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al soils and is important for taller crops where this nutrient can't be applied after they have achieved some height. However, phosphorus can be applied at any time to turf and ornamentals. Most agronomic and horticultural crops actually grow well under a wide soil pH range, provided they are supplied with the correct amounts of nutrients. Alfalfa and sweet clover would grow well on slightly acidic soils provided they were supplied with calcium, and acid-loving plants could thrive under alkaline soil conditions if supplied with micronutrients (Tisdale et al., 1993). Many tree species also prefer acid soils because of their high micronutrient requirements. Adjustment of pH is important for disease control in some crops, primarily because of its influence on pathogen populations and activity, as well as its influence on micronutrient availability which is important for certain disease reductions.

Turfgrass and landscape managers are usually overly concerned about the pH of the alkaline soils that they are managing. Often they believe that plants will not perform to their genetic potential if not grown in moderately acidic to slightly acidic soil. As a result, the manager often requests a recommendation on how to reduce soil pH. However, acidification of alkaline soils is usually not necessary.

Problems due to alkalinity are less common than problems due to acidity. As mentioned previously, the primary problems are nutritional and, for turf and ornamentals, can usually be corrected at any time during the growing season.

The acidification of alkaline pH soils may not be practical or possible. A soil that is alkaline can also be calcareous, i.e., it contains inorganic carbonates. Often referred to as "free lime" inches or "free calcium carbonate" inches this term includes both calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Calcite in soil is the size of coarse clay and fine silt particles. Dolomite (calcium and magnesium carbonate) is the size of silt and fine sand. These two minerals are sparingly soluble salts. Dolomite has a dissolution rate of about 100 times less than calcite because of its larger size (Loeppert and Suarez, 1996).

Calcite and dolomite are referred to as alkaline-earth carbonates. They are the primary forms of inorganic carbonate in soil with calcite being the most predominant. Their hydrolysis in the soil is an alkaline reaction that generates hydroxyl and bicarbonate ions that neutralize H^+. The dissolution of the carbonates decreases as the H^+ concentration is reduced and the rate at which OH^- is removed from solution decreases.

$$CaCO_3 + HOH <==> Ca^{+2} + 2OH^- + HCO_3^-$$

Alkaline conditions actually favor calcium carbonate accumulation in the soil by consuming H^+ ions and driving the following reaction to the right.

$$Ca^{+2} + H_2O + CO_2 => CaCO_3 + 2H^+$$

Calcium carbonate precipitates out of soil solution at pH 8.2, but calcareous soils can range in pH from 7.3 to 8.5 when averaged across the soil depth (Carrow et al. 2001). A pH of more than 8.3 is indicative of the presence of exchangeable sodium which hydrolyzes to form NaOH (sodium hydroxide), a strong base, in the soil solution.

Soil is a buffered system. It requires more acid or base to neutralize it than would be indicated by its pH value. Buffering occurs because weak acids, weak bases and salts (which give rise to weak acids or bases) have a low ionization rate when strong acids or strong bases are added. In other words, a weak acid or base does not give up all of its H^+ or OH^- at any one time. For example, acetic acid (CH_3COOH) will dissociate only 1 percent of its H^+ while hydrochloric acid (HCl) will dissociate 100 percent of its H^+. Acetic acid is a weak acid while hydrochloric acid is a strong acid. The dissociated H^+ is active acidity inches, the undissociated H^+ is potential acidity inches and the total H^+ is "total acidity. inches. If active acidity or basicity is nearly equal to total acidity or basicity, you have a strong acid or base.

Carbonates are salts of weak acids. As a result, they contribute to the buffering capacity of a calcareous soil, along with the organic and inorganic colloids, bicarbonates, phosphates and other salts present in the soil. The hydrolysis of these salts gives rise to hydroxyl ions that can be neutralized by an acid. However, neutralized hydroxyls are immediately replaced through further hydrolysis of the salt because

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The Andersons:
Snow Mold Control Products

The Andersons offers a wide variety of snow mold protection products in both granular and sprayable formulations. These products have been and continue to be in university snow mold testing each year with additional work being done on new and improved formulations. These products have many years of solid performance at golf courses around the country in preventing both pink and gray snow molds.

