BY JEFF HAAG

# Grow playable, healthy turf

## A look at factors that damage chloroplasts and the defenses that protect them

The goal of every turfgrass manager is to provide a playable surface and aesthetically pleasing green turfgrass. Achieving the latter involves a reciprocal balance between soil, fertility, moisture, temperature, humidity, grass species, mowing techniques, cultural practices and cooperation from Mother Nature. All these aspects have to be working in sync for turfgrass to perform properly and be appealing colorwise.

Protecting and strengthening chloroplasts would seem like the logical action to take because this is where chlorophyll, a pigment that gives turfgrass its green appearance, is developed.

The most important characteristic of plants is their ability to photosynthesis – to make their own food by connecting light energy into chemical energy. This process is carried out in specialized organelles called chloroplasts. A photosynthetic cell contains anywhere from one to several thousand chloroplasts. The electrons from chlorophyll molecules in photosystem II replace the electrons that leave chlorophyll molecules in photosystem I.

Located inside the chloroplast are thylakoid membranes where light reactions take place. This is where chlorophyll is found, therefore, there's a synergistic relationship between keeping the chloroplasts and the thylakoid membranes as healthy as possible.

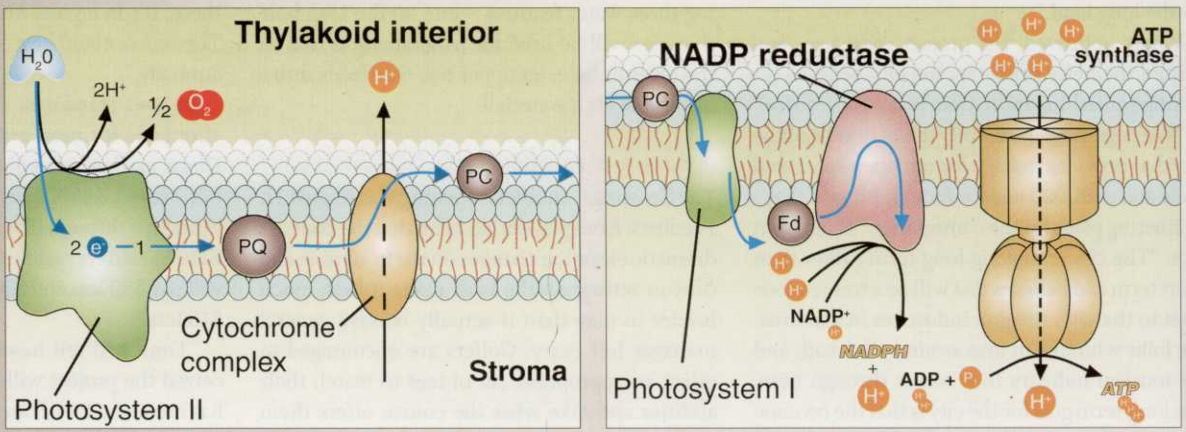
There are events that can be harmful to chloroplasts and thylakoid membranes, as well as necessary components that can prevent damage to them.

### FREE RADICALS

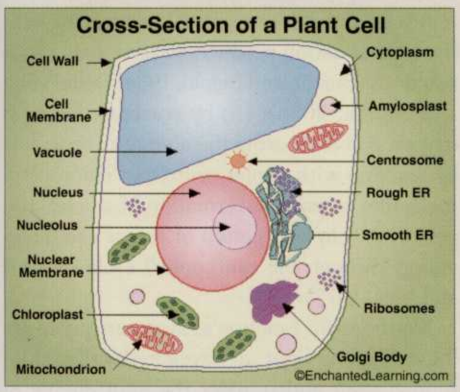
One event that can damage chloroplasts is the development of free radicals. The medical profession has shown that free radicals can cause diseases in the human body. Likewise, turfgrass managers know that research throughout the past several years has shown free radicals can damage lipids, proteins and DNA inside cells of turfgrass plants, including chloroplasts.

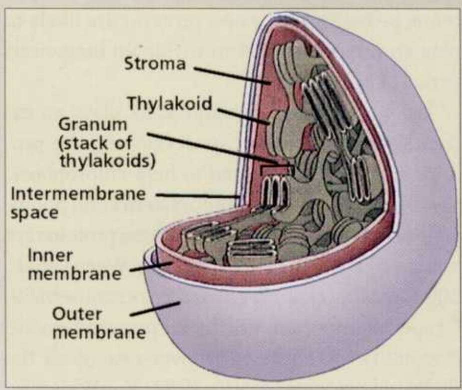
Typically, free radicals are stable molecules that contain pairs of electrons. When a chemical reaction breaks the bonds that hold the paired electrons together, free radicals are produced. They contain an odd number of electrons, which make them unstable, short-lived and highly reactive. As they combine with other atoms that contain unpaired electrons, new radicals are created, and a chain reaction begins (Droge, 2002; Haag, 2005).

