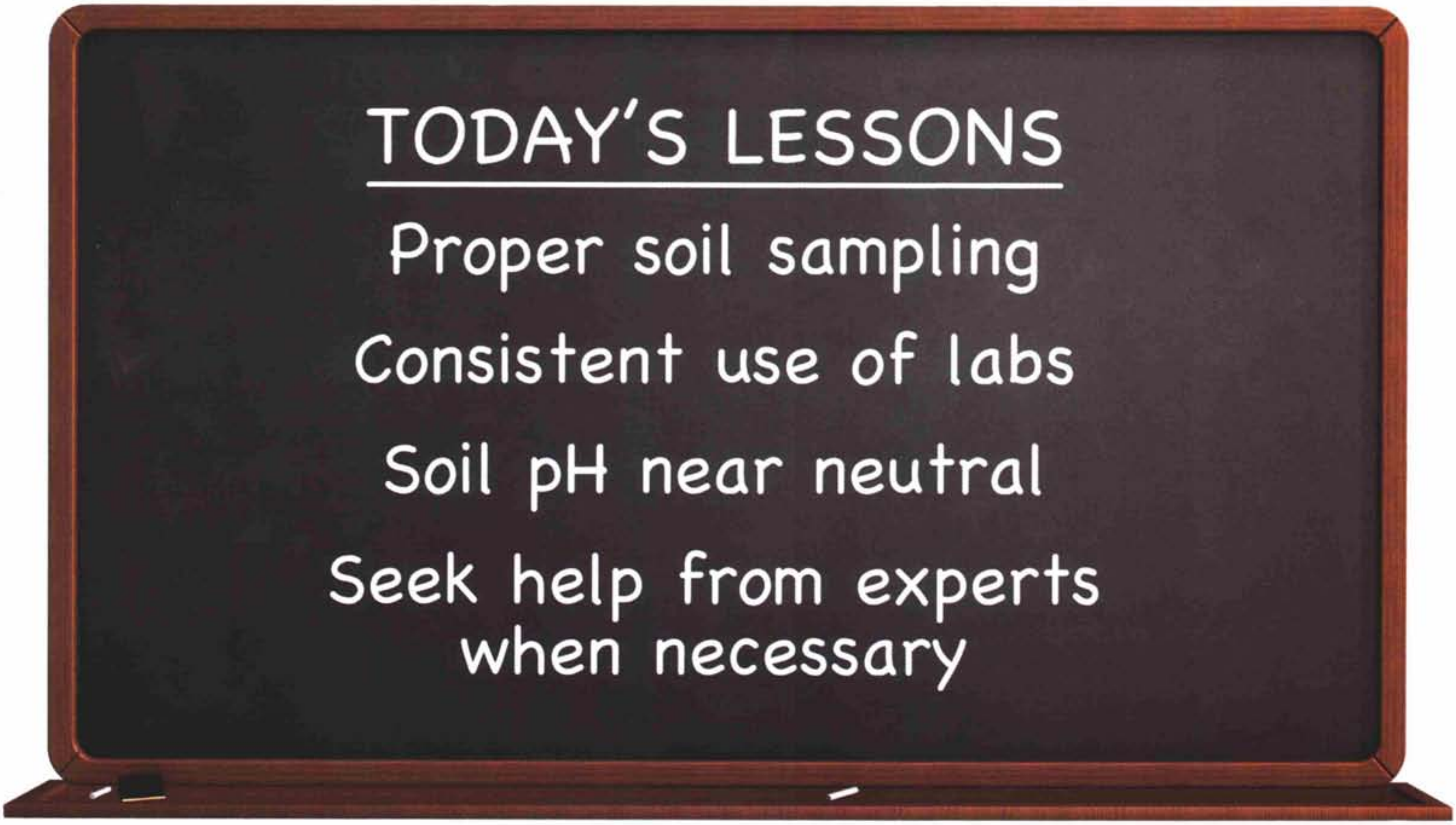


Soil Fertility and Turfgrass Nutrition 101

Some important concepts you might have missed in or outside of the classroom.

