organic</td>
</tr>
<tr>
<td>White</td>
<td>Not applicable†</td>
<td>Titanium dioxide</td>
<td>Inorganic</td>
</tr>
</tbody>
</table>

†There is no PMS number for white paint.

widespread use on athletic fields. After sodding, the pots were placed into a growth chamber maintained at 29/24°C (day/night) with a 12 h photoperiod (0700 to 1900 h) and a photosynthetic photon flux density of approximately 1000 μmol m⁻² s⁻¹ provided by a combination of incandescent and fluorescent lamps. Water and nutrient solution were applied twice daily throughout the bermudagrass establishment period and then once daily during experimental periods to support adequate growth by preventing water or nutrient deficiencies. The “standard nutrient solution” is described in detail in the North Carolina State University Phytotron Procedural Manual (NCSU, 2011). Pots were mowed 1 d before paint application and 2 d after photosynthesis measurements at 2.5 cm using a handheld shear (194380 Oster Showmaster; Oster).

**Paint Application**

Before application of paint treatments, turf in all 60 pots was allowed to reach maturity, defined as uniform coverage and maximum density and quality, and then experimental units were randomly divided into two sets for replication over time. Each replicate experiment, referred to hereafter as Exp. 1 and 2, consisted of 10 colors of athletic field turf paint (Table 1) and three replications per color. Paint applications were made every 7 d for five consecutive weeks within each experiment, and Exp. 2 began after completion of Exp. 1. Paint treatments were applied to pots using a CO₂–pressurized sprayer with flatfan nozzles (Teetjet8004VS; Teetjet Spraying Systems Co.) calibrated to apply approximately 168 L ha⁻¹. This rate was achieved by four applications in multiple directions to each pot, which ensured uniform paint coverage on turfgrass leaves.

**Photosynthesis Measurements**

Carbon exchange rates were measured 24 h after each of five weekly paint applications and were determined by enclosing the turfgrass canopy in a transparent plexiglass chamber (956 cm³) connected to a portable gas exchange system (LI-6400; LI-COR Inc.). Measurements of C exchange rate were always taken between 1000 and 1500 h. Carbon exchange rates were measured in full light in the growth chamber and in total darkness immediately after light measurements were recorded (achieved by covering the plexiglass chamber with opaque black fabric). Measured C exchange rates under dark conditions were considered to represent canopy, root, and soil respiration. Total canopy photosynthesis was calculated by adding the absolute value of dark respiration to the observed C exchange rate in the light (Singh et al., 2011). Canopy temperature was measured immediately before enclosure of the turfgrass in the transparent plexiglass chamber using an infrared digital thermometer with an error range of ±3°C (Fluke 63IR; Fluke Inc.).

**Statistical Analysis**

Data from spectroradiometry and growth chamber experiments were subjected to ANOVA to determine treatment effects using SAS PROC GLM (SAS Institute, 2012). Total canopy photosynthesis and canopy temperature data produced significant treatment effects, but TCP also showed interactions with experiment. Therefore, TCP data from Exp. 1 and 2 were analyzed and presented separately with treatment × experiment interactions reported in the appropriate ANOVA table. Canopy temperature data showed no interaction with experiment and were therefore pooled for analysis. Treatments within all experiments were subjected to Fischer’s protected LSD test at the 0.05 probability level when F-tests indicated significant treatment effects. Pearson’s correlation coefficients were calculated using SAS PROC CORR (SAS Institute, 2012) to examine the relationship between TCP and reflection, transmission, and absorption of light at various wavelengths.

**RESULTS**

**Spectroradiometry Analyses**

Reflection, transmission, and absorption of PAR and light in the broad- and narrowband wavelengths were found to be different (P ≤ 0.001) for all colors (Table 2). Broadband spectroradiometry indicated that white paint reflected the highest amount of PAR and black paint reflected the least. Reflection of PAR varied strongly by color with white reflecting 92.6% followed by yellow (63.1%), light blue (51.6%), orange (47.0%), and red (41.2%) reflecting the highest amounts. Reflection of PAR by the darker colors was much smaller and included maroon (20.9%), green (11.9%), purple (10.7%), dark blue (6.8%), and black (4.5%) reflecting the least. Inversely, absorption of total PAR was much higher by the darker colors than the lighter colors, with black absorbing the most (95.4%) and white the least (0.0%). Transmission of PAR also varied by color, but the magnitude of differences was much smaller. Transmission ranged from 12.4 to 18.0% in the lighter colors white, yellow, orange, and red while in the darker colors maroon,
green, purple, dark blue, and black transmission ranged from 0.1 to 4.7%.