This chain reaction, or accumulation of reactive oxygen species, in plants is generally ascribed to several possible sources (Klessig and Malamy, 1994; Corpas et al.,2001; Desikan et al., 2001; Blokuna et al., 2003): cell-wall-bound perxidases, membrane-located NADPH oxidases, amine oxidases, xanthine oxidase, chloroplastic electron transport chains, mitochondrial electron transport chains, and peroxisomal fatty acid B-oxidation, which includes the $H_2O_2$-generating argyl-coenzyme A oxidase steps (Couee et al., 2006). These sources can be attributed to environmental causes such as




The electrons from chlorophyll molecules in photosystem II replace the electrons that leave chlorophyll molecules in photosystem I. Images: Sinauer Associates and WH Freeman




There is a synergistic relationship between keeping chloroplasts and thylakoid membranes as healthy as possible. Images: Sinauer Associates and WH Freeman.

drought, heat, and ultraviolet light, or chemicals such as herbicides (Haag, 2005).

Accumulation of reactive oxygen species is central to plant response to several pathogens. One of the sources of reactive oxygen species is the chloroplast because of the photoactive nature of the chlorophylls (Kariola et al.,2005). The free radicals, or reactive oxygen species, are singlet, hydroxyl, superoxide and hydrogen peroxide.

## LIGHT

There's a catch-22 with light. Light is necessary for photosynthesis to occur; however, it also can play a part in the degradation of chlorophyll.

When photosynthetic organisms are exposed to ultraviolet radiation, significant, irreversible damage to important metabolic processes within the cell might occur (such as lesions in DNA and inhibition of photosynthesis). Through these reactions and others, radical forms of oxygen are often created. Many reports suggest this damage is because of oxidative stress resulting from UV-A, (Dring et al., 1996, Jeffrey and Mitchell, 1997, Turcsanyi and Vass, 2000) UV-B (Teramura and Ziska, 1996, Gotz et al., 1999, Mazza et al., 1999, hideg et al., 2000, Estevez et al., 2001) or both (Krause et al., 1999, Muela et al., 2000, Vega and Pizzaro, 2000, Laloi et al., 2006).

Photosynthetic light absorption and energy usage must be kept in balance to prevent formation of reactive oxygen species in the chloroplasts. Drought causes stomatal closure, which limits the diffusion of carbon dioxide to chloroplasts and thereby causes a decrease of carbon dioxide assimilation in favor of photorespiration that produces large amounts of hydrogen peroxide (Noctor et al., 2002). Under these conditions, the probability of singlet oxygen production at phtosystem II and superoxide production of photosystem I is increased (Niyogi, 1999; Foyer et al., 2005). These can cause direct damage or induce a cell suicide program (Tambussi et al., 2000).

It has been known for a long time wavelengths in the ultraviolet-B region of the spectrum are effective in inactivating photosynthesis, and the molecular target is photosystem II (Jones and Kok, 1966., Chen and Gallie, 2005). An excess of light brings about the inactivation of oxygenic photosynthesis, a phenomenon known as photoinhibition (Powles, 1984), and the molecular target of photoinhibition is photosystem II, a thylakoid multisubunit pigment-protein complex (Bergo et al., 2003). The major effect of ultraviolet-B light on the thylakoid proteins is the breakdown of the reaction centre D1 protein (Trebst and Depka, 1990; Friso et al., 1994; Barbato et al., 1995).

One must question whether ultraviolet-B radiation will become an even more serious factor in the future. The depletion of the stratospheric ozone is causing renewed concern about the increased level of ultraviolet-B radiation reaching the earth's surface (Smith et al., 1995). It's also known exposure to environmental ozone can cause significant damage to turfgrass by imposing conditions of oxidative stress (Chen and Gallie, 2005; Grimes et al., 1983; Schraudner et al., 1998). This might be the case because we're seeing a gradual increase in yearly temperatures throughout the world and an increase in skin cancers in humans. How it affects crops and turfgrass plants in the future remains to be seen.

## SENESCENCE

Senescence results in massive levels of cell death, but the purpose of senescence isn't cell death; rather death only occurs when senescence has been completed. Senescence occurs in two stages. The first stage is reversible, and the cells remain viable throughout. The second stage results in cell death (Buchanan-Wollston et al., 2003; McGlaughlin and Smith, 1995; Mothes et al., 1960; Riefler et al., 2006; Venkatrayappa et al., 1984).

The key enzyme in the pathway to chlorophyll degradation during senescence appears to be pheophorbide *a* oxygenase. The activity of pheophorbide *a* oxygenase increases dramatically during senescence, implicating this enzyme as a control point in the process (Buchanan-Wollston et al., 2003; Hortensteiner et al., 1998). Light absorption by pheophorbide *a* oxygenase also is believed to cause the production of singlet oxygen (Pruzinska et al., 2005), which is a free radical.

Because senescence is reversible, it suggests that fully developed chloroplasts retain enough genetic information to support regreening and chloroplast reassembly.

