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Continued from page 50
found no evidence that fertilization of fairways causes an increase in nitrates in adjacent streams.

Stream nitrate levels generally were low (less than .5 ppm) and actually tended to decrease during water passage through the golf course. All the superintendents maintained vegetation along streams, which evidently absorbed a portion of the available nitrates.

Pollution potential is low

The results from the field studies are consistent among all locations, always indicating a low potential for nitrate contamination of ground and surface waters.

In the past two years, the research has been expanded to include five additional sites in other parts of North Carolina where soils and topographies are different than those in the East. Up to this time, we have not found any evidence indicating significant pollution problems.

Our findings may come as a surprise to many people working in the water-quality area, just as they were to us. Turfgrass systems have particular characteristics, however, that are atypical of the agricultural world, where almost all previous landscape-scale research has been done. One is the fertility approach. Turfgrasses are usually fertilized three or four times during the growing season with relatively small amounts of nitrogen (about 42 pounds per acre), so the system is not overloaded and predisposed to leaching. Most of the root system is fully developed when the fertilizer is added.

By contrast, a corn crop would receive the same total amount of fertilizer, but in one or two applications early in the growing season. It has been estimated that corn takes up only about 50 percent of the nitrogen applied.

A second notable difference with turfgrasses is the density of the root system. Nitrogen uptake efficiency is a function of root absorption surface. The fine roots of turfgrasses typically form a dense matrix several inches into the soil, and individual roots can extend downward as much as 2 feet to 3 feet. Nitrogen entering the root zone is rapidly taken up from the soil solution.

A third difference is the high microbial activity in the soil just beneath turfgrasses (Lee et al., 2001). The thatch layer at the soil surface provides an ideal environment for microbial communities, and microbial biomass greatly exceeds that found in natural or agricultural soils. High microbial activity and efficient uptake by the roots are key components of efficient nitrogen cycling, which causes fertilizer N to be retained within the system.

Another key characteristic of turfgrasses that is different from traditional agriculture is the large amount of carbon being deposited into the soil. With irrigation and frequent fertilizations, bermudagrass is being grown in a relatively stress-free environment. Large amounts of organic material are generated, and none is removed by harvesting. The carbon in the organic material provides an energy source for microbial activity that in turn drives degradation and denitrification processes.

The evidence that we have assembled thus far suggests that managed turfgrasses may serve a similar function as the riparian buffers being constructed to protect streams and lakes from nitrate contamination. The primary purpose of the riparian buffers is to intercept nitrate in subsurface water flows (Osmond, Gilliam and Evan, 2002). Buffers function by providing a carbon source that is used by microbes for denitrification in the anaerobic conditions close to stream banks, an effect analogous to that observed in our research. With this in mind, it is conceivable that turfgrass systems may occupy an important role in strategies to protect water supplies in the future.

Rufty is a professor in the Departments of Crop Science and Botany at North Carolina State University. The authors acknowledge their collaborators: D.K. Cassel, J.W. Gilliam, C.H. Peacock and A.G. Wollum.

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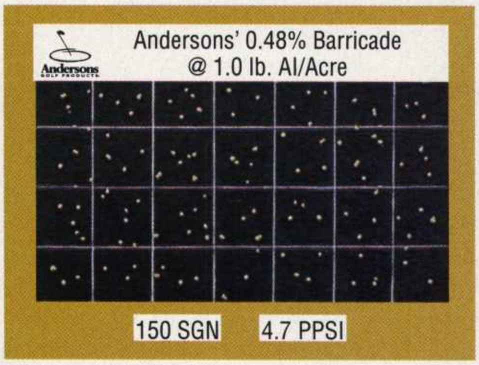