BY JAMES H. BAIRD

Few would dispute that there are both an art and a science to growing high-quality turf. However, these days it seems that soil fertility and turfgrass nutrition practices are becoming less scientific and more illogical than artistic.

While science continues to move forward, it appears to me that most of the new theories or so-called *advancements* are professed by companies or individuals who stand to gain by selling their products or consultation services. Most turf managers won't hesitate to apply a new product if they believe that it won't hurt anything and could only help their situation. Unfortunately, applying the wrong nutrient or too much of a nutrient can result in deficiencies of other nutrients, greater potential for disease outbreak due to changes in soil acidity, or perhaps unfavorable changes in soil physical properties. Given today's uncertain economy and increased scrutiny over chemicals applied in the turfgrass environment, all turf managers need to re-evaluate their fertilization practices by using science as the foundation upon which personal experience and *feel* are built.

Soil fertility and plant nutrition are complex subjects, but they're far from incomprehensible. An article of this length cannot begin to address all of the basic principles of soil fertility and turfgrass nutrition. Rather, the objective is to help

Table 1
General trends of soil pH on nutrient availability and various turf problems.

<5.0	5.0–5.5	5.5–6.0	6.0–6.5	6.5–7.0	7.0–7.5	7.5–8.0
	Deficiency (<5.5) Nitrogen Phosphorus Potassium Magnesium Molybdenum Sulfur					**Deficiency (>7.5)** Phosphorus Iron Manganese Boron Copper Zinc
	Disease (>5.3) Spring dead spot		**Disease (>6.0)** Summer patch	**Disease (>6.5)** Pink snow mold Take-all patch		
Al, Mn Toxicity (<5)	Thatch Accumulation (<5.5)					N (urea) Volatilization (>7.5)

simplify several concepts that are critical to ensuring turf health and both environmental and fiscal responsibility. Emphasis will be placed on soils and turfgrass nutritional needs in the Northeast, although the principles will apply more broadly. For more information, please see the references that follow. Let's begin our lesson.

TAKE CHARGE OF YOUR SOIL TESTING PROGRAM

Before applying any nutrient, it's important to determine which ones are deficient and in what amounts. Nutrient deficiencies, including nitrogen (N), iron (Fe), and phosphorus (P), are sometimes visually detectable to the well-trained eye, although quantification of the supplemental amount required is difficult if not impossible. Tissue testing provides a much more objective and quantitative evaluation of the nutritional status of the plant. However, more research is needed to correlate nutrient levels in tissue with turfgrass response. Tissue testing is best used as a diagnostic procedure since a plant must be under nutrient stress for a deficiency to show.

Although far from perfect, soil testing remains the most common and best method of determining the nutrient availability to the turfgrass plant since it attempts to identify potential problems before they occur. Judging by the number of turf managers who hire soil consultants or the number of times I have been asked to interpret reports, I gather that many turf managers are uncomfortable with deciphering soil test results. In the reference section, several articles address soil testing in one capacity or another. The four principal components of soil testing are: 1) sampling, 2) laboratory analysis, 3) interpretation of results, and 4) recommendations for chemical changes, if needed.

DON'T UNDERESTIMATE THE IMPORTANCE OF PROPER SAMPLING

Improper sampling for soil testing can be one of the greatest sources of error in soil testing programs. A few things to keep in mind about soil sampling are: 1) take at least 20 sub-samples (cores) of a representative area to be pooled, mixed, and sampled for testing; 2) sample at a uniform depth (e.g., usually 2 to 4 inches for putting greens; 3) if a true thatch or topdressing layer is present, consider subdividing each core into thatch or mat and underlying soil to determine chemical and nutrient properties of each component; and 4) sampling time and frequency are important for determining consistency of test results and effectiveness of fertilizer applications. Chemical change following fertilization can occur within days or weeks in sandy soils compared to months or years in clay soils. In the Northeast on sand-based greens or tees, consider sampling in spring, prior to aeration, and again 6-8 weeks after fertilization with granular formulations as a follow-up analysis. Sample once again 6-8 weeks following aeration and fertilization in late summer.