When deciding on the best snow mold program approach to take, it should be based on historic levels of disease pressure at your golf course, along with prior history of infestations and the amount and times of snow fall cover. Timing of applications prior to snow events can be tricky in many northern areas, especially high altitude mountain regions. The fungicide treatment program you choose needs to attack both types of snow mold—pink snow mold (*Microdochium nivale*) and gray snow mold (*Typhula incarnata* and *Typhula ishikariensis*). Pink snow mold is the most common form of snow mold. It can be present with or without snow cover. It occurs under conditions of cool wet weather, high humidity, high nitrogen levels, soil pH above 6.5, and excess thatch. Gray snow mold occurs primarily in heavy snowfall areas. In addition to extensive snow cover, excess thatch and high nitrogen levels can promote disease activity.

Managing a golf course that is under snow for periods in excess of 120 days can be quite challenging for any snow mold control program. Here are a few cultural techniques to help prevent snow mold damage:

The snow mold free strips were treated with the Andersons FFII 14-3-3. Winter 2001 and 2002 Pullman, WA

- Mowing heights should be maintained going into fall.
- Green surfaces should be maintained with little to no leaf litter or needle debris.
- Look at the impact of tree shade in winter, especially on north-facing locations. Try to reduce risk by increasing winter sun.
- Thatch control is key. Active ingredients become tied up in excess thatch.
- Review your fertility program. Apply less N and more K going into fall.
- Surface and subsurface drainage is the key. Consider deep tine aeration in the fall to improve poor drainage.
- Sulfur applications can help. A soil pH above 6.5 favors pink snow mold.
- Reduce the amount of inoculant by early application of contact and systemic fungicides in the fall.
- Map areas that are prone to snow mold, implement additional preventative measures.

When it's time to plan your snow mold protection program, give the Andersons products a good look. You will see very solid performers in our product line as noted in the table below. The active ingredients in our product line continually deliver great control. Michigan State studies report, "18 of 19 best performing treatments in turf trials all included PCNB or chlorthalonil." Never before has it been easier and safer to apply products for snow mold control. Several of our granular fungicides now utilize our new DG Pro carrier that makes granular applications precise and easy to apply. The use of granular fungicides in fall and winter makes good sense. They allow for ease of application during freezing temperatures and lighter traffic on greens vs. spraying.

Article contributed by Ed Price, Territory Manager of The Andersons.

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Product	Product Code	Form	A.I.	Disease
FFII/14-3-3	AGC8566	Granular	PCNB	Pink and Gray Snow Mold
10-0-14 + 15% PCNB	ATT10PC4.1	Granular	PCNB	Pink and Gray Snow Mold
23-3-5 + Fungicide VIII	AGC8569	Granular	Thiophanate-methyl + iprodione	Pink Snow Mold
Bayleton 1%	ATTBY13	Granular	triademefon	Pink and Gray Snow Mold
Fungicide V on DG Pro	AGC87135	Granular	chloroneb	Gray Snow Mold
Fungicide IX on DG Pro	AGC8549	Granular	Thiophanate-methyl +chloroneb	Pink and Gray Snow Mold
Fungicide X	AGC8510-1	Granular	Iprodione	Pink and Gray Snow Mold
Systemic Fungicide on DG Pro	AGC8539	Granular	thiophanate-methyl	Pink Snow Mold
Sulfur	AGC8870	Granular	Elemental Sulfur	Pink and Gray Snow Mold
Penstar Flo	AGC85005	Sprayable	PCNB	Pink and Gray Snow Mold
Fluid Fungicide	AGC833861	Sprayable	Thiophanate-methyl + iprodione	Pink and Gray Snow Mold
Fungo Flo	AGC85225	Sprayable	thiophanate-methyl	Pink Snow Mold
Fungo 50 WSB	AGC85050	Sprayable	thiophanate-methyl	Pink Snow Mold

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only a small portion of the salt will dissociate at any one time.

$$Ca_{50}X + 5H_2SO_4 => Ca_{45}H_{10}X$$

The partially neutralized salt still contains an excess amount of calcium. Therefore, the buffering capacity of a calcareous soil is greatly supplemented by the presence of carbonates. As such, a calcareous soil will require large amounts of an acidifying amendment to neutralize all of the free lime before a permanent reduction in pH is achieved.

