CHAPTER 1

SPECTRAL IRRADIANCE AVAILABLE FOR TURFGRASS GROWTH IN SUN AND SHADE

ABSTRACT

The spectral quality of solar irradiance may affect plant growth and development. Light energy reductions and spectral quality adjustments in shaded environments have detrimental effects on both morphological and physiological characteristics of turfgrass. Little research has addressed spectral irradiance in shade for the past 30 years. The purpose of this study was to assess the spectral quality of deciduous shade, coniferous shade, building shade, and full sun in a natural turfgrass environment throughout the growing season in Columbus, OH. A spectroradiometer was used to scan the solar spectrum in these four light environments between 300 and 850 nm wavelength in 5 nm increments on an hourly basis from 7:30 AM to 7:30 PM, bi-weekly, from the vernal equinox to the autumnal equinox at The Ohio State University Turfgrass Research Center. Scans were also made in the shade of industrial shade cloth and compared to other shade environments. No significant
difference was found in photosynthetic light quality [(red light + blue light) / green light] among coniferous, deciduous, and building shade or among tree shades and shade cloth. Significant differences were detected among full sun, tree shade, and building shade, for blue photoreceptor potential (far red light / blue light) and for phytochrome potential (far red light / red light). Results indicated that the relationship of blue, red, and green light is not significantly affected by shade but that receptor pigments affecting many plant processes may be differentially affected by shade and full sun and by different shade types. This study provides information concerning the quality of light in the shaded environment that can be useful to turfgrass managers, but more importantly, to turfgrass researchers in the pursuit of model systems for turfgrass health that balance the use of trees and turfgrass in the landscape.
Solar irradiance available for turfgrass growth occurs in a spectral band from 400 to 700 nm wavelength and is referred to as photosynthetically active radiation (PAR)(Figure 1.1). Plant pigments, including chlorophylls and carotenoids, absorb light at specific wavelengths. Chlorophyll a has peak spectral absorption at approximately 410, 430, and 660 nm (French 1961). Chlorophyll b absorbs most effectively at 430, 455, and 640 nm and carotenoids, including xanthophylls, absorb best at approximately 450 nm. Phytochrome, a pigment implicated in cell elongation, chloroplast development, and carotenoid biosynthesis (Harding and Shropshire 1980) absorbs wavelengths preferentially near 730 nm (Grant 1997). Using these findings, PAR can be divided into active and inactive wavelengths based on pigment absorption bands. PAR from 400 to 500 nm, referred to as blue light (B), and PAR from 600 to 700 nm referred to as red light (R), is active for photosynthesis, photomorphogenesis, and chlorophyll synthesis (Blackwell 1966). PAR from 500 to 600 nm, referred to as green light (G), is basically inactive for plant growth and development.
Shade, regardless of the shade source, reduces PAR and affects plant photosynthesis (Figure 1.1). Low light intensities and other components of the shaded environment such as tree root competition and restricted air movement result in morphological and physiological conditions detrimental to turfgrass growth (Dudeck and Peacock 1992). The severity of these conditions may be affected by low levels of irradiance, by spectral quality of irradiance, or both.

Light quality, the proportions of spectra included in available irradiance, may have significant effects on turfgrass health. McBee (1969) reported that growth of bermudagrass (*Cynodon dactylon* L.) improved when B was present and R was filtered compared to R present and B filtered. McKee (1963) used a color temperature meter to characterize light quality in the shade of buildings, the shade of tree canopies, and the shade of herbaceous plants. Blue light in comparison to red light was enriched in the shade of a deciduous tree canopy and in the shade of a building, but declined in the shade of conifers and in herbaceous shade. Gaskin (1965), using a similar instrument, found no difference between light quality under green saran shade cloth and light quality in tree shade providing the shade cloth used resulted in light reductions between 25 and 75% full sun. Yet, it was suggested that building shade filtered less blue light than oak (*Quercus* sp.) and maple (*Acer* sp.). Vezina et al. (1966) demonstrated a reduction in red and blue wavelengths and a proportionate increase in green and far red wavelengths under a deciduous forest canopy but
found a neutral shade with respect to light quality under a coniferous forest canopy. The results of these studies appear contradictory in some cases.

