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has to be absorbed and translocated by plant tissues to work effectively.

SU herbicides or any other ALS or AHAS inhibiting herbicides should not be used continuously over a long period of time. These herbicides should be rotated with other herbicides which have different modes of action, such as pronamide (Kerb), which inhibits mitotic cell division in sensitive plants.

Conclusions

The discovery of SU herbicides is one of the most exciting breakthroughs in the field of herbicide research in several decades.

With their unprecedented herbicidal activity, the application rates have plummeted to grams rather than kilograms per hectare. Thus the potential of groundwater contamination through seepage, percolation or infiltration is also very low.

The site of action of the SU's has been pinpointed as the enzyme acetolactate synthase (ALS). Inhibition of this enzyme results in cessation of production of the three essential amino acids — valine, leucine and isoleucine. This leads to retarded growth and eventually plant death. The absence of this enzyme in mammals helps explain low toxicity of the SU's. Hence, they can be regarded as safe herbicides (LD_{50} greater than 4,100 milligram per kilogram of body weight).

All plants contain the target enzyme, making them prone to attack, but the ability of these herbicides to control grasses in a stand of monocotyledonous plants like turfgrasses has been a challenging job. Plant tolerance has been credited to the ability of some plants to rapidly convert the herbicide to inactive products. This inactivation occurs so rapidly that the active molecule never reaches the enzyme in sufficient quantities to effectively inhibit it.

SU's degrade under field conditions at rates similar to and often faster than conventional herbicides. Chemical hydrolysis and microbial breakdown are the main modes of dissipation.

The SU's are weak acids and under acidic soil conditions often undergo rapid dissipation by chemical hydrolysis. Under alkaline soil conditions microbial breakdown is the predominant dissipation method.

With the help of mutant forms of the acetolactate synthase gene that codes for insensitive forms of the enzyme, it is possible to work on genetic engineering of plants with high levels of SU resistance.

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REFERENCES

Hatzios, K. K., and C. M. Howe. 1982. "Influence of the herbicides hexazinone and chlorsulfuron on the metabolism of isolated soybean leaf cells." *Pesticide Biochemistry and Physiology.* 17:207-214.

Heap, I., and R. Knight. 1986. "The occurrence of herbicide cross-resistance in a population of annual ryegrass, *Lolium rigidum*, resistant to diclofop-methyl." *Australian Journal of Agricultural Research.* 49:156.

Kearney, P. C., and D. D. Kaufman, (eds.) 1988. "Herbicides Chemistry, Degradation and Mode of Action." 1988. p.118-183. Marcel Dekker Inc. New York.

Koog, H. J. Jr. 1966. (To deutsche Gold and silver- Scheidean-stalt Vormals) Netherlands Patent. 121,788.

Levitt, G. (to DuPont). 1983. U. S. Patent. 4,398,939.

Mallory-Smith, C.A., D. C. Thill and M. J. Dial. 1990. "Identification of SU herbicide resistant prickly lettuce (*Lactuca serriola*)." *Weed Technology.* 4:163-168.

Ray, T. B. 1982. "The mode of action of chlorsulfuron: A new herbicide for cereals." *Pesticide Biochemistry and Physiology.* 17:10-17.

Ray, T. B. 1984. "Site of action of chlorsulfuron." *Plant Physiology.* 75:827-831.

Sweetser, P. B., G. S. Schow and J. M. Hutchinson. 1982. "Metabolism of chlorsulfuron by plants: Biological basis for selectivity of a new herbicide for cereals." *Pesticide Biochemistry and Physiology.* 17:18-23.

Sauers, R. F., and G. Levitt. 1984. p.21 in P. S. Magee, G. K. Kohn and J. J. Mean, (eds.) "Pesticide Synthesis Through Rational Approaches." *American Chemical Society Washington.*

Sax Irving. N. 1979. (ed.) "Dangerous Properties of Industrial Materials." Van Nostrand Reinhold Com. New York. 5:978.

