PROTECTION COVERS FOR TRAFFICKED TURF

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Abstract

Large public events, such as concerts, rallies, and festivals, impact turf health when held on natural turfgrass surfaces. The impact associated with these events is due to the placement of physical structures such as stages and seating areas and pedestrian and vehicular traffic on the turf surface. Trafficked turf protection covers, which are field covers meant to be placed directly on the turf surface where pedestrian or vehicular traffic is expected and/or equipment will be placed, can be used to minimize damage to the turf surface. Scientific data on turf response to these covers is lacking. Four cover treatments comprised of a non-covered non-trafficked control, plywood, plywood + Enkamat Plus, and white high-density polypropylene [single sided (Terratile) or double sided (Matrax)] were applied to tall fescue (*Festuca arundinacea* Schreb.) and effects of light intensity, duration of covering, season and soil moisture were evaluated. Growth chambers and field experiments were conducted in 2010-2011. Tissue samples were taken in growth chambers experiments every four days over the 20-day period to analyze chlorophyll (Chl *a,* Chl *b,* Chl *a+b*) and carotenoids (carot) under split factors of light intensity (12hr, PAR 530 μmol m^{-2} s^{-1}, 5 μmol m^{-2} s^{-1}) and soil moisture (50%, 75% of pot soil moisture capacity). Field trial treatment effects were observed every two days and eight days after cover removal in the spring, summer and fall and a normalized difference vegetative index (NDVI) measure was used at the conclusion of each trial period to confirm visual ratings. Covers that allowed light transmission to the canopy provided the best visual retention of percent green cover and higher contents of Chl *a,* Chl *b,* Chl *a+b* and carot. However, when treatments were tested under conditions that simulated low light under a concert stage (PAR 5 μmol m^{-2} s^{-1}), covers performed similarly. Moderate soil moisture increased Chl *b* and carot content under covers. Field trials showed that plywood and plywood + Enkamat allowed for acceptable covering periods of six days in spring, four days in fall, and zero days in summer. Summer conditions shortened the number of days (8 -10) that tall fescue could be covered with Matrax and Terratile and still maintain an acceptable level of green cover. Matrax performed the best during high temperatures and did not tend to sink into the turf in saturated soil. All covers exhibited desirable qualities and limitations that should be considered for turf protection during an event.

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Introduction

Large public events, such as concerts, rallies, and festivals, impact turf health when they are held on natural turfgrass surfaces. The impacts associated with these events are due to placement of physical structures such as stages and seating areas, and pedestrian and vehicular traffic on the turf surface. For example, large concerts are often held on sports fields during the playing season, damaging the playing surface (Figure 1). Reestablishing turfgrass can be problematic, either because of the limited time available to reseed or the difficulty in establishing a level, stable, rooted, and safe surface from new sod (Henderson et al., 2009). Therefore, minimizing turf damage before, during, and after public events is important to facility managers and owners.

Trafficked turf protection covers, which are rigid covers meant to be placed directly on the surface where pedestrian or vehicular traffic is expected and/or equipment will be placed, can be used to help minimize damage (Cockerham, 1994). Traffic stress to turfgrass is caused primarily by wear and soil compaction. Wear injury occurs from tearing and abrasion from traffic on aboveground plant parts (Beard, 2006; Shearman and Beard, 1975), while soil compaction has an indirect influence on plant responses by altering soil physical characteristics (Carrow, 1980). When turf protection covers are used, direct wear injury does not occur, although soil compaction may still occur. The protective surface of the cover creates other stressors, such as restricted airflow and blocked or restricted moisture and irradiance infiltration. Typically these covers are placed on the turfgrass for four to eight days, with some events or festivals lasting up to 20 days.

In general, four types of trafficked turf protection covers are currently commercially available, either used singly or in combination: plywood, polyester mesh fabric, single-sided plastic covers, and double-sided plastic covers. Plywood over a polyester mesh fabric does not allow irradiance transmission, while single-sided and double-sided plastic covers transmit varying levels of light. The use of each type of cover is typically situation-dependent. For example, covers that do not allow irradiance are used under stages while covers that allow irradiance are typically used for seating areas. Limited studies have been conducted on turfgrass response after various covering time periods.

Researchers at the University of Connecticut investigated soil compaction associated with the use of certain turf protection covers (Tencza and Henderson, 2011). They compared the use of plywood, plywood over a polyester mesh fabric, and double-sided plastic covers to a control (no cover) on a mixed stand of Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) in May 2010. Soil compaction and turfgrass quality were evaluated after being covered for three, six, or nine days. Traffic was simulated with a dump truck (213 kPa) by traveling over the covers 10 times at the beginning and end of each trial period. The actual ground force exerted from this dump truck was not presented, however the ground force is roughly equal to the tire inflation pressures (Thompson and Sorvig, 2000). Increasing the tire size while maintaining the same tire inflation pressure increases the compaction at greater depths (Fang, 1991). However, this study showed that these covers prevented compaction two to three times better than the control. Double-sided treatments performed slightly worse than plywood in terms of soil compaction prevention; they performed best in terms of post-cover turfgrass quality. When combining post-cover quality and compaction prevention, the double-sided cover performed the best overall. According to this study, soil compaction is not the limiting factor affecting turfgrass quality after cover removal.

In addition to soil compaction, lack of air circulation has been postulated to be the problem to covered turf. Airflow is important to turfgrass health because it allows for the cooling effect of transpiration, reduces soil moisture, promotes carbon dioxide exchange, and redistributes heat (Koh et al., 2003). Some of the covers, such as the polyester mesh fabric and the single-sided solid covers, allow for airflow beneath the protective surface, while other systems do not (Tompkins et al., 2008). The University of California conducted a study evaluating plywood and plywood over a polyester mesh fabric as protection covers under vehicular traffic (Cockerham, 1994). All covers were evaluated for two or four days. A forklift (690 kPa) simulated traffic by driving over the plots 20 times per day for each experimental period. Two post-cover irrigation strategies were also evaluated. Plywood over mesh slightly enhanced turf quality following removal when compared to plywood alone in both irrigated and non-irrigated treatments after cover removal. Overall, the protection covers provided an option for heavy traffic to pass over the turfgrass surface compared to the control.

In addition to soil compaction and lack of air when turf is covered, lack of irradiance is a contributing factor to turf damage. The quantity and quality of light is the most vital factor under no- or low-light conditions for turfgrass survival (Harrison, 1934; Wherley et al., 2005). For example, different types of blankets used on turfgrass for fall frost and winter cold protection have been evaluated with respect to turf quality in the spring

(Goatley et al., 2007a; Goatley et al., 2007b; Goatley et al., 2009; Minner et al., 2001; Roberts, 1984). Blankets that allowed more transmission of photosynthetically active radiation (PAR), wavelengths of light between 400 and 700nm (Monteith, 1959), resulted in a better quality turf in the spring. However, PAR increase can led to extreme heating potential that might limit use for long-term coverings into late spring (Goatley et al., 2009). A major component of turfgrass heat load is absorbed irradiance (Beard, 2006). Plant temperature is primarily dependent on relative rates of irradiance absorption and energy loss by re-radiation when transpirational cooling is impaired and convectional cooling is minimal (Pessarakli, 2008). Heat and drought stress on turfgrass often occur together. Since turf under covers cannot be irrigated when in place, heat accumulation due to solar radiation and soil moisture availability can become a very important factor affecting turf quality.

Other studies investigating winter survival of plants found that solid ice is nearly impervious to respiratory gas exchange (Rakitina, 1965) and consequently has the potential to induce severe anoxia. Field survival rates are known to increase when plants are illuminated at low levels during the ice encasement period (Andrews, 1996). After ice melt, illuminated plants had greater freezing tolerance than plants frozen in the dark (Andrews and Pomeroy, 1989). Evidence of oxygen generation by photosynthesis indicates that survival is promoted by small amounts of transmitted light. Light intensity also affects levels of total adenylates (ATP, ADP and AMP) and adenylate energy charge in plant cells. Differences were seen at after two days and five days of ice encasement, with large differences in survival between the treatments noted and greater total adenylate levels in plant tissues treated with light (Andrews, 1996; Andrews and Pomeroy, 1989).

LIGHT ENERGY

Approximately one to five percent of the total solar energy reaching earth is utilized for photosynthesis (Cooper, 1970). During photosynthesis, light energy from the sun is converted into chemical energy by photoautotrophic plants. Respiration is the process by which the plant releases energy stored in the chemical bonds produced by photosynthesis (Bell, 2011). Respiration takes in oxygen (O_2) and gives off carbon dioxide (CO_2), whereas photosynthesis takes in CO_2 and gives off O_2.The intensity of light at which the rate of CO_2 uptake equals the rate of CO_2 released by respiration is referred to as the light compensation point. The rate of CO_2 uptake by plants generally increases proportionally to the amount of solar energy (Fang and Moncrieff, 2001). In addition, a plant that is not under stress conditions, such as drought, shade, or heat, absorbs more CO_2 than is produced during respiration.

The process of respiration requires a carbohydrate (preferred) or other form of chemical energy (such as lipids and proteins) (Plaxton, 1996). In optimal growing conditions, carbohydrate reserves are utilized for respiration at night (or in shaded conditions) (Plaxton, 1996). Carbohydrate reserves can also become depleted at high temperatures due to increases in the rate of respiration.