BE CONSISTENT WITH LABORATORY ANALYSES

Several university and commercial laboratories are available for soil sample analysis. Be cautious about analyses and recommendations that are offered free of charge from fertilizer manufacturers or turf distributors. Also, it is important to know that results are likely to vary from laboratory to laboratory due to different extraction methods and chemicals used for analyses. See the articles by Carrow et al. (2003 and 2004) that describe differences among soil analytical procedures. For the sake of your soil testing program, it is important to choose a laboratory that uses procedures and nutrient ranges that are appropriate for the soil types on your golf course. Once that information is gathered, the important thing is to use the same laboratory year in and year out to analyze trends in nutrient availability and deficiencies.

YOU TOO CAN INTERPRET A SOIL TEST REPORT

Interpretation from the laboratory or a consultant aside, every turf manager should feel comfortable with understanding soil test results. The following is a description of information likely to be found on a soil test report in the Northeast.

Soil Acidity or pH

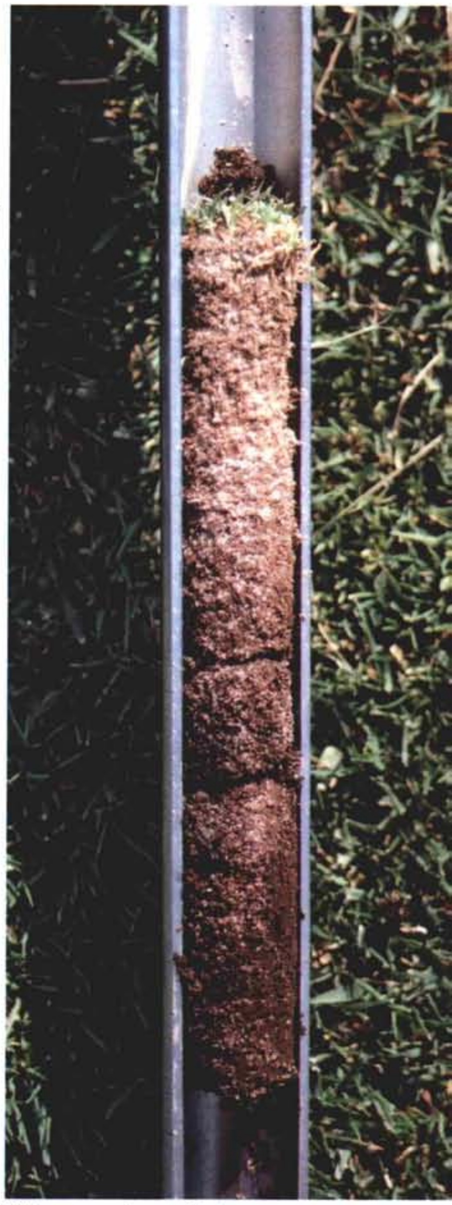
Soil acidity or pH is the negative logarithm of the hydrogen ion concentration on a scale from 0 to 14, with 7 being neutral (concentration of hydrogen ions equals hydroxide ions). Table 1 shows a diagram of nutrient deficiencies and other turf problems that are likely to occur at varying pH levels. In general, soil acidity at or near neutrality ensures maximum availability of all essential nutrients in the soil. This pH range favors the nutrients being in a plant-available form. This is one of the simplest and most important principles to remember about soil fertility and plant nutrition.

Lime Requirement

Lime requirement is the quantity of limestone ($CaCO_3$) required to raise the pH of an acid soil to a desired level. A buffer solution is added to the soil to determine buffer pH. The value itself is not significant to the turf manager, but it is instead used by the lab to determine liming rate recommendations, when necessary. The ability to lower pH of alkaline soils with the addition of sulfur or acid is largely dependent upon free lime present in the soil, with higher quantities providing greater buffer capacity against pH change. Thus, it is not recommended that pH reduction be attempted in soils with even a low percentage of lime due to the very large acid quantities required and the potential for turf injury.