Smith, W. F., J. C. Cotterman and L. L. Saari. 1990. "Effect of ALS-inhibitor herbicides on SU-resistant weeds." *Proceedings of the Western Society of Weed Science.* 43:24-25.

Stidham, M. A. 1991. "Herbicides that inhibit acetohydroxyacid synthase." *Weed Science* 39:428-434.

Subramanian, M. V., V. L. Gallant, J. M. Dias, and L. C. Mireles. 1991. "Acetolactate synthase inhibiting herbicides bind to the regulatory site." *Plant Physiology.* 96:310-313.

Thill, D. C., C. A. Mallory-Smith, L. L. Saari, J. C. Cotterman and M. M. Primiani. "SU resistance-mechanism of resistance and cross-resistance." *Weed Science Society of America Abstracts.* 29:132.

Yelverton, F. 2004. "New weed control in warm-season grasses." *Golf Course Management.* January 2004:203-206.

Stunt the Leaf, Save the Nutrients

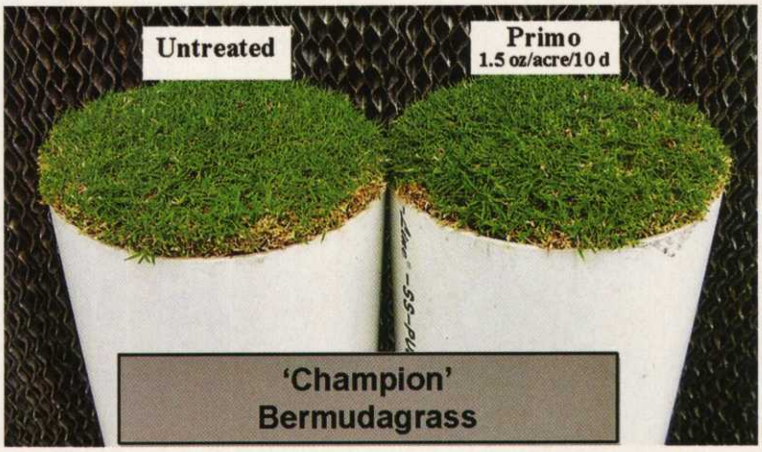
Plant growth regulators may improve efficiency of bermudagrass greens

By Patrick McCullough, Haibo Liu and Bert McCarty

Bermudagrass putting greens are the most heavily fertilized grasses in golf course management. Annual nitrogen requirements of bermudagrass greens range from 8 pounds to 24 pounds of nitrogen per 1,000 square feet to meet growth requirements and compensate for nutrient loss through daily clipping removal (McCarty and Miller, 2002). In some areas of the country, annual nitrogen inputs may even exceed this range to maintain bermudagrass putting green color and quality.

Routine close mowing and active shoot growth cause greater amounts of nutrients and photosynthate to be allocated to leaf tissue for nutrient assimilation. Inhibiting leaf growth with a plant growth regulator, such as trinexapac-ethyl, may alter the source-and-sink relationship to redirect photosynthate and nutrient partitioning away from leaf tissue production.

Greater amounts of nutrients stored in below-ground tissues could therefore improve nutrient-use efficiency of these heavily fertilized grasses. Greenhouse experiments were conducted to evaluate the effects of four nitrogen levels with and without trinexapac-ethyl on nutrient allocation of TifEagle bermudagrass.



Picture 1. TifEagle bermudagrass treated weekly with 0.125, 0.25, 0.375 and 0.5 pounds of nitrogen per 1,000 square feet shown after two months without (left) and with trinexapac-ethyl at 6 ounces per acre every three weeks.

Experiments

Research was conducted at the Clemson (S.C.) University Greenhouse Complex from September 2002 to January 2003 (Study 1) and January to May 2003 (Study 2).