LEAF ORIENTATION

Light transmission through a turfgrass canopy to the soil varies from 15 to 30% in reduction (Angstom, 1925). The relative degree of light absorption and reflection is affected by the orientation of the leaf surface to incident radiation. On a diurnal basis, light penetration into the turfgrass canopy is at its greatest near midday (Brougham, 1958). Under full sunlight, less than 25% of the light absorbed by the upper surface is utilized in photosynthesis, with the majority of the residual excitation energy being dissipated thermally. A greater fraction of light absorbed by the lower surface of the leaf is utilized in photosynthesis, ranging from one-third to more than two-thirds of the total energy absorbed (Adams et al., 1996). The stand geometry of most dense turfs is primarily an upright leaf orientation that is not typically favorable for light absorption. Mowing, vertical mowing, and grooming (mat drag, brushing, sweeping, and blowing) are designed to enhance this type of growth habit since dense, vertical leaf growth is desired for high turfgrass quality (Beard, 2006). When oriented vertically, only the uppermost leaves in turfgrass populations are fully exposed to the incident solar radiation. Turfgrass leaves with a semi-vertical orientation are exposed to considerable light intensity variation along their length. Light absorption occurs on the lower side of a leaf as well as the upper surface (Moss, 1964). A significant amount of reflected light is absorbed by the lower leaf surface in turfs having vertical and semi vertical leaf orientations. Other factors affecting light absorption include pubescence, leaf thickness, nature and distribution of pigments in the leaf, location, number, and orientation of chloroplasts and degree of shading due to interleaf orientation. In this study, we evaluated the effects of protective covers on many of the dynamics reviewed above. For example, some covers may force horizontal leaf orientation favorable for light absorption. However, this sudden change may impact leaves in the turfgrass population. Degrees of shading due to interleaf orientation, light reflection, pigment distribution, and location and orientation of chloroplasts may change due to cover placement.

LIGHT QUALITY

In environments with reduced PAR, quality of light may become the most vital factor for turfgrass health. In plants, chlorophylls and carotenoids are pigments that absorb PAR. Specifically, chlorophyll *a* selectively absorbs light within the visible spectrum, peaking at 410, 430 (blue light), and 660 nm (red light) (Wherley et al., 2005). Absorption of light energy by chlorophyll *b* peaks at 430, 455, and 640 nm. The carotenoid pigments lutein and β-carotene absorb strongly in the blue region with maximum absorption occurring at 448 and 454 nm (Lefsrud et al., 2008; Taiz and Zeiger, 1998). Far-red light is the region of the spectrum between 700 and 800 nm. While not absorbed by chlorophyll for photosynthesis, far-red light has a strong influence on photomorphogenesis, an influence on plant architecture (Casal and Sánchez, 1994; Wherley et al., 2005). Thus, growth and development of turfgrasses are greatly influenced by the quality and the quantity of light available for photosynthesis (Wherley et al., 2005).

LIGHT QUANTITY

Depending on locality, species, and management, 22-35% of full sunlight is required for normal cool-season turfgrass persistence (McBee and Holt, 1966). Cool-season turfgrasses growing in continuous 92% artificial shade display many of the adverse physical changes associated with the decline of naturally-shaded turf (Wherley et al., 2005). Under reduced irradiance, morphological changes have been observed within four to seven days in absence of traffic (Langham, 1941; McBee, 1969; McBee and Holt, 1966; Newell et al., 1999). Morphological responses of grasses to reduced irradiance are as follows: shoot etiolation characterized by reduced pigments; decreased evapotranspiration; reduced nonstructural carbohydrates; reduced tillering and shoot density; increased number of lateral stems; longer internodes; reduced stem diameter; increased leaf length; decreased leaf width; thinner leaves; more vertical leaf orientation; and decreased roots (Burgess, 1985). Etiolation processes increase the likelihood that the plant will reach a light source when covered with soil or leaf litter, but not under a cover.

When light is not present for several days, leaves may appear yellow rather than green due to xanthophyll pigments present in the leaf (Figure 2). High concentrations of chlorophyll in healthy turfgrass leaf tissues masks the color of these other pigments. The xanthophylls make up the second largest concentration of pigments in turfgrass leaves (McElroy et al., 2006; Turgeon and Lester, 1976). The etiolated makeup of shaded turf and reduced carbohydrate availability for recovery from damage decreases traffic tolerance (Jiang et al., 2005). If light is nonexistent for an extended length of time, tissues will die (Beard, 2006).

EVAULATION OF TURF QUALITY

Multispectral radiometry measures plant light reflectance in the visible and near-infrared ranges, and provides an objective, quantitative method for estimating turfgrass quality or green cover. Plant tissues readily absorb light in the visible portion of the spectrum and reflect a small amount (typically 2%-10%). Plant tissues aslo reflect NIR light (35% to

60%) due to a discontinuity in the refractive indexes between cell walls and intercellular air gaps (Qi et al., 1991). When near infrared and visible light emitted from the sensor is moved over the plant canopy, a portion of that light is reflected back to the sensor and is detected by an array of photosensors.

PROTECTION MATERIALS FOR TRAFFICKED TURF

Various turf protection materials used include grated plastic soil structures, reinforced soil fibers, plywood, plywood with geotextile fabric mat, and plastic covers. Among all the available turfgrass rigid covers, the more practical include plywood, plywood with geotextile fabric mat, and plastic covers because they are portable, strong, rentable, and lightweight. Moreover, these rigid covers have been consistently used on professional sports fields. However, relative comparisons of these covers have not been documented. For example, reduced PAR transmission through covers has been shown to have an effect on turf quality after removal of winter covers (Goatley et al., 2009) but, little information about how turf protection covers affect turf quality is available. Thus, we hypothesized that increased PAR transmission will improve tall fescue persistence; with positive or negative effects varying to some extent with seasonality and soil moisture. Further, we hypothesized that the effects of covers placed under low irradiance will be similar over all treatments with only slight variations.

These studies evaluated turfgrass responses under rigid covers in a growth chamber and in the field. Growth chambers were used to mimic stage conditions and open field conditions in the summer time to evaluate differences between cover and the effect of soil moisture (75% of pot field capacity (FC) and 50% FC). Field trials were conducted to evaluate effects of temperature and recovery of tall fescue when covered with various covers for extended periods of time (up to 20 days) in the spring, summer and fall.

Materials and Methods:

Studies were conducted in growth chambers at the Virginia Bioinformatics Institute facility and in the field at the Virginia Tech Turfgrass Research Center [Blacksburg, VA (Latitude: 37°12’47.43’’N, Longitude: 80°24’45.52’’W)]. Growth chambers were established to evaluate two different irradiance and soil moisture conditions. Field studies were conducted in spring, summer and fall with event covers in place from two to 20 days.

The covers chosen in this study were selected based on a literature review, previous studies, the author’s personal experience, and communication with sports turf managers across the world. Light transmission characteristics of covers were determined during the field trial. Five measurements of PAR were taken at the surface of the turf canopy in the non-covered and covered plots during peak irradiance hours of a cloudless day on August 20, 2010. Mean values of PAR radiation at the canopy surface for both non-covered and covered plots were determined. Fifteen PAR measurements were taken under a concert stage in summer 2011 and averaged to determine light levels to be used in the growth chamber.

Four covers were evaluated in the growth chamber and in the field: 1) plywood (single layer 1.9 cm, PAR 0); 2) polyester mesh fabric in combination with plywood [plywood + Enkamat Plus (Coldbond Netherlands) PAR 0]; 3) single-sided plastic cover [Terratile (Terraplas USA Kilgore, TX) PAR 25]; and 4) double-sided plastic cover [Matrax LD

(Matrax Inc. Newfoundland, NJ) PAR 5] (Figure 3). All four covers were compared against an uncovered control. The plywood + Enkamat Plus, Terratile, and Matrax are widely used in event productions; however, effects of season and number of days under cover on tall fescue green cover (or resulting visual quality) after removal of these protective covers is unknown. Standard commercial sizes of covers were utilized in the field trial, while 45 cm x 15 cm sizes were used in growth chamber trials.

GROWTH CHAMBER

Sod pieces of tall fescue (*Festuca arundinacea* Schreb.) were transplanted from field plots into PVC pots (10-cm diameter and 5-cm length) filled with sand (90% sand, 5% clay, 5% silt). Plants were maintained in a greenhouse under natural light conditions for two weeks from May 30th to June 13th, 2011 (approximate 12-h photoperiod) to allow plants to root and recover from transplant shock under an automatic sprinkler system. Plants were maintained with trimmer shears at a 7.5 cm height of cut, a height representative of turf maintenance practices at public parks. The plants were fertilized with a complete soluble fertilizer of $28N–8P_2O_5–18K_2O$ at a rate of 48 kg N ha^{-1}, 14 kg P_2O_5 ha^{-1}, 32 kg K_2O ha^{-1} one week after transplanting. Half of the plants were not watered for two days (June 10th, 2011) before placement in growth chambers to simulate soil moisture contents of 75% FC and 50% FC going into an event.

All pots were moved into two growth chambers on June 13th, 2011. The growth chambers were set to mimic summertime conditions in a temperate climate: 70% humidity, 12-h photoperiod, and a day/night temperature cycle of 30°C/25°C. One growth chamber was fitted with light sources to mimic treatments being placed in an open field (high light, fluorescent and incandescent light, PAR 530 μmol $m^{-2}s^{-1}$) and one growth chamber was fitted with light sources to mimic treatments being placed under a stage (low light, incandescent light, PAR 5 μmol $m^{-2}s^{-1}$). PAR levels in each chamber were measured with a Quantum Sensor-LQM50-3 (Apogee Instruments, Logan, UT).

A HH2 Delta-T Moisture Meter (Delta-T Devices, Cambridge, UK) was used to measure volumetric soil moisture content, Θv, by measuring changes in the apparent dielectric constant (McCarty, 2009). Volumetric soil moisture content is the ratio between total volume of water present and total volume of the sample. A volumetric soil moisture calibration chart was developed for the soil type used prior to the growth chamber study as follows: Two pots were saturated with water and left to dry until no water drained from the holes in the bottom of the pots. The point where water is no longer draining is considered pot field capacity soil moisture. At this point, a HH2 Delta-T Moisture Meter (Delta-T Devices Cambridge, UK) was used to measure percent soil moisture at a 5-cm depth and then the pots were weighed. This process was repeated over time. At the conclusion of this process, the soil from the pots was kiln dried. Pots and sand were then separated and weighed, data compiled and analyzed. Correlation of volumetric water loss and the percent loss given on the device is shown in Figure 4.

For the growth chamber, half of the pots were kept at 75% field capacity (moderate moisture) while the other half of the pots were maintained at 50% field capacity (low moisture). Volumetric soil moisture (VSM) levels that corresponded to 75 or 50% of FC were re-established every two days by supplying the pots with an amount of water equal to soil losses as determined by the moisture probe.