A comparison of spectroradiometry data in the 400 to 500 nm and 600 to 700 nm broadband wavelengths indicate the different impacts that pigments have within PAR. White and black did not vary as much by broadband wavelength, as can be seen in Table 2 where white reflected 91.8% of light between 400 and 500 nm and 94.1% between 600 and 700 nm while black paint reflected <5% of both, effects that aligned with those on overall PAR. However, all other colors varied greatly by broadband wavelength. Yellow, for example, reflected 76.1% of light between 600 and 700 nm but only 13.2% between 400 and 500 nm. Orange reflected almost 10 times more light between 600 and 700 nm than 400 to 500 nm while red reflected almost nine times as much. Green paint reflected light within 400 to 500 nm and 600 to 700 nm ranges at approximately equal amounts while light blue, dark blue, and purple were the only colors to reflect more light between 400 and 500 nm than 600 to 700 nm.

The effects of color on transmission of light were also wavelength dependent for all colors, yet the magnitude of differences between broadband wavelengths were much smaller within each color. The effects on absorption of light were also wavelength dependent in all colors except white and black and were inversely related to reflection, as expected. Although narrowband data are not presented, they support the broadband wavelength data in that differences in narrowband data based on color were similar to the reported differences in broadband data with regard to reflection, transmission, and absorption at all measured wavelengths.

### Growth Chamber Experiments

Reductions in TCP as a result of all paint treatments were different ($P \leq 0.0001$) in Exp. 1 and 2 despite an interaction between treatment and experiment ($P \leq 0.0006$) (ANOVA in Table 3). Experiment ($P = 0.6276$) and replication ($P = 0.8414$) were not different while week and treatment × week interaction were both different ($P \leq 0.0001$).

White paint proved to have the least impact on TCP of Tifway bermudagrass in both experiments (Fig. 2). Total canopy photosynthesis was maintained at 78% of the unpainted control throughout 5 wk in Exp. 1 and 83% in Exp. 2. Applications of yellow and orange paint resulted in higher TCP rates than all other colors except white in both experiments, ranging from 65 to 69% of the control in Exp. 1 and 71 to 75% in Exp. 2. Further reductions in TCP based on severity included red paint, which had TCP rates of 50 and 53% of the unpainted control in Exp. 1 and 2, light blue (48 and 47%), purple (36 and 33%), maroon (41 and 32%), green (26 and 25%), black (15 and 18%), and dark blue (13 and 8%).

Canopy temperature was influenced by paint color and was different ($P \leq 0.001$) within and across Exp. 1 and 2. Canopy temperature data for both experiments were
values of canopy temperature measurements ranged from 0.3°C in orange to 0.7°C in green.

Pearson's correlation coefficients in Table 4 and Fig. 3 define the relationship between PAR and TCP over the range of paint colors. In Exp. 1, TCP was most highly correlated with absorption of PAR ($r = -0.96, P \leq 0.001$) followed by positive correlations with reflection ($r = 0.93, P \leq 0.001$) and transmission of PAR ($r = 0.84, P \leq 0.001$).
In Exp 2, the correlations were similar. The correlations between TCP and the reflection, transmission, and absorption of light within the 600 to 700 nm wavelengths were approximately one and a half to two times higher than within the 400 to 500 nm wavelengths in both experiments. For example, in Exp. 1, Pearson’s correlation coefficient for TCP and reflection of 600 to 700 nm wavelengths (\(r = 0.95, P \leq 0.001\)) was more than twice as high as the correlation coefficient for TCP and reflection of the 400 to 500 nm wavelengths (\(r = 0.45, P \leq 0.05\)). Also in Exp. 1, Pearson’s correlation coefficient for TCP and absorption of 600 to 700 nm wavelengths (\(r = -0.93, P \leq 0.001\)) was also more than twice as high as the coefficient for TCP and absorption of 400 to 500 nm wavelengths (\(r = -0.45, P \leq 0.05\)). Pearson’s correlation coefficients for narrowband wavelengths and TCP support the relationships between broadband wavelengths and TCP (data not shown).

Canopy temperature increases as a result of paint color were most positively correlated with absorption of PAR in Exp. 1 (\(r = 0.87, P \leq 0.001\)) and Exp. 2 (\(r = 0.87, P \leq 0.001\)). Canopy temperature was negatively correlated with reflection and transmission of PAR and broadband wavelengths. Correlation coefficients for canopy temperature and reflection, transmission, and absorption were higher and more significant between 600 and 700 nm than between 400 and 500 nm in both experiments. Like TCP, data for correlations of canopy temperature and narrowband wavelengths supported the broadband data.