Getting started

Before embarking on a pH reduction program it is important for the turf manager to determine if the soil is alkaline or alkaline-calcareous. If a soil test shows a pH greater than 7.5, exchangeable calcium greater than 5,000 pounds per acre and a cation exchange capacity greater than 15, you are most likely dealing with an alkaline-calcareous soil (personal communication, Dr. Charles Darrah, CLC Labs, Westerville, Ohio).

The total amount of inorganic carbonates must be determined in an alkaline-calcareous soil to correctly determine how much acidifying amendment must be used to reduce pH. In many ways, this is equivalent to determining the lime requirement of an acid soil. There are numerous procedures that can be used to determine the quantity of total inorganic carbonate. For the most part they all require the complete acid dissolution of the carbonates in the soil (Loeppert and Suarez, 1996). In Ohio, the Ohio EPA Neutralization Potential Test is often used (Ohio EPA, 1978).

In this procedure either .1 nitrogen (N) or .5 N HCl is added to 2 grams of soil (less than .25 millimeters). The volume and concentration of the acid are dependent on a visual fizz rating with concentration and volume increasing as the fizz becomes stronger. The soil:acid solution is heated to nearly boiling until no gas evolution is visible. The sample is then boiled with distilled water to complete the reaction. The remaining unconsumed acid is measured by titrating with standardized .1 N or .5 N NaOH until the pH of the solution return is 7. The results are expressed as tons $CaCO_3$ *equivalent* per 1,000 tons of soil.

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Elemental sulfur (S^0) is the most common amendment used to reduce soil pH. When sulfur is added to the soil it undergoes oxidation with the general reaction being:

$$S^0 + H_2O + 3/2\ O_2 <=> 2\ H^+ + SO_4^{2-}$$

Two classes of bacteria carry out this reaction. *Thiobacilli* uses the energy released during the oxidation of S^0 to fix CO_2 from organic matter (Tisdale et al., 1993). It is usually considered the most important class of S oxidizer in the soil. The second class includes many heterotrophic bacteria that are particularly important in the root rhizosphere. Most S^0 oxidizers are aerobic and require soil conditions favoring plant root growth.

It requires only 32 pounds S^0 to neutralize 100 pounds $CaCO_3$. However, a soil with 1 percent $CaCO_3$ contains 230 pounds $CaCO_3$/1,000 square feet/3 inches depth. Therefore this soil would require 74 pounds S/1,000 square feet. Alkaline calcareous soils can contain 40 percent or more of inorganic carbonates, but even amounts as low as only 2 percent or 3 percent can make pH reduction impractical, if not impossible. This is because surface applications of sulfur are usually limited to 5 or 6 pounds S^0/1,000 square feet twice per year. It would take 6 to 7.5 years to apply enough S^0 to dissolve this limestone and cause a permanent change in pH. One-half this annual amount is recommended for low CEC sand-based putting greens.

Limitations on S^0 applications are based on the potential for excessive acidity to occur at the soil surface or in the thatch layer. Excess acidity can be as low as pH 2.5 in this zone and can cause direct injury to the crown and roots, as well as Al^{+3}, Mn^{+2} and H^+ toxicity (Carrow et al., 2001). Low S application rates reduce the possibility that large amounts of sulfuric acid (H_2SO_4) can be produced at the same time.

When to make a move

The question then is: Under what conditions should soil acidification of alkaline pH soils be attempted?

First, consider soil acidification if the soil is alkaline and contains no free lime. Then the pH of the soil can be significantly and permanently reduced over a period of time. However, the actual need to reduce pH may not exist if plants are well adapted to alkaline soil conditions and their nutritional needs are being met.