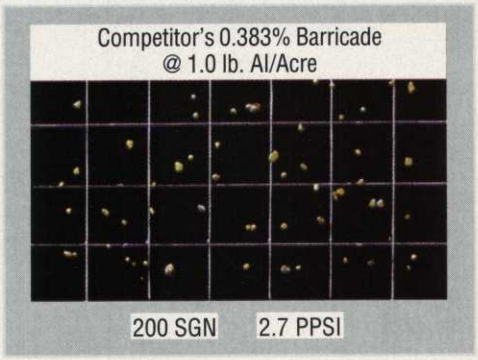

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175	6.9	4.0	2.5	1.4	1.0
200	7.9	4.5	2.9	1.5	1.1
225	8.8	5.1	3.2	1.7	1.2
250	9.8	5.7	3.6	1.9	1.4
300	11.8	6.8	4.3	2.3	1.7

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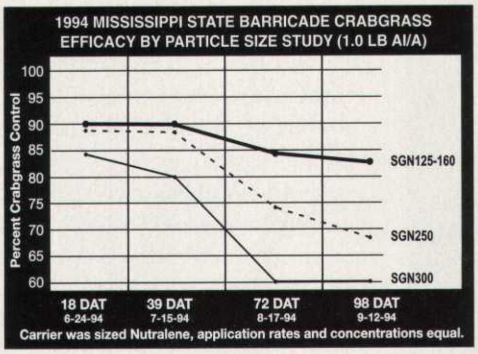

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Winter Injury Causes Problems on Annual Bluegrass Greens

By Darrell K. Tompkins

For many golf courses with creeping bentgrass greens, annual bluegrass invasion is a major weed problem. Consequently, older turf is often overtaken. When this happens, maintenance, rather than eradication, becomes the major consideration. Unfortunately, winter damage to annual bluegrass greens is a significant problem in cold climate areas.

Winter damage to annual bluegrass greens can be due to a number of factors including reduced levels of cold hardiness compared to creeping bentgrass, early dehardening in the spring, reduced cold hardiness associated with crown hydration and mortality under ice cover. This article will examine the manner in which each of these factors can contribute to winter injury in annual bluegrass.

Cold hardiness levels

During the warmer summer months, plants have little ability to tolerate cold temperatures, and temperatures of 24.8 degrees Fahrenheit may be cold enough to cause plant mortality. In preparation for the colder temperatures of winter, plants undergo a number of changes. This process is called cold hardening.

A number of factors can induce cold hardening including low temperature, shorter day length, reduced soil and plant moisture and plant nutrition (Gusta et al., 1983). Typically, temperatures near freezing are more effective in promoting rapid hardening (Gusta and Fowler, 1979), and a period of below-freezing temperatures may be required to achieve the full level of cold hardiness (Gusta and Fowler, 1977).

Cold hardiness levels can fluctuate from year to year, and soil temperature during the hardening period plays a critical role in determining the hardiness level (Tompkins et al, 2000). Upon exposure to conditions that induce hardening, plants will achieve their maximum levels of cold hardiness at the start of the winter (Gusta and Fowler, 1979). This hardiness level will gradually decrease throughout the winter. Therefore, a plant that can tolerate temperatures of –4 degrees Fahrenheit in December may only be able to tolerate temperatures of 17.6 degrees Fahrenheit in April (Tompkins et al., 2000).

Cold hardiness levels can vary widely for different grass species (Gusta et al., 1980).

Crown hydration predisposes the plant to freezing injury because of a loss of cold hardiness.

For example, creeping bentgrass has a much greater ability to cold harden than does annual bluegrass. In Alberta in the western Canadian prairies, creeping bentgrass can cold harden to levels of at least –40 degrees Fahrenheit, while annual bluegrass can cold harden to –5.8 degrees Fahrenheit (Tompkins et al., 2000). Biotypes of annual bluegrass found in other regions may have less ability to cold harden.

As plants cold harden, there is an associated decline in moisture levels in the crown tissue. One difference between creeping bentgrass and annual bluegrass is that creeping bentgrass plants have a lower percent moisture in the crown tissues at levels of maximum cold hardiness.