Greenhouse day/night temperatures were approximately 24 degrees Celsius and 19 degrees Celsius, respectively. The experimental design was a randomized complete block with four replications of eight experimental units per block. To minimize local environmental variations, blocks were rotated weekly and experimental units re-randomized within. Supplemental lighting was added for three hours per day to compensate for reduced natural lighting during winter months.

Sod was collected from a TifEagle bermudagrass green established in July 2002 at the Turf Service Center in Clemson. Soil was washed and plugs placed in polyvinyl chloride containers with 40-centimeter depths and 324-square-centimeter surface areas built to United States Golf Association specification (USGA Green Section Staff, 1993) with an 85:15 (by volume) of sand and peat moss rootzone mix. Starting fertilizer (9-18-17) at 48 kilograms of nitrogen per hectare was mixed into the soil, and bermudagrass was established four and six weeks in Studies 1 and 2, respectively, before treatments.

Urea-based nitrogen fertilizer (16-4-8) with complete micronutrients was applied to all containers at 24 kilograms of nitrogen per hectare two weeks before initial treatments and at 12 kilograms of nitrogen per hectare eight weeks after experiment initiation.

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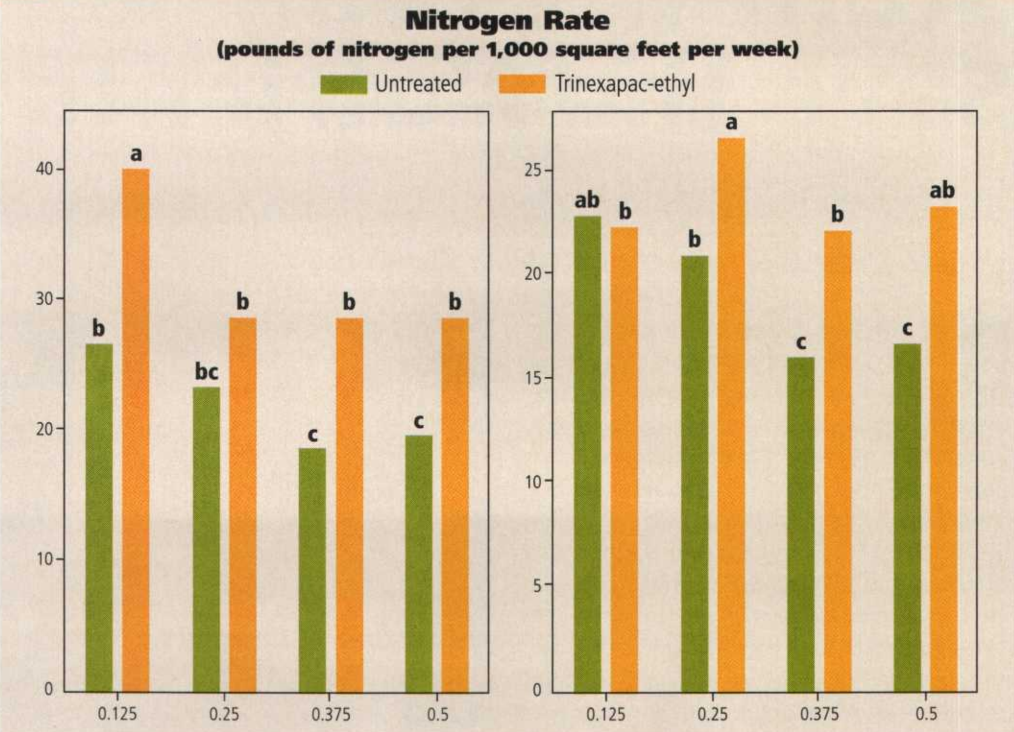
FIGURE 1



Editor's note: There is no significant statistical difference between results within each of the a,b,c categories; however, there is a significant performance difference between each category.

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Bermudagrass was irrigated and mowed daily with automatic grass sheers (Black and Decker, Towson, Md.) at 4 millimeters. The eight treatments were a factorial combination of four nitrogen levels and two trinexapac-ethyl levels. Ammonium nitrate (34-0-0) solution was applied at 6, 12, 18 and 24 kilograms of nitrogen per hectare per week.