Shoot tissue samples from each pot were taken at four day intervals, beginning on the day they were placed in the growth chamber and every four days thereafter. Chlorophyll a, b, chlorophyll a+b, and carotenoids were analyzed according to the procedures of (Lichtenthaler, 1987). Briefly, leaf samples (25 mg fresh weight) were clipped and placed in 7 ml of 100% acetone. The homogenate was soaked in acetone for three days. The supernatant absorbance at 661.6, 644.8 and 470 nm was measured using a BioMate 3 spectrophotometer (ThermoSpectronic Rochester, N.Y.) Concentration of chlorophyll and carotenoids were calculated by the equations of (Lichtenthaler, 1987) as follows:

Chl a = (11.24 x absorbance at 661.6 nm) – (2.04 x absorbance at 644.8 nm)

Chl b = (20.13 x absorbance at 644.8 nm) – (4.19 x absorbance at 661.6 nm)

Chl $a+b$ = (7.05 x absorbance at 661.6 nm) – (18.09 x absorbance at 644.8 nm)

Carotenoids (xanthophylls and β-carotene) = (1,000 x absorbance at 470 nm) – (1.9 x Chl a – 63.14 x Chl b) ÷ 214

Experimental results were analyzed as a spilt-split plot design with light as the main factor and all combinations of moisture and cover as sub factors. All data were subjected to an analysis of variance (ANOVA) and mean separation procedure using Student’s t-test ($P \leq 0.05$) employed where appropriate (SAS Institute Inc., Cary, NC).

FIELD TRIALS

Field trials were conducted over a two-year period with two trials in each season: (Spring: Apr 1 – Apr 30, 2011; May 2 – Jun 1 2011); (Summer: Jul 22 – Aug 21, 2010; Jul 26 –Aug 25, 2011); and (Fall: Sept 27 – Oct 27, 2010; Sept 20 – Oct 20, 2011). Soil utilized was a Groseclose silt loam (clayey, mixed, mesic, Typic Hapludalfs) with 3% organic matter, phosphorus (P) and potassium (K) contents of 26 and 90 mg kg^{-1}, pH 6.0, and a cation-exchange capacity (CEC) of 4.1 meg/100g. The turfgrass was fertilized with a complete fertilizer (10-10-10) at 48 kg N ha^{-1} and irrigated one week before field trials started. Once the field trials began, the turfgrass was irrigated only as needed to maintain active growth. Tall fescue was mowed with a rotary mower two times per week (clippings returned) at 7.5 cm during active growing periods prior to starting the trial. No fungicides were used over the course of trials; however, a preemergent herbicide (Barricade®WG; prodiamine) was applied at 4.4 kg ha^{-1} in the spring of 2010 and 2011 to control summer annual weeds in the research plots. Each day during the trial periods a pickup truck (Ford F-150, Virginia Tech Department of Crop and Soil Environmental Sciences) weighing approximately 2268kg (230kPa) was driven over each cover (not the control) to simulate compression that would occur during a public event. Covers were the same as used in the growth chamber but standard commercial sizes were utilized in the field.

Temperature data were recorded during the course of each trial. A digital max/min thermometer (Forestry Suppliers Inc. Jackson, MS), installed face down at the interface of the tall fescue canopy and the cover, recorded the maximum and minimum temperatures every 24 hours.

Turf quality was evaluated by visual assessments at two and eight days after cover removal (DACR). A scale of 1-10, with 1 = 0% turfgrass green cover (grass in entire plot appeared dead) while 10 = 100% green cover (no visual damage to the turfgrass).

In addition to these visual cover ratings, basic reflectance data, and a calculated vegetative index value were used at the end of the trial as an overall assessment of the treatment effects. A multi-spectral radiometric light sensor (Crop Circle optical sensor, Holland Scientific Lincoln, NE) was used to measure near infra red (NIR) reflectance and visible (VIS) reflectance at the turf canopy surface. These values were then used to calculate a normalized difference vegetative index (NDVI), one of the most commonly used indices to evaluate the status of plant health in crop management (Tucker, 1979). Higher NDVI readings are known to be positively correlated with increased visual turf quality, shoot density, and color (Fitz-Rodríguez and Choi, 2002). Also, NDVI is more sensitive to sparse vegetation and less sensitive to high vegetation densities (Qi et al., 1991). NDVI was calculated by the equation:

$$\frac{\mathrm{NIR}^{-}\mathrm{VIS}}{\mathrm{NIR}^{+}\mathrm{VIS}}$$

NIR = Near Infra Red reflectance at 880 nm

VIS = Visible reflectance (2% to 10%)

For interpretive and guideline purposes a threshold of 0.6 (= 60% green cover) at eight DACR was designated as the threshold for functionality of cover use. NDVI was also added to two and eight DACR as another measurement tool to test the effects of cover.

The experimental design was a split block where season was the main plot and cover the subplots. Days were a fixed effect and were regressed over time. All data were subjected to ANOVA and mean separation procedures using Fischer's least significance difference (LSD) test (*P* = 0.05) and Student's t test where appropriate (SAS Institute Inc., Cary, NC).

Results and Discussion

GROWTH CHAMBER

The ANOVA for Chl *a*, Chl *b*, Chl *a+b,* and carotenoids contents of tall fescue after 20 days under cover in a growth chamber is presented in Table 1. Significant sources of variation for all four parameters included light, cover, moisture, days, and cover by light. The non-covered control was not included in the ANOVA but was used to validate grass quality. In addition, subsamples at day zero were not included in the ANOVA because of their similarity and lack of expression of cover effects. Moisture by cover, day by light, and three and four way interactions were analyzed but were not significant.

Light

Interactions of cover by light on mean (measured at days 4, 8, 12, 16, and 20) Chl *a*, Chl *b*, Chl *a+b,* and carotenoids contents of tall fescue shoot samples in a growth chamber are presented in Table 2. Highest chlorophyll and carotenoid contents were observed in tall fescue covered with Matrax or Terratile under high light conditions. These data indicate that the amount of light reaching the turf is the most important factor, not cover types.

Growth chamber low light stage conditions

The ANOVA for Chl *a*, Chl *b*, Chl *a+b,* and carotenoids contents of tall fescue under low light conditions after 20 days under cover in a growth chamber is presented in Table 3. The only significant source of variation for all four parameters was the number of days under cover. Non-significant sources of variation were cover, moisture, and cover by moisture under low light conditions. Effects of days under low light conditions of the four parameters are presented in Figure 5. Matrax and Terratile had almost identical slopes as plywood over the course of the 20 days for the four parameters measured. Stage conditions reduced the amount of light available (5 μmol m^{-2} s^{-1}) for transmission through both Matrax and Terratile. These covers reduce the 5 μmol m^{-2} s^{-1} by 95% (Matrax) and 75% (Terratile) allowing little or no light to reach the turfgass. McBee and Holt (1966) found that 22-35% of full sunlight is required for normal turf persistence. Our findings show that under simulated low light conditions, there is insufficient light to positively influence turf quality. Additionally, others have reported that morphological changes in turfgrass were observed within four days under reduced irradiance (Langham, 1941; McBee, 1969; McBee and Holt, 1966; Newell et al., 1999). These data imply that any cover evaluated in this research did not provide turfgrass persistence under stage-covering conditions beyond four days. From a practical standpoint, this means that an inexpensive, readily available cover such as plywood would be a suitable protective cover for short-term covering ($\leq$ 4 days).

Growth chamber high light (*mimicking open field conditions*)

The ANOVA for plant tissue pigments of tall fescue in high light (to mimic open field conditions) as influenced by cover, soil moisture content, and days under cover in a growth chamber is presented in Table 4. Significant sources of variation for all four parameters included cover and days. Soil moisture availability was not a significant source of variation for Chl *a* and Chl *a+b*. The interaction of cover by moisture was not significant for any of the parameters.

Effects of cover type on mean (measured at days 4, 8, 12, 16, and 20) content of Chl *a*, Chl *b*, Chl *a+b,* and carotenoids of tall fescue shoots under cover are presented in Table 5. Chlorophyll and carotenoid contents were significantly higher for Matrax and Terratile compared to plywood + Enkamat and plywood in high light conditions. Light transmission through Matrax and Terratile covers allowed enough photosynthesis to continue resulting in higher relative concentrations of chlorophyll and carotenoids.

Effects of soil moisture availability when using covers were relatively unknown prior to our research. Cockerham, (1994) found that irrigation following cover removal increased turf quality. However, soil moisture levels were not considered prior to placement of covers in their trials. In our study, the effects of mean soil moisture levels (moderate and low) measured at days 4, 8, 12, 16, and 20 on Chl *a*, Chl *b*, Chl *a+b*, and carotenoids under all covers are presented in Table 6. The tissues of plants in pots irrigated to a moisture level of 75% FC exhibited greater Chl *b* and carotenoid levels than pots with 50% FC, but no effect was observed on concentrations of Chl *a* or Chl *a+b* in fescue shoots under all cover types. These results indicate that soil moisture of 75% FC improved mean Chl *b* and carotenoids content in shoots under all cover types. Attaining 75% FC prior to placement of a protection-covering event can help maintain Chl *b* and carotenoids under cover.

Effects of days under cover in high light (to mimic an open field) conditions for the four parameters measured are presented in Figure 6. Y-intercepts of translucent covers are two times higher than non-translucent covers in chl *a*, chl *b*, and chl *a+b*.

In summary, growth chamber results indicate that use of translucent covers under staging equipment does not provide a significant advantage relative to plywood or plywood + Enkamat for maintaining turf quality. However, under high light, open field conditions, translucent covers (Matrax and Terratile) provided better protection of turfgrass quality than plywood and plywood + Enkamat. In addition, turf managers should estimate soil moisture levels prior to a protection-covering event and adjust soil moisture levels to approximately 75% FC shortly before placement of covers. Our growth chamber trials indicate the need to conduct field trials to evaluate recovery after various days of cover.