Dehardening and winter Injury

Dehardening is the process that occurs when temperatures warm, and plants lose their ability to tolerate cold temperatures. During the later part of winter, plants undergo a series of thawing and freezing cycles. A plant loses some of its cold tolerance each successive time it is exposed to warmer temperatures.

Dehardening occurs much more rapidly than hardening (Gay and Eagles, 1991). Once cold hardiness is lost, it may be possible to partially re-induce cold hardiness, but this level will never be the same as the initial cold hardiness level (Tompkins, et al., 2000) because the plant has fewer energy reserves to draw on.

While annual bluegrass is not able to attain the same level of cold hardiness as creeping bentgrass, an additional problem is that annual bluegrass can deharden earlier in the spring, making it more susceptible to a late spring frost. For example, in a two-year study conducted at the Prairie Turfgrass Research Centre in Olds, Alberta, the average cold hardiness level in mid-March for annual bluegrass was 8.6 degrees Fahrenheit compared to –20.2 degrees Fahrenheit for creeping bentgrass (Tompkins, et al., 2000).

However, with the advent of much warmer temperatures in April, the cold hardiness differences between species rapidly disappeared. By mid-April, the cold hardiness level was around 14 degrees Fahrenheit for both species.

One way to protect greens from winter injury in the late winter is to maintain a snow cover as long as possible. First, the snow protects plants from low temperatures, preventing injury. Second, as the air temperature warms, the presence of cover can maintain the plants in a dormant state, which helps prolong cold hardiness. This extension of the dormant period may only last for a few days as the snow rapidly melts once daytime temperatures warm, but this may be enough to provide protection from cold nighttime temperatures during this transition period.

Crown hydration

Crown hydration is the process whereby cells in the crown tissue take up water. The crown tissue is a meristematic region in the grass plant that has the ability to produce new growth in the spring.

The problem with crown hydration is that it predisposes the plant to freezing injury because of a loss of cold hardiness. It is a problem in poorly drained areas where water collects and is a particular problem in the spring, when temperatures fluctuate rapidly. When temperatures drop suddenly, cells within the critical crown tissue are susceptible to damage.

During the early spring, plants can deharden considerably before there are any visual signs of growth. This loss of hardiness is associated with an increase in the percentage of crown moisture. In addition, there is a strong correlation between increased crown hydration and increased soil temperature (Tompkins, et al., 2000). Therefore, prolonging the period of dormancy through the use of an insulating cover can delay the increase in crown hydration, which helps to maintain cold hardiness.

In some years, fluctuating temperatures can cause snow to melt and refreeze. Melted water can percolate through the snow to the soil surface where it refreezes, producing a layer of ice on the soil surface (McKersie and Lesham, 1994). Ice can also form when freezing rain occurs on frozen soils. The density of the ice cover can vary depending on whether the rainfall occurs in the presence or absence of snow. Greater damage may occur when plants are encased in ice as compared to ice cover only (Andrews and Pomeroy, 1975; Beard, 1964).

The relationship between tolerance to ice cover (or encasement) and cold hardiness has not been clearly established. Some reports indicate a correlation between the two factors, and other reports indicate that the two factors are not correlated (McKersie and Hunt, 1987; Andrews and Pomeroy, 1989; Gudleifsson et al., 1986). In addition, flooding as the ice melts may reduce cold hardiness as a result of crown hydration (Gao et al., 1983).

As plants cold harden, there is an associated decline in moisture levels in the crown tissues.

The Prairie Turfgrass Research Centre recently completed a two-year study that examined the effect of snow and ice cover on annual bluegrass and creeping bentgrass. Snow and ice covers were established on annual bluegrass and creeping bentgrass greens and maintained for 90 days. At 15-day intervals, plants were sampled, and cold-hardiness levels were determined.