## CALCIUM AND POTASSIUM

From a nutritional standpoint, there are various nutrients and compounds that can be applied in the process of strengthening and defending chloroplast damage.

Because the chloroplasts and thylakoid membrane are located inside the plant cell, the first line of defense would seem to be to strengthen the plant cell by keeping calcium and potassium at optimal levels. Calcium plays a key role in strengthening the cell walls of the turfgrass plant, while potassium helps strengthen cell walls inside the turfgrass plant, which makes it harder for physiological problems to occur inside the cell wall (Haag and Serrato, 2006).

With regard to calcium applications, add a light amount of zinc along with the calcium because zinc helps calcium to translocate to the cell walls (Haag and Serrato, 2006).

## AMINO ACIDS

Amino acids are the building blocks of proteins. Under optimal conditions, proteins are able to perform the normal physiological function to synthesize amino acids, but intensively manicured turfgrass, such as golf courses and athletic fields, are rarely operating under optimal conditions because of stress caused by low mowing heights and traffic (Haag and Serrato, 2006).

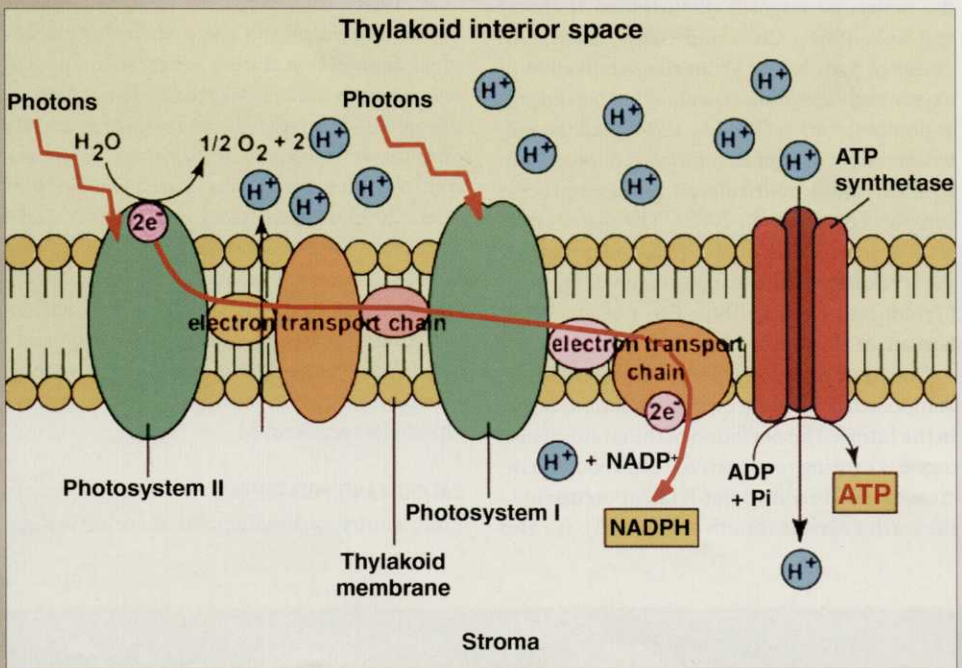
To date, 154 proteins in the turfgrass plant have been identified – 76 (49 percent) are integral membrane proteins. Twenty-seven new proteins without known functions, but with predicted chloroplast transit peptides, have been identified – 17 (63 percent) are integral membrane proteins. These new proteins are likely to play an important part in thylakoid biogenesis (Friso et al., 2004).

The application of amino acids plays an extremely important part in developing the proteins specifically designed to help chloroplasts, thylakoid membranes, photosystem I and photosystem II to function properly. These proteins are known as D1, D2 CP43, CP47 (de Weerd et al., 2002, Zheleva et al., 1998) and cytochrome b559. Of special importance is the D1 protein because it exhibits the highest turnover rate of all the thylakoid proteins (Matto, 1984; VonWettstein et al., 1995; Prasis et al., 1992; Aro et al., 1993; Schuster et al., 1988) and is highly vulnerable to singlet oxygen (Barber, 1984), a free radical.

## ANTIOXIDANTS

The antioxidants a-tocopherol (vitamin E), ascorbic acid (vitamin C), carotenoids (B-carotene), vitamin B6 and mannitol in some biostimulants play a vital role in scavenging free radicals (Barna et al., 2003) and helping protect chloroplasts, thylakoid membranes inside the chloroplasts, photosystem I and photosystem II.

The best biostimulant that I've encountered to date is the N.O.G. product.




## CAROTENOIDS (B-CAROTENE)

In terms of its antioxidant properties, carotenoids can protect photosystem I and photosystem II in one of four ways: (i) by reacting with lipid peroxidation products to terminate chain reactions (Burton and Ingold, 1984; DellaPenna and Pogson, 2006); (ii) by scavenging singlet oxygen and dissipating the energy as heat; (iii) by reacting with triplet or excited chlorophyll molecules to prevent formation of singlet oxygen, or (iv) by dissipation of excess excitation energy through the xanthophyll cycle (Mathis and Kleo, 1973).

