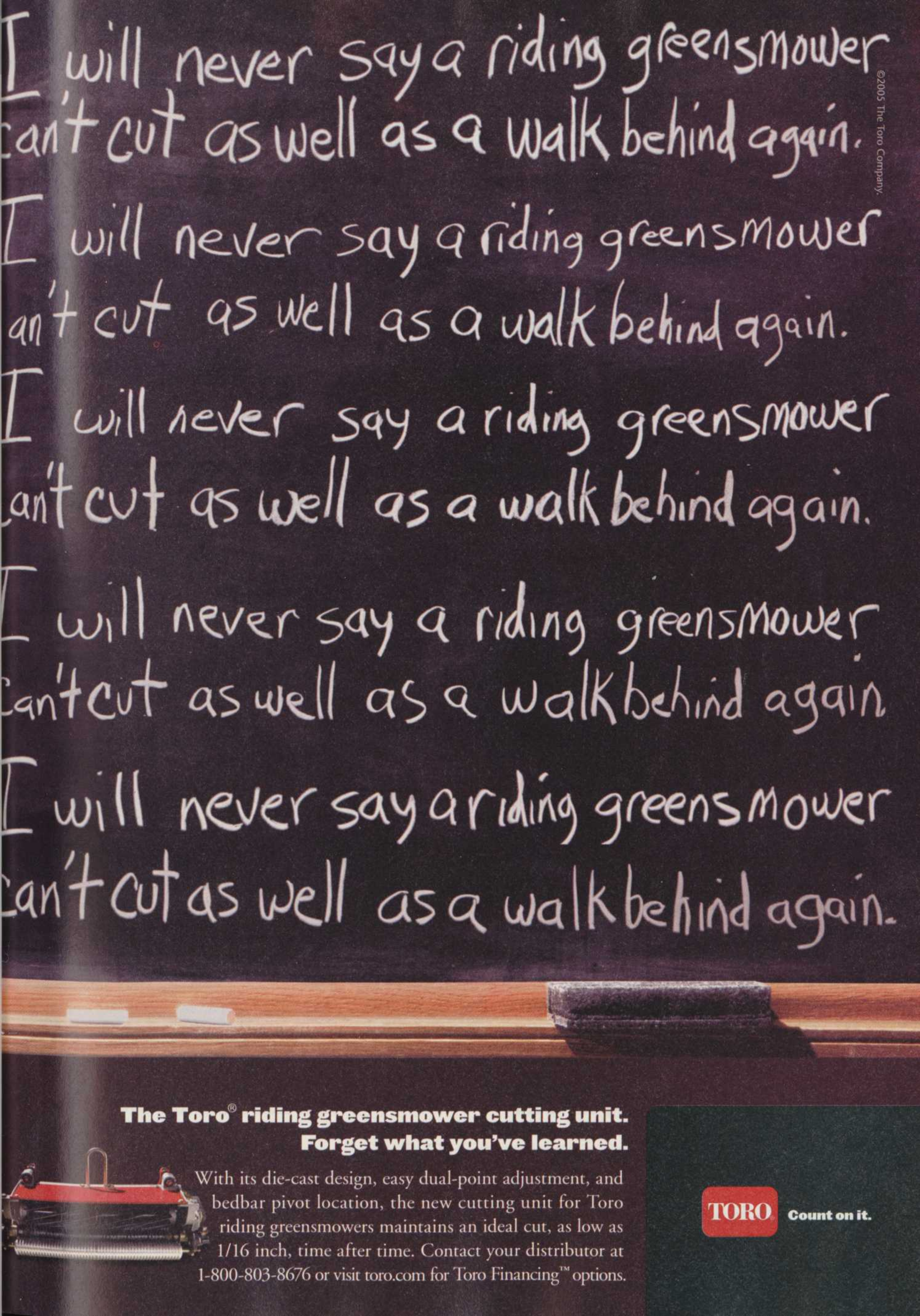
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TABLE 1

Salt load in irrigation water based on different application rates over a typical 90-acre golf course (1 acre-inch irrigation over 90 acres = 2,443,860 gallons):

Salinity level (parts per million) Pounds of salt per application

Total dissolved salts	500,000 gallons	750,000 gallons	900,000 gallons
500	2,075	3,113	3,735
1,000	4,150	6,225	7,470
1,500	6,225	9,338	11,205
2,000	8,300	12,450	14,940
3,000	12,450	18,675	22,410
4,000	16,600	24,900	29,880
5,000	20,750	31,125	37,350
10,000	41,500	62,250	70,008
15,000	62,250	93,375	112,050
20,000	83,000	124,500	149,400
34,500	143,175	214,763	257,715

Continued from page 70

based on the salinity impact of the soil plus the nutrient concentrations that the turf can take up and utilize. Micronutrient imbalances usually occur as salinity increases in the ecosystem.