SOLUBLE SALTS

Measurement of soluble salts is especially important for determining salinity on salt-affected soils. Electrical conductivity (ECe) is reported in units of decisiemens/meter (dS/m) or millimhos/centimeter (mmhos/cm). An ECe above 4.0 dS/m is considered saline. The saturated paste extract (SPE) is considered to be the standard procedure for measuring ECe, sodium absorption ratio (SAR), and boron (B) concentration. Although not typically reported on a test in the Northeast, the SAR is a measure of the potential for excess sodium (Na) to cause structural deterioration of soil. SAR levels above 12 are considered problematic for soil and plant health, whereas ideal levels should be 3 or lower. If soil tests reveal problems with soluble salts or Na, it is important to have the water source tested and seek help from a qualified consultant or university specialist.



Soil test results are likely to generate very different results when samples are taken at varying depths. In the case of a longer soil sample, separate and analyze the upper sandy portion of the profile separately from the mineral soil below.

ESSENTIAL NUTRIENTS

Laboratories use chemical extractants to estimate the levels of soil nutrients that are readily available to plants. Values are reported in parts per million (ppm) or pounds per acre (lbs/A). In addition, most labs will categorize each nutrient in terms of availability to the plant from below optimum to above optimum, or very low to very high. This method is referred to as the sufficiency level of available nutrients (SLAN), which attempts to correlate plant response to extractable soil nutrients. Although it could be said that there are limited data directly correlating soil nutrient levels with specific and desirable

Table 2
Essential nutrient elements, their function, and potential for deficiency or toxicity in plants.

