long to set the cycles for the different areas of the course.

These decisions are most likely based on the underlying assumption that there will always be an adequate supply of available irrigation water, with very little to no consideration being given to the total amount of water that will be used for the entire growing season. Most of us have operated this way for years.

Unfortunately, we can no longer afford to manage our irrigation practices in this manner. We need to start budgeting our water use more like we budget our fertilizer and pesticide use. By forcing ourselves to examine the amount of water used on our courses on a daily, monthly and annual basis, we begin to change our outdated and potentially dangerous mindset when it comes to water management.

> "We need to start budgeting our water use more like we budget our fertilizer and pesticide use.

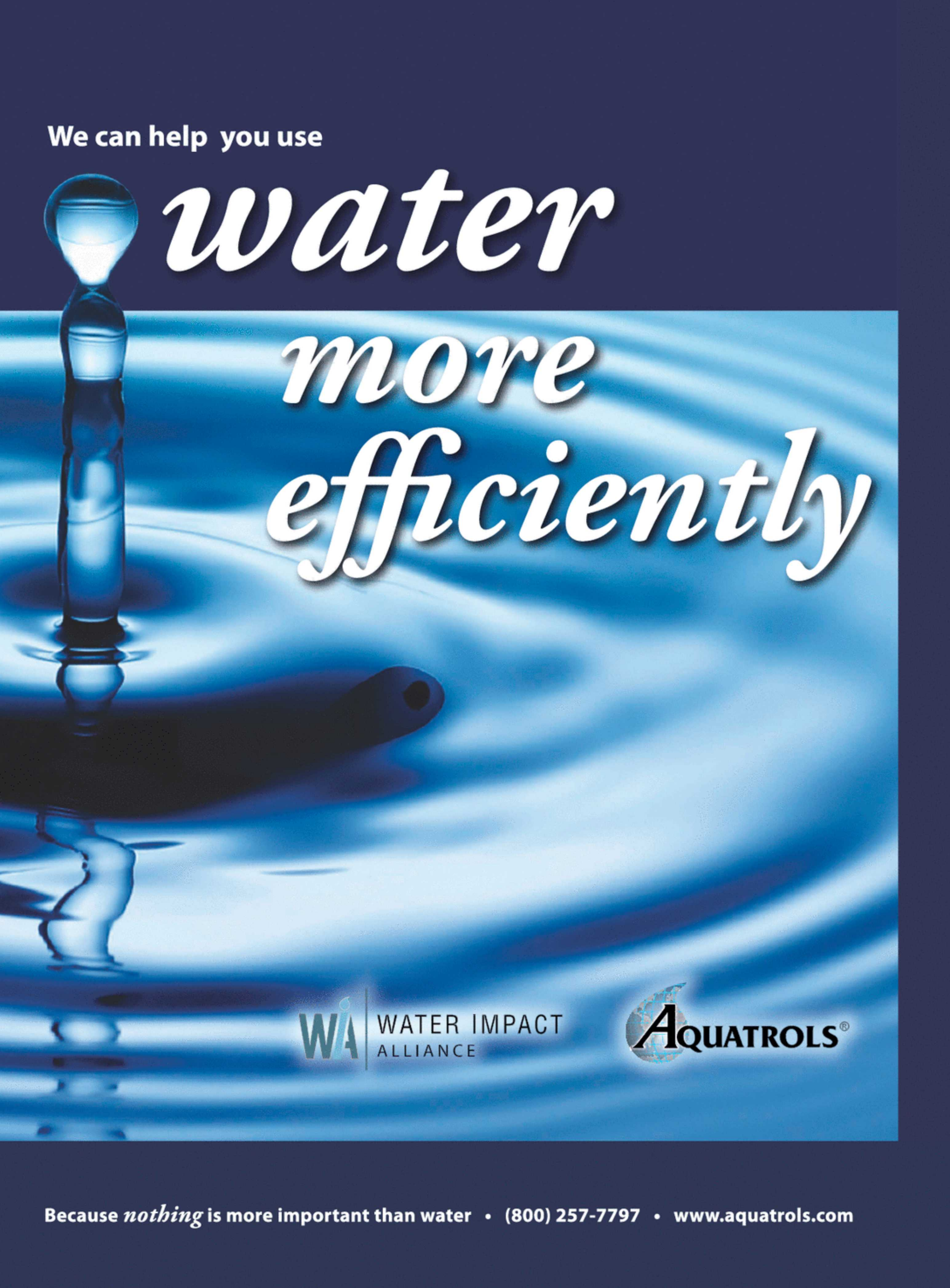
When I interview people for assistant positions, I always tell them, "If you don't like change, I suggest you leave the golf industry." I will always believe this is true.