In the book *Turfgrass soil fertility and chemical properties*, Carrow et al. (2001) present a table showing the approximate amounts of elemental sulfur (99 percent purity) necessary to reduce the top 6 inches of soil to pH 6.5 (see Table 1). These S0 rates are based on assumptions about how soil texture influences cation exchange capacity and the final amount of H+ saturation on the cation exchange sites. S0 rates can range from a low of 2 pounds to 5 pounds/1,000 square feet to as high as 70 pounds/1,000 square feet

Even with non-calcareous soil, it can take many years to apply enough sulfur to reduce pH. Therefore, the best time to reduce pH of an alkaline soil is prior to establishment when larger quantities of sulfur can be incorporated into the soil. Under these conditions it has been recommended that rates as high as 70 pounds S^0/1,000 square feet can be safely incorporated into the upper 6 inches of soil (Carrow et al., 2001). However, S^0 rates up to 20 pounds/1,000 square feet/4 inches soil are usually considered safe when incorporated pre-planting incorporated. Rates over 25 pounds/1,000 square feet incorporated into the upper three to four inches of soil should be used with caution.

The pH reduction of alkaline-calcareous soils should occur only under specific conditions. Each 1 percent calcium carbonate in the soil requires that an additional 130 pounds S^0/1,000 square feet be added to the amounts recommended in the table by Carrow et al. (2001). This essentially makes it impossible to change the pH of a calcareous soil in a reasonable time frame. Fry et al. (2002) reported that no significant change in pH occurred following the application of 40 pounds S^0/1,000 square feet over a two year period to a calcareous (1.5 percent free lime) sand green.

In lieu of pH reduction, routine soil testing should be performed to determine if any nutritional imbalances are present. Bicarbonate-extractable P should be determined to insure adequate plant available P levels in the soil. Magnesium levels should be monitored to insure a Ca:Mg ratio of more than or equal to 8.5:1 and exchangeable Mg levels should be in sufficient quantities to optimize plant growth.

Soil micronutrient levels should also be monitored, particularly for iron. Chelated iron products (especially EDDHA) have the longest lasting effects when applied to soil, but ferrous sulfate sprays may provide a more cost-effective way to provide foliar-fed and some root-absorbed iron. Acidification of irrigation water to reduce high bicarbonate levels can also improve Fe availability in the soil.

Some situations actually do warrant the use of acidifying amendments on alkaline-calcareous soils. The first is when inorganic carbonates precipitates near the soil surface. This caliche layer is a weakly or strongly cemented layer of soil particles and carbonates. It can develop in both sand and finer-textured soils. It usually forms when soils are irrigated year-round with water high in Ca^{+2}, Mg^{+2} and bicarbonate. It is not uncommon for the pH of a soil to increase when irrigation is initiated with this type of water.

Unlike sodium bicarbonate and potassium bicarbonate, calcium and magnesium bicarbonates only exist in solution. The following reaction illustrates what happens when a soil dries following irrigation with a hard and alkaline water:

$$Ca(HCO_3)_2 \Rightarrow CaCO_3 + CO_2 + H_2O$$

These precipitates form the caliche layer that can act as an impediment to soil water movement (Soil Improvement Committee — California Fertilizer Association, 1985). The use of pH reduction, along with cultivation, is recommended in this situation to prevent or reverse caliche formation (Carrow, 2001). An advantage to a shallow layer of caliche is that the depth of soil that needs to be affected by added acidifying amendments is usually only 1 inch to

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TABLE 1

Approximate quantities of elemental S (99 percent purity) required to lower the pH of the top 6 inches of a non-calcareous soil to pH 6.5.

Soil pH	Sand to loamy sand	Loam	Clay or organic soil
8.5	30 to 50	50 to 60	60 to 70
8	15 to 25	25 to 35	35 to 50
7.5	10 to 15	15 to 20	20 to 25
7	2 to 5	3 to 6	5 to 10

(Adapted from Carrow et al. 2001)

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2 inches. Guidelines for the amounts of acidifying amendments still need to be followed even if core cultivation is performed at the same time. An annual pH acidification program should be considered when irrigation water is the primary source of free lime.

Elemental sulfur (S^0) is the most common amendment used to reduce soil pH.

A turf manager can also consider following a long-term pH acidification program for alkaline-calcareous soils if the total inorganic carbonate level is 2 percent or less. Routine applications of sulfur can be made in conjunction with routine testing for soil pH. However, this program will require time for any permanent change in soil pH to occur. Soils with 2 percent to 3 percent free lime may also respond to acidifying amendments if they are mixed into the soil as a pre-plant treatment. However, it's my guess that soils that respond dramatically to sulfur are alkaline rather than alkaline- calcareous in nature.