Ice cover had a much more dramatic impact on the loss of cold hardiness (and eventual plant mortality) for annual bluegrass than for creeping bentgrass. For example, by 60 days the ice-covered annual bluegrass

Continued on page 56

Continued from page 55

plants had a cold hardiness level of only 21.2 degrees Fahrenheit and were dead by day 75. In contrast, the ice covered creeping bentgrass plants had a cold hardiness level of –32.8 degrees Fahrenheit at day 60 and –20.2 degrees Fahrenheit at day 90. These results compare favorably with previous research by Beard, who reported significant damage to annual bluegrass when ice covers were present for longer than 75 days (Beard, 1964) while creeping bentgrass was able to survive periods of 120 days under ice cover without damage (Beard, 1965).

Annual bluegrass is much less tolerant than creeping bentgrass of cold temperatures.

Annual bluegrass and creeping bentgrass plants that were snow covered only maintained cold hardiness throughout the 90-day period. At 90 days, annual bluegrass had a cold hardiness level of 6.8 degrees Fahrenheit (compared to –7.6 degrees Fahrenheit at the start of the experiment) and creeping bentgrass had a cold hardiness level of –20.2 degrees Fahrenheit (compared to –43.6 degrees Fahrenheit at the start of the experiment).

The study also examined the effects when ice was removed after 45 days. It would appear that ice removal after 45 days was too late to improve survival of the annual bluegrass, as there was no improvement in cold hardiness in the annual bluegrass plants at 60 days. By 75 days, they were dead. Therefore, much earlier removal of ice would be most appropriate for annual bluegrass, while creeping bentgrass may not warrant ice removal at all.

Summary

Annual bluegrass is much less tolerant than creeping bentgrass of cold temperatures and is particularly susceptible to injury when covered by ice for a prolonged period. Maintaining dormancy by retaining a snow cover is one way to prolong the period of acceptable cold hardiness for annual bluegrass greens.

Current research at the Prairie Turfgrass Research Centre is focusing on strategies to remove ice and minimize damage as well as exploring the effectiveness of winter covers to protect greens.

Tompkins is the research director at the Prairie Turfgrass Research Centre in Olds, Alberta, Canada, and teaches at Olds College.

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Low Use Rates Are the Future for Sulfonylurea Herbicides: Background and Basics

By Clint Waltz and Tim Murphy

It is interesting that at a time when relatively few herbicides are being developed by chemical companies, new herbicides are being introduced into the turf arena. Most of these newly introduced herbicides are in the sulfonylurea (SU) family.

Sulfonylurea herbicides are not new to the turfgrass market. Products like metsulfuron (Manor and Blade) and sulfometuron (Oust) have been used since the 1980s for broad-spectrum weed control in warm-season turfgrasses (Table 1). While the older SUs were broader in the number and type of weeds controlled, the newer SUs are more weed specific with minimal to no phytotoxicity on tolerant grasses. Halosulfuron (Manage) is an excellent example, as it is very effective at controlling problematic sedges like purple nutsedge, yellow nutsedge, and *Kyllinga* species, but is noninjurious on warm- and cool-season turfgrasses.

Sulfonylureas were developed in the mid-1970s by DuPont. This class of chemistry represented a major development in the pesticide industry. In 1989, there were 375 patents issued to 27 agrochemical companies covering tens of millions suspected biologically active structural variations (Brown, 1990).

In 2002, there were 27 SUs listed in the "Herbicide Handbook," which was the largest number of herbicides for any family (WSSA, 2002). Interestingly, only 17 were labeled for use in North America, but since the printing of that publication two SUs (flazasulfuron and foramsulfuron) have been registered or are seeking turfgrass registrations.

Since the mid-1970s, numerous SUs have been synthesized and their herbicidal activity confirmed. Over time, several have been registered for use in the agrichemical market. Because of the great number of potential active ingredients from this class and the relatively short patent periods (17 years), companies have continued to work with this class of chemistry and have released new herbicides often enough to maintain a patent protected chemical on the market.

Characteristics of SU herbicides

Herbicidal activity: The SUs are characterized by high biological activity on susceptible weeds, short half-lives and low toxicities to animal species.