Many research projects attempt to study the effects of shade using industrial shade cloth to create light reductions. Shade cloth of neutral color does not affect light quality in relation to full sun (McMahon et al. 1990) and may not differ considerably from the shade of trees (Gaskin 1965). Little research has been done concerning light quality in shade since the 1960's and much of this research was done using light temperature meters which only assess quantities of blue and red light. More recent research has focused on assessing light quality within tree canopies (Grant et al. 1996; Gilbert et al. 1995) or within forests (Turnball and Yates 1993; Baldocchi et al. 1984). Because of the influence of diffuse light, which may strike the earth's surface at almost any angle infiltrating the shade created by a single tree or small group of trees, and because of reflection occurring within a tree canopy, assessment of light quality within tree canopies is not consistent with light quality beneath the canopy. Few plants are adapted for growth in forests and the absence of diffuse light in forest environments is not consistent with light quality in shaded situations where horticultural plants are grown. Sophisticated equipment is now available for the measurement of light spectra and may provide more definitive results than those previously demonstrated. In addition, recent research has implicated relationships between phytochrome and an unknown blue light receptor, often
called cryptochrome, which affect many plant processes. The purpose of this study was to assess the spectral quality of deciduous shade, coniferous shade, building shade, and full sun in a natural environment common to turfgrass growth throughout the growing season in Columbus, OH.
MATERIALS AND METHODS

Spectral irradiance data were collected using a model LI-1800 spectroradiometer (LiCor, Lincoln, NE) hourly from 7:30 AM to 7:30 PM, bi-weekly, from the vernal equinox to the autumnal equinox in 1997. Scans were made at The Ohio State University Turfgrass Research Center beginning April 11, 1997 and ending September 10, 1997. Deciduous trees were in full leaf beginning with scans made on June 6, 1997 and comparisons among deciduous, coniferous, and building shade were made after that date. Data collected beginning April 11, 1997 were used for comparisons not involving deciduous shade.

Scans were made in the shade of a single tree or building and in full sun at the same location each time and in the same order each hour. Scans were made so that direct solar irradiance was measured after passing through approximately the same portion of the canopy each time. The distance from the trunk of the tree where scans were made varied with the height of the sun in the sky at the time of scanning. During solar noon, scans were made very close to the trunk of the tree providing shade. At this time, direct radiation was required
to pass through a large portion of the tree canopy before reaching the detector. In the early morning or late afternoon, scans were made much farther from the tree and the canopy density filtering direct solar radiation was somewhat reduced because of sun angle. The trees used were a Norway spruce (*Picea abies*), approximately eight meters tall, and a black walnut (*Juglans nigra* L.), approximately 10 m tall. Sunny or cloudy weather was considered a random occurrence and a part of the natural environment and scans were made regardless of cloud conditions. Scans were not made during periods of rain because moisture could affect the accuracy of the sensing mechanism.

Scans were also made in the shade of black industrial shade cloth (Chicopee, Gainesville, GA) resting on structures constructed of polyvinyl chloride pipe at the Turfgrass Research Center. Two of these structures were vertical and covered with shade cloths rated for 80% light reduction or 100% light reduction. A third structure was covered on top and on two sides with shade cloth rated at 80% light reduction. Each of these structures were replicated three times. Scans were made twice, morning (AM) and afternoon (PM), on July 15, July 29, and August 26, and once on June 5 (PM), and July 2 (AM) for a total of eight replications. Data from these scans were averaged over the three structural treatments and compared to scans of deciduous shade, coniferous shade, and the shade of a partial red brick and partial white aluminum building under variable skies.
Data for all scans were collected for total photosynthetic photon flux density (PPFD) and for radiant energy from 300 to 850 nm wavelength in 5 nm increments. Photon flux density (PFD) was calculated for B from 400 to 500 nm, for G from 500 to 620 nm, and for R from 620 to 680 nm. These spectral ranges identified active (R + B) and inactive (G) light based on spectral absorption of plant pigments (Figure 1.2). Peak absorption of phytochrome occurs at approximately 730 nm so a range from 710 to 750 nm was used to evaluate FR. Analyses of variance were performed to compare photosynthetic potential [(B + R) / G], blue photoreceptor potential (FR/B), and phytochrome potential (FR/R) in deciduous, coniferous, and building shade. Time of day and month were used as blocking criteria to limit variation due to daily and seasonal changes in spectral intensity and quality. Mean light responses were separated using least significant difference. Significance was tested at the P < 0.05 level for all analyses.
RESULTS AND DISCUSSION