**DISCUSSION**

The hypothesis being tested in this research was that alterations in visible light by paint pigments to produce a specific color would be coupled with alterations in PAR and TCP within a painted turfgrass canopy. This hypothesis was based on the overlap of visible light and PAR between 400 and 700 nm as well as the requirement that all paints be opaque enough to adequately cover a leaf surface. Each of these has the potential to reduce total PAR as well as “filter” wavelengths within PAR reaching leaf surfaces.

The results of the spectroradiometry analyses and the measurement of TCP of Tifway bermudagrass clearly support this hypothesis. A significant negative correlation was present between absorption of PAR and Tifway bermudagrass TCP over the broad range of colors examined. Darker colors absorbed a larger proportion of PAR, resulting in greater suppression of TCP. Therefore, it is reasonable to conclude that alterations in the amount of light reaching the leaf surface and inhibited TCP are a major cause of suppressed growth and subsequent declines in turfgrass health when painting occurs. Furthermore, it would be expected that darker colors lead to greater damage to turfgrass health over extended periods. This is supported by observations of the clipping collections throughout both experiments. Darker colors had more suppressed growth than lighter colors, particularly in the later weeks of both experiments. This likely results in less paint being removed through mowing as a result of less vertical growth, more paint remaining in the turfgrass canopy, and thus more shading. Attempts to collect and weigh clippings for analysis by color were unsuccessful due to the inability to separate clippings from paint residue.

In addition to the effects of shading, another potential factor contributing to lower TCP may have been increased plant and root respiration rates caused by increased canopy temperatures. Leaf canopies painted with darker paint colors had higher canopy temperatures, and it is generally understood that respiration increases with temperature until 40 to 50°C (Taiz and Zeiger, 2010).

Increases in respiration as a result of increased canopy temperatures based on paint color could potentially contribute to the observed reductions in TCP given that TCP was calculated by adding the absolute value of dark respiration to the observed C exchange rate in the light.
Figure 3. Correlations of reflection, transmission, and absorption of photosynthetically active radiation (PAR) (400–700 nm) with normalized total canopy photosynthesis (TCP) rates of Tifway bermudagrass 24 h after application of 10 colors of athletic field paint during two 5-wk experiments in a controlled environment growth chamber. Values for TCP were averaged over 5 wk and are reported as percent of unpainted control.
However, an analysis of dark respiration data used for TCP calculations minimize that possibility as a confounding variable in painted turfgrass canopies. Dark respiration data indicate that respiration actually increases in canopies painted with darker colors, despite any implications that respiration rates may increase as a result of increased temperature. This likely reflects the dependence of respiration on concurrent photosynthesis and its supply of carbohydrate.

Our results with paint are somewhat analogous with those from shading studies (e.g., Bell et al., 2000; McBee, 1969; Ngouajio and Ernest, 2004; Trappe et al., 2011). More specifically, Baldwin et al. (2009) found that shade fabrics filtering wavelengths from 360 to 720 nm reduced warm season grass clipping yields by as much as 79%. Decreases in Tifway bermudagrass quality were wavelength dependent, with yellow and red shade cloth less damaging than cloth that was blue or black. For example, blue shade cloth that allowed only passage of blue light for 1 and 4 wk resulted in lower visual quality ratings than yellow and red shade cloths that only allowed passage of yellow and red light. After 8 wk of filtered light, blue and yellow shade cloths resulted in lower visual quality ratings than red shade cloths. These results indicate the importance of red light on the health of Tifway bermudagrass. Pearson’s correlation coefficients presented in Table 4 support this in that TCP of Tifway bermudagrass was less affected by paint colors that absorbed a higher percentage of blue light as opposed to red light. For example, darker colors including black, dark blue, purple, and green absorbed the highest percentage of red light and also had the greatest impacts on TCP, in addition to maroon. Inversely, lighter paint colors including white, yellow, and orange that reflected the highest percentage of red light were the least harmful to TCP.

Spectroradiometry data presented in Tables 2 and 4 indicate the ability of paint to selectively absorb wavelengths within PAR, and are important for several reasons. First, they accurately represent the expected properties with regard to the pigments used to produce a specific color, that is, blue paints reflect more blue light than red light, red paints reflect more red light than blue light, etc. Second, previous research has shown that various sources of shade can selectively alter wavelengths within PAR, red:far-red ratios, etc. (Baldwin et al., 2009; Bell et al., 2000). This supports the notion that various colors of paint can also create various shading effects much like varying tree species, buildings, etc. create various shading effects. Lastly, while blue light is important in many plant growth processes, red light is more often associated with photosynthetic processes including the enhancement effect and the red light response to stomatal opening (Taiz and Zeiger, 2010; Shimazaki et al., 2007).