Superintendents cannot manage turfgrass with salinity challenges unless they take a comprehensive, whole-systems approach to management. Being one-dimensional in approaching salinity management will cause turfgrass performance to suffer. Salts are unforgiving and will slowly and silently accumulate in the soil over years to suddenly cause significant problems in turf density, cosmetic color and playability.

Getting educated

Education starts with becoming familiar with terms such as total dissolved salts (TDS), electrical conductivity of soils and water (ECe and ECw), sodium absorption ratio (SARe and SARw), adjusted sodium absorption ratio (adjSARe and adjSARw), residual sodium carbonates (RSC), impact on general plant growth (ECw, TDS), impact from root contact (sodium [NA], chlorine [Cl], boron [B]), impact from foliage contact (Na, Cl), impact on soil structure (SARw and adjSARw, ECw, TDS).

Critical salinity impacted nutrients that are often at near-toxic or toxic levels include Na, Cl, B, bicarbonates and carbonates and sulfates. Nutrients that are often imbalanced in turfgrasses include calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), nitrogen (N), manganese (Mn), zinc (Zn), copper (Cu) and iron (Fe).

Saline soils have high total dissolved salts. Sodic soils are dominated by excess Na, and saline-sodic soils contain a combination of both high total salts and excess Na.

In addition to irrigation water adding significant levels of nutrients or elements, the leaching program to control soluble salts can also change the availability of soluble nutrients. All

Continued on page 74

Continued from page 72
components of salinity significantly affect turf rooting and long-term turf performance, lending credence to adoption of the whole systems or holistic approach to management.

The turfgrasses

Current development of grass cultivars with improved levels of salinity tolerance is providing previously unavailable options for managing grasses, using variable quality recycled and increasingly saline irrigation water.

Development of seashore paspalum (*Paspalum vaginatum* Swartz), the most salt-tolerant warm-season grass species, for golf course use has provided flexibility in managing a turfgrass that is more forgiving as salinity increases in the turf environment. The added advantage of this grass is the tournament-quality attributes and the cosmetic appearance resembling Kentucky bluegrass that occurs with proper management.

Private companies are developing cool-season grasses that have higher salinity tolerance than in the past. The availability of these salt-tolerant cultivars is and will continue to improve turf performance on golf courses. However, there must be a reality check involved.

Just because a course uses a high-salinity-tolerant cultivar does not mean that ocean or highly brackish water should be used long term on the golf course. A primary concern is what impact the increasingly saline irrigation water will have on accumulation of total salts in the soil.

Data in Table 1 provide the realism. If excess total salts accumulate and layer in the soil rhizosphere, a turfgrass salinity threshold level will be reached that will eventually overwhelm the grass. The first impact will be on root system development, redevelopment and maintenance. Secondarily, carbohydrate allocation to shoot maintenance will be decreased, the turf becomes less aggressive and the grass is predisposed to secondary stresses, especially greater disease infestation and occasionally insect problems.

Normally, the first symptom recognized by turfgrass managers is a disease problem. However, salt loading in the soil profile and especially in the upper 2 inches to 4 inches (5 centimeters [cm] to 10 cm) near the crown region will normally be the primary limitation. Water uptake and nutrient availability is usually decreased because of the desiccation of root hairs, branch roots and rhizomes.

Excess salts in the shoot system will suppress stolon growth and tillering because of its growth-regulator effect on gibberellin and cytokinin production. The turf plant reverts to the injury repair mode using carbohydrate reserves and becomes more vulnerable to pathogen and insect attack. Reduced turf canopy density and dead turf are normally the end results. Turf management shifts to a reactive strategy and since high salinity is applied to the turf ecosystem with each irrigation cycle, the battle to manage turfgrasses for survivability and performance becomes an increasing challenge.

The central benefit of a more salt-tolerant grass is that it provides more leeway for the turf manager to manage salts without immediate turf injury. But salts must be managed or the salt-tolerant grass will be overcome because its tolerance threshold level has been surpassed. A common misconception in using a highly salt-tolerant grass is that the grass is "the answer" if poor-quality water is used. But the grass is only one component of the whole system.