Changes in PPFD occurred parabolically throughout each day (Figure 1.3). Irradiance increases slightly after solar noon. Conversely, this study demonstrated a nonsignificant decline in irradiance after solar noon probably due to increasing cloud cover. The average PPFD for 2, 3, and 4 h before solar noon throughout the study was 23,710,861 \( \mu \text{mol s}^{-1} \text{m}^{-2} \) and for 2, 3, and 4 h after solar noon was 18,983,792 \( \mu \text{mol s}^{-1} \text{m}^{-2} \). Continental climates, such as that in Columbus, OH, tend to have more cloud cover in the afternoon compared to cloud cover in the morning during the growing season. Cloud cover scatters light and may affect light quality (Salisbury and Ross 1992). Over the season and in full sun, B compared to PPFD was significantly less in the morning (0.197) than in the afternoon (0.205); G was basically the same (AM = 0.538; PM = 0.539); R proportion was significantly greater in the morning (AM = 0.266; PM = 0.255); and FR proportion did not change (AM = 0.120; PM = 0.118). (B+R)/G and FR/R were unaffected by time of day but FR/B decreased significantly in the afternoon compared to the morning. This decrease in FR/B is consistent with results predicted for cloud cover. Under cloud cover, B irradiance was proportionately
higher than under clear sky due to increased diffusion and cloud reflection and FR was proportionately lower due to absorption of FR by water vapor. Because cloud cover did not significantly effect FR/R levels and because B during daylight is in a saturating condition for blue photoreceptors, these differences between light quality in the morning and in the afternoon were not considered to have major impacts on plant development. Persistent periods of cloud cover, however, may affect photosynthetic production if light levels fall below light compensation points for desirable plant species (Figure 1.3).

During the course of the study, PPFD in deciduous shade averaged 61% of PPFD in full sun, coniferous shade was 16% of full sun, and building shade was 23% of full sun. PPFD under vertical shade structures covered with 80% shade cloth averaged 35% of PPFD in full sun. Under vertical shade structures covered with 100% shade cloth the average PPFD was 27% of full sun and under structures covered on top and two sides with 80% shade cloth, the average was 20% of full sun. (B+R)/G and FR/B did not vary among deciduous, coniferous, building, and shade cloth treatments but FR/R showed significant variation (Table 1.1). There was no variation in PAR among deciduous shade, coniferous shade, and shade cloth supporting Gaskin (1965) but variation was detected between coniferous shade and shade cloth for levels of FR/R not considered by that study. Because of this variation, shade cloth did not accurately mimic tree canopy shade. Increases in phytochrome r which are likely
to occur in coniferous shade may not occur in the shade of industrial shade cloth. The results for this test did not indicate the variation expressed in the season-long study among full sun, deciduous shade, coniferous shade, and building shade (Table 1.2) possibly because replication was not sufficient to reduce experimental error.

Scans made from June through September at the Turfgrass Research Center indicated that \( \frac{B+R}{G} \) did not vary among deciduous shade, coniferous shade, building shade, and full sun, but \( FR/B \) and \( FR/R \) varied significantly (Table 1.2). These results suggest that all shade treatments created a spectral environment conducive to photosynthesis. Photosynthesis, however, may be affected directly (Eskins et al. 1991) or indirectly by the relationship between blue light photoreceptors and phytochrome in shade. Graphic analysis of deciduous, coniferous, and building shade (Figure 1.4) suggested variation between light quality in these shade environments compared to full sun. In each shade type, the proportion of \( B \) increased compared to full sun, the proportion of \( G \) remained the same, \( R \) proportion declined, and \( FR \) increased.

Full sun contained significantly higher \( FR/B \) and significantly lower \( FR/R \) than any of the shade treatments. \( FR/B \) was significantly higher in full sun than in coniferous or deciduous shade and these tree shades contained significantly higher \( FR/B \) than building shade. \( FR \) increased in intensity in relation to \( R \) in the shade of a plant canopy compared to the shade of a building and to full sun and
all shade treatments contained higher levels of FR/R than full sun (Table 1.2). Recent research has demonstrated that starch and sucrose synthesis and degradation (Doelger et al. 1997; Dewdney et al. 1993), nitrate uptake, reduction, and utilization (Teller et al. 1996; Kamiya 1995; Lopez-Figueroa and Ruediger 1991), stem and hypocotyl elongation (Ahmad and Cashmore 1997; Casal and Sanchez 1994; McMahon et al. 1991), leaf area expansion (Eskins 1992; Van Volkenburgh et al. 1990), and cell division (Furuya et al. 1997; Zandomeni and Schopfer 1993; Muenzner and Voigt 1992) are affected by the proportions of B, R and FR in the light environment, but these relationships have not been fully elucidated. An antagonistic relationship is believed to exist between blue photoreceptors and phytochrome, often dominated by the blue photoreceptors. The extent of that domination is currently unknown but the results of this study demonstrated that reasonable evidence exists to indicate differential plant metabolism in shade compared to full sun and in building shade compared to tree shade.