Beginning nine days after initial fertilizations, trinexapac-ethyl (1 emulsifiable compound) was applied at 0 or 0.05 kilograms of nitrogen per hectare every three weeks. Treatments were made at 300 liters per hectare with a greenhouse spray cabinet, Devries Manufacturing (Hollandale, Minn.) model SB6-094, with a Craftsman model 919.165110 pump supplying air pressure.

Tissue and soil tests were conducted at the Clemson Agriculture Service Laboratory. Nitrogen concentrations were determined using a LECO FP528 Nitrogen Combustion analyzer (Warrendale, Pa.). Other plant tissue nutrients were determined using wet ashing procedures with a Digestion Block Magnum Series Block Digester and an ICP model TJA-61E auto sampler (Madison, Wis.). Soil nitrate-nitrogen extractions were made with an ISE Electrode (Beverly, Mass.). Data analyses were made using the analysis of variance with SAS General Linear Model procedure.

Results

One week after the first application, TifEagle bermudagrass treated with trinexapac-ethyl had 6-percent lower leaf nitrogen concentrations (Figure 1). This trend continued through week 12 with lower leaf nitrogen concentrations in trinexapac-ethyl-treated turf, ranging from 2-percent to 10-percent reductions.

Bermudagrass putting greens have the highest nitrogen fertilization requirements of all grasses in the turf industry.

Root and thatch nitrogen concentrations ascended linearly with increasing nitrogen rate. For turf treated with trinexapac-ethyl, root nitrogen concentrations were approximately 10-percent higher than the untreated after 16 weeks.

Leaf phosphorus and potassium concentrations in trinexapac-ethyl-treated bermudagrass

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WORKMAN
It's the same beast.
We just sent it to obedience school.

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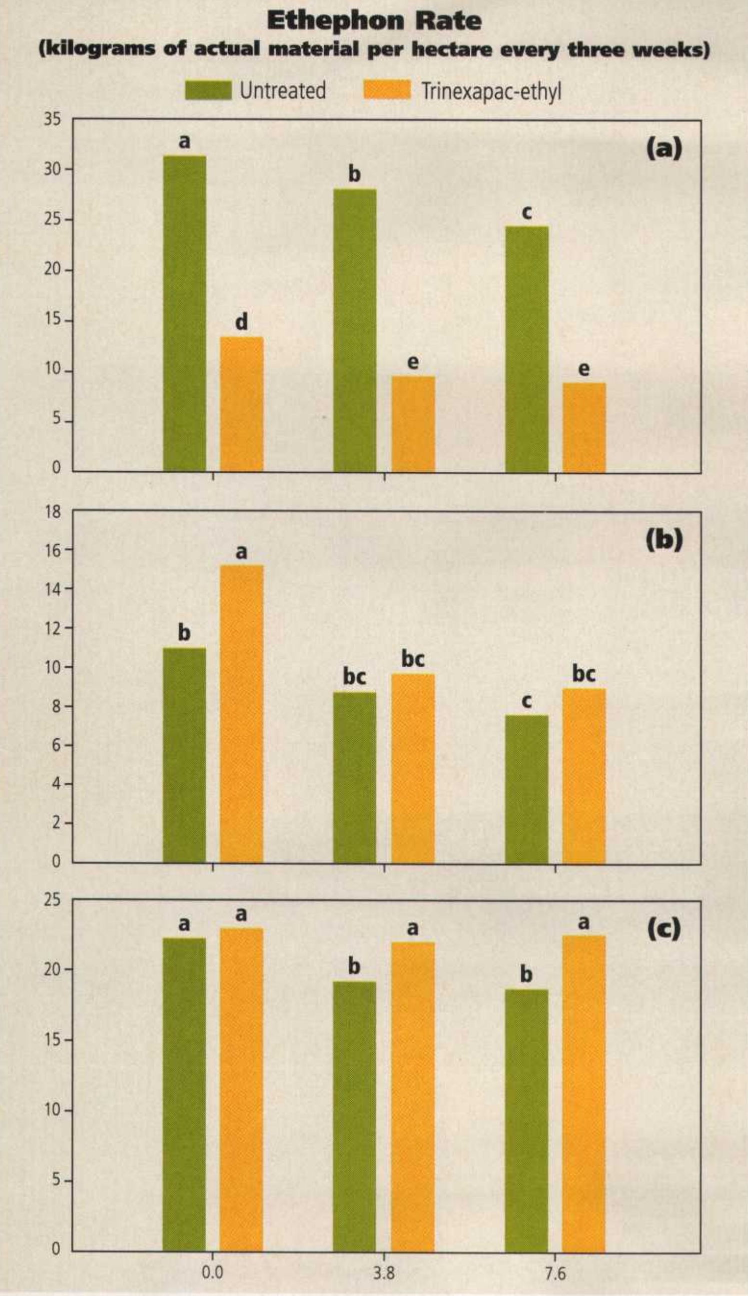
were reduced 8 percent and 14 percent, respectively, one week after initial trinexapac-ethyl treatments. However, higher nitrogen rates increased phosphorus concentrated in leaf tissue and reduced phosphorus concentrations in roots and thatch.