Essential Macronutrient	Chemical Symbol	Plant-Available Form	Primary Role	Mobility in Plant	Frequency of Deficiency in Turfgrasses	Deficiency Occurrence	Toxicity or Excessive Occurrence
Carbon	C	CO_2	Many	—	Sometimes	Drought stress	—
Hydrogen	H	H_2O	Many	—	Sometimes	Drought stress	—
Oxygen	O	CO_2 / O_2	Many	—	Sometimes	Compaction; waterlogged conditions	—
Nitrogen	N	NO_3^- NH_4^+	Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, etc.	Mobile	Common	Sandy soils; high leaching; clipping removal; denitrification; low pH (<4.8)	Salt toxicity; excessive growth; succulence
Phosphorus	P	$H_2PO_4^-$ HPO_4^{-2}	Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, etc.; key role in reactions involving ATP	Mobile	Sometimes	Sandy, low CEC, irrigated soils; low pH (<5.5); high pH (>7.5-8.5); high clay content soils; subsoils; high P demand during establishment; reduced uptake in cold soils; clipping removal	Excessive P may induce Fe deficiency under some conditions
Potassium	K	K^+	Required as a cofactor for many enzymes; stomatal movements; maintains electroneutrality in plant cells	Mobile	Sometimes	High rainfall or leaching; sandy or low CEC soils; acidic soils (pH<5.5); clipping removal; sites receiving high Ca, Mg, or Na additions; under high N fertilization; soils high in vermiculite, illite, or smectite at high pH	Salinity stress; suppresses Mg, Ca, or Mn uptake; fertilizer burn
Calcium	Ca	Ca^{+2}	Constituent of middle lamella of cell walls; required as a cofactor by some enzymes	Immobile	Rare	Low pH (<5.5) conditions on low CEC soils receiving high Na levels or with high Al, Mn, or H; high leaching; true deficiencies are most probable in root rather than shoot tissues	Excessive Ca can induce Mg, K, Mn, or Fe deficiencies
Magnesium	Mg	Mg^{+2}	Constituent of chlorophyll molecule	Mobile	Sometimes	Low pH (<5.5); sandy soils due to low CEC and high Al, Mn, H; under high Na, Ca, or K addition; high leaching	Excessive Mg can induce deficiencies of K, Mn, and Ca
Sulfur	S	SO_4^{-2}	Component of some proteins	Somewhat mobile	Sometimes	Low OM; sandy, low CEC soils; high rainfall and leaching; low atmosphere additions; high N with clipping removal	Foliar burn; induces extreme acidity in soils not buffered by free lime; contributes to black layer under anaerobic conditions
Iron	Fe	Fe^{+2} Fe^{+3} Fe-chelates	Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N_2 fixation, and respiration	Immobile	Common	High pH (>7.5); poor rooting; excessive thatch; cold and wet soils; high soil P at high pH; high pH calcareous soils in arid regions; irrigation water with high HCO_3, Ca, Mn, Zn, P, or Cu; low OM soils, heavy metals from sewage sludge	High foliar Fe can blacken leaves, possibly causing tissue injury; can induce Mn deficiency; acidic, poorly drained soils can produce toxic levels of soluble Fe for roots
Manganese	Mn	Mn^{+2} Mn-chelate	Required for activity of enzymes and photosynthetic evolution of O_2	Immobile	Sometimes	High pH, calcareous soils; peats and muck soils that are at pH>7.0; dry, warm weather; high levels of Cu, Zn, Fe, Na, especially on leached, low CEC soils	Toxicity to roots in acidic soils (pH<4.8); anaerobic soils, high Mn levels can induce Ca, Fe, and Mg deficiencies; Si and high temperatures increase plant tolerance to Mn toxicity
Zinc	Zn	Zn^{+2} $ZnOH^+$	Constituent of enzymes	Somewhat mobile	Rare	Alkaline soils; high levels of Fe, Cu, Mn, P, or N; high soil moisture; cool, wet weather and low light intensity; highly weathered, acidic soils	Some municipal wastes may be high in Zn; high Zn may cause chlorosis by inducing Fe or Mg deficiencies
Copper	Cu	Cu^{+2} $Cu(OH)^+$ Cu-chelate	Constituent of enzymes	Somewhat mobile	Rare	Strong binding of Cu on organic soils; heavily leached sands; high levels of Fe, Mn, Zn, P, and N; high pH	Toxic levels can occur from some sewage sludge or pig/poultry manures
Molybdenum	Mo	MoO_4^{-2} $HMoO_4$	Constituent of nitrate reductase, essential to N_2 fixation	Somewhat mobile	Rare	Deficiencies are usually on acid, sandy soils; acid soils high in Fe and Al oxides; high levels of Cu, Mn, Fe, S suppress uptake	Mo toxicities are important for grazing animals and are associated with high pH soils that are wet
Boron	B	H_3BO_3 BO_3^{-3}	Indirect evidence for involvement in carbohydrate transport	Somewhat mobile	Rare	High pH can induce deficiencies, especially on leached, calcareous sandy soils; high Ca can restrict B availability; dry soils; high K may increase B deficiency on low B soils	B toxicity is much more likely than deficiencies due to irrigation water high in B; soils naturally high in B; overapplication of B; use of some compost amendments
Chlorine	Cl	Cl^-	Required for photosynthesis reactions involved in O_2 evolution	Mobile	Never	Cl uptake is suppressed by high NO_3^- and SO_4^{2-}	Cl is a component of many salts that can be directly toxic to leaf tissues and roots; more often it reduces water availability by enhancing total soil salinity
Nickel	Ni	Ni^{+2}	Essential part of enzyme urease, which catalyzes hydrolysis of urea to CO_2 and NH_4^+	—	Never	Conditions associated with Ni deficiency are not clear due to the rare occurrence of Ni deficiency	Ni toxicity can arise from use of some high Ni sewage sludges

Adapted from Carrow et al., 2001

responses of all of the turfgrass species, overall SLAN has been the most tried and true method for estimating plant-available nutrients.

Remember, the numbers that you see on your report and the associated sufficiency levels are based upon factors such as type of extractant used and the specific sufficiency index chosen for interpretation. The articles by Carrow et al. (2003 and 2004) contain information about what are considered medium ranges for various nutrients based on the extractant used. It is possible that the recommended range provided in your report is so high that almost every situation would indicate fertilizer need. It is all right if a lab uses a slightly different range as long as it brackets the ranges provided in the articles. Your decision, whether or not to apply fertilizer based on these results, should take into account the likelihood for nutrient deficiencies to occur in your situation (see Table 2) as well as existing turfgrass health and performance.