Typical safe rates are 20 pounds S/1,000 square feet per 4 inches of soil. An annual acidification program can then be carried out after the turf or landscape is established and a long-term acidification program is acceptable to the landscape manager.

Carrow et al. (2001) recommend that a pH monitoring program be initiated when soil acidification is attempted. They recommend that two sets of samples be taken. The first set represents the top 0 inches to 1 inch depth of soil while the second set is from 0 inches to 4 inches. If turf crowns are located in the thatch layer, include the thatch with the shallower soil sample. Sample the thatch separately if it is less than or equal to 1 inch thick. Do not allow the thatch and surface soil pH to drop below 5. Neutralize it with 2 pounds to 4 pounds $CaCO_3$/1,000 square feet if it does.

Summary

In summary, alkaline and alkaline-calcareous soils conditions, unlike acidic soil conditions, rarely pose a problem in turfgrass management. Any problems associated with alkaline pH are usually nutritional and can be overcome effectively with alterations in fertilizer practices. While alkaline soil pH can be changed using acidifying materials, the pH of alkaline-calcareous soils is very resistant to change due to the buffering capacity of calcium and magnesium carbonates. The amount of total inorganic carbonate in the soil must be determined in order to know how much sulfur is required to neutralize it.

Limitations on annual application amounts of acidifying materials may essentially make pH reduction impractical, if not impossible. Therefore, only a few situations exist where pH reduction should be attempted. They include the reduction of an alkaline soil with very little or no inorganic carbonates present; the establishment phase when large quantities of acidifying material can be incorporated into the soil *and* total inorganic carbonates are less than 3 percent; when irrigation water is the primary source of carbonates and a caliche layer can or has formed in the top 1 inch to 2 inches of soil; and, if soil carbonates are 2 percent or less and a long-term soil acidification program is acceptable.

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Benefits of Turfgrass Technology Are on the Horizon

By Bob Harriman and Lisa Lee

With more than 25 million golfers playing an estimated 550 million rounds of golf a year, turfgrass managers should feel proud about their impact on America's health, fitness and happiness. Unfortunately, today's turfgrass managers don't have the luxury to take a minute to appreciate the impact of their work. Time, budget and natural resource issues are constantly pulling them in different directions.

Superintendents are constantly striving to improve turf while being held hostage by both the clock and dollar, not to mention trying to reduce pesticide applications and water use.

Companies that supply products to turfgrass professionals have realized the presence of these pressures and are working diligently to develop products to minimize them. Breeders have been working to improve attractiveness, durability, pest resistance, stress tolerance and yield for decades (Barker and Kalton, 1989). However, many of the traits desired by turfgrass professionals are not attainable by traditional breeding.

For over a decade, biotechnology has been touted as the new tool that will help us use modern science to overcome many of the obstacles that face breeders. In fact, several reviews [Lee, 1996; Chai and Sticklen, 1998; Edminister, 2000] and a book [Sticklen and Kenna, 1998] have been written on the targets and potential of biotechnology. The Scotts Co. has been using biotechnology since 1995 to develop new turfgrass products that improve performance and reduce pesticide inputs.

While turfgrass biotechnology has certainly advanced since the development of transgenic orchardgrass in 1988, the industry still does not have a biotech-enhanced turfgrass on the market. Despite the lack of a current commercial product, biotechnology's future is bright.

In 1996, The Scotts Co.'s Lisa Lee presented an update on the current state of affairs of plant biotechnology and highlighted herbicide-tolerance as one of its important targets. Benli Chai and Mariam Sticklen from Michigan State University outlined four categories for "Application(s) of Biotechnology in Turfgrass Genetic Improvement" in their 1998 review article, including:

- applications of molecular markers to assist breeding practice;
- in vitro manipulations for regenerable tissue culture;
- genetic engineering by DNA transfer techniques; and
- the use of fungal endophytes to improve turfgrass performance.

These categories have not only remained pertinent, but significant scientific advancement has occurred.

