BY ERIK H. ERVIN, PH.D.

Surviving summer

A seaplant extract-based foliar nutrition program might improve stress tolerance

Given prolonged stress, root tip cytokinin production will decline sharply, resulting in little or no cytokinin xylem transfer to leaves. Adequate leaf tissue cytokinin levels signal the plant to keep producing antioxidants and resist senescence (or programmed cell death). Once leaf tissue cytokinin levels fall, antioxidant production isn't maintained, and programmed cell death (and accompanying translocation of energy reserves to crown storage tissues) is allowed.

How can we intervene and forestall this decline? First, we can fine-tune our irrigation, mowing, cultivation and fertilization practices so as to produce as robust a plant as possible (within the demands of your budget and clientele) before the summer stress season. A balanced, but not overzealous, nutrition program is a must, and True Foliar nutrition appears to offer the right balance.

Second, application of a university-tested biostimulant based on cytokinin-containing seaplant extracts before the onset of summer stress might help forestall decline.

FOLIAR FERTILIZATION

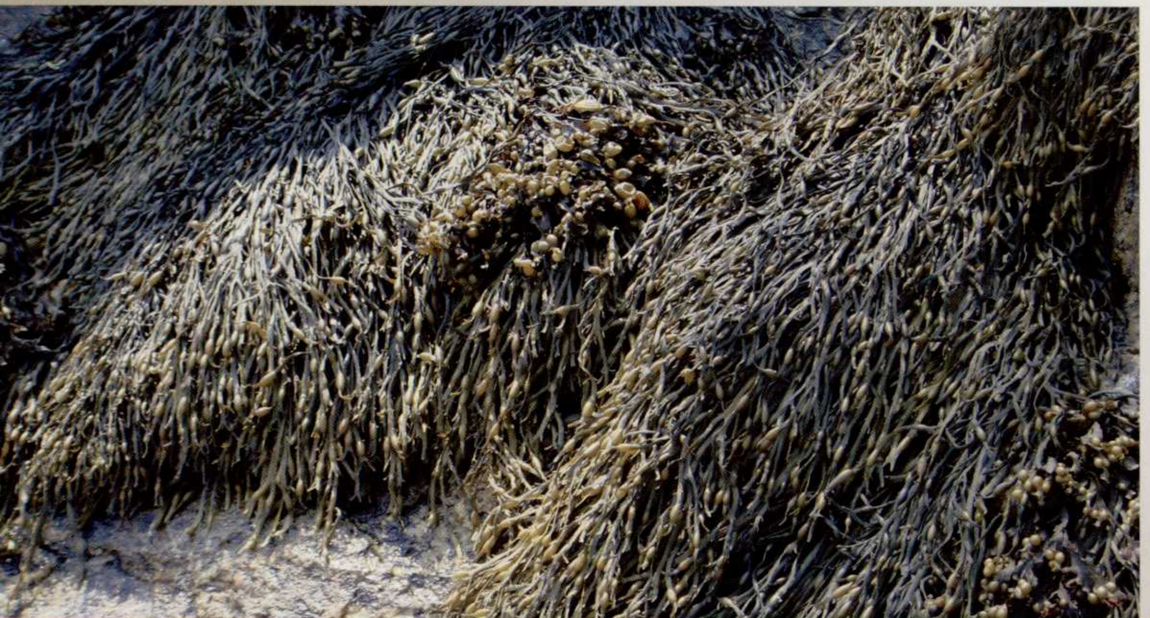
Bob Carrow, Ph.D., and others define foliar fertilization as the application of a nutrient solution in a low volume of water (less than one gallon per 1,000 square feet or 40 gallons per acre). Typically 95 to 100 percent of the water and nutrients remain on the foliage and are able to move into the leaf apoplasm through cuticle and stomatal pores.

Application of nutrient solutions at higher water volumes (three to 25 gallons per 1,000 square feet) as done by liquid lawn care companies and with fertigation isn't considered to be true foliar fertilization because these higher application volumes function to wash most nutrients off the leaf surface, resulting in nutrient uptake by shallow roots.

When open, stomatal pores are greater than 10 micrometers, while cuticular pores are 1,000 times smaller at 1 nanometer or less. Urea (COH_4N_2) in solution, for example, has a radius of 0.44 nanometer and is uncharged making foliar uptake quite fast. Thus, smaller molecules such as ammonium (NH_4^+) and nitrate (NO_3^-) will be absorbed foliarly but at different rates because of their charge differences.

For example, D.C. Bowman and J.L. Paul (1992) reported that foliar application of three nitrogen sources to perennial ryegrass resulted in about 40 percent urea and ammonium uptake after 24 hours, while only 25 percent nitrate was absorbed. Synthetic chelates, such as FeEDTA, are much larger molecules and will be excluded from cuticular pore uptake but not stomatal uptake. Organic chelates, like ferrous citrate, most likely will allow cuticular pore uptake because they're much smaller molecules.