Cation Exchange Capacity and Base Cation Saturation

Soils have a net negative charge, which attracts positively charged ions. Thus, cation exchange capacity (CEC) is a measure of the amount of cations that a soil can hold at a given pH that are potentially exchangeable for plant uptake. CEC is often expressed on a weight basis as milliequivalents (meq) per 100 grams of dry soil or centimoles per kilogram (cmol/kg). A 100 g sample of soil with a CEC of 1 meq (considered very low) contains 6.02×10^{20} (602,000,000,000,000,000,000) negative charge sites. Without other information about a sample, knowledge of the CEC can provide some indication of the soil texture. Sands with low organic matter by weight (1-2%) typically have very low CEC values ranging from 1-3 cmol/kg, whereas most clay or clay loam soils are 20 cmol/kg or greater.

The CEC is the sum total of basic or base (K^+, Ca^{+2}, Mg^{+2}, and Na^{+2}) and acidic (Al^{+3} and H^+) cations. The amount of each listed in the report, divided by the CEC, is the saturation of that ion. It appears that a majority of turf agronomic consultants (excluding the USGA Green Section and university scientists) subscribe to the Basic Cation Saturation Ratio (BCSR) theory for interpretation of soil test results and fertilizer recommendations. The theory is based upon having a base saturation of 80% comprised of 65% Ca, 10% Mg, and 5% K. Fertilizer recommendations are made to attain not only these percentages, but also desired balances between any combinations of the nutrients. Having listened to presentations by those who purport this "feed the soil" theory, I am not surprised that a significant number of turf managers buy into this theory, as it is an impressive display of pseudoscience and salesmanship.

Unfortunately, the BCSR theory is largely unfounded, and those who attempt to balance soil cations on a routine basis are simply wasting their time and the club's money. To be more specific, subscribing to the BCSR theory will likely lead to the following: 1) Increased fertilizer recommendations and usage that are not necessary relative to the SLAN method. 2) Raising base saturations in sand-organic matter soils to near 80% can result in a significant increase in soil pH, which may lead to other problems such as greater incidence of take-all or summer patch diseases. 3) When relying on percentages rather than quantities of nutrients present in the soil, it is possible to have a sub-optimum percentage of a basic cation such as K^+ but sufficient levels of extractable K^+ or vice versa. 4) The theory often overestimates soil Ca and underestimates soil CEC in greens or other areas containing calcareous sands or after continuous irrigation with Ca- and Mg-rich water. 5) It usually results in over-application of one base cation, which in turn depletes the availability of the others. Overall, Ca and Mg deficiencies are rare in plants except in unusual circumstances (Table 2).

Until recently, the BCSR theory has not been tested on turfgrass. However, research conducted thus far further substantiates the lack of validity of the theory. When appropriate amounts of basic cations are applied, based on sufficiency data, the percent levels of cations adjust naturally according to soil type. Does all of this mean that the CEC and base cation saturation data should be ignored? Not necessarily. This information can be useful for managing salt-affected soils (i.e., high Na) and as a supplement to sufficiency levels to help determine and evaluate fertility programs.

Soil Nitrogen

Your soil testing laboratory may or may not report tests of soil N because most forms of this nutrient fluctuate too rapidly in the plant-soil system to be accurate and reliable predictors of available N. However, there is hope on the horizon with utilization of the Illinois Soil Nitrogen Test. The test, which predicts a more stable amino form of N, has been developed for use in production agriculture and currently is being used to predict either N fertility needs for turfgrass, or identify turfgrass areas that have increased potential for nitrate leaching if N fertilizer is applied. In the meantime, fertilizer recommendations for N are based on turf response and are adjusted by the turf manager depending on factors such as turfgrass species composition (e.g., *Poa annua* versus bentgrass), traffic, disease susceptibility, and environmental stress conditions.