I can't think of one superintendent who has survived any length of time being complacent and sitting on his or her laurels unwilling to embrace the constant changes of our industry.

You should be no different. The last thing I want for any of us is to suddenly realize that times have changed and we've been left behind wearing spandex running shorts and sporting timeworn mullets.

Lead or be left behind. It's our call. ■

Gray, general manager and superintendent of the Marvel Golf Club in Benton, Ky., is a Golfdom contributing editor and editorial advisory board member. Gray was the 2008 recipient of Rain Bird's Intelligent Use of Water Award.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TURFGRASS TRENDS

TALL FESCUE AND IRRIGATION

Tall Fescue Rooting in Response to Irrigation Management

By Jack Fry

Tall fescue has become a popular turfgrass in the Midwest transition zone because of its deep rooting and capacity for drought tolerance. Under well-watered conditions, however, tall fescue's ET (evapotranspiration) rate is higher than most cool-season turfgrasses (Fry and Huang, 2004).

A deep, infrequent approach to irrigation reportedly increases rooting in some turfgrasses, and tall fescue is no different. Drying the soil from 0 centimeters (cm) to 20 cm under tall fescue in the greenhouse resulted in greater root mass at 0-cm to 20-cm and 20-cm to 40-cm depths compared to turf where the entire 0 cm to 40 cm soil profile was consistently maintained near field capacity (Huang and Fu, 2001). The authors of the study also reported greater carbon allocation to roots when the surface-to-20-cm range was allowed to dry, which may have resulted from a reduction in vertical shoot growth rate.

Soil quality is one limitation to enhancing rooting with deeper, more infrequent irrigation. In many cases, tall fescue may be growing on shallow, fine-textured soils where its genetic potential for rooting cannot be realized. On such soils, tall fescue may not be a desirable choice for water conservation, since it rapidly uses the relatively shallow pool of available water. This creates a need for more frequent application.

Deficit irrigation, or returning water in amounts less than typically required by well-watered turf, is one process used to conserve water. Ultimately, the goal is to use less water while maintaining an acceptable level of turf quality. In Kansas, for example, tall fescue quality can be maintained with deficit irrigation levels of 40 percent or 60 percent ET between June and September, assuming a turf manager can tolerate a week or two in which quality is just below a visually acceptable level (Fu et al., 2004).

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The study explored the impact of deficit irrigation on tall fescue rooting. Evapotranspiration of well-watered turf was measured using small weighing lysimeters. The shelter in this photo was moved to cover plots with the onset of precipitation.

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Because smaller amounts of water are applied with deficit irrigation, soil is wetted to a more shallow depth than with traditional deep, infrequent irrigation. Periodically wetting the surface few centimeters of soil, but not deeper soil, could influence growth and distribution of roots. Therefore, surface roots may experience little drought effect since they receive periodic moisture. Roots deeper in the soil profile might be exposed to drying soil, which may influence their development. Despite the positive water-saving benefits of deficit irrigation, effects of this practice on tall fescue root development were only recently evaluated.

In 2001 and 2002, a study at Kansas State University explored the impact of deficit irrigation on tall fescue rooting. Water was applied on Monday and Friday between June and September to Falcon II tall fescue growing on a silt loam soil. Evapotranspiration of well-watered turf was measured using small weighing lysimeters, and based on these values, was returned at 20 percent, 60 percent or 100 percent to 1.2 meter x 1.8 meter plots that were located underneath an automated rainout shelter. The shelter moved to cover plots with the onset of precipitation. Turf was mowed twice weekly at 5 cm using a walk-behind rotary mower, and clippings were collected. Nitrogen was applied at 49 kilograms per square hectare (kg ha-1) on May 3, Sept. 19, and Nov. 8, 2001, and May 3, Sept. 18, and Nov. 15, 2002.