Light quality did not vary among deciduous, coniferous, and building shade with respect to photosynthetically active radiation. Photosynthetically active radiation did not differ significantly in spectral quality between industrial shade cloth and normal shade environments but may vary in FR content. The proportion of FR/B varied among full sun, coniferous and deciduous shade, and
building shade. Proportions of FR/R were highest in the shade of a plant compared to the shade of a structure.

This study provides information concerning the quality of light in the shaded environment that can be useful to turfgrass managers, but more importantly, to turfgrass researchers in the pursuit of model systems for turfgrass health that balance the use of trees and turfgrass in the landscape.


Bell, G.E. 1997. Temporal Shade on Creeping Bentgrass Turf. Dissertation. The Ohio State University, Columbus, OH.


Table 1.1. Means of active in relation to inactive light [(B+R)/G], blue light receptor potential (FR/B), and phytochrome potential (FR/R) for spectroradiometric scans made on June 5 (PM), July 2 (AM), July 15 (AM and PM), July 29 (AM and PM), and August 26 (AM and PM) in Columbus, OH. Scans were made in the shade of industrial shade cloth, coniferous shade, deciduous shade, building shade and full sun. Letters following treatment means indicate significance (P = 0.05). B refers to photon flux density (PFD) between 400 and 500 nm wavelength. G is PFD between 500 and 620 nm and R is PFD between 620 and 680 nm. FR represents PFD between 710 and 750 nm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(B+R)/G</th>
<th>FR/B</th>
<th>FR/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>0.8801 a</td>
<td>0.5778 a</td>
<td>0.5595 a</td>
</tr>
<tr>
<td>Coniferous</td>
<td>0.8724 a</td>
<td>0.5545 a</td>
<td>0.5165 ab</td>
</tr>
<tr>
<td>Deciduous</td>
<td>0.8708 a</td>
<td>0.5331 a</td>
<td>0.4764 b</td>
</tr>
<tr>
<td>Cloth</td>
<td>0.8603 a</td>
<td>0.4993 a</td>
<td>0.4606 b</td>
</tr>
<tr>
<td>Full Sun</td>
<td>0.8521 a</td>
<td>0.4478 a</td>
<td>0.4479 b</td>
</tr>
</tbody>
</table>

P = 0.08  P = 0.19  LSD = 0.69
Table 1.2. Means of active in relation to inactive light [(B+R)/G], blue light receptor potential (FR/B), and phytochrome potential (FR/R) for spectroradiometric scans made hourly from 7:30 AM to 7:30 PM on a bi-weekly basis in Columbus, OH from the vernal equinox to the autumnal equinox. Scans were made in coniferous shade, deciduous shade, building shade and full sun each hour. Letters following treatment means indicate significance (P = 0.05). B refers to photon flux density (PFD) between 400 and 500 nm wavelengths. G is PFD between 500 and 620 nm and R is PFD between 620 and 680 nm. FR represents PFD between 710 and 750 nm.
Figure 1.1. Solar radiant energy graphed according to wavelength in full sun and in building shade on a clear day. The white area displays photon flux density in full sun. The black area displays photon flux density in the shade of a building and is graphed over levels of full sun for visual comparison. Notice the severe restriction of irradiance available in building shade compared to full sun.
Figure 1.2. Spectral composition of plant pigments in creeping bentgrass (Agrostis palustris Huds.) leaf tissue extracted in 80% (v/v) acetone. The spectrum was identified in 1 nm increments using a Cary 3E spectrophotometer. Peak absorption of pigments may vary depending on the solvent used for extraction.
Figure 1.3. Photosynthetic photon flux density (PPFD) under variable skies in Columbus, OH. Measurements in full sun, deciduous shade, coniferous shade, and building shade are displayed hourly from 7:30 AM to 7:30 PM. Hourly results are averaged over 12 spectral scans made biweekly from vernal equinox to autumnal equinox.
Figure 1.4. Solar irradiance in deciduous, coniferous, and building shade displayed by wavelength and as a proportion of irradiance in full sun. Radiant energy at each wavelength in shade was divided by radiant energy in full sun. A horizontal line would indicate no change in light quality between sun and shade. Irradiance was averaged over 146 spectral scans made hourly from 7:30 AM to 7:30 PM, bi-weekly, from vernal equinox to autumnal equinox in Columbus, OH.