At the Millennium Turfgrass Conference held in Melbourne, Australia, in June 2000, Craig Edminister of Cebeco International Seeds identified herbicide resistance, insect resistance, salt tolerance and disease resistance as important traits that would be extremely difficult (if not impossible) to deliver using traditional breeding methods.

In *Turfgrass Biotechnology*, edited by Mariam Sticklen (MSU) and Mike Kenna (USGA) in 1998, Mike challenged turfgrass scientists to "aim for the moon." For this article, we will focus on

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Here are biotechnology-derived bluegrass plants exhibiting dwarfing characteristics. The plant on the far right is a control plant. The second plant from the right has been modified but is not showing a response. The remaining plants are showing varying degrees of dwarfing right down to the bonsai bluegrass plant on the far left.

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QUICK TIP

Kentucky bluegrass has been used in cool-season regions in the United States for a long time, but one of its downfalls is survival in summer heat and humidity. The introduction of Thermal Blue, a new heat-tolerant Kentucky bluegrass developed by The Scotts Co., provides a variety that performs well in even the harshest summer conditions in the transition zone and further north.

TABLE 1

Significant Milestones in Turfgrass Biotechnology

Event	Species	Year	Reference
1st Transgenic Grass	Orchardgrass	1988	[Horn et al.,]
1st Herbicide – tolerant event	Tall Fescue	1992	[Wang et al.,]
1st Field Trial	Creeping Bentgrass (GUS marker)	1993	[Zhong et al.,]
1st Petition to Deregulation	Creeping Bentgrass (RR)	2002	[this article]
1st Production acres planted	Creeping Bentgrass (RR)	2002	[this article]
1st Commercial Launch	??	??	??

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biotech-enhancement through gene insertion, often referred to as genetic engineering. Will science deliver on Edminister's list of traits? You decide if scientists are indeed aiming for the moon and likely to make a successful landing in efforts to develop improved turfgrass performance.

Herbicide resistance

As predicted [Lee, 1996] and suggested in an outline of significant biotechnology milestones (Table 1), the first turfgrass enhanced by biotechnology should be herbicide-tolerant creeping bentgrass.

Table 1 also points out the lengthy timelines involved in the development, testing and regulatory review needed to introduce a biotechnology-derived product. It often takes several years of research to develop even the well-understood, single-gene modifications currently on the market. New genes or complex traits can take a decade or more to identify, refine and develop.

Once a commercial candidate is identified, the regulatory process can take from five to seven years to navigate. Therefore, even for technology that is "proven," it will take six to nine years for a product's benefits to be experienced.

The development of Roundup Ready creeping bentgrass is certainly baring this out.

Disease resistance

Commercial-level disease resistance has proven elusive. Expression of single and even multiple forms of disease-resistance genes, such as chitinase, glucanase and anti-fungal proteins, slowed the rate of infection but have not resulted in long-lasting disease control.

New efforts aimed at expressing a battery of resistance genes or approaches that detoxify products generated by attacking pathogens hold promise that engineered resistance may one day be available to turfgrass managers [Hirt, 2002].

Insect resistance

Insect resistance in agriculture is a banner child of biotech's awesome potential.

The National Center for Food and Agricultural Policy has determined that biotechnological corn resulted in a 3.5 billion pound yield increase and $125 million in additional income, while biotechnological cotton contributed 185 million more pounds and $102 million in additional income (Council For Biotechnology Information — *www.whybiotech.com*).

While biotechnological advances are the primary sources of insect resistance, additional protein leads are being evaluated, such as cowpea protease trypsin inhibitor in oil palm [Abdullah et al., 2002]. In spite of agriculture's success with insect resistance, we are unaware of any turfgrass biotechnology group currently evaluating the potential of insect resistance.

Salt and drought tolerance

With the variable weather conditions superintendents experienced the past several years, drought tolerance would be a useful trait, so it should come as no surprise that researchers in universities and industry settings have been working to develop such technology. Another option to conserve is to develop grasses that are more salt-tolerant and could be irrigated with effluent water.

The scientific literature is loaded with papers on enhanced performance of transgenic plants under water and/or salt stress conditions. Several of these technologies are currently being tested in the field. Will these tests identify genes that could lead to drought and/or salt-tolerant fairways or lawns? Only time will tell.

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