High biological activity is the reason for low use rates associated with this chemistry, which has several advantages such as reducing the amount of active ingredient applied to the environment, reducing handling and container disposal issues. An example of this is the use of halosulfuron for the control of nutsedge compared to the traditional use of MSMA. In a single year, if two applications of halosulfuron were applied at the high label rate (.06 pounds active ingredients per acre, or a.i./A), it would take more than 16 years to equal the amount of active ingredient from one application of MSMA (2 pounds ai/A).

In fact, often two to five annual applications are usually needed for effective control of sedges with MSMA. Sulfonylureas offer a distinct advantage over many other herbicides such as MSMA because effective, weed-specific control can be achieved with "fewer pounds on the ground."

Soil persistence: Under acidic soil conditions, the half-life of herbicides in this family typically ranges from four to 56 days with an average of 35 days (McCarty et al., 1997). Sulfonylurea herbicides are degraded by chemical hydrolysis and microbial breakdown, and both processes are accelerated under acidic conditions.

Additionally, water and soil pH influences the water solubility, sorption to organic matter, and soil mobility of Sus, which have relatively low organic carbon partition coefficient (K_{oc}) values. The K_{oc} value is a measure of a chemical's affinity for the organic carbon component of the soil. A chemical with a high K_{oc} value is more strongly attached to the soil than one with a low value. Photodegradation

Continued on page 58

FIGURE 1

Sulfonylurea herbicides labeled or seeking registration for use on turfgrass.

TURFGRASS LABEL	COMMON NAME (lbs ai / acre)	TRADE NAMES (oz product / acre)	FORMULATION	TOLERANT TURF SPECIES
✔	chlorsulfuron (0.05 – 0.25)	Corsair (1 – 5.3)	75 DF	Bahiagrass Bentgrass (fairways) Bermudagrass Fine fescue Kentucky bluegrass
	flazasulfuron*	Katana	25 WG	Bermudagrass Centipedegrass Seashore Paspalum Zoysiagrass
✔	foramsulfuron (0.01 – 0.02)	Revolver (8.8 – 17.4)	2.25 SC	Bermudagrass Zoysiagrass
✔	halosulfuron (0.03 – 0.06)	Manage (0.67 – 1.33) Sempra	75 WP	Bahiagrass Bermudagrass Centipedegrass St. Augustinegrass Fine Fescue Kentucky Bluegrass Tall Fescue
✔	metsulfuron (0.01 – 0.02)	Manor (0.5 – 1.0) Blade Escort	60 DF	Bermudagrass Centipedegrass St. Augustinegrass Zoysiagrass
✔	rimsulfuron (0.02 – 0.06)	TranXit GTA (1 – 4)	25 WSP	Bermudagrass
✔	sulfometuron (0.05 – 0.19)	Oust (1 – 4)	75 DF	Bermudagrass
	sulfosulfuron* (0.04 – 0.06)	Batallion (0.75 – 1.33)	75 DF	Bahiagrass Bermudagrass Zoysiagrass
✔	trifloxysulfuron (0.005 – 0.026)	Monument (0.1 – 0.56)	75 WG	Bermudagrass Zoysiagrass

* Not all herbicides are currently labeled for use on turfgrass. However, this chart represents labeled materials and herbicides being investigated for potential use on turfgrass. Always follow the label recommendations.

Continued from page 57
has little impact on this class of herbicides.

At neutral and alkaline conditions, some materials may persist for two years, which may influence the planting of various plant species. Many of the SUs have herbicidal activity on cool-season turfgrass species, like the perennial ryegrass commonly used as an overseeding species on bermudagrass tees, fairways and greens. However, SUs which have short soil half-lives, such as foramsulfuron and rimsulfuron, can be applied for annual bluegrass control 14 days prior to ryegrass overseeding.

Toxicology: Sulfonylureas act upon a specific plant enzyme (acetolactate synthase), which is not found in mammals or other animals (Brown, 1990). For this reason, SUs have very low acute and chronic toxicity. Therefore, they are considered essentially nontoxic to animals.

