Shade from trees surrounding a putting green vary throughout the year due to the changing angle of the sun. The quantity of light for plant growth not only changes based upon shade, but on the time of day.

to measure PAR over the course of an entire day is needed rather than a method to measure PAR at any given moment.

Scientists measure PAR as the number of photons striking a square meter every second. This measurement is sometimes referred to as the Photosynthetic Photon Flux Density, and the units to express the intensity of PAR light are micromoles per square meter per second. For the purposes of measuring the total amount of PAR an area receives in a 24-hour period, scientists use the term Daily Light Integral (DLI). The DLI is expressed as the number of moles of PAR per square meter per day. Figure 2 shows an example of DLI for a clear summer day with no shade. Note how PAR peaks in the early afternoon and is substantially lower in the hours just after sunrise and just before sunset. PAR will peak at your location at solar noon, which is defined as the time when the sun reaches its highest point and crosses the meridian. Depending on the time of year, solar noon can occur before or after 12 noon. More details on solar noon can be found at http://www.sundials.co.uk/equation.htm.

Dr. Todd Bunnell and Dr. Bert McCarty identified in a research project at Clemson University that a Daily Light Integral of 32.6 was needed for TifEagle Bermudagrass to provide an acceptable level of quality. Practically speaking, Bunnell and McCarty recommend eight to ten hours of sunlight for TifEagle Bermudagrass in Clemson, S.C. (Bunnell and McCarty, 2004a). Four of those hours should be between approximately 11 am to 3 pm, when PAR levels are highest. This is excellent information to know when assessing sunlight levels.

Bunnell and McCarty continued shade-related research and examined the effect of the plant growth regulator Primo, mowing height, and nitrogen rate on TifEagle Bermudagrass grown under varying levels of shade. They found that plots with four hours of sun (12 noon to 4 pm), applications of Primo, and a 3/16" height of cut, produced acceptable turf quality at a DLI of 22.1. These researchers concluded, "Therefore, applying a plant growth regulator that inhibits gibberellic acid and raising mowing heights will improve the growth, quality, and performance of ultradwarf Bermudagrass greens in shade (Bunnell and McCarty, 2004b)."

MEASURING DAILY LIGHT INTEGRALS. With a solid background now established in light terminology and more confidence in how much light an ultradwarf needs, attention can shift to measuring sunlight levels on a golf putting green.

Equipment Needed. The first step in assessing shade levels is to identify the Daily Light Integral on the area in question. This can be done through the acquisition of both a light sensor and a meter to read the light sensor. A popular sensor model contains a row of three to six sensors and comes with detailed instructions for use. Based on 2011 prices, the cost is approximately \$600 - \$650. Other less-expensive light sensors can be purchased for several hundred dollars, but these meters may only express DLI within a range, not as a specific number. Spectrum Technologies (Plainfield, Ill.) is a company with many available choices that would work well in determining the DLI on a putting green.

WHEN TO TAKE MEASUREMENTS. Summer: The Clemson studies were conducted over two years, and data were collected between late June and mid-August. During this time of year, Bermudagrass is producing the greatest quantity of vegetative growth, so it makes sense to assess shade levels for the purpose of growing acceptable ultradwarf turf. Use the light sensor to take measurements sometime between mid June and early August. Because the light sensor will need to be at a given location all day long,

Affordable technologies are available for in-field use to more effectively observe the path of the sun and identify trees that block sunlight. When only a few trees may be an issue, a superintendent using the Sun Seeker can identify the trees that block sunlight to a putting green and the approximate length of time these trees cause shade.

there may be interference with play, even though the actual sensor is less than 18 inches long. Make plans to communicate where the sensor is, and make a local rule to deal with any interference.

Spring and Fall: Consider taking measurements in spring and fall, also. These are times of the year when metabolic changes are occurring within the plant in response to day length and temperature. Although plant physiologists have quantified that changes do occur in the plant at these times of year, there is minimal research that quantifies minimum levels of sunlight necessary for adequate long-term growth. We do know that as day-length decreases and temperatures decrease, the plant begins to store carbohydrates that ultimately will be used during greenup the following spring. Therefore, shade in the fall may have an effect on winter survival and spring green-up.

Conversely, sunlight levels in the spring will have an impact on soil temperature and spring green-up, too. It stands to reason that areas receiving less sunlight may be slower to greenup in the spring months. Superintendents have aided the green-up process by increasing canopy temperature through the application of turf paints or dyes and green or black topdressing.

Taking a few measurements during fall and spring will help identify shaded areas. Because we do not have a recommended minimum DLI for the fall, determining acceptable shade levels in the fall will be a judgment call.

WHERE TO TAKE MEASUREMENTS. A golf course superintendent can identify the putting greens that historically have battled issues caused by shade. It is common on some greens that there is only a small corner or area that may receive more shade than other parts of the green. It is a good idea to take two or three measurements on a putting green to assess both the highest and lowest levels of shade on a putting green.