Increasing nitrogen rate reduced root and thatch potassium concentrations. Root potassium concentrations were 29-percent greater in trinexapac-ethyl-treated turf after 16 weeks. Furthermore, trinexapac-ethyl-treated turf had a 0.06-percent range of root potassium concentrations from low to high nitrogen inputs vs. the 0.25 percent range from low to high nitrogen inputs in untreated turf.

FIGURE 2



Editor's note: There is no significant statistical difference between results within each of the a,b,c categories; however, there is a significant performance difference between each category.

On five sampling dates, trinexapac-ethyl-treated bermudagrass had higher leaf calcium, magnesium and sulfur concentrations, increasing to 27 percent, 11 percent, and 15 percent, respectively. Trinexapac-ethyl did not influence primary or secondary thatch nutrient concentrations. Increasing nitrogen rate caused reductions in thatch sulfur concentrations but differences were not observed in roots or thatch of trinexapac-ethyl-treated turf.

For micronutrients, higher nitrogen inputs increased leaf concentrations with the exception of iron. Similarly, increased nitrogen rate resulted in higher micronutrient concentrations in thatch and roots. Bermudagrass treated with trinexapac-ethyl had approximately 15-percent reduced zinc, copper and manganese in thatch and 30-percent reduced root copper concentrations.

Leaf iron levels were unaffected by nitrogen input; however, trinexapac-ethyl-treated turf had lower leaf iron concentrations from week 9 to week 16. Increasing nitrogen rate linearly increased root and thatch iron concentrations but remained similar to the untreated when treated with trinexapac-ethyl.

From six sampling dates, nitrogen and trinexapac-ethyl effects were highly significant for total nitrogen, phosphorus, potassium, magnesium, sulfur, zinc, copper and manganese recovered through clippings. Increased nutrients removed through clippings occurred with increased nitrogen rates; however, total nutrient recoveries were reduced 69 percent to 79 percent when trinexapac-ethyl was applied (Table 1).

Bermudagrass treated with trinexapac-ethyl, regardless of nitrogen input, had similar amounts of nutrients removed through clippings as the low rate of nitrogen without trinexapac-ethyl. TifEagle bermudagrass treated with trinexapac-ethyl had 50-percent higher nitrogen recovered in roots after 16 weeks compared to untreated turf from increased root nitrogen concentrations plus greater root mass (Table 1). Primary, secondary and micronutrients recovered in roots ranged from approximately 25-percent to 105-percent greater in trinexapac-ethyl-treated bermudagrass than the untreated.