Xanthophylls function as accessory pigments for harvesting light at wavelengths that chlorophyll can't and transfer the light energy to chlorophyll. But, they also absorb excess light energy and dissipate it to avoid damage in the xanthophyll cycle.

## A-TOCOPHEROL (VITAMIN E)

A-tocopherol (vitamin E) is considered a major antioxidant in chloroplasts in at least two different but related roles. It protects photosystem II from photoinhibition and thylakoid membranes from photooxidative damage (Havaux et al., 2002; Havaux et al., 2005; Delong and Steffen, 2002, Flohe and Traber, 1999). The antioxidant properties of vitamin E are the result of its ability to quench singlet oxygen and peroxides (Fryer, 1992; Sattler et al., 2006).

Although vitamin E is a less efficient scavenger of singlet oxygen than B-carotene, it might function in the thylakoid membrane to break carbon radical chain reactions by trapping peroxyl radicals (Fryer, 1992; Burton and Ingold, 1984; Mathis and Kleo, 1973).

## ASCORBIC ACID (VITAMIN C)

It's generally believed maintaining a high ratio of ascorbic acid is essential for the scavenging of free radicals (Mitler, 2002) and are needed in high concentrations in the chloroplasts to be effective in defending the turfgrass against oxidative stress (Noctor and Foyer, 1998).

The image to the left depicts how the electron transport chain moves through the thylakoid interior. Image: Gary E. Kaiser, Ph.D.

Although ascorbic acid can directly scavenge the free radicals superoxide and singlet oxygen, the main benefit ascorbic acid plays in the prevention of free radicals is that it's an excellent scavenger of the hydroxyl radical (Blokhina et al., 2002; Yoshida et al., 2006). The hydroxyl radical is dangerous to turfgrass because it can inhibit carbon dioxide assimilation by inhibiting several Calvin cycle enzymes (Asada, 1996).

#### VITAMIN B6

Apart from its function as a cofactor, vitamin B6 is also thought to act as a protective agent against reactive oxygen species, such as singlet oxygen (Bilski et al.,2000; Chen and Xiong, 2005; Ehrenshaft et al.,1999; Drewke and Leistner, 2001). Vitamin B6 is also the master vitamin in processing amino acids and plays an important role in developing proteins specifically designed to help chloroplasts, thylakoid membranes, photosystem I, and photosystem II to function properly.

#### MANNITOL

The antioxidant mannitol has the ability to protect and quench two damaging free radicals: singlet oxygen and hydroxyl. Singlet oxygen is damaging because it can react with proteins, pigments and lipids and is thought to be the most important species for light-induced loss of photosystem II activity, as well as the degradation of the D1 protein (Krieger-Liszkay, 2004). It has been demonstrated that when mannitol is present in the chloroplasts, it can protect plants against oxidative damage by the hydroxyl radicals (Senn, 1987; Shen, 1997).

#### MANGANESE AND MAGNESIUM

Both of these nutrients are attached to the chlorophyll molecule that's located inside the chloroplasts. These two nutrients play a part in making turfgrass greener by helping develop chlorophyll. They also transport other vital nutrients and are responsible for many enzymatic functions and help prevent chlorophyll degradation in the cells (Haag and Serrâto, 2006).

#### CARBON

There's new evidence carbon plays a role in the development of the turfgrass plant leaf, and that a reduction in carbon reduces photosynthetic activity, which reduces carbohydrate availability to the turfgrass plant. There's also new evidence to suggest proper development of the turfgrass plant can't occur without proper amounts of carbon in the chloroplast (Raines and Paul, 2006). There's more evidence to suggest that, if there's an abundant source of carbon in the thylakoid membranes inside the chloroplasts, it can be mobilized for use as an energy source during senescence (Graham and Eastmond, 2002).

#### HUMIC ACIDS

Humic acids are another compound that contain antioxidant properties that promote the scavenging of free radicals. The added benefits of humic acid are that they increase the availability of micronutrients, phosphate and potassium to the plant and enhance the chlorophyll content of turfgrass.

Humic acids also stimulates root initiation because of the auxin-like activity they contain, which is most likely because of their ability to inhibit indoleacetic acid oxidase breakdown (Haag, 2005; Haag and Serrato, 2006). GCI

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*Editor's note: Literature cited in this article can be found on GCI's Web site, www.golfcourseindustry.com, posted with this article.*

## IMPACT ON THE BUSINESS
# The plant health dilemma

BY PAT JONES

The evolution of turfgrass science is, in many ways, similar to the evolution of human medical science. In less than a century, we've gone from the most rudimentary forms of nutrition and treatment (manure and heavy metal fungicides like cadmium and mercury) to feeding plants with key elements and treating pathogens that cause disease with highly specific and environmentally benign inoculants. It's not too different than medical science moving from leeches and bleeding to lasers and non-invasive surgery in the same time frame.