In other types of studies with cotton (Gossypium hirsutum L.), higher reflection of PAR had positive effects on plant growth when plastic surfaces painted white were placed beneath canopies (Kasperbauer, 2000). Similarly with carrot (Daucus carota L.), lighter colored plastic mulches had greater benefits than darker mulches (Antonious and Kasperbauer, 2002). With athletic field tarps covering ‘Midnight’ Kentucky bluegrass (Poa pratensis L.) at different times during the year, Minner et al. (2001) found that orange, white, yellow, and red tarps consistently had the most positive effects on turf color after tarp removal while darker colored tarps were much more injurious. Goatley et al. (2007) showed that various colored tarps altered PAR available for use on ultradwarf bermudagrass putting greens where black, green, gray, white, and translucent tarps reduced PAR by 91 to 99%, 69 to 79%, 36 to 49%, and 34%, respectively. It is worth mentioning that increased temperatures as a result of all tarps, especially the darker colored tarps, have the potential to confound shading effects in a manner that is different from painted turfgrass canopies given that paint and tarps cover the turfgrass canopy by different means. However, the effects of different colored tarps on turfgrass health are consistent with results from our paint experiments and illustrate the dependence on color.

Ultimately, the key for understanding color effects on PAR lies within the optical properties of the pigments that produce different colors. Pigment sources for athletic field paints include both organic and inorganic sources, each of which contribute various properties with regard to color and application. Pigment classification in this paper will be defined using the traditional properties associated with organic and inorganic pigments as defined by Lambourne and Strivens (1999).

Inorganic pigments possess excellent hiding power, extreme fastness to light and weathering, and excellent color stability (Endrib, 1998). They also produce various optical effects through nonselective or selective reflection and absorption of light. The extreme reflectiveness of white is produced by the nonselective scattering of visible light by the base pigment TiO2, which is recognized as having the highest brightening power of all industrially produced pigments (Stoye and Freitag, 1998). In contrast, the extremely high absorption (>95%) of visible light and PAR by black is characteristic of the nonselective inorganic pigment carbon black (Buxbaum and Pfaff, 2005). Carbon black is so effective at absorbing light that it comprises approximately only 10% of the paint formulation (v/v) whereas other colors contain as much as 31% pigment (v/v). Therefore, even at the lowest pigment concentration of any color tested, black was still capable of absorbing the highest amount of visible light based solely on the optical properties of black pigments.

Unlike with white and black, colors such as red and yellow that are derived from inorganic pigments selectively reflect and absorb light in a wavelength-dependent manner (Herbst and Hunger, 2004). Yellow Fe2O3, for example, is known to reflect up to three times more light in the longer wavelengths than in shorter wavelengths (Endrib, 1998), as was seen in the spectroradiometry measurements (Table 2).

Regardless of reflective and absorptive properties, many inorganic pigments such as TiO2, carbon black, and
Fe$_2$O$_3$ are limited in the range of colors they can produce. Furthermore, most inorganic pigments lack tinting strength and therefore produce dull shades when added to white to produce various colors (Herbst and Hunger, 2004). Therefore, organic pigment sources are often incorporated to produce colors that inorganic sources alone cannot (Table 1). For example, colors used in this study that contain both organic and inorganic pigment sources include light blue (TiO$_2$ and phthalocyanine blue) and yellow (yellow Fe$_2$O$_3$ and pyrazolone orange).

Spectroradiometry analysis of each of the paint colors tested in this study accurately represents the reflection and absorption characteristics one would expect based on the pigment properties found in each color. Furthermore, low transmission (relative to reflection and absorption) accurately represents the fact that all paints, regardless of color, must meet the basic opacity requirement of blocking enough visible light to hide the turfgrass leaf.

The results presented in these experiments illustrate the color-dependent relationship between available PAR and subsequent TCP within painted turfgrass canopies. This is a direct result of the fact that visible light and PAR overlap between 400 and 700 nm and therefore any alterations by paint pigments to produce a specific desired color are also very likely to impact PAR and turfgrass growth. Reflection and transmission of PAR by lighter colors of paint is likely still available for use within the turfgrass canopy in areas with cracked leaf surfaces or partial paint coatings as well as on abaxial leaf surfaces and lower portions of the canopy that may not have received paint. Furthermore, as painted turfgrasses are mowed, reflection and transmission of PAR by lighter colors of paint can be useful for photosynthesis in newly formed, unpainted leaves. However, the overwhelming ability of pigments found in darker colors of paint to absorb PAR create such a profound shading effect that it is unclear how damage to painted turfgrass can be avoided when using these colors. Further research is needed on paint application techniques, rates, and product selection as well as turfgrass management strategies that may reduce the amount of time leaves remain painted, thus reducing duration under shade.

Acknowledgments

The authors of this paper would like to gratefully acknowledge George Sajner, technical director for Pioneer Manufacturing Company for his intellectual input as well as product support throughout this research.

References