If someone is interested in determining the percent shade that a putting green receives, it will be necessary to also take a DLI reading on any area in full sun. To determine the percentage of shade, use the following equation.

$$\% \text{ Sun} = \frac{\text{DLI of Shady Location}}{\text{DLI of Sunny Location}} \times 100$$

$$\% \text{ Shade} = 100 - \% \text{ Sun}$$

A word of caution is in order – when determining the percentage shade, be sure to take the DLI measurements for both areas on the same day. Try to pick a day with full sun and minimal clouds. Cloud cover can and does impact DLI, so if data were taken on two different days, results could be skewed.

How many measurements to take? This is a judgment call on the part of the end user. The Clemson study took data for almost two months and had the ability to take an average of all those days. At the local level, it would be a good idea to record data on several days that one would consider to be sunny or a typical summer day. A typical summer day in the Southeast would be one

with clear skies in the morning and some isolated clouds in the afternoon. Please note that in the Bunnell and McCarty study the two year DLI for plots in full sun was 41.6, with a maximum DLI reading of 52.1.

Is it necessary to measure every putting green? Probably not. Start first with the putting greens most influenced by shade. Generally, there are two or three greens that cause the most concern. Measure them first and make a determination if other less-shaded greens need to be measured. If the shaded greens have DLIs more than 33, it won't be necessary to evaluate less-shaded greens. Also, look for corners of greens that may have shade issues and measure them. The edge of the green with the cleanup lap has more mower traffic and turning, therefore solve the shade issues on the edges and the rest of the green should be okay.

DATA INTERPRETATION. After taking the Clemson studies into account, a superintendent or course official has solid information in hand to make an educated assessment to determine whether adequate sunlight for growing an ultradwarf exists or if additional action is warranted. Please note that the target of 32.6 is an indicator, not an absolute, and does not take into account additional stress factors, such as traffic, water quality, soil-borne pests, etc. Added stress will require higher DLI.

The initial measurements described above will yield several different outcomes.

- Summer DLI comfortably above 32.6; no action needed. Sunlight is adequate for an ultradwarf. There may be some minor tree issues to deal with, but even if no trees were removed, the ultradwarf will have enough sunlight to grow sustainably.
- Summer DLI at mid 20s-33; potential action needed. Are there trees that can be removed, or is the course able to manage this green differently? Primo use will be essential. A putting green in this scenario is going to require closer attention. Assess the percentage of the putting green that has a DLI below 32.6. A secondary issue for putting greens in this range is to look at DLI levels in the fall and spring, too. The lower a summer DLI level is, the more important it will be to have as much sun in the fall and spring as possible.
- Summer sunlight below DLI of 22-30; action needed or green will be deemed unsuitable for an ultradwarf. In this case, removing trees or moving the green is necessary

INCREASING SUNLIGHT LEVELS. On a shaded putting green, it may not be difficult to agree that trees need to be removed, but there may be disagreement on which ones need to be removed. The trees that need to be removed are the ones that will provide the greatest increase in DLI. Fortunately, there are several tools that are available to assist in this process

- Commercial Services – Companies such as ArborCom Technologies use computer modeling technology to determine the shade impact of individual trees on a given putting green. Shade patterns on a putting green can be modeled for any day of the year and any time period during the day. Within the model, an almost unlimited number of scenarios can be run, examining the impact of the removal of a given tree or multiple trees on sunlight levels. This is a highly precise process.
- Applications on Handheld Devices (i.e., apps) – An app developed for the real estate industry has found a niche in shade management. This app is called SunSeeker and is available on iTunes for a nominal fee for owners of an iPhone or an iPad2. With the app running and the device in camera mode and facing the object(s) potentially causing shade, the user will see several lines across the screen. A blue line traces the path of the sun on the winter solstice, December 21. A red line traces the path of the sun on the summer solstice. A third line traces the path of the sun on the day of the user's choice, with the

During the summer months, this app is quite helpful in identifying trees that block sunlight and determining the duration of time that they block sunlight. This app is a good tool to assist in identifying the fewest trees to remove to achieve the largest increase in direct sunlight.

A WORD ABOUT WINTER SHADE. The angle of the sun decreases by about 36% over the course of a year, and, as a result, shade levels may increase dramatically during the winter months if there are trees along the western, southern, and eastern sides of a putting green. Questions involving whether to measure winter shade are common. A warm-season species, such as Bermudagrass, moves from periods of rapid vegetative growth in the warmer summer months to periods of slower to no growth in winter months. The times and rates of growth change are dependent on upon temperature and day length.

In the fall and winter, changes in temperature and light intensity trigger changes in a Bermudagrass plant. Dr. James Beard explains it this way,

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Meters with multiple sensors are now financially affordable and can be used as a tool in assessing the quantity of photosynthetically active radiation (PAR) for turfgrass plants.

"High light intensities and low temperatures interact to cause winter discoloration of Bermudagrass leaves. High light intensities cause degradation of the existing chlorophyll, while low temperatures impair clorophyll synthesis. The result is typical winter discoloration since the chlorophyll degradation rate exceeds the rate of synthesis" (Beard, 1973).