FIELD TRIAL

The ANOVA for ratings of tall fescue percent green cover for all seasons under cover 2- and 8-DACR, and NDVI at the conclusion of each trial period are presented in Table 7. Significant sources of variation included year, season, day, cover, and cover by day. Since year is a random effect we pooled pool the data over the two years and we removed year from the analysis.

Weather

Weather conditions varied considerably between the six trials, significantly affecting the results. These climate data are presented in Table 8.

Temperature under cover

Temperature readings were taken at the interface of cover and turf because of the relationship between respiration rates and temperature (Table 9). Temperatures under Terratile were consistently higher across all seasons (Table 9). These elevated temperatures (observed under Terratile due to 25% PAR transmission) resulted in considerable summer heat stress and turf decline. Temperatures under Matrax and plywood + Enkamat were similar in the summer and fall. Matrax allowed 5% PAR transmission and its double-sided high-density polyethylene plastic performed like a double pane window insulating the turf from heat. An ordinary double-pane window offers almost three times as resistance to heat conduction as a single-pane window when the wind is blowing (Gillette et al., 1917; Hinrichs and Kleinbach, 2012). Thus, turf under Matrax displayed a lower degree of heat stress symptoms in summer, compared to the other covers.

Season

The effects of cover and season on average tall fescue percent green cover at 2- and 8-DACR, and NDVI are shown in Table 10. Covers that allowed greater PAR transmission (Matrax and Terratile) were significantly different across all parameters measured over spring, summer and fall compared to the covers that did not allow PAR transmission (plywood + Enkamat and plywood). Plywood + Enkamat and plywood alone were not significantly different in spring, summer and fall across all parameters measured. Terratile and Matrax varied slightly in mean percent green cover ratings for 2-DACR and NDVI in the summer and fall. Slightly lower NDVI ratings as measured by the optical sensor in the summer and fall for Matrax compared to Terratile may have been due to a matting effect. Previous studies have shown slightly lower NDVI ratings after mowing and rolling of greens (Fitz-Rodríguez and Choi, 2002).

Spring

Tall fescue ratings at 8-DACR showed that percent green cover declined rapidly under plywood and plywood + Enkamat (Figure 7). The reasons behind this are likely that the photosynthetic process was shut down in the plants due to a continual lack of light. Etiolated symptoms of low irradiance shoots were observed under plywood and plywood + Enkamat. Etiolation reduces carbohydrate availability and thereby slows recovery of turf due to injury from foot and vehicle traffic (Jiang et al., 2005). The addition of Enkamat under plywood and the added airflow or “air space” did not contribute to turfgrass quality under plywood after cover removal in any season. These data suggest that air alone cannot prevent turfgrass decline under low irradiance. In addition, turf persistence in the spring was highest compared to summer and fall (Table 10). This seasonal difference may have been due to the lower soil temperatures usually experienced in spring resulting in reduced respiration.

Terratile and Matrax maintained better percent green cover 20 days under cover 2-DACR and 8-DACR. Regression equations predicted that the maximum number of days the turf could be covered and still recover was greater than 20 for Matrax and Terratile. Plywood and plywood + Enkamat only provided functional quality turf following six days under cover (Table 11). NDVI readings, taken at the end of each trial, also showed that when plywood and plywood + Enkamat were used as covers, only six days of functional turf quality (0.6) could be achieved.

Summer

The effects of the four covers tested on percent green cover after 14 days under cover during the summer of 2011 are shown in Figure 8. Tall fescue showed little tolerance for covering with plywood or plywood + Enkamat. Tall fescue percent green cover at 2-DACR showed that turfgrass declined within one to two days under plywood and plywood + Enkamat and never did achieve a functional percent green cover after removal (Figure 9). Matrax allowed for better percent green cover during high temperature periods when compared to Terratile (Figure 8). Predicted number of days for the 60% threshold for percent green cover was 12 days (Matrax) and 10 days (Terratile), respectively (Table 12).

NDVI readings taken at the end of trial periods showed varying results of percent green cover after cover removal (Figure 9). Variability between Matrax and Terratile are most likely due to factors of turf moisture, heat stress and the variability of climate. Moisture influences the plant's ability to cool itself through transpiration. At high relative humidity the plant is much less able to effectively cool itself and as a result is even more prone to heat buildup and direct heat injury. Heat stress results in the grass becoming weakened to the extent that it becomes much more vulnerable to both mechanical and biological stresses.

Fall

Ratings of percent green cover during the fall trials revealed that plywood and plywood + Enkamat exceeded the designated 6.0 threshold allowing four days of covering before unacceptable recovery occurred (Figure 10, Table 13). Enkamat did not significantly contribute to turfgrass persistence. Similar to the spring results, the Terratile and Matrax panels provided excellent long-term protection (> 20 days) and turf recovery (Figure 11, Table 13). NDVI readings showed similar trends to percent green cover at 8-DACR (Figure 12 vs. Figure 11). However, Terratile sunk into the turf (when driven over) resulting in damage to the turfgrass (saturated soil conditions present at the beginning of the 2010 season) leaving the potential for an uneven surface that might affect footing or ball bounce/roll (Figure 11). The Matrax cover resisted such "creasing" but caused matted turf but use of a backpack blower, rotary mower or other grooming activities may alleviate this problem by lifting up the shoots to minimize creasing.

Conclusion

Turf covers possessed both desirable and undesirable attributes depending on the season, soil moisture levels, light intensity and cover period. Matrax provided the advantages of greater protection in summer heat and quality retention in all seasons. However, the lack of sunlight penetration might limit its use under stages because plywood and plywood + Enkamat performed similarly to double pane natural HDPE. Moreover, the addition of Enkamat did not contribute to turfgrass persistence under plywood. The degradation of chlorophyll and carotenoids under low irradiance affects plant ability to absorb PAR after cover removal thus leading to unacceptable recovery. Turfgrass responses under Terratile and Matrax resulted in functional turf quality in the spring, summer and fall. Crane tires should be deflated slightly to reduce soil compaction while driving over covers. Turf managers should estimate soil moisture levels prior to a protection-covering event and adjust soil moisture levels to approximately 75% of field capacity shortly before placement of covers. Moreover, turf managers should be able to set event guidelines, establish company/park best management practices, formulate cost analysese and ultimately predict percent green cover at 2- and 8-DACR in any given season and duration of covering period based on the best-fit formulas and management practices provided in this paper. Overall, the covers tested in this work exhibited both desirable qualities and limitations that should be considered prior to their selection for an event. Further research is warranted to examine the effects of air (oxygen, carbon dioxide, and methane, e.g.) on turf quality while under protection covers.

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Appendix

Figure 1. Pictures of turf damage after a concert at a Major League Baseball field in the summer of 2010. Left: Squares of damage in the outfield where plywood was placed under the stage. Right: Close-up of damage after plywood plus Enkamat covering on Kentucky bluegrass for eight days. Photo: John Royse

Figure 2. Etiolated turf under low irradiance conditions following covering with plywood for 4 days in the summer of 2011. Photo: John Royse

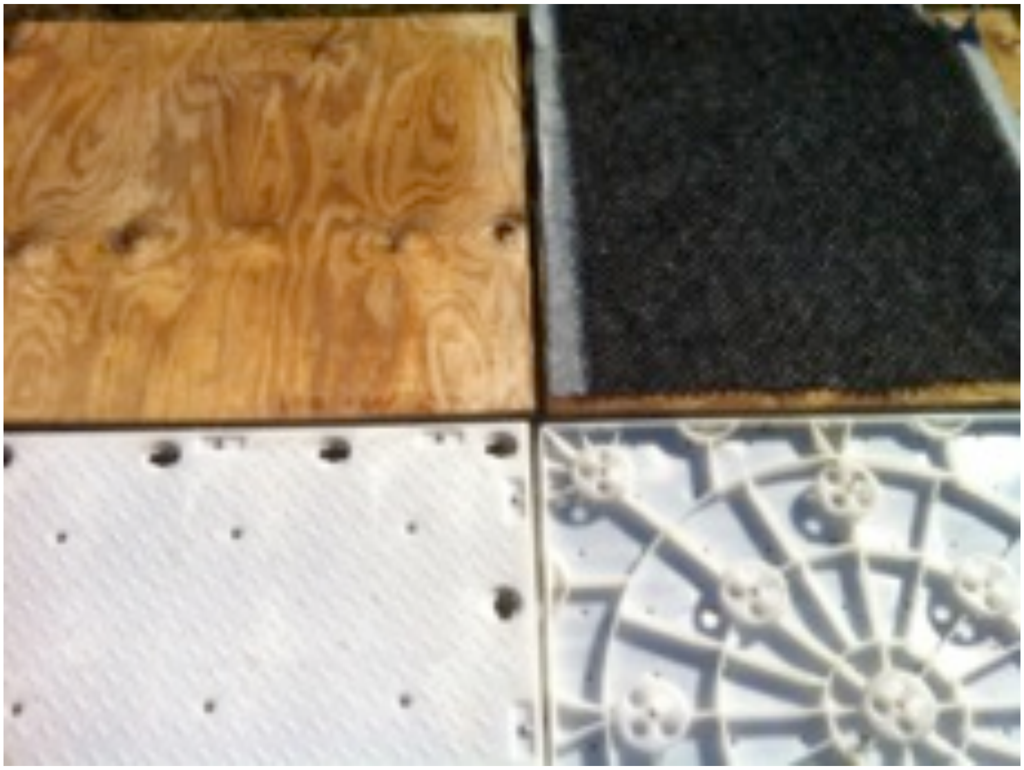

Figure 3. Treatments included Plywood (top left), Plywood + Enkamat (top right), Matrax (bottom left), and Terratile (bottom right). Photo: John Royse