#### BACK TO BASICS

One of the bigger trends during the past decade has been the "back to basics" approach of combining traditional granular fertilization with liquid/foliar nutrition programs that are tailored to meet the needs of the turf and soil. The article above focuses on a core aspect of this trend – finding the right combination of nutrient elements to feed the plant what it needs to thrive.

By identifying the key aspects of photosynthesis and making sure your program meets those needs, you can make an excellent start toward creating a customized "diet" that fits your turf's photosynthetic requirements. More importantly, by understanding the basic nature of plant self-feeding, you can think about your nutrition program at its most fundamental level.

#### IT'S ELEMENTAL, WATSON

The author effectively points out how a variety of elements and proteins help build up turf health from the inside out. Calcium, potassium, amino acids and various vitamins are all photosynthetic enhancers. The question is, how do you know which to use and in what combination?

The answer lies in a combination of soil and tissue testing and trial and error. By establishing a baseline and working with your local university, consultants and colleagues, you can determine the best mix of supplements. It's no different than getting a physical exam or blood test from you doctor to determine the best combination of diet, exercise, nutrition and preventative medicines for your own health.

#### RETURN ON INVESTMENT

Many of the articles that we run in GCI's research section offer immediate opportunities for cost-savings or instant improvement in turf quality or health. This is a different approach. The payback here is that, by understanding the building blocks of healthy plants, a superintendent can look at his nutrition program with a new set of eyes and develop a long-term approach.

In the long run, healthy turf is the best defense against pathogens and pests. GCI

BY LARRY J. STOWELL, PH.D., CPAG

# Greens management

## Water management, aerification and topdressing are keys to desired firmness

On Jan. 23, 2006, Santa Ana Country Club and the PACE Turfgrass Research Institute embarked on a multimonth study to analyze greens firmness by characterizing the current situation and then identifying management practices that can help achieve more consistent greens firmness throughout the year.

Factors contributing to greens firmness were identified, with soil moisture a key component. Greens were characterized by golfers as performing well, with good surface firmness, on the aforementioned date. Based on data collected Jan. 23, a tentative range of 15 percent to 25 percent soil moisture was identified as the target for producing optimal levels of firmness (tentatively characterized as ranging from 70 to 125 gravities on a Clegg meter).

Maintaining this level of performance throughout the year will be difficult, especially during the hot summer months when irrigation demand is highest. However, practices including modified aeration, topdressing and irrigation strategies, along with a soil moisture and surface firmness monitoring program will assist in achieving the best firmness possible while still maintaining turf health and quality.

**Figure 1.** Operation of the Clegg impact soil tester. The hammer of the tester contains a sensitive decelerometer that measures the speed of deceleration on impact with the greens surface. The 2.25 kg hammer is lifted to a height of 18 inches and dropped. The measurement unit is gravities (g). In the example below, the Clegg recorded a firmness of 81 g. Values between 70g and 125g are desired for firm greens surfaces.


### DESCRIBING THE PROBLEM

The golfer controversy about greens trueness and firmness has been ongoing for many years. The following quote from the U.S. Golf Association's "Timely Turf Topics" in May 1947 illustrates the persistent focus on firm and true greens:

"Putting surfaces should be firm to avoid foot printing and should be resilient so that a properly played shot will hold, but should be sufficiently solid so that a poorly played shot will roll over. The surface should be smooth and true as a billiard table. Density of the turf should be so great that individual grass blades are crowded to a true vertical position. "Graininess," "sponge," or "mat" destroy the accuracy and fun in golf. Governing factors include: choice of grass, soil texture, drainage and aeration, fertility level, and watering practices."

Not much has changed in the desire of golfers for firm and true greens surfaces since 1947. Despite this, methods for addressing the problem haven't been extensively researched and documented. This is partly because the nature of the problem varies widely from one golf course and one group of golfer's perceptions to another. It's also because the management practices that are required to improve firmness frequently require long-term overhauls of the greens.

#### FACTORS INVOLVED

At Santa Ana Country Club, the governing factors that will influence firmness are the same as those listed in the aforementioned quote. Unfortunately, major reconstruction is required to modify the factors most directly implicated in greens firmness. These are the nature of the root-zone sand (which should optimally be changed to a firmer mixture), the turfgrass variety (which should optimally be changed to bentgrass, which provides a firmer surface than *Poa annua*) and improved drainage (which, by allowing water to move more easily through the soil profile, would increase the firmness and homogeneity of the greens). Without these major changes, greens firmness can't be fully maximized at Santa Ana Country Club.

There are, however, several less dramatic management practices that can lead to improvements. These include modifications in aeration, topdressing and watering practices.