Clippings vs. nutrients

The presence of clippings on golf greens interferes with the direction and velocity of ball roll and their removal is necessary (Beard, 1973). However, substantial amounts of essential plant nutrients are removed through routine clipping collection on bermudagrass putting greens (Williams and McCarty, 2005).

Inhibiting leaf growth with trinexapac-ethyl decreases nutrient losses through daily clipping collection and may help balance photosynthate and nutrient partitioning within the plant. Redirected nutrients away from leaf growth for storage in below-ground plant tissues may improve nutrient-use efficiency and reduce fertility requirements of ultradwarf bermudagrass putting greens treated with trinexapac-ethyl.

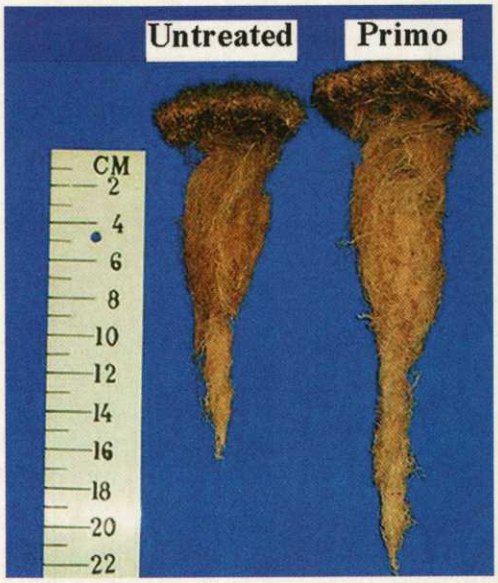
Increased nitrogen rates resulted in higher phosphorus concentrations in leaf tissue and reduced phosphorus concentrations in below-

TifEagle bermudagrass reallocated nitrogen to roots and rhizomes when leaf growth was inhibited.

ground plant tissues. This likely occurred as bermudagrass required higher adenosine triphosphate concentrated in actively growing leaf tissue for nitrogen assimilation. Conversely, lower leaf nitrogen, phosphorus and potassium concentrations occurred one week after initial trinexapac-ethyl applications, while increased concentrations were observed in roots after 16 weeks.

These results exemplify an altered bermudagrass source and sink relationship under shoot growth inhibition with trinexapac-ethyl.

TifEagle bermudagrass reallocated nitrogen to roots and rhizomes when leaf growth was inhibited. Decreased phosphorus concentration in leaf tissue may occur from higher adenosine triphosphate concentrations in below-ground tissues. Less nitrate moving to leaves results in more energy and plant sugars directed to roots for root nitrate assimilation (Hull, 2003).



TifEagle bermudagrass treated with trinexapac-ethyl had 50-percent higher nitrogen recovered in roots after 16 weeks compared to untreated turf.

TifEagle bermudagrass may therefore have improved nutrient-use efficiency as higher amounts of nutrients are concentrated in below-ground tissue which may be readily allocated to leaves to prevent nutrient deficiencies.

Improved nutrient-use efficiency will reduce the high fertility requirements of these grasses. This is an important finding since bermudagrass putting greens have the highest nitrogen fertilization requirements of all grasses used in the turf industry. Inhibiting shoot growth with trinexapac-ethyl reduced nutrients removed through clippings; consequently color enhancements resulted to where fertilizations may be unnecessary to promote turf quality.

Overall, consistent maintenance with trinexapac-ethyl may effectively enhance turf quality and improve nutrient-use efficiency of dwarf-type bermudagrass.

REFERENCES

Beard, J.B. 1973. *Turfgrass: Science and Culture.* Prentice-Hall, Inc. Englewood Cliffs, NJ.

Hull, R.J. 2003. Small amounts of molybdenum streamlines nitrogen uptake. *Turfgrass Trends* 12(1):42-44.