Soil water content from a depth of 0 cm to 25 cm was measured using a time domain reflectometer. Root growth and production were measured using a mini-rhizotron imaging technique, which allows roots to be monitored as they grow without destructive sampling. Before the study began, two soil cores (5 cm in diameter by 90 cm long) were removed from each plot at a 45-degree angle from the soil surface. Clear butyrate tubes the size of the remaining voids were plugged with a black rubber stopper at the bottom end and manually forced into holes. On the upper side of each tube were etched frames (1.3 cm long by 1.8 cm wide) that extended along the length of the tube, allowing a camera to return to the exact location when repeated measurements were taken.

Video images of roots visible against the surface of the tubes were recorded using a high-magnification minirhizotron camera and a camcorder. Root images were taken every two weeks through 43 days of irrigation treatments, and then every four weeks each year until the end of the experiment. Video root images were recorded beginning at nearly 1-cm increments from a 4-cm soil depth to a 51-cm depth. Tall fescue irrigated at 20 percent ET had higher root numbers than well-watered turf at a 17.9-cm depth in 2001, and at 8.7-cm, 13.3-cm, and 17.9-cm depths in 2002. Root surface areas and lengths were also higher at the 20 percent ET irrigation regime at 8.7-cm, 13.3-cm, and 17.9-cm depths in 2002.

One of the concerns regarding deficit irrigation is the potential to restrict deep rooting

Research done by Huang and Fu in 2001 demonstrated that allowing the surface 0 to 20 cm of soil to dry down resulted in more extensive rooting at 20 to 40 cm (center). Treatment represented on the left is tall fescue that was watered to maintain soil at field capacity. Treatment on the right shows roots exposed to excessive drying.

because the surface is periodically wetted, but deep irrigation does not occur. However, we observed that soil water content from the surface to a depth of 25 cm was lower under tall fescue receiving 20 percent ET than under well-watered turf beginning after eight days of irrigation in 2001 and after seven days in 2002. At 20 percent ET, average irrigation ranged from 3 mm to 4.5 mm, and we observed that this typically served to wet the soil to a depth of less than 3 cm. Soil drying under the 20 percent ET regime enhanced tall fescue root development between 8.7 cm and 17.9 cm. The TDR probe measures average water content over its entire 25 cm length; as such, there were periods when the surface few centimeters were likely more wet than the rest of the profile for a short period after irrigation, but this was not detected by the TDR measurement.

Irrigation at 60 percent ET had no effect on tall fescue rooting or soil water content in either year compared to turf irrigated at 100 percent ET. Irrigation at this level was, on average, 13 mm and resulted in soil wetting to a depth of about 10 cm. The lack of effect by 60 percent ET irrigation level on soil water level likely resulted because ET rates were lower in this treatment than in turf receiving 100 percent ET. Also important to note is that rooting did not proliferate at 4.7 mm or 8.1 mm depths under a 60 percent ET irrigation regime, depths to which the soil wetting front reached twice weekly.

Irrigation at 20 percent reduced visual quality below a level that was considered acceptable after 60 days in 2001 and about 35 days after treatments were initiated in 2002. Irrigation at 60 percent ET was sufficient to maintain quality equivalent to turf receiving 100 percent ET throughout each summer of the experiment. Despite the reduction in visual quality at 20 percent ET, we found that tall fescue rooting was concomitantly enhanced under this irrigation regime

Tall fescue evaluated in this study and subjected to 20 percent ET irrigation had a vertical growth rate approximately 40 percent lower than that of turf irrigated at 100 percent ET (Fu et al., 2006). A similar re-allocation of carbohydrates from shoot to roots resulting from slower shoot development, as described by Huang and Fu, (2001), may have contributed to root growth enhancement in turf receiving irrigation at 20 percent ET. However, unlike the results reported in Fu et al. (2004), a drier soil between a depth of 0 cm and 25 cm in this field study did not promote tall fescue rooting at depths greater than 17.9 cm.