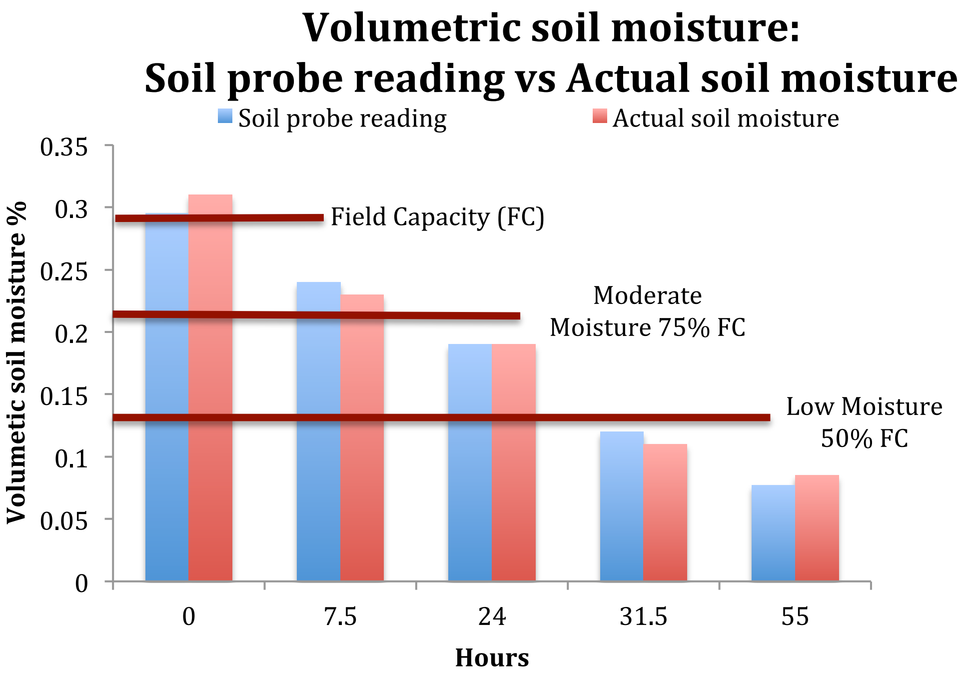

Figure 4. Water loss from tall fescue turf grown in sandy loam soil in a growth chamber (expressed as percentage measured by a Delta-T Moisture Meter) and measured in g over 130 h.

Table 1. Analysis of variance for plant tissue pigments chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) of shoots of tall fescue after 20 days under cover in a growth chamber maintained at 30°C day/25°C night.

Source	df	Chl *a*	Chl *b*	Chl *a*+*b*	Carot
Light (L)	1	*[a]	NS	*	NS
Cover (C)	3	**	**	**	**
Moisture (M)	1	*	*	*	*
Days (D)	4	**	**	**	**
L × C	3	**	**	**	**
L × M	4	NS[b]	NS	NS	NS
C × M	3	NS	NS	NS	NS
C × D	15	NS	NS	NS	NS
L × C × M	3	NS	NS	NS	NS
L × C × M × D	15	NS	NS	NS	NS

[a] **, and * = significant at $p < 0.01$ and 0.05, respectively.

[b] NS: not significant.

Table 2. Interactions of Cover (C) x Light (L) on mean (measured at 4, 8, 12, 16, and 20 days under cover) chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a+b* (Chl *a+b*) and carotenoids (Carot) content of tall fescue shoot samples in a growth chamber maintained at 30°C day/25°C night.

	Light level							
	Chl *a*		Chl *b*		Chl a+b		Carot	
Cover	High	Low	High	Low	High	Low	High	Low
Terratile	0.84aA	0.44aB	0.31aA	0.18aB	1.15aA	0.63aB	1.28aA	0.82aB
Matrax	0.96aA	0.43aB	0.36aA	0.17aB	1.32aA	0.61aB	1.37aA	0.81aB
Plywood + Enkamat	0.37bA	0.42aA	0.14bA	0.14aA	0.51bA	0.59aA	0.74bA	0.79aA
Plywood	0.34bA	0.38aA	0.13bA	0.15aA	0.47bA	0.53aA	0.64bA	0.74aA

[a] Means followed by same lower case letter within a column are not significantly different according to Fisher's LSD test (P = 0.05). LSD= Least Square Difference.

[b] Means followed by the same upper case letter within a row are not significantly different according to Fisher's LSD test.

Table 3. Significance from analysis of variance for mean (measured at 4, 8, 12, 16, and 20 days under cover) chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) content of shoots of tall fescue under cover in low light (stage conditions) in a growth chamber maintained at 30°C day/25°C night.

Source	Df	Chl *a*	Chl *b*	Chl *a*+*b*	Carot
Cover (C)	3	NS	NS	NS	NS
Moisture (M)	1	NS	NS	NS	NS
Days (D)	4	**	**	**	**
C × M	3	NS	NS	NS	NS

**, and * = significant at $p < 0.01$ and 0.05, respectively. NS = not significant.

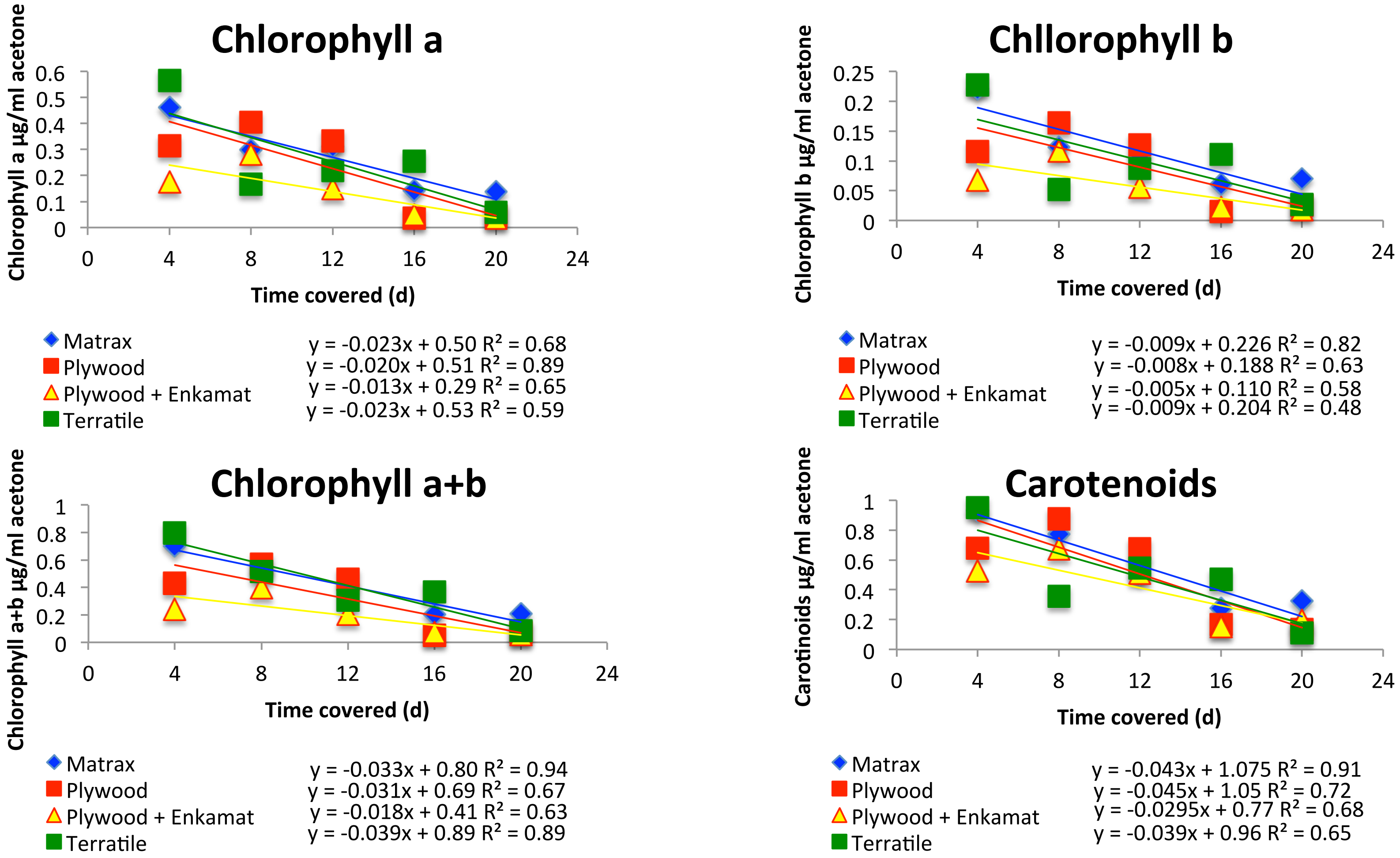

Figure 5. Effects of days (4, 8, 12, 16, 20) under cover on chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) content (µg/ml acetone) of tall fescue shoots under low light (stage conditions) in a growth chamber maintained at 30°C day/25°C night.

Table 4. Significance from analysis of variance for mean (measured at days 4, 8, 12, 16, and 20) chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) contents of shoots of tall fescue under cover in high light (mimic open field) for cover, turf moisture content, and days under cover in a growth chamber maintained at 30°C day/25°C night.

Source	DF	Chl *a*	Chl *b*	Chl *a*+*b*	Carot
Cover (C)	3	**	**	**	**
Moisture (M)	1	NS	*	NS	*
Days (D)	4	**	**	**	**
C x M	3	NS	NS	NS	NS

**, and * = significance at $p < 0.01$ and 0.05, respectively. NS = not significan

Table 5. Effects of cover type on mean (measured at days 4, 8, 12, 16, and 20) content of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a+b* (Chl *a+b*) and carotenoids (Carot) tall fescue shoots under cover in high light (mimic open field) conditions in a growth chamber maintained at 30°C day/25°C.

	μg/ml acetone[1]			
Cover	Chl *a*	Chl *b*	Chl *a+b*	Carot
Matrax	0.96A	0.36A	1.15A	1.37A
Terratile	0.84A	0.31A	1.32A	1.28A
Plywood + Enkamat	0.42B	0.16B	0.59B	0.74B
Plywood	0.34B	0.13B	0.47B	0.64B

[1] Means followed by same letter within each column are not significantly different at $P = 0.05$ based on Fisher's LSD test. LSD= Least Square Difference.