A salt-tolerant grass must be used in conjunction with adoption of management options such as salt leaching, a possible need for water and/or soil treatments, drainage improvements, fertilization adjustments, to name a few, for long-term turfgrass sustainability and performance. Do not create an environment to grow grass that is worse than the one you started with or inherited. Mismanagement of salts can result in this problem, which is both expensive and difficult to remediate.

Even low levels of salts can accumulate in soils because salt is added with each irrigation application, i.e., 500 parts per million (ppm) irrigation water dispersing 1 ton of salt over the irrigated acreage with one 500,000 gallon application (Table 1).

Low-level salinity might not initially cause problems, but if the salts are not managed properly to minimize accumulation and layering in the soil over years, turf quality traits will eventually deteriorate. Ocean water irrigation (at 34,500 ppm TDS) is not recommended in any situation because of the massive salt-loading potential.

Development of certain seashore paspalum ecotypes that can tolerate ocean-water salinity is important, and not just because superintendents would want to use ocean water for irrigation. There are two more reasons salinity tolerance is beneficial. First, it allows the turf manager time to make management adjustments under normal high-saline irrigation practices with saline water at lower salt levels than ocean water. Second, on sites susceptible to ocean flooding, storm surge, or persistent salt spray, a tolerant variety would allow survival and recovery from periodic catastrophic events.

Additional limitations

When excess sodium, chlorides, sulfates, boron and bicarbonates/carbonates accumulate in the soil, they impact soil and turf nutritional stability. When high levels of sodium (concern levels greater than 200 ppm or greater than 5 percent cation base saturation) build up in the soil to the level of displacing calcium in the colloids, soil structural breakdown can occur, leading eventually to sodic soils.

Sodium can dominate the cation exchange sites, and granular fertilizer utilization efficiency can be decreased. Excess chlorides greater than 355 ppm can affect nitrogen nutrition. Excess sulfate levels greater than 180 ppm can accumulate and layer in the soil profile, leading to potential black layer problems in conjunction with anaerobic conditions.

Excess boron levels greater than 3 ppm can lead to additional nutritional imbalances. Bicarbonate levels greater than 120 ppm and carbonate levels greater than 15 ppm have a propensity to complex with calcium, magnesium and phosphates to form insoluble precipitates, layer in the soil and reduce the availability of these key nutritional elements for turf uptake. Infiltration/percolation rates are good indicators of increasing problems.

Actual levels of Ca and Mg are key concentrations that must be balanced in the soil and the plant to maintain turf health.

The increasing use of poorer quality irrigation water dramatically affects the soil's chemical and physical properties, which in turn can adversely affect turfgrass performance — and these challenges will be persistent. The level of turfgrass management skills to deal with the diverse direct and indirect effects of poor water quality will be substantially greater than for the same site with good (lower salinity) irrigation water.

The whole plant-soil-water-climatic system becomes much more dynamic and the changes must be systematically monitored. Site-specific management must be the norm. Turf managers must resist the temptation to look for a magic-bullet solution — such as a salt-tolerant grass, irrigation water acidification, sand-capping and other management options.

All of these options are potential tools that require strategically planned implementation in conjunction with grass management adjustments made across the whole ecosystem for long-term success.

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Will Any PGRs be Safe for Ultradwarf Bermudagrass?