An increased frequency of aeration will lead to firmer greens, but the compromise is that the trueness of the surface will be impacted for about 14 days following each aeration event. New, smaller diameter aeration tines might improve recovery and allow more frequent aeration to increase firmness, but increased aeration to improve firmness will have to be weighed against the negative (though temporary) impact on surface trueness. Even if increased aeration can't be tolerated, application of sand as topdressing without aeration is a practice that might be evaluated to increase the firmness of the greens during the summer.

A second, and more controversial factor is watering practices. Is it possible to reduce summertime irrigation or hand-watering while maintaining healthy *Poa*? Irrigation water reduction to increase firmness carries the greatest risk. Once the soil has dried to a level that exceeds the ability of the *Poa* plant to extract the water, the plants will wilt and die. If the *Poa* dies, a minimum of six weeks of conducive weather conditions will be needed before the stand of *Poa* will return to acceptable putting conditions. In the peak heat of the summer, this period of time will be longer, and if traffic is allowed on the damaged areas, the time to recovery will be extended further.

Even though soil water management to levels that provide firm greens without damage to the *Poa* plant is a risky venture, one of goals of this project will be to determine if there is a way to reduce the risk of drying out *Poa* greens. How dry is safe? Can we monitor soil moisture to better adjust irrigation practices? What levels of soil moisture are adequate for the plant yet low enough to provide the desired firmness?

Soft greens have been described as greens that don't have sufficient ball bounce and roll after driving onto the green. Additionally, soft greens are more susceptible to severe ball marking. These subjective measures of firmness will help guide management practices and development of objective measures of firmness. The current firmness of greens was reported to be nearly ideal by golfers at Santa Ana Country Club during the day of sampling (Jan. 23, 2006). The range of firmness measured during this preliminary study will be used as a benchmark to measure the impact of future management practices. These guidelines will need to be re-evaluated during the year to be sure they're valid and the health of the *Poa* isn't compromised.

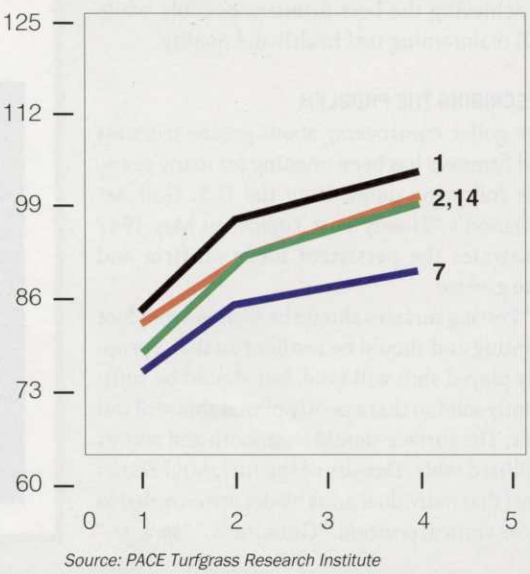
Sometimes fertility is mentioned as a factor in greens firmness. Fertility has been monitored at Santa Ana Country Club for more than 10 years. Soil nutritional guidelines have been managed within the range needed for good greens performance. Attempts to reduce fertility with the goal of firming greens will compromise the integrity of the *Poa* and increase susceptibility to diseases such as anthracnose and susceptibility to wear damage.

#### MEASURING FIRMNESS

Firmness has been measured using a variety of tools. Baker et al. (1996) used simulated golf ball launchers that mimicked the impact of a ball hitting a green with the impact that might be typical for a 5 iron (53 degree impact angle, velocity of 22.7 m/s, backspin 750 rad/s) and a 9 iron (53 degree impact angle, velocity 18.8 m/s, backspin 880 rad/sec).

This unique research equipment isn't available for us to use, but fortunately, Baker et al. found there was a significant correlation between firmness evaluated using the ball impact simulators and the Clegg impact soil tester. Based on their fairly extensive surveys of golf courses in Britain, a range of Clegg measurements between 70 gravities and 120 gravities

**Figure 2. Average of four drops of the Clegg hammer (Impact) at each of four sites for each of four green evaluated. G represents the average number of gravities of deceleration (a measure of firmness) for each of the four greens. Greens performance was near ideal at the time of sampling indicating these values are within the target guideline for firmness at Santa Ana Country Club.**