ROOTS ARE THE PRIMARY SITE OF NUTRIENT UPTAKE

These days I hear a lot about foliar nutrient applications and products touted as being truly foliar in function. While nutrients can be taken up by shoots, primarily through trans-cuticular pores, let's not forget that foliar uptake of nutrients is minor compared to the effectiveness of the root system. When you think about it, the leaf is engineered to absorb light and prevent water loss. Factors that are likely to limit foliar uptake include cuticle thickness, rapid drying before uptake, removal by mowing or precipitation, and volatility. Last but not least, true foliar feeding requires a low volume of water (<1 gallon per 1,000 ft^2) for retention of spray droplets in the foliage; conversely, most turf managers that I know use higher sprayer carrier volumes to distribute turf protectants deeper into thatch or the underlying rootzone.

Sometimes it can be difficult to differentiate between a nutrient deficiency and a disease or insect problem. Examine the turf thoroughly. In this case, damage from the annual bluegrass weevil caused yellowing of the turf.

There is no doubt that light and frequent nutrient application is important in turfgrass nutrient management, especially on putting greens and other intensively managed areas. Call it semantics, but the term liquid fertilization would better describe the practice whereby nutrients are sprayed on the foliage, since uptake can occur by both shoots and roots. The bottom line is, how much are you spending for your "true foliar" fertilizer?

NITROGEN UPTAKE

Nitrogen is taken up by the plant primarily in the forms of ammonium (NH_4^+) and nitrate (NO_3^-) ions and to a lesser extent as urea, which are then assimilated into amino acids and other important N compounds for growth and metabolism. The question then becomes, is it better or more efficient for plants to circumvent this process and absorb amino acids directly? Although uptake of amino acids is possible, my search of the literature revealed only a scant reference to amino acid uptake by arctic sedge! Yet again I pose the question, how much are you spending for products containing amino acids and other biostimulants? More research and product testing are needed to justify both the cost and efficiency of supplying nutrients to turf using products like these.

GET THE MOST OUT OF LATE-SEASON FERTILIZATION

Late fall, or what some call "dormant" fertilizer applications, are typical on cool-season turf in northern, temperate climates. The ultimate goal of late fall fertilization is to supply N to the plant for carbohydrate storage, which can enhance stress tolerance and early spring root growth. Additional benefits include early spring greenup and reduced need for early spring fertilization, which can further enhance shoot growth and increase mowing frequency. Since soil temperatures remain warmer than the air in the fall, roots are capable of taking up nutrients even though shoot growth has essentially ceased. At the same time, photosynthesis can still be active.

Disease or over-application of fertilizer? The granules tell the story.

Thus, proper timing is achieved between the time of the first hard freeze and continuous snow cover or ground freezing when true plant dormancy occurs.

Slow-release forms of N, including natural organics, are commonly applied in the late fall to avoid an unwanted flush of growth in the unlikely event that temperatures rise to above normal. Unfortunately, depending on the carrier, much of the N is not likely to be available to the plant until the following spring, which defeats the purpose of promoting root rather than shoot growth. Furthermore, N may be lost in runoff or leached into groundwater.

It would be better to apply soluble, readily available forms of N such as ammonium sulfate to ensure maximum root uptake and carbohydrate storage in late fall. If slow-release N sources are to be used, then application should be timed earlier in the fall, when warmer temperatures permit availability and root uptake. Less than 1.0 pound of N per 1,000 ft^2 applied when the turf is able to take up and utilize N will help to avoid potential losses due to leaching or runoff. There is little evidence that late fall application of N contributes to low-temperature injury of cool-season turfgrasses as long as proper rates and timing are followed. On the other hand, late fall N fertilization may enhance snow mold activity on turf without a preventative fungicide application; however, the added N can also help to hasten turf recovery from disease or other winter damage.