Mode of action: Herbicides of this family are absorbed by foliage and roots, and inhibit growth at both locations. Once absorbed into the plant, SUs are rapidly translocated acropetally from the root to the shoot, and basipetally from the shoot to the root in the xylem and phloem to the areas of active growth.

Research has shown that SUs work by inhibiting the plant-specific enzyme acetolactate synthase (ALS), which is required for the biosynthesis of branched-chain amino acids. Furthermore, SUs are ALS inhibitors solely and have no influence on other biochemical processes or a second site of activity. This site specificity can lead to the development of SU-resistant weeds, which has been reported after repeated use of chlorsulfuron and metsulfuron in cereal production (Brown, 1990), and sulfometuron for Italian ryegrass control.

Branched-chain amino acids, like valine, leucine and isoleucine are required components of the growth processes of cell division. By blocking ALS and preventing branched-chain amino acid production, sulfonylurea herbicides rapidly inhibit cell division at the root and shoot tips. Studies detected cell division inhibition as quickly as one to two hours after application (Brown, 1990). However, whole-plant symptoms, such as vein reddening, leaf chlorosis and terminal bud death were not evident for several days. Usually one to three weeks are required from the time of application to complete control of the target weed (McCarty, 1997).

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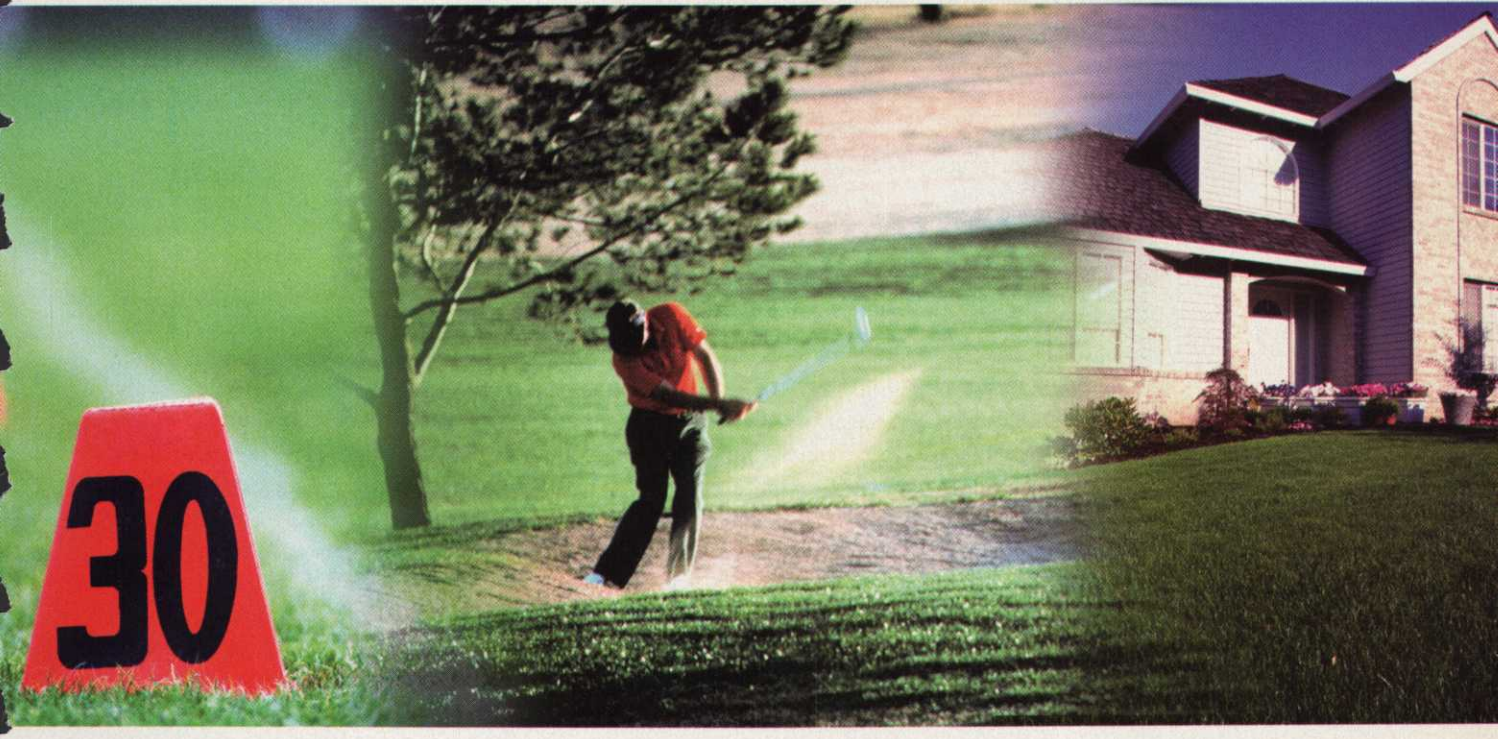