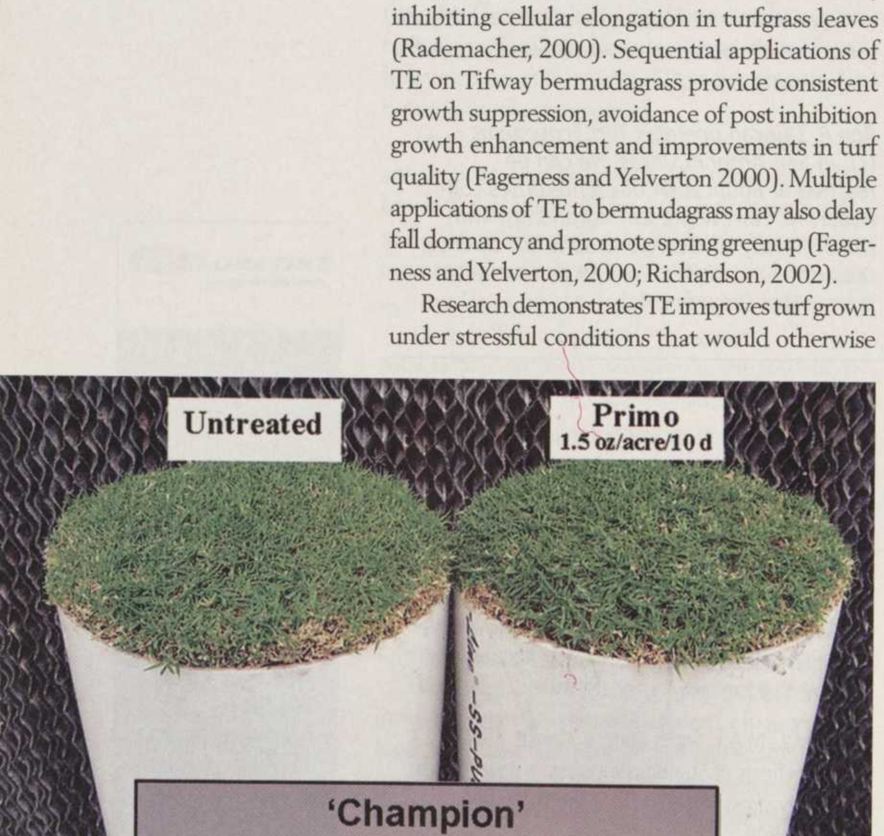
By Patrick McCullough, Haibo Liu and Bert McCarty

Successful course management is based on turfgrass quality and not total yield. Turf managers fertilize putting greens to promote color and plant health. However, luxuriant growth often disrupts surface uniformity and decreases green speeds. Inhibiting undesirable shoot growth with plant growth regulators (PGRs) provides more consistent putting surfaces and may further enhance turfgrass color and quality.

Currently, trinexapac-ethyl (TE) is the most popular PGR in the turfgrass industry. TE (Primo Maxx) represents a newer generation of gibberellic acid (GA) inhibitors that interferes with the 3b-hydroxylase conversion of GA20 to GA1, inhibiting cellular elongation in turfgrass leaves (Rademacher, 2000). Sequential applications of TE on Tifway bermudagrass provide consistent growth suppression, avoidance of post inhibition growth enhancement and improvements in turf quality (Fagerness and Yelverton 2000). Multiple applications of TE to bermudagrass may also delay fall dormancy and promote spring greenup (Fagerness and Yelverton, 2000; Richardson, 2002).

Research demonstrates TE improves turf grown under stressful conditions that would otherwise result in poor turf quality and substandard rooting. Diamond zoysiagrass (*Zoysia matrella* (L.) Merr) receiving monthly and bimonthly TE applications displayed higher root mass, higher root viability and improved photosynthesis under reduced light conditions (Qian and Engelke, 1999). Applications of TE on creeping bentgrass (*Agrostis palustris Huds.*) greens under low light intensities did not affect root mass but did increase turf cover from 6 percent to 33 percent (Goss et al., 2002). Monthly applications of TE in a two-year field study were safe on rooting of Penncross creeping bentgrass (Fagerness and Yelverton, 2001). Research is currently lacking, however, on the safety of TE applications to dwarf bermudagrass putting greens.

Recently introduced dwarf bermudagrass varieties provide Southern golf courses with a putting-green quality that is comparable to creeping bentgrass (McCarty and Miller, 2002). However, with potentially reduced photosynthetic capacity from closer mowing heights, dwarf bermudagrass turf maintained as close as one-eighth-of-an-inch may have depletion of carbohydrates available for root growth. Low cutting height and frequent mowing are directly correlated with decreases in root growth and carbohydrate reserves (Beard, 1973; Hull, 1992). Translocation of reserve carbohydrates in roots occurs after mowing for utilization in the production of new leaf tissue (Younger, 1969). Therefore, balancing photosynthate allocation away from shoot growth with TE may provide more favorable growing conditions for dwarf bermudagrass root systems. Research at Clemson University investigated effects of TE with various nitrogen (N) levels and PGR combinations on ultradwarf bermudagrass growth.



Picture 1. Untreated Champion bermudagrass vs. Champion bermudagrass treated with Primo at 1.5 ounces per acre every 10 days.

Materials and methods

Experiments were conducted at the Clemson (S.C.) University Greenhouse from September 2002 to May 2003. Experimental designs were randomized, complete blocks with four replications.