POTASSIUM FERTILIZATION: MORE IS NOT ALWAYS BETTER

In addition to its role in important physiological processes, K also influences tolerance to drought, cold, high temperature, wear, and salinity stresses. We also associate the term "luxury consumption" with K, in that tissue levels adequate for stress tolerance may be above what is considered

Liquid application can be an effective turf fertilization method, but be skeptical of claims that hype foliar uptake when root uptake is more common.

sufficient for growth. Knowing this, it appears that some turf managers have adopted the "more is better" approach and apply 2-3 or more times more K than N on an annual basis. With the exception of situations involving salt-affected soils and salt-tolerant species, research has demonstrated optimal turfgrass stress tolerance when soil K is maintained in the sufficient range. Remember that excessive K can contribute to salinity stress; suppress Mg, Ca, or Mn uptake; and promote greater incidence of snow mold diseases.

SUMMARY

Soil fertility and turfgrass nutrition can be daunting subjects to many turf managers. I hope this article has helped to clarify and simplify key principles and practices, and has empowered you, the turf manager, to take charge of your turfgrass nutrient program. It doesn't require a lot of money or guessing to meet the nutritional needs of your turf. Let science be your teacher.

REFERENCES

Carrow, R. N. 1995. Soil testing for fertilizer recommendations. Golf Course Management. 63(11):61-68.

Carrow, R. N., D. V. Waddington, and P. E. Rieke. 2001. Turfgrass soil fertility and chemical problems: Assessment and management. Wiley, Hoboken, N.J.

Carrow, R. N., L. Stowell, W. Gelernter, S. Davis, R. R. Duncan, and J. Skorulski. 2003. Clarifying soil testing: I. Saturated paste and dilute extracts. Golf Course Management. 71(9):81-85.

Carrow, R. N., L. Stowell, W. Gelernter, S. Davis, R. R. Duncan, and J. Skorulski. 2004. Clarifying soil testing: II. Choosing SLAN extractants for macnutrients. Golf Course Management. 72(1):189-193.

Carrow, R. N., L. Stowell, W. Gelernter, S. Davis, R. R. Duncan, and J. Skorulski. 2004. Clarifying soil testing: III. SLAN sufficiency ranges and recommendations. Golf Course Management. 72(1):194-197.

Chapin, F. S. III, L. Moilanen, and K. Kielland. 1993. Preferential use of organic N for growth by a non-mycorrhizal arctic sedge. Nature. 361:150-153.

Gardner, D., and B. Horgan. 2006. 2006 Turfgrass and Environmental Research Summary. p. 15.

Happ, K. A. 1994. Tissue testing: Questions and answers. USGA Green Section Record. 32(4):9-11.

Happ, K. A. 1995. Sampling for results: The methods are important. USGA Green Section Record. 33(5):1-4.

Kopittke, P. M., and N. W. Menzies. 2007. A review of the use of the base cation saturation ratio and the "ideal" soil. SSSAJ. 71(2):259-265.

Kussow, W. R. 2000. Soil cation balance. The Grass Roots. 29(2):58-61.

Marschner, H. 1995. Mineral nutrition in higher plants. Academic Press, New York, N.Y.

Skorulski, J. E. 2001. Unlocking the mysteries: Interpreting a soil nutrient test for sand-based greens. USGA Green Section Record. 39(1):9-11.

Skorulski, J. E. 2003. Digging deeper into soil nutrient testing. Tee to Green. 33(1):3-5.

Skorulski, J. E. 2003. Micro-managing. USGA Green Section Record. 41(5):13-17.

St. John, R., and N. Christians. 2007. Basic cation ratios for sand-based greens. USGA Turfgrass and Environmental Research Online. 6(10):1-9.

Taiz, L., and E. Zeiger. 1991. Plant physiology. Benjamin/Cummings. Redwood City, Calif.

Woods, M. S. 2006. Nonacid cation bioavailability in sand rootzones. Ph.D. dissertation. Cornell University, Ithaca, N.Y.

THANKS TO *Drs. Robert N. Carrow, University of Georgia; Paul E. Rieke, Michigan State University; and James A. Murphy, Rutgers University; for their assistance.*

JIM BAIRD *is a Green Section agronomist in the Northeast Region, where he visits golf courses in Connecticut, New Jersey, New York, and Ontario, Canada.*