A drier soil between a depth of 0 cm and 25 cm in this field study did not promote tall fescue rooting at depths greater than 17.9 cm.

Of greatest importance to the turfgrass manager is that there are no detrimental effects on rooting of irrigating tall fescue at 20 percent or 60 percent ET from June to September, when irrigation requirements are highest and restrictions are most common. Despite a drier soil in the surface 20 cm under the 20 percent ET irrigation regime, an increase in tall fescue root number, length and surface area occurred.

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REFERENCE

Fry, J. and B. Huang. 2004. Applied Turfgrass Science and Physiology. John Wiley and Sons, Hoboken, NJ.

Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. HortScience 39:1740-1744.

Huang, B. and J. Fu. 2001. Growth and physiological responses of tall fescue to surface soil drying. International Turfgrass Society Research Journal. 9: 291-296.

Does Research Offer Answer to Problem of Summer Decline?

By Richard J. Hull and John T. Bushoven

To the average turf manager, research on the physiology of turfgrasses addressing some challenging problem such as summer decline of cool-season grasses often appears to be abstract and frankly rather irrelevant to the problems confronted in turf management.

Even a turfgrass physiologist, when asked to name a problem in turfgrass culture that has been solved by his/her research, will probably have to think for a while before giving a less than convincing response. To be sure, basic research in any branch of horticulture is rarely directed to the resolution of a specific practical problem. However, every now and then, basic scientific understanding that is slowly being advanced by such research reaches a point where a major management problem suddenly appears capable of being solved. This article will describe the convergence of two research lines in turfgrass physiology that soon just may solve the problem of summer decline in cool-season turf.

In recent articles published in *TurfGrass Trends*, we discussed a basic research program on the impact of nitrate-nitrogen (NO_3-N) absorbed by roots of cool-season turfgrasses on the subsequent growth of their leaves and roots. Like many before us, we observed that high NO_3 levels stimulated leaf growth but at the expense of root growth, causing a dramatic reduction in the plant's root:shoot ratio and its eventual decline. This response was restricted to NO_3-N because when ammonium-nitrogen (NO_4-N) was absorbed in elevated amounts, shoot growth was again preferentially stimulated but root growth was not depressed (Hull & Bushoven, 2007b) and the turf remained healthy.

During several years of experimentation, we observed that most NO_3 was transported from roots to leaves in cool-season turfgrasses. There it was reduced to NH_4 and assimilated into amino acids that, in turn, serve as building blocks for proteins, nucleic acids and many enzymes, hormones, mineral chelates, stress-responsive metabolites and secondary metabolites.

The capacity of roots to metabolize NO_3 proved to be decidedly limited, becoming saturated when soil-solution concentrations exceeded 0.035 millimeter (mm) (0.5 parts per million) NO_3-N. Considering that turfgrass soils often contain five times that much NO_3, it is not surprising that more than 95 percent of absorbed NO_3 passes through the roots and into the leaves, where it is reduced and assimilated by means of photosynthetic energy. When NO_3 is metabolized in the leaves, the amino acids produced stimulate growth of the nearest growing points: namely, shoot apical and intercalary meristems. This metabolic activity in the shoots consumes a substantial amount of energy generated by photosynthesis, leaving little available for transport to the roots. There is also good evidence that NO_3 itself acts as a signal molecule in leaves, diverting photosyntheticly fixed carbon toward amino acids and shoot growth and away from sugars that could be translocated to and support the growth of roots (Champigny & Foyer, 1992). This pretty much explains the NO_3-stimulated shift from root growth to shoot growth.

There are turf-management practices that can capitalize on this information to lessen NO_3-induced suppression of root growth. The trick is to maximize photosynthesis so sufficient energy (sugar) is available to assimilate NO_3 and support root growth. Raising the mowing height, insuring adequate light conditions, irrigating so as to minimize drought injury to roots,

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Mid-summer heat injury on turf composed of cool-season grasses is often a combination effect of drought and heat stresses.