Table 6. Effects of mean (measured at days 4, 8, 12, 16, and 20) turf moisture contents on chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) of tall fescue shoots under cover in high light (mimic open field) conditions in a growth chamber maintained at 30°C day/25°C night.

	µg/ml acetone			
Moisture	Chl *a*	Chl *b*	Chl *a*+*b*	Carot
Moderate	0.73A[1]	0.28A	1.00A	1.15A
Low	0.56A	0.21B	0.76A	0.86B

[1] Means followed by same letter within each column are not significantly different at $P = 0.05$ based on student's t test.

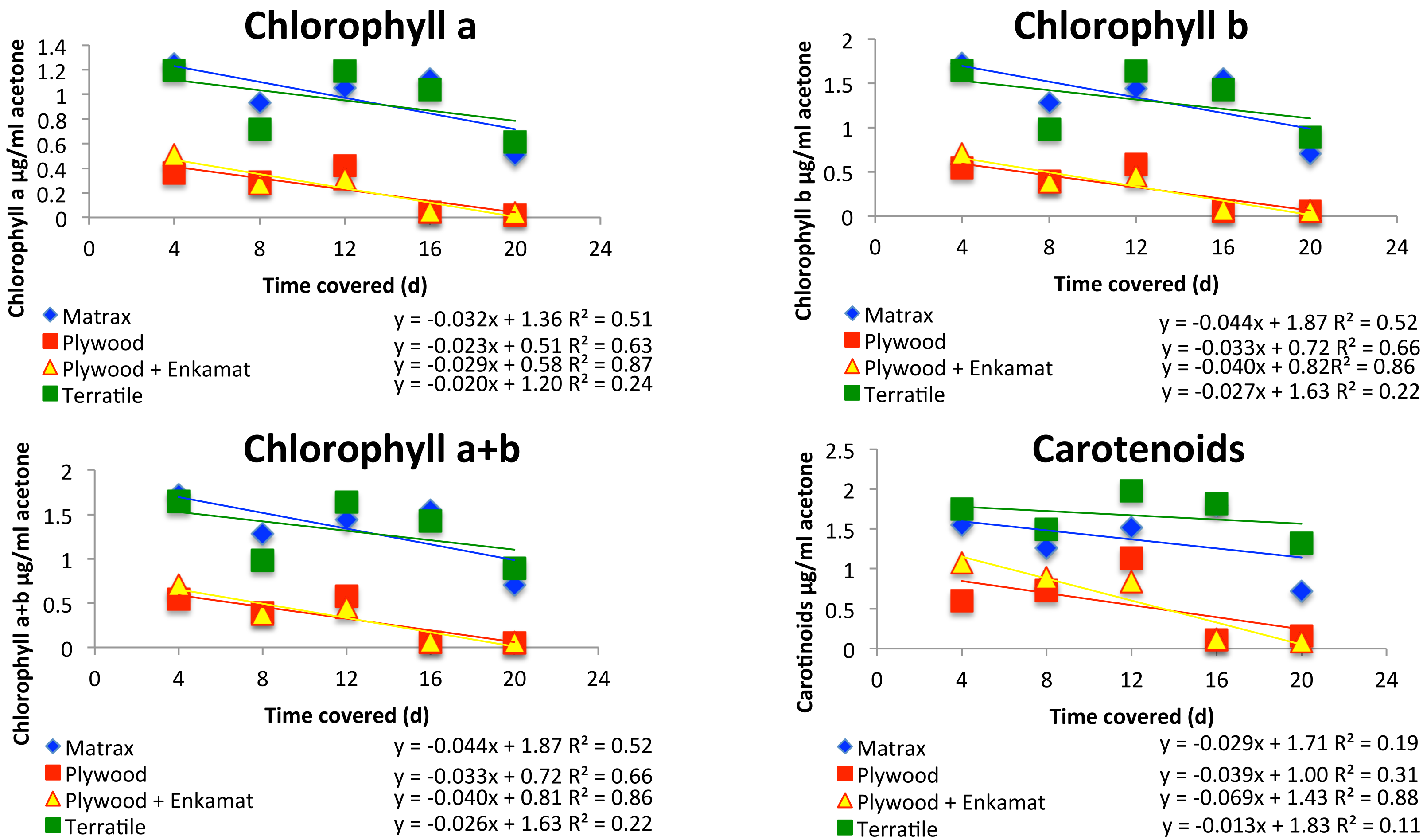

Figure 6. Effects of days (4, 8, 12, 16, 20) under cover on chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), chlorophyll *a*+*b* (Chl *a*+*b*) and carotenoids (Carot) content (µg/ml acetone) of tall fescue shoots under high light (open field conditions) in a growth chamber maintained at 30°C day/25°C night.

Table 7. Significance based on analysis of variance for all seasons combined, including means of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 days under cover treatment for tall fescue visual color at 2-days and 8-days after cover removal (DACR) and normalized difference vegetative index (NDVI) at the conclusion of each trial period.

		Days after cover removal (DACR)		
Source	DF	2	8	NDVI
Block (year)	1	**	NS	*
Season	2	**	**	**
Day (D)	1	**	**	**
Cover (C)	3	**	**	**
C × D	3	**	**	**

**, and * = significance at $p < 0.01$ and 0.05, respectively. NS = not significant.

Table 8. Field trial designation and dates, average high and low temperatures, relative humidity and precipitation for 2010 and 2011 as provided by the National Weather Service in Blacksburg, VA.

Trial	Date	Avg. High (C)	Avg. Low (C)	Avg. Relative humidity (%)	Precipitation (cm)
Summer 1	Jul 22 – Aug 21 2010	39.4	18.3	82	12.2
Fall 1	Sept 27 – Oct 27 2010	19.8	6.6	75	12.2
Spring 1	Apr 1– Apr 30 2011	20.1	6	71	13.7
Spring 2	May 2 – Jun 1 2011	23.4	10.6	80	21.6
Summer 2	Jul 26 - Aug 25 2011	29.6	17	76	3.8
Fall 2	Sept 20 - Oct 20 2011	20.1	9.5	80	7.6

Table 9. Effects of turf cover on photosynthetically active radiation (PAR) transmission and temperature parameters measured at the interface of turf and cover for spring, summer, fall and means of all three seasons combined.

		Temperature (°C)[a]							
	PAR	Spring		Summer		Fall		Mean all seasons	
Cover	Transmission	High	Low	High	Low	High	Low	High	Low
Terratile	25	34.9A[b]	9.6A	43.8A	20.8A	31.6A	12.4A	36.8A	14.3AB
Matrax	5	29.5B	10.2A	38.4C	21.1A	25.2C	12.6A	32.5B	14.6AB
Plywood + Enkamat	0	26.8C	10.4A	38.2C	21.5A	24.8C	13.3A	29.9C	15.1A
Plywood	0	26.2C	9.7A	41.3B	20.5A	26.8B	11.1B	29.9C	13.7B

[a] Temperatures recorded from beginning to end of each trial.

[b] Means followed by same letter within each column are not significantly different at *P* = 0.05 based on Fisher's LSD test. LSD= Least Square Difference.

Table 10. Effects of cover and season on percent green cover at two and eight days after cover removal (DACR) and Normalized Difference Vegetation Indices (NDVI) of tall fescue

		Tall fescue percent green cover and NDVI measurement[a,b]											
		Spring			Summer			Fall			Mean all seasons		
	PAR[c]	DACR			DACR			DACR			DACR		
Cover	Transmission	2	8	NDVI	2	8	NDVI	2	8	NDVI	2	8	NDVI
Matrax	5	88A	93A	0.77A	62A	63A	0.52A	92A	95A	0.67A	80A	84A	0.65A
Terratile	25	88A	92A	0.77A	52A	60A	0.57A	93A	97A	0.72A	78A	83A	0.69A
Plywood + Enkamat	0	31B	37B	0.57B	15B	16B	0.35B	28B	33B	0.45B	25B	28B	0.46B
Plywood	0	31B	37B	0.55B	15B	15B	0.35B	27B	32B	0.45B	24B	28B	0.45B

[a] Tall fescue quality response data were compared by rating turf quality in both treated- and non-treated areas. Means followed by same letter within each column are not significantly different at *P* = 0.05 based on Fisher's LSD test. LSD= Least Square Difference

[b] Percent green cover scale of 10-100, where 10 = grass in entire plot appeared complete browning while 100= percent green cover (no visual damage to grass). NDVI scale (measured at the conclusion of the trial) of 0.2 – 0.8, where 0.2 = poor turf color (grass in entire plot dead) while 0.8 = excellent color (no damage to turfgrass).

[c] PAR, photosynthetically active radiation.