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Continued from page 58

Selectivity: All plants have the enzyme ALS, but not all plants are susceptible to injury from SUs. Differential susceptibility may be because of several factors, including:

1) differential uptake and /or translocation;
2) differential active-site sensitivity; and
3) metabolic inactivation by the tolerant plant.

Although differences in leaf uptake between tolerant and sensitive plants have been measured, it has been concluded these minimal differences are unlikely the principle mechanism of selectivity (Brown, 1990).

Likewise, since SUs are target-site specific, differential active-site sensitivity is not the reason some plants are tolerant and others are not. Most plant physiologists agree that metabolic inactivation, where one plant can inactivate or breakdown the herbicide more quickly than another, is most likely the primary means of selectivity. Tolerant plant species have been shown to metabolize an applied SU in four to six hours, while sensitive species and weedy species have internal plant half-lives more than 50 hours (Brown, 1990).

SUs are generally highly water soluble, so they are subject to tracking and lateral movement to off-target sites.

Potential problems

Because the SUs are generally highly water soluble and have a low K_{oc}, they are subject to tracking and lateral movement to off-target sites.

While one of their positive attributes is having great herbicidal activity at low rates, it can be problematic. It does not take much herbicide to injure sensitive species. Under the right conditions, which would be free water at the soil surface or ponded water on the soil surface shortly following application, these materials can move laterally onto off-target areas. Despite being diluted in the excess water, SUs can still cause extensive damage to sensitive grasses.

Where this problem has occasionally occurred is around creeping bentgrass putting greens, where a turf manager has intended to control annual bluegrass or chemically transition ryegrass right up to the perimeter of the green. Herbicide movement and subsequent injury has occurred when the application was made to saturated clay soils or when an irrigation cycle was used to water in the application but instead washed the diluted herbicide across the green.

In extreme cases, the manager suffered complete loss of bentgrass, but in many incidences the putting green turned yellow and thinned and then recovered. These symptoms typically followed the surface drainage pattern of the putting green.

To prevent these types of problems, read and follow label directions carefully. Use short, frequent irrigation cycles that do not allow water to stand on the soil surface and apply these cycles prior to allowing foot or equipment traffic to cross the treated area to access the putting green. If possible, allow two to three hours after application and irrigation before entry into the treated area. Many of the SUs are rainfast within this time interval, and two to three hours should allow for adequate infiltration of applied water. Do not apply herbicides to areas that are saturated or have standing water.

Summary

From the standpoint of high activity at low use rates and being environmentally benign, the SUs have revolutionized the herbicide industry.

The basic SU molecular structure can be easily altered to produce many derivatives such that designer herbicides can be synthesized to target specific weeds in particular crops. In all likelihood, more SUs will enter the market. In the future, look forward to new herbicides from this class of chemistry that address weed specific problems.

Waltz is an assistant professor in the Department of Crop and Soil Sciences at the University of Georgia's Griffin, Ga., location. Murphy is a professor in the Department of Crop and Soil Sciences at the University of Georgia.

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