Plugs were collected from a TifEagle bermudagrass green located at the Turf Service Center in Clemson. Soil was washed and plugs

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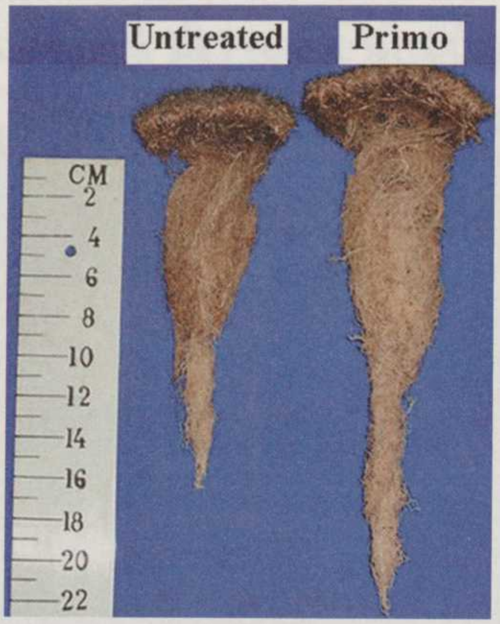


Picture 2. TifEagle bermudagrass treated weekly with 0.5 pounds of nitrogen per 1,000 square feet vs. 0.25 pounds of nitrogen per 1,000 square feet with trinexapac-ethyl every three weeks.

Continued from page 76

placed in PVC lysimeters with 40 centimeter (cm) depths and a total surface area of 324 square centimeters built to United States Golf Association specification (USGA Green Section Staff, 1993) to help mimic field conditions. Lysimeters were irrigated to field capacity and maintained daily at five-thirtyseconds of an inch (4 millimeter [mm]) mowing height. Turf quality was measured visually on a 1 to 9 scale, where 9 equaled ideal, dark green turf and 1 equaled dead or dormant turf. For all experiments, clippings were harvested weekly and oven-dried at 100 degress Celsius for 48 hours and then weighed. Roots and verdure were harvested from entire lysimeters at the termination date, dried and weighed. Root length was determined by measuring the distance from where roots were no longer present in the soil profile to the top of the container.

Response of six cultivars

An application method commonly implemented in dwarf bermudagrass maintenance is applying TE at 1 ounce to 2 ounces per acre every seven to 10 days. Using low rates and incremental applications is a safer regimen to reduce bermudagrass injury by allowing growth adjustments to the introduced compound.

Furthermore, applying TE at low rates and frequent intervals may coincide with routine fertilizations and fungicide applications. From the success of applying TE to TifEagle bermudagrass, it is reasonable to consider that other dwarf-type bermudagrasses would benefit from its use. However, research is lacking to verify this. The objective of this experiment was to investigate growth responses of six-dwarf type bermudagrasses with and without TE applications.

Two 60-day greenhouse experiments evaluated the response of six dwarf-type bermudagrass cultivars to applications of TE at 0 ounces and 1.5 ounces per acre every 10 days.

Cultivars studied included: Champion, FloraDwarf, MiniVerde, MS Supreme, Tifdwarf and TifEagle. Turf injury was not observed from TE applications for any bermudagrass cultivar (data not shown). Trinexapac-ethyl significantly enhanced visual quality for all cultivars on every observation from 20 DAIT to 60 DAIT and effectively inhibited leaf growth (Picture 1). From four samples, TE averaged clipping yield reductions ranging 45 percent to 65 percent for all cultivars.

Root mass was enhanced approximately 25 percent for MiniVerde and FloraDwarf bermudagrass, respectively, following TE applications (results not presented). Champion, MS Supreme, Tifdwarf and TifEagle bermudagrasses treated with TE had similar root mass to the untreated respective cultivars. All bermudagrass cultivars treated with TE had similar root length to untreated turf. Overall, the TE application regime of low rates at frequent intervals appears to be effective and safe for various dwarf-type bermudagrasses.

Response to TE plus N

In this experiment, weekly nitrogen inputs were applied to TifEagle bermudagrass with an ammonium nitrate (34-0-0) solution at 0.125 (N^{6}), 0.25 (N^{12}), 0.375 (N^{18}) and 0.5 (N^{24}) pounds of N per 1,000 square feet per week. Beginning one week after the first fertilization, TE was applied at six ounces per acre (0.05 kg per hectare) every three weeks.