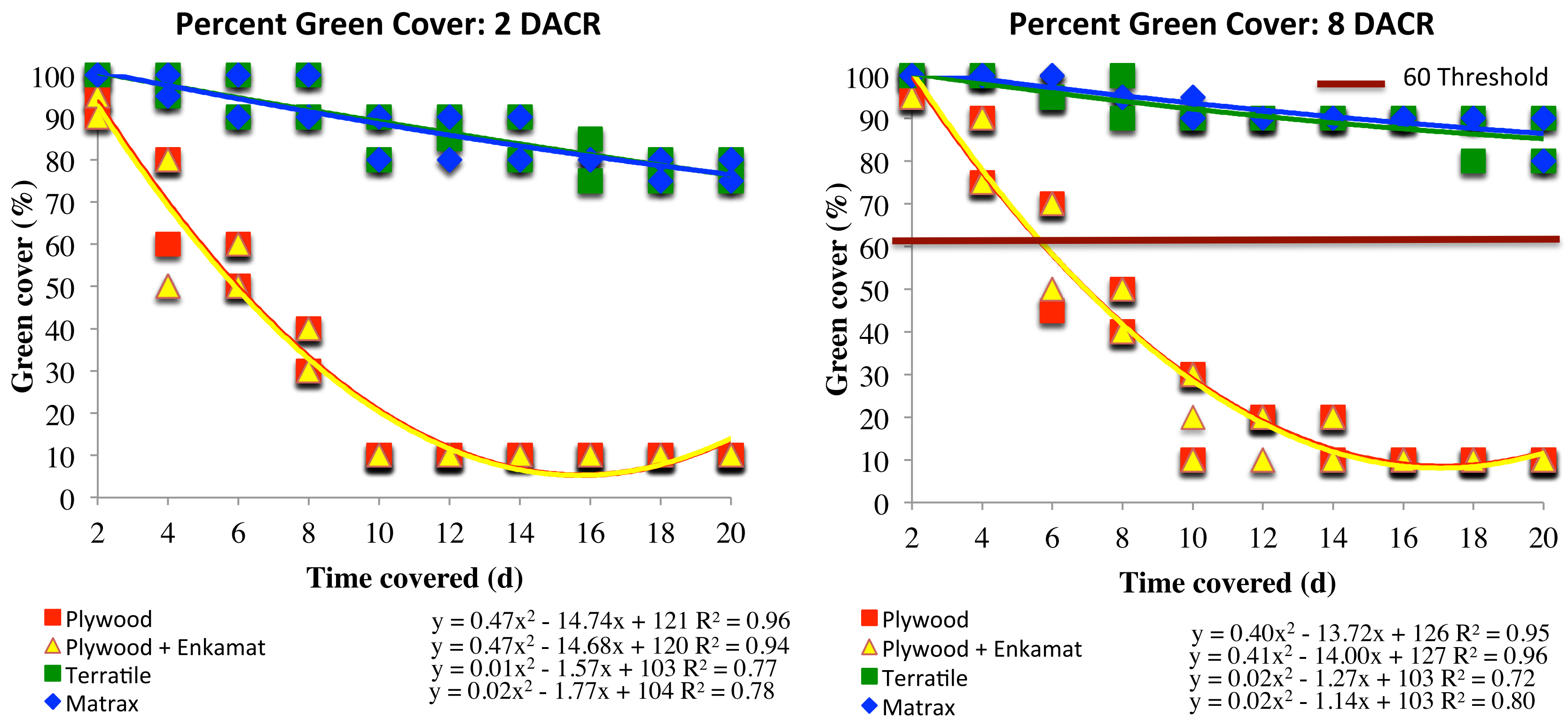

Figure 7. Percent green cover as affected by time covered and cover type when assessed at 2 and 8 days after cover removal (DACR) in the spring. Data pooled over two years.

Table. 11. Prediction equations and predicted maximum number of days of covering for 60% green cover of tall fescue for four cover types in spring.

Cover	Spring	
	Equation $\hat{y} = 60$	Predicted maximum days of covering for 60% green cover
Matrax	$60 = 0.02x^2 - 1.14x + 103$	20+[a]
Terratile	$60 = 0.02x^2 - 1.27x + 103$	20+[a]
Plywood + Enkamat	$60 = 0.41x^2 - 14.00x + 127$	6
Plywood	$60 = 0.47x^2 - 14.74x + 121$	6

[a] Extrapolation of data beyond the 20 days of cover is unwarranted by our experimental design and should be interpreted with caution.

Matrax Terratile Plywood + Enakmat Plywood

Figure 8. Effects of cover left on for 14 days on tall fescue quality during summer of 2011.

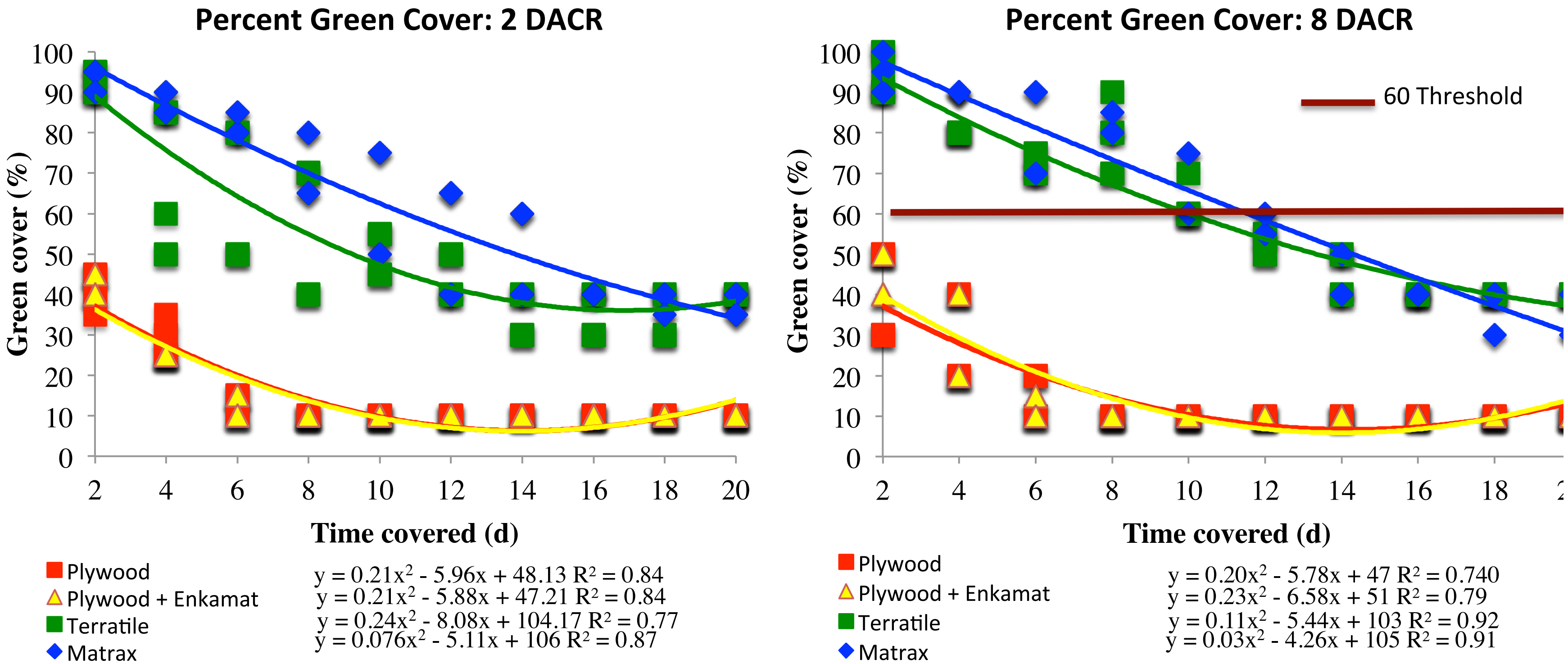

Figure 9. Percent green cover as affected by time covered and cover type when assessed at 2 and 8 days after cover removal (DACR) in the summer. Data pooled over two years.

Terratile

Matrax

Figure 10. Symptoms of high temperature stress on tall fescue after eight days under Terratile (left) and Matrax (right) in summer 2011.

Table. 12. Prediction equations and predicted maximum number of days of covering for 60% visual color of tall fescue for four cover types in summer.

	Summer	
Cover	Equation $\hat{y} = 60$	Predicted maximum days of covering for 60% green cover
Matrax	$60 = 0.03x^2 - 4.26x + 105$	12
Terratile	$60 = 0.11x^2 - 5.44x + 103$	10
Plywood + Enkamat	$60 = 0.23x^2 - 6.58x + 51$	0
Plywood	$60 = 0.20x^2 - 5.78x + 47$	0

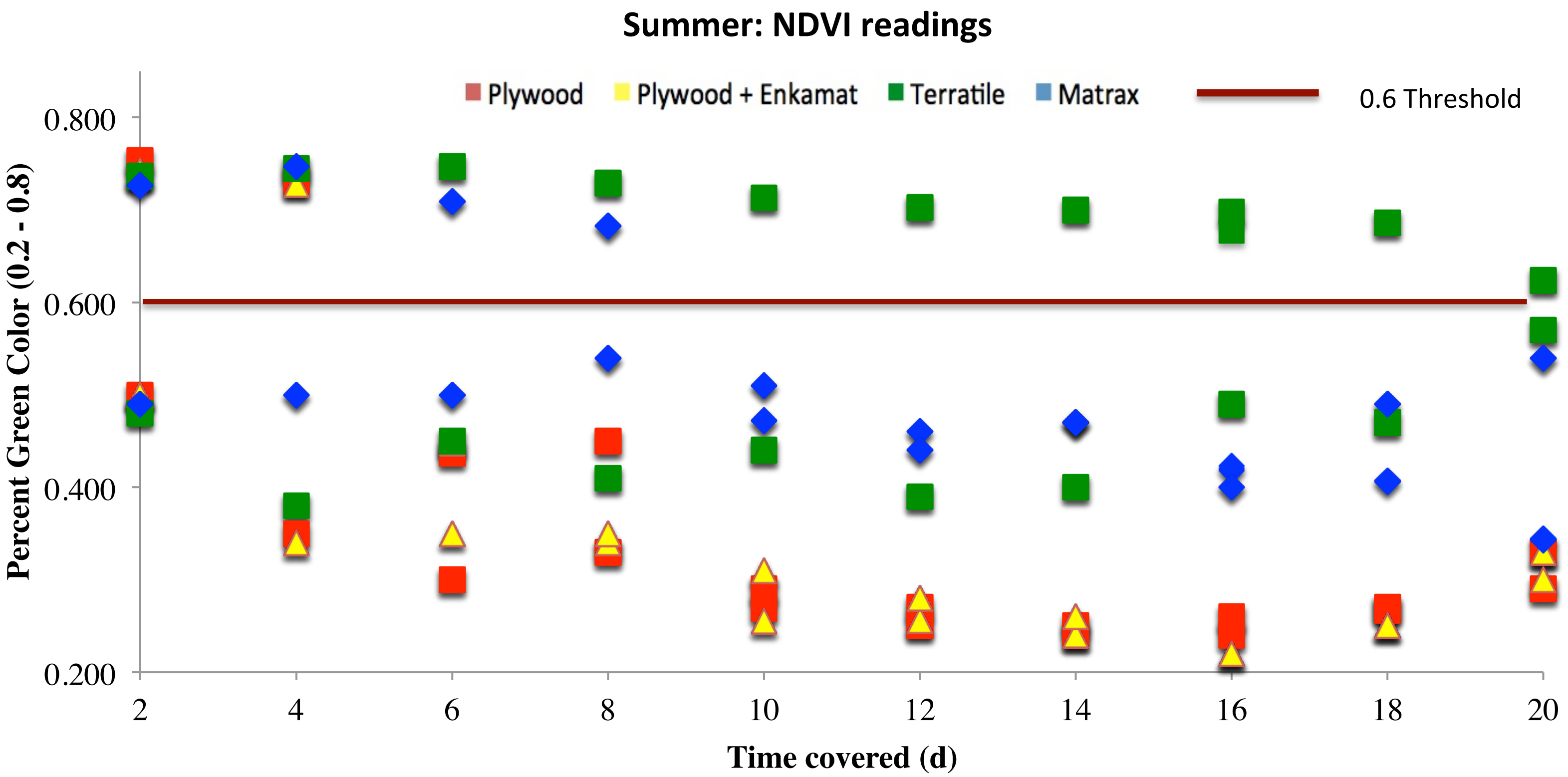

Figure 11. The effects of four cover types (plywood, plywood +Enkamat, Terratile, Matrax) left on for 2-20 days on percent green color in summer (combined data for two year). Rating of 0.80= excellent turf color; 0.20= poor turf color. Threshold of 0.6 considered acceptable quality.