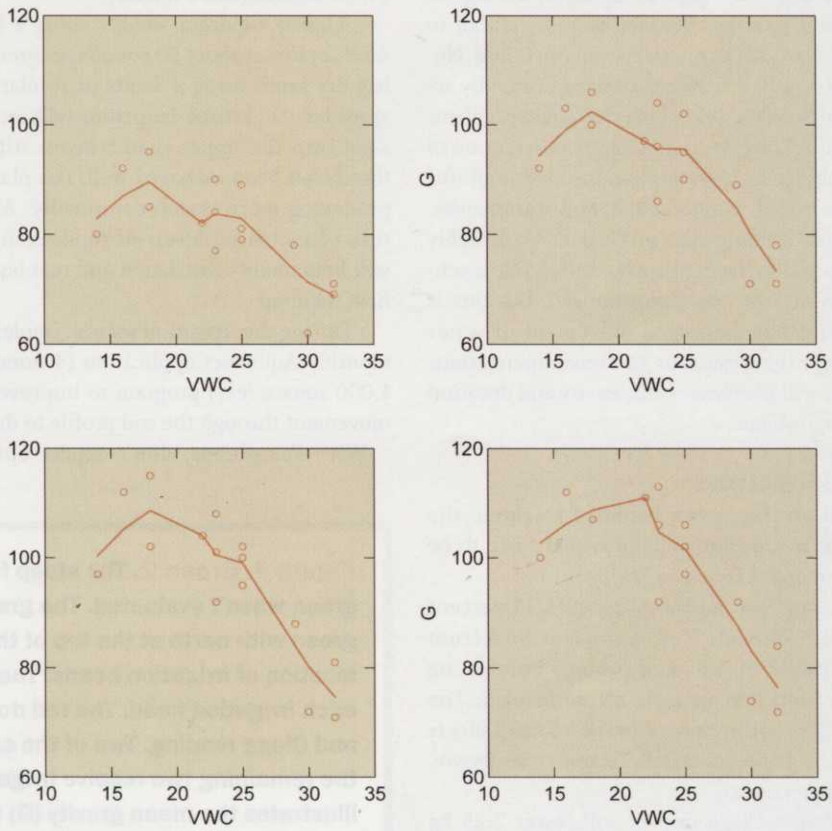

Source: PACE Turfgrass Research Institute was considered to result in good ball bounce and roll – not too soft and not too hard.

In a similar study conducted in New Zealand, Linde found greens reporting Clegg values of less than 50 gravities were too soft and greens that reported Clegg values of more than 140 gravities were too hard. The average for high-end golf courses in New Zealand ranged between 78 and 122 gravities. Based on this information, we have identified a range of 70 gravities to 125 gravities as an initial target for the Santa Ana Country Club. This range will be modified, if necessary, as work progresses.

The Clegg values observed at the Santa Ana Country Club during this preliminary study ranged between 62 gravities and 125 gravities. Based on this initial research, the greens are currently performing almost completely within the guidelines considered ideal for golf play (only two readings were below the guideline of 70 gravities).

Golfer's positive evaluations on firmness, obtained January 2006, confirm this conclusion. It's expected that as hot weather and increased irrigation demands occur during the summer months, firmness might decline. It's during the warmer months that the greatest challenge in terms of maintaining green firmness occurs.

**Figure 3.** **The relationship between TDR300 VWC (volumetric water content as a percentage) and Clegg deceleration (G). Higher G values indicate increased firmness. Firmness declines when soil moisture levels increase above 25 percent. The upper left graph represents the first drop of the Clegg hammer. The upper right graph represents the second drop of the Clegg hammer. The lower left represents the third drop of the Clegg hammer. The lower right represents the fourth drop of the Clegg hammer.**




*Source: PACE Turfgrass Research Institute*

## MEASURING SOIL MOISTURE

Soil moisture conditions also were monitored during the Jan. 23 evaluation. The correlation between low soil moisture and firm conditions were confirmed at Santa Ana Country Club (Figure 3). Soil moisture levels ranged between 14 percent and 32 percent, although the majority of readings were within the guideline of 15 percent to 25 percent moisture. For sand-based greens, we generally target a range of roughly 15 percent to 25 percent for optimal turf growth and optimal firmness. Although moisture levels below 15 percent produce good firmness, turf health might be seriously compromised. A reading of 12-percent soil moisture resulting in turfgrass stress and damage.

Targeting soil moisture from 15 percent to 25 percent, and with *Poa* plants having roots that can extract water from the top 1.5 inches of soil during the summer, the plant will have just enough water to make it through a maximum water demand (evapotranspiration) day in the summer – about 0.3 inch of water. For that reason, the surface moisture in the top 1.5 inches of soil will almost have to be replenished daily.

If the *Poa* plant were capable of forming longer roots, less water would need to be applied daily because the deeper roots would have access to deeper soil moisture. The ultimate problem we will encounter when trying to manage *Poa* at lower soil moisture levels is that the short roots will require almost daily irrigation or syringing. Compounding the high water demand of *Poa* is that water must be applied through the surface of the green resulting in a higher water concentration at the surface of the green.

A further challenge with regard to managing soil moisture relates to the inherent flaws of irrigation system designs. Compounded by the irregular shape of greens, it's unfortunate that portions of the same green might be irrigated from anywhere between two to five different irrigation heads. This results in uneven application of water and, therefore, uneven soil moisture levels. To compensate, superintendents must combine a series of tactics, including targeted hand-watering (to areas that receive too little water), irrigation system adjustments (micromanagement of irrigation head run cycles) and constant adjustment and readjustment of the system.