McCarty, L.B. and G.L. Miller. 2002. *Managing Bermudagrass Turf: Selection, Construction, Cultural Practices and Pest Management Strategies.* Sleeping Bear Press. Chelsea, MI.

United States Golf Association Green Section Staff. 1993. USGA recommendations for a method of putting green construction. The 1993 Revision. *USGA Green Section Record.* 31(2):1-3.

Williams, D. and B. McCarty. 2005. Cultural practices for golf courses. p. 423-455. In: McCarty, L.B. (ed). *Best Golf Course Management Practices,* 2nd ed. Prentice-Hall, Upper Saddle River, NJ.

From Something Old, Something New

Coated-sand topdressing improves core hole recovery

By Max Schlossberg, Robert Kerr and Karl Danneberger

Sand topdressing improves turf quality in a variety of ways. The most obvious is in remediation of soils having suboptimal physical properties. Compared to silt or clay loams, a macroporous sand layer accepts surface water rapidly.

Furthermore, a dry, water-repellent thatch layer is more easily wetted once topdressed with sand. Many superintendents question whether sand topdressing actually accelerates thatch decomposition or just dilutes thatch (and subsequently organic matter). It likely does both. Sand is hard enough to remove paint and has an abrasive-scouring action on thatch. Further, increased water-holding capacity from sand additions make the thatch environment more suitable for microbes to dwell and eat.

After four years of treatments and monitoring, R.N. Carrow and colleagues (1987) found that sand topdressing of Tifway bermudagrass reduced thatch more rapidly than coring or vertical mowing.

Another approach to amend soil or minimize surface organic matter accumulation is coring (a.k.a. core aerification) and backfilling with coarse-textured sand. Many a compacted push-up green have been steadily converted to macroporous media through annual (or biannual) hollow-tine aerification prac-

FIGURE 1

There was a systematic introduction of divots to plots at Penn State University for the study.

tices, followed by sand backfilling.

In theory, a fine-textured native soil could be completely renovated to a predominantly sand upper profile by aerifying and sand-backfilling only 12 times. Of course, luck would be a prerequisite, as the tines must strike only native soil (no repeat core evacuations) for the complete conversion to take place so quickly.

Unbeknownst to many, the researchers that first reported the benefits of topdressing putting greens had envisioned the topdressing

Recovery of a treated L93 fairway was four to five times more rapid than ordinary sand.

process to include more than just sand (Madison et al., 1974). This original topdressing research showed sand topdressing to be a uniform and reliable mechanism of delivering seed, fertilizer, lime and pesticides to greens; all in one pass of the spreader.

Over time, superintendents likely found mixing all of these materials to be problematic and tedious and resorted to simple straight–sand topdressing for the benefits mentioned above.

A common thread known to weave through these common cultural practices is the need for rapid turf recovery. Lingering core aerification holes are the scourge of the putting public. Unincorporated topdressing wreaks havoc on meticulously maintained reels, and makes more work for your overworked mechanic. Hence, vigorous shoot growth facilitates rapid recovery and blissful sentiment, having conducted these disruptive cultural practices.

Recovery practices

As mentioned above, rapid recovery is an important part of keeping disruptive cultural practices temporary. Coordinating optimal shoot growth with aerifying and/or topdressing is a practice successfully used by superintendents. Managers using growth regulators often time post-growth regulation surge to coincide with these practices. Others fertilize with nitrogen just prior to or immediately following these practices.

D.C. Bowman (2003) recently showed nitrogen fertilization at a uniform daily rate significantly benefits turf health when compared to less-frequent fertilization (at equal total rates). Scientists at Georgia-Pacific asked, "Can we help managers achieve faster turfgrass recovery by developing a product that will simultaneously amend soil and fertilize turf?" Soon after, the patent-pending Nitamin Coated Sand was born.