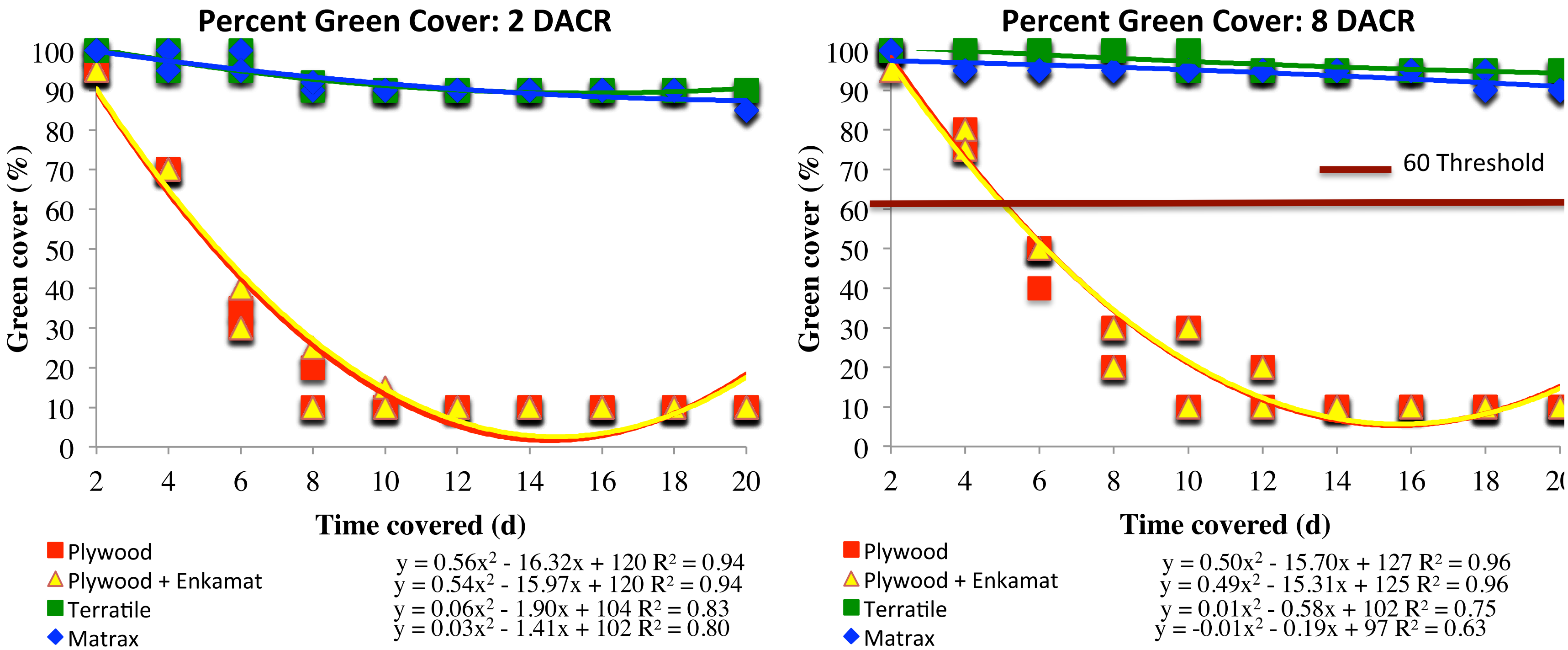

Figure 12. Percent green cover as affected by time covered and cover type when assessed at 2 and 8 days after cover removal (DACR) in the fall. Data pooled over two years.

Table 13. Prediction equations and predicted maximum number of days of turf covering for 60% visual color of tall fescue under four cover types in fall.

Cover	Equation ŷ = 6	Predicted maximum days of covering for 60% green cover
Matrax	$60 = -0.01x^2 - 0.19x + 97$	20+[a]
Terratile	$60 = 0.01x^2 - 0.58x + 102$	20+[a]
Plywood + Enkamat	$60 = 0.49x^2 - 15.31x + 125$	4
Plywood	$60 = 0.50x^2 - 15.70x + 127$	4

[a] Extrapolation of data beyond the 20 days of cover is unwarranted by our experimental design and should be interpreted with caution.

Figure 13. Effects of three cover types on turf and soil impacts. Left: Matrax (Top) and Plywood + Enka (bottom) caused matting over of the shoots. Right: Terratile sunk into turf/soil (when driven over) resulting in turf damage (beginning of the 2010 fall trial).

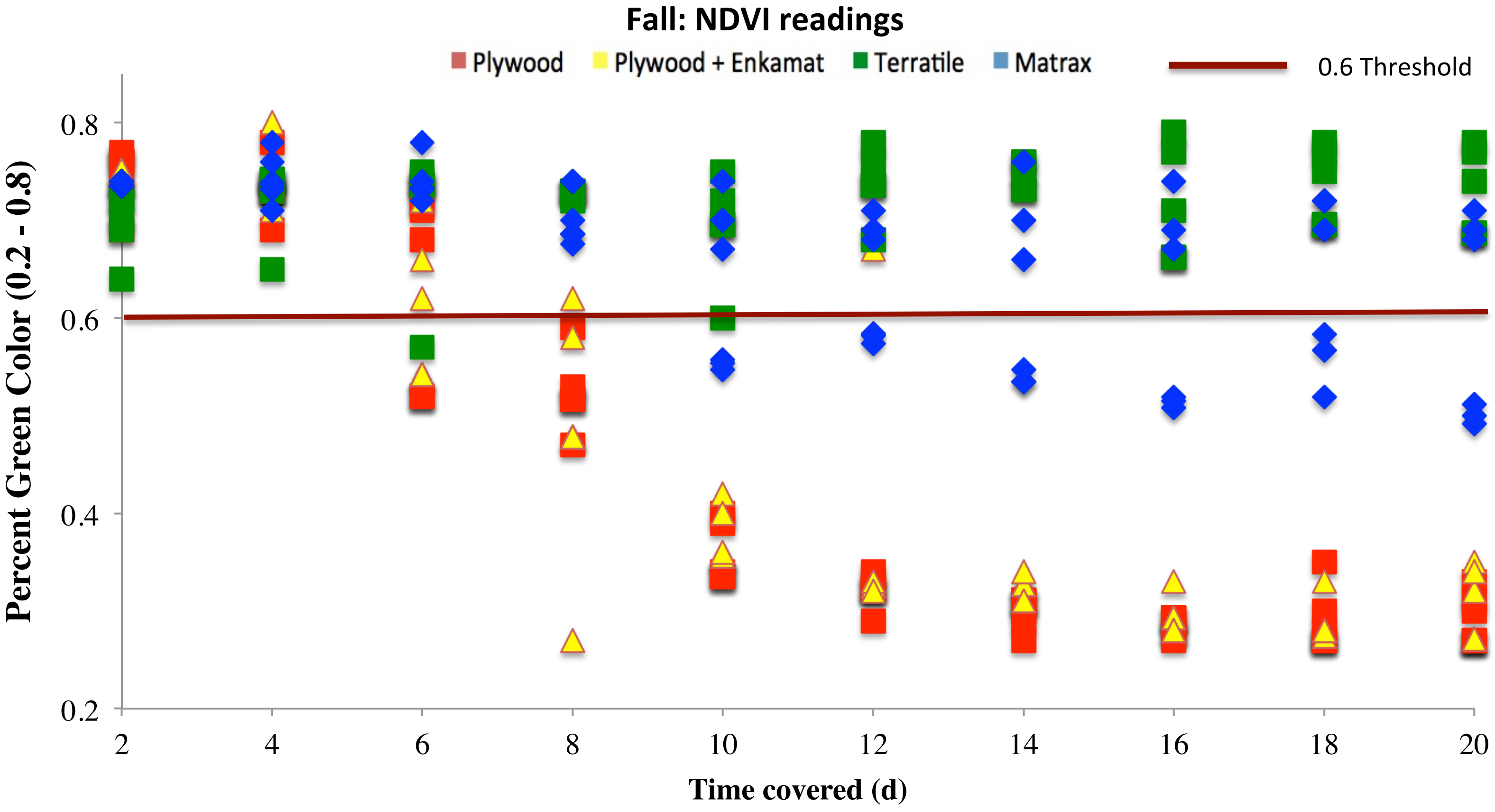

Figure 14. Effects of four cover types (plywood, plywood +Enkamat, Terratile, Matrax) left on tall fescue turf for 2-20 days fall of 2010 and 2011 on NDVI readings. Percent green color of 0.80= excellent turf color; 0.20= poor turf color. Threshold of 0.6 = rating considered acceptable.