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and employing foliar applications of urea and NO_4-N sources for summer fertilization should help maintain root health and turf quality. In the long run, genetic modification of turfgrasses to increase the root's capacity for NO_3 metabolism and at least partially to inhibit NO_3 loading into and transport through the root's xylem and into the leaves will be necessary to maintain a favorable root:shoot ratio of 1:1 for intensively managed cool-season turfgrasses.

There remains another major problem with maintaining turf quality under summer conditions. The roots of cool-season grasses cannot tolerate high soil temperatures. Turfgrasses could metabolize nitrogen ideally, as described above, but if their roots are exposed to temperatures greater than 25 degress Celsius (77 Fahrenheit), they will sustain serious injury. If these high temperatures persist for several days, heat-caused death will likely follow. The summer decline often observed in cool-season turfgrasses is primarily the result of high-temperature stress.

However, research reported from Rutgers University by Bingru Huang, her colleagues and her students has shed considerable light on the nature of heat injury in cool-season turfgrasses. Over the past decade, Huang's studies have demonstrated that high-temperature stress results in the production of highly reactive oxygen free radicals that readily oxidize lipids and proteins in cell membranes, causing leakage of electrolytes (ions) and disrupting numerous cellular functions, such as water and nutrient uptake, photosynthetic electron transport and hormone synthesis. Roots were shown to be most sensitive to heat stress, resulting in a failure to deliver adequate nutrients and water to the shoots as well as cytokinins, the plant hormones that are essential for normal shoot growth (Huang et al., 2001; Wang et al., 2004). Fundamental to these physiological disturbances was a failure of the antioxidant enzyme system within roots and shoots to keep heat-induced oxygen-free radicals below injurious concentrations.

The classical approach to identifying those plant responses to stress conditions that may contribute to greater stress tolerance has involved comparing stress responses of plants that are susceptible with those that are at least partially resistant to the stress. Huang employed this approach; comparing creeping bentgrass cultivars (*Agrostis stolonifera*) that were somewhat tolerant to heat (PennA-4, Independence and L-93) with those that showed less tolerance (Kingpin, Century and Putter). A few years ago, her efforts were assisted tremendously by the discovery of a genuinely heat-tolerant bentgrass (*Agrostis scabra*) growing in geothermal areas of Yellowstone National Park, where soil temperatures are as high as 50 degrees C (122 degreesF). When this thermal bentgrass was compared with creeping bentgrass cultivars, it proved to be vastly more tolerant to elevated soil temperatures by maintaining much greater respiratory control and more efficient energy utilization (Rachmilevitch et al., 2006; Huang, 2007). When grown for 28 days in soils at 99 degrees F compared with 68 degrees F, root respiration rates of thermal bentgrass increased by 50 percent while those of creeping bentgrass cultivars showed a 100 percent increase. The thermal bentgrass generally showed a lesser high temperature-induced decline in root growth, cell membrane stability and NO_3 uptake. At elevated temperatures, NO_3 allocation to shoots was also greater. In this case, NO_3 metabolism in leaves might be an advantage since it would make less of a demand on energy in the roots.

Using tools from molecular biology, Huang identified several genes that were more actively expressed under high temperatures and several that were less expressed. While both bentgrass species exhibited such genes, the thermal bentgrass responded to temperature stress by altering the expression of more genes, especially those that were stimulated. Two-dimensional protein displays were also prepared from heat-stressed and unstressed plants. Again, several proteins become more abundant under heat stress while others remained unchanged or declined. Of course, a number of heat shock proteins (common response proteins to stress conditions) were observed to become more abundant but a few others were as well. One protein in particular, that was the product of a heat-enhanced gene in tissues of both bentgrasses, was especially abundant in roots and shoots of heat-stressed thermal bentgrass. This protein was identified as an α-expansin enzyme (alpha-expansin).