Trinexapac-ethyl enhanced turf visual quality 15 percent four weeks after applications compared to untreated turf (data not shown). Turf fertilized with high nitrogen rates (N^{18} and N^{24}) reached their peak quality ratings by week 8, and then declined until week 16.

From week 10 to 16, TE treatments resulted in roughly 25 percent higher visual quality from untreated turf, apparently masking quality decline of high N fertility. Visual quality enhancements are consistent with higher total chlorophyll concentrations in TE treated turf after eight weeks.

Increased N rate resulted in linear increases in clipping yield but applications of TE reduced clippings 52 to 65 percent (data not shown). Total clipping yield from all 16 sampling dates for turf treated with N^{12}, N^{18} and N^{24} with TE were similar to turf fertilized with the lowest N rate, N^{6}. After 16 weeks, TE enhanced root mass 43 percent and root length 22 percent (Picture 2 and Figure 1).

Increased N levels resulted in reduced root mass and root length, especially for N^{18} and N^{24} treated turf. However, root masses for turf treated with higher N rates with TE were similar rooting to turf treated with lower nitrogen rates without TE. The absence of a significant N x TE interaction for root mass suggests TE applications masked the influence of high N fertility on root decline.

Ethephon plus TE

A popular PGR combination in golf course management is TE plus ethephon (Primo plus Proxy). Inhibiting seedheads of the most problematic winter annual weed on bermudagrass golf courses, *Poa annua L.* (McCarty and Miller, 2002), may be achieved by combining GA inhibitors with ethephon (Proxy), a compound that decomposes to release ethylene (Gelertner and Stowell, 2001).

Synergistic growth suppression of the desired turf may occur from simultaneous GA inhibition, such as from TE and the induction of ethylene within the plant from ethephon. Turf discoloration from ethylene applications is common in both warm- and cool-season grasses. In contrast, mixing ethephon with TE has shown to reduce discoloration and prevents thinning of creeping bentgrass (Kane and Miller, 2003). This nine-week greenhouse experiment was conducted to analyze the effects of ethephon combined with trinexapac-ethyl on visual quality, rooting and clipping yield of TifEagle bermudagrass. Applications were made every three weeks with ethephon (2 liters [L]) at 0 ounces, 5 ounces and 10 ounces per 1,000 square feet with and without TE at 5 ounces per acre.

TE-treated bermudagrass had enhanced turf color from the untreated after one month. Turf treated with ethephon had up to 36 percent quality decline with initial and repeated applications.

An initial combination with TE increased phytotoxicity with ethephon treatments. However, visual quality recovered and was similar to the untreated. TE enhanced chlorophyll concentrations in both studies while ethephon treatments reduced chlorophyll concentrations 14 percent.

Ethephon reduced total clipping yield from non-PGR treated turf by 10 percent and 22 percent at 5 ounces and 10 ounces per 1,000 square feet every three weeks (Figure 2a).

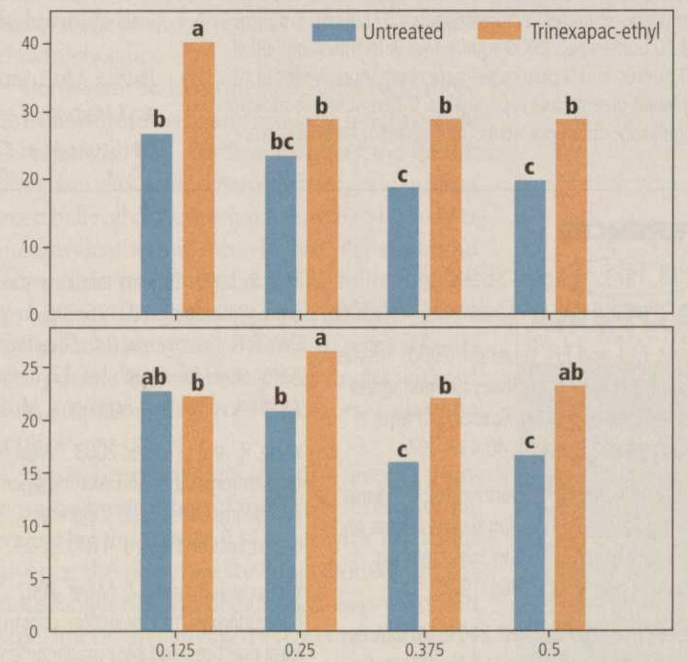
In the presence of TE, bermudagrass clipping yield was reduced from non-PGR treated turf by 57 percent, 70 percent and 72 percent when ethephon was applied at 0 ounces, 5 ounces and 10 ounces per 1,000 square feet every three weeks, respectively. After nine weeks ethephon reduced root mass from non-PGR treated turf and bermudagrass treated with ethephon at 10 ounces per 1,000 square feet without TE had 33 percent less root mass (Figure 2b).