The implication for the topic in this article is that sunlight levels in the winter do not contribute much to plant growth. Therefore, the key issue with winter shade relates to direct or indirect low temperature injury. Shaded putting greens or shaded areas on a putting green are going to have lower soil temperatures because they receive less solar radiation. The focus for superintendents then switches to monitoring air and soil temperatures and turfgrass covers as needed.

CONCLUSION. Trees and turf are an everyday occurrence on golf courses. The desire of all superintendents is to find the proper balance between the locations of trees in relation to areas of turf, particularly the putting greens. As new grasses are being used in the Southeast, the need for assessing unlight levels has started anew. Fortunately, important research and a variety of tools are now available to every superintendent. Applied appropriately, these resources provide the most accurate measurement and assessment of shade on your golf course, setting the stage for sustainable turfgrass for many years. **GCI**

Chris Hartwiger, USGA senior agronomist, enjoys his time in the shade during the hot summer months in the Southeast Region.

Editor's Note

This article is reprinted from the May 11, 2012, Vol. 50 (10) of the USGA Green Section Record.

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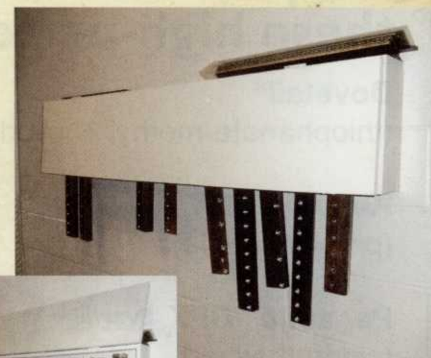
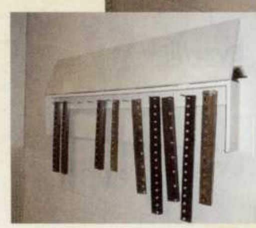
Travels With Terry

Globetrotting consulting agronomist Terry Buchen visits many golf courses annually with his digital camera in hand. He shares helpful ideas relating to maintenance equipment from the golf course superintendents he visits – as well as a few ideas of his own – with timely photos and captions that explore the changing world of golf course management.

BEDKNIFE RACK





Robert Smith, equipment manager at the Merion Golf Club in Ardmore, Pa., built this rack to keep the bedknives from warping by hanging them vertically. Three-quarter-inch plywood was used measuring 5 feet long by 12⅝ inches high by 4¾ inches deep. A 2-by-4 board, with ¼-inch-by-4-inch hex-driver ceramic-coated nails mounted to it, with the nail heads ground off, hold the bedknives in place. A ¾-inch plywood cover using the same dimensions, with 3-inch hinges, folds up and down nicely. This rack is mounted with concrete bolts into the cinderblock wall in the grinding room of the new state-of-the-art maintenance facility and it was painted the same color as the walls. It took about one hour to build and scrap materials were used (about $20 if purchased new).

CUSTOMIZED EQUIPMENT MANAGER'S VEHICLE

This 2010 Kubota RTV900 4 WD has a homemade lift tailgate ($200) for easy lifting of walk-behind greens mowers for transporting them back and forth to the mechanic's shop. A separate winch is used with a 1,500-pound capacity that has the yellow-colored up-and-down control mounted on the left side rear. The bed was extended approximately 15 inches on either side using the existing tailgate cut to fit and welded in place. A used ramp from a Dual Express Model 3000 DX reel grinder is used as the new tailgate – and a 4-foot by 12-inch by ⅛-inch piece of flat steel tailgate extension is used that slips in place over two 1$\frac{1}{16}$-inch diameter steering-shaft rods from a Toro Workman. Two pieces of 1¼-inch "L" channel welded together, with the grooves cut vertically on each side, is where the tailgate slides up and down from the ⅛-inch winch cable. Two chains hold the tailgate in a horizontal position. Additional equipment includes a Mile Marker PE 2.5 electric winch ($100), with a 2,500-pound capacity, that is bolted to the front bumper, which is bolted to the frame with ¼-inch box steel added for bracing. A 1,500 watt/12.5 continuous amp 12-volt to 110-120-volt inverter ($150) is mounted underneath the hood for operating an air compressor with air tools, a battery charger and grinder. A 6-inch vise ($30) is mounted behind the passenger seat that slides 2 feet outwards from the bed that is mounted on a steel plate and sliding square tubing. Two red flashers ($10) are mounted in the rear below the roof, as this vehicle is licensed with a recreational license plate. A Craftsman toolbox is mounted on the left side with "L" brackets and angle iron. The 3-cylinder, 36-horsepower Kubota diesel engine has a SSS Turbo ($1,600) installed for 15 additional horsepower. Robert Smith, equipment manager, at the Merion Golf Club in Ardmore, Pa., has been spending about two months on and off on this project and he is still adding more custom features.