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When It Comes To Turf Quality, Ask Those Closest To It.
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Expansins are cell wall proteins that play a critical role in cell expansion and tissue growth. They've been identified in many plants and are most abundant in growing organs where cell divisions and enlargement occur. Expansins have also been found to increase in abundance during stress conditions in plants that exhibit some tolerance to the stress. So it was that Dr. Huang found an α-expansin protein present in thermal bentgrass leaves, increased dramatically within four hours of exposure to heat (40°C to 104°F). The same protein also increased in leaves and roots of creeping bentgrass cultivars following exposure to heat but the response was not as great. A significant positive correlation was observed betweenα-expansin increase and greater heat tolerance of bentgrasses, with thermal bentgrass having the most expansin and being most heat tolerant while some creeping bentgrasses (Pennlinks, Backspin, Kingpin and Putter) had very little expansin and were highly heat sensitive. Creeping bentgrasses: Declaration, Penn-A4, Shark, L93, Century and Independence all produced intermediate levels of expansin and ranged from heat tolerant to moderately so. Roots of thermal bentgrasses contained high levels of α-expansin even when grown at low temperatures.

Heat tolerance in cool-season turfgrasses undoubtedly depends on more than a single, or even family of, expansin proteins. But the close correlation between heat tolerance and induction of an α-expansin in bentgrasses certainly is highly suggestive of a functional relationship. The presence of toxic oxygen radicals is most likely to occur when metabolism is being stimulated by high temperature, but growth is suppressed by some failure in the energy-growth coupling system.

When chemically reactive metabolites are not utilized efficiently, they produce free radicals often with oxygen. These radicals can oxidize membrane lipids and enzymatic proteins causing irreparable damage resulting in cell and eventually tissue death. If expansins are not induced sufficiently to meet cell needs during heat stress, growth will be inhibited, toxic radicals will be formed and accumulate with the result being death. Thus, failure of a single critical step in a complex plant response to stress may be the cause of metabolic disruption and plant injury.

Only further research and time can tell if Huang's discovery of a heat responsive α-expansin will provide an explanation of heat tolerance in all cool-season turfgrasses. Nevertheless, the convergence of her findings with those of nitrogen partitioning and metabolism on grass growth clearly offer hope for developing heat tolerant cool-season turfgrasses and effective strategies for managing them as fine turf.

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REFERENCES

Champigny, M-L. and C. Foyer. 1992. Nitrate activation of cytosolic protein kinases diverts photosynthetic carbon from sucrose to amino acid biosynthesis: Basis for a new concept. Plant Physiology 100:7-12.

Huang, B. 2007. Root carbon metabolism associated with bentgrass tolerance to heat stress. Turfgrass & Environmental Research Online, USGA, 6(8):1-7.

Huang, B., X. Liu and Q. Xu. 2001. Supraoptimal soil temperatures induced oxidative stress in leaves of creeping bentgrass cultivars differing in heat tolerance. Crop Science 41:430-435.

Hull, R.J. and J.T. Bushoven. 2007a. Recognizing the nitrate effect on root growth and development. TurfGrass Trends (Golfdom 63(7):64-66).

Hull, R.J. and J.T. Bushoven. 2007b. Turfgrass root growth, increasing nitrate metabolism. TurfGrass Trends (Golfdom 63(8):56-58).

Hull, R.J. and J.T. Bushoven. 2008. Optimum root growth hinges on nitrogen partitioning and metabolism. TurfGrass Trends (Golfdom 64(1): 75-76 & 78).

Rachmilevitch, S., H. Lambers and B. Huang. 2006. Root respiratory characteristics associated with plant adaptation to high soil temperature for geothermal and turf-type Agrostis species. Journal of Experimental Botany 57:623-631.

Wang, Z., Q. Xu and B. Huang. 2004. Endogenous cytokinin levels and growth responses to extended photoperiods for creeping bentgrass under heat stress. Crop Science 44:209-213.

Xu, J., J. Tian, F.C. Belanger and B. Huang. 2007. Identification and characterization of an expansin gene AsEXP1 associated with heat tolerance in C3 Agrostis grass species. Jour. of Experimental Botany, 58:3789-3796.

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