TifEagle bermudagrass treated with TE without ethephon averaged 38 percent more root mass than the untreated. Ethephon at 5 ounces and 10 ounces per 1,000 square feet every three weeks reduced TifEagle bermudagrass root length by approximately 15 percent, compared to non-PGR treated turf (Figure 2c).

Continued on page 80

FIGURE 1

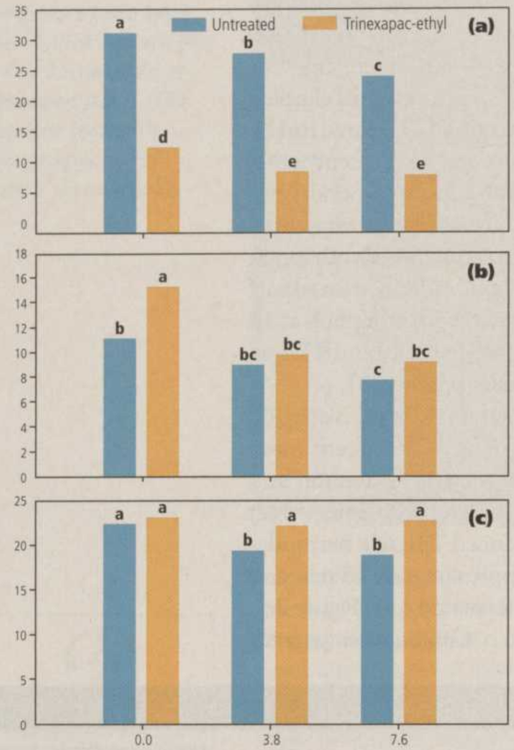
Nitrogen Rate (pounds of nitrogen per 1,000 square feet per week)



Dry root mass and root length after 16 weeks for TifEagle bermudagrass treated with weekly nitrogen inputs and trinexapac-ethyl at 6 ounces per acre every three weeks with trinexapac-ethyl at 0 ounces and 5 ounces per acre every three weeks in two combined greenhouse experiments. Different letters indicate a significant difference across all treatment combinations.

FIGURE 2

Ethephon Rate (kilograms of actual material per hectare every three weeks)



Clippings and root samples after nine weeks for TifEagle bermudagrass treated with ethephon at 0 ounces, 5 ounces and 10 ounces per 1,000 square feet with trinexapac-ethyl at 0 ounces and 5 ounces per acre every three weeks in two combined greenhouse experiments. Different letters indicate a significant difference across all treatment combinations.

Continued from page 79

Bermudagrass treated with ethephon at 5 ounces and 10 ounces per 1,000 square feet plus TE had 12 percent and 20 percent higher root length compared to respective ethephon rates without TE after nine weeks.

This study demonstrates potential reductions in rooting and turf quality from ethephon may be counteracted by tank mixing TE on TifEagle bermudagrass. However, ethephon will probably not be a suitable PGR for regular dwarf bermudagrass management due to high phytotoxicity and turf thinning with and without TE applied.

PGR field studies at Clemson

Field studies are currently underway on dwarf bermudagrass research greens.

The first experiment is investigating four N rates with TE, similar to the greenhouse study mentioned. Another is investigating a spoon-feeding PGR approach. Despite minimal to no phytotoxicity with TE in the controlled greenhouse environment, early summer applications may result in undesirable discoloration.

Turf injury, however, could be minimized by rationing TE treatments in low rates at more frequent intervals. For example, applying 6 ounces per acre every three weeks of TE is likely to cause discoloration from initial applications. On the other hand, applications of 1 ounce to 2 ounces per acre every week could minimize phytotoxicity. This study is examining TE at 2 ounces per acre every seven days, 4 ounces per acre every 14 days and 6 ounces per acre every 21 days. Physiological responses including shoot growth, root growth and chlorophyll content will be evaluated.

Patrick McCullough is a research program associate at Rutgers University, and Haibo Liu and Bert McCarty are professors in the department of horticulture at Clemson University.

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