The coated sand contains 1 percent nitrogen by weight (1-0-0). The term "low-analysis fertilizer" may conjure images of natural organics or nutrient-impregnated degradable carriers. It is unique in this respect. Best Sand, available in various particle-size distributions, is coated with Nitamin nitrogen fertilizer and stabilized, providing a homogenous, steady-release fertilizer with the following characteristics:

- very low burn potential (low salt index);
- low size guide number (SGN ~ 50); and
- high particle density (facilitating rapid canopy penetration).

Conceptually, the coated sand seemed like an innovative product, but its field perform-

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FIGURE 2

Number of core holes visible 11 days after aerification at Ohio State University.

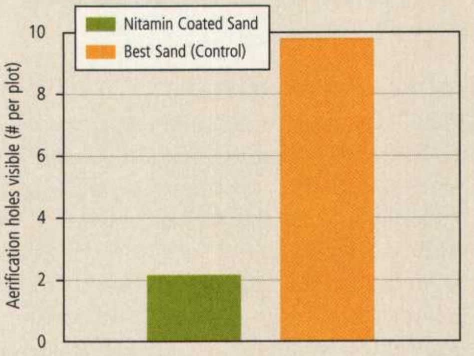

FIGURE 3

Recovery of aerified plots at Ohio State University 14 days following treatments with coated sand (left) and control sand.

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ance required testing. Thus, replicated experimentation by two independent universities was contracted to make a determination, and the results are in.

Field experiments

Field experiments were conducted at a number of locations, including The Ohio State University and the Pennsylvania State University.

The Ohio State University: This study was conducted at the Ohio Turfgrass Foundation Research and Education Facility in Columbus. The objective was to determine if backfilling coring holes with the coated sand vs. traditional sand would enhance core hole recovery.

The study was initiated on a 3-year-old L93 bentgrass fairway established on native soil and mowed at one-half inch. Plots 3 x 6 feet in area were set up in a complete randomized block design (RCBD) and aerified with five-eighth-inch tines on Aug. 13, 2004.

Three days previous, plant growth regulator treatments had been applied at the following rates: 0.125 ounce Primo per 1,000 square feet, 0.38 ounce Trimmit per 1,000 square feet, or 5 ounce Proxy per 1,000 square feet (both alone and in combination with Primo). Following aerification, cores were removed and the plot area was allowed to settle and dry. On Aug. 16 the core holes were filled with either the coated sand or dry Best Sand. Eleven days following treatment, the number of visible core holes in the L93 was recorded (Table 1).

The Pennsylvania State University: This study was conducted at the Valentine Turfgrass Research Facility in University Park. The objective was to determine any advantages in

TABLE 1

Divot area per plot (initially ~2800 cm²) over experimental period:

Treatment	Mean divot size (cm²)	
Control (sand topdressing only)	1073	B*
IBDU (blended with sand topdressing)	931	AB
$(NH_4)_2SO_4$ (blended with sand topdressing)	1002	AB
Nitamin Coated Sand (1% N topdressing)	853	A

* — Different letters following means signify statistical differences (a = 0.05).

FIGURE 4

Plot topdressed with coated sand 25 days after treatment (top) and 49 days after treatment at Penn State University.

topdressing typical divot damage with the coated sand compared to ordinary sand, ordinary sand blended with isobutylidene diurea fertilizer or ordinary sand blended with ammonium sulfate at equivalent nitrogen rates. Twelve blocks of four 2x4-foot plots, established on a PennEagle bentgrass fairway (native soil, half-inch mowing height) received divot-inducing attention on four separate dates (June 20, July 9, 29 and 30; three blocks per date).

The following day plots were hand-topdressed with the above-mentioned treatments to provide nitrogen at a rate equivalent to 3 pounds of nitrogen per 1,000 square feet (control plots received no nitrogen). All plots in the recombinant collagen-binding domain possessed ideal soil nutrient levels and were foliarly fertilized with 0.5 pounds of magnesium sulphate per 1,000 square feet to standardize sulphate sufficiency.

Digital images of the plots were taken periodically over the seven weeks following divot topdressing. Images were analyzed and