By monitoring soil moisture and surface firmness parameters throughout the year, this study hopes to identify irrigation practices that can combine sometimes contradictory demands of keeping the turf quality high while keeping the playing surface as firm as possible.

A final soil moisture challenge relates to the need for periodic leaching (high volume irrigation) of the greens, especially during the summer months. Because lack of rainfall in Southern California between April and November, salts from irrigation water rapidly accumulate in the soil, where they cause problems including turf stress and death, destruction of soil physical properties and instigation of turf diseases such as rapid blight and anthracnose. Without leaching, the survival of *Poa* is highly unlikely. Surface firmness following leaching events will be compromised, but this is unavoidable. Improved movement of water through the greens via the recommendations below will decrease the intensity and duration of the problem.

### RECOMMENDATIONS

Based on the aforementioned research, the follow are recommendations that were to be implemented February 2006.

- Target soil moisture between 15 percent and 25 percent. You can use a Spectrum TDR300 with 4.8 inch probes. Purchasing a soil moisture meter is recommended. The TDR 300 soil moisture probe ($1,195.00) is available from Spectrum Technologies (www.specmeters.com).
- Target Clegg impact soil tester 2.25 kg hammer deceleration between 70 gravities and 125 gravities.
- In the spring, aerify using three-eighths-inch hollow tines on a 2-inch-by-2-inch spacing and sand fill the holes using Caltega 7 USGA specification sand.
- A more aggressive aerification program than the one described above can be substituted if a club is willing to tolerate disruption of optimal golf play to achieve more dramatic results.

In the spring of the year, aerify using five-eighths-inch hollow tines and collect the plugs. Apply one-quarter-inch depth of Caltega 7 USGA specification silica sand. Vertidrain using three-quarter-inch solid tines and sweep the sand into the holes and fill all holes to the top. This process will aid in firming the entire root zone, but it will require a repeat of the process for at least three years in the spring before the process can be terminated. This aggressive program will disrupt the trueness of the greens for an extended period of time and might result in stronger *Poa* growth in the aeration holes that will result in a slightly bumpy surface. This negative impact can be partially managed using Primo and increased fertility.

- Lightly topdress weekly using a No. 30 sand applied at about 50 pounds per green (one bag dry sand) using a Scotts or similar rotary spreader. Nighttime irrigation will move the sand into the upper thatch layer. Although thatch has been managed well, *Poa* plants are producing more thatch continually. Application of increased levels of topdressing sand will help modify the thatch and mat layer and firm them up.
- During the irrigation season, implement a monthly Aqueduct application (4 ounces per 1,000 square feet) program to improve water movement through the soil profile to drain.

With *Poa* greens, don't expect optimum greens performance during the months of July, August and September. Prevent turf loss during these months so that fall winter and spring greens performance will be premiere. It's unlikely that optimum performance can be provided throughout the year. If summer is the target for good performance, more aggressive aeration will be needed at other times of the year to improve the root-zone composition and allow deeper rooting and improved drainage. **GCI**

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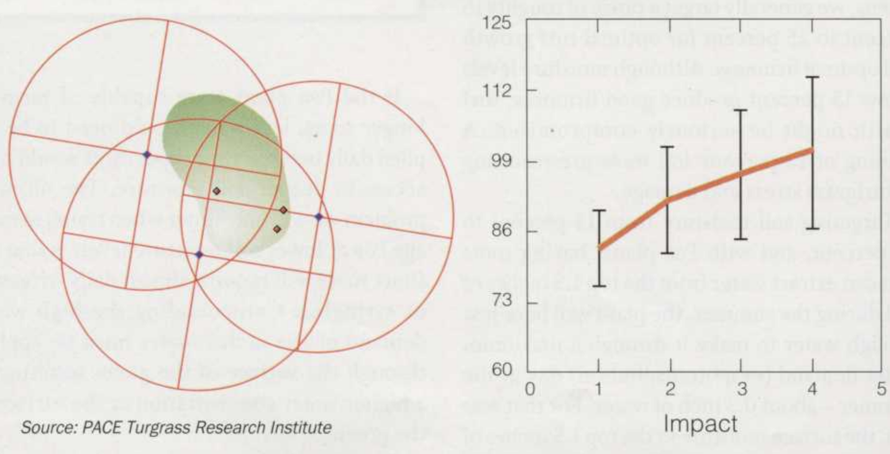
**Figure 4. Green 2. The steep front of this soil-based, 3,540-square-feet green wasn't evaluated. The green area illustrates the orientation of the green with north at the top of the illustration. The blue dots illustrate the location of irrigation heads. The red circles illustrate the 67-foot throw of each irrigation head. The red dots illustrate the location of each soil moisture and Clegg reading. Two of the samples receive irrigation from two heads, and the remaining two receive irrigation from three irrigation heads. The graph illustrates the mean gravity (G) recorded for each impact with the hammer. The vertical bars illustrate the standard error of each mean.**




*Source: PACE Turgrass Research Institute*