The cuticle consists mainly of cutin, a mixture of long-chain fatty acids. The outer surface of the cuticle is hydrophobic, while the inner surface is more hydrophilic. Cuticular pores are lined with fixed negative charges (mainly from polygalacturonic acids)



Seaplant extract contains cytokinin, which contributes to heat- and drought-stress resistance. Photo: Nick Seaver increasing in density from the outside of the cuticle to the inside. Accordingly, cation permeability along this gradient is enhanced whereas anions are repulsed from this region, but not completely excluded as seen with the Bowman and Paul data mentioned above.

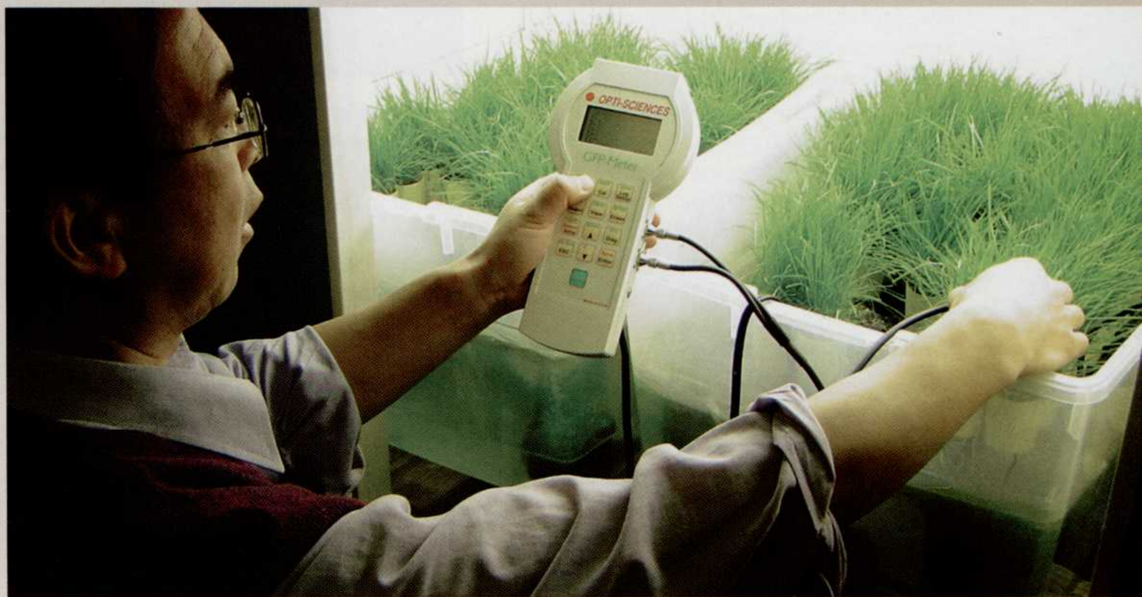
What about cuticular pore uptake of phosphorus, potassium, and micronutrient sources? Ingredients such as potassium citrate and potassium acetate will most likely disassociate in water, leaving potassium to move easily into the leaf. The same is true for manganese citrate, zinc sulfate, copper sulfate and ammonium polyphosphate. Thus, the textbook evidence indicates mineral elements can be absorbed by foliage successfully.

So what's the fate of mineral elements that aren't absorbed by the foliage? In the case of foliarly applied urea, for example, Wesely and others (1987) reported about 30 percent was volatilized as ammonia during the four days following application. In a two-year field study, Miltner and others (1996) estimated about 20 percent of nitrogen from applied urea was lost to volatilization, while about 38 percent was found in clippings, and 40 percent was immobilized in soil and thatch layers.

Reducing potential volatilization and immobilization are areas where nitrogen-use efficiency could be increased due to proper formulation and foliar fertilizer use.

Proper formulation of foliar sources to decrease potential nitrogen volatilization and nitrogen immobilization would involve applying nitrogen sources that are most readily foliarly absorbed – urea and ammonium – and are recommended to be applied at a concentration (0.05 to 0.20 of a pound of nitrogen per 1,000 square feet) and volume (one gallon per 1,000 square feet) low enough so as not to overload the leaf's capacity to absorb them during a 24-hour period.

Less ammonia volatilization will occur because small rates of urea and ammonium are absorbed readily through pores and not left on the leaf surface for urease to convert urea to ammonia. Furthermore, less soil/thatch immobilization of nitrogen will occur because less nitrogen will be available to be washed from the leaf surface by rainfall or irrigation. Of course some irrigation or rainfall washing of nutrients from the leaf surface will happen, but the small concentrations reaching the surface soil solution most likely will be effectively root absorbed, again leaving little nitrogen to be immobilized and stored in soil organic matter or microorganisms or to be leached.



Adequate cytokinin levels in leaf tissue signal plants to keep producing antioxidants and resist programmed cell death.
Photo: Virgina Polytechnic Institute and State University

However, a potential drawback to such efficient use of foliar nitrogen might be no stored organic pool of nitrogen to be released by microbial mineralization following cessation of the summer foliar fertility program (as Richardson's research indicated). Supplementing foliar fertilization with a sound spring and fall granular program will easily overcome this limitation.

Is there any experimental data that indirectly supports the above reasoning concerning greater nutrient use efficiency? Putting it another way, can fewer overall nutrients be applied, compared to conventional approaches, and still provide equivalent or better summer bentgrass performance? Two recent studies are helpful in answering these question.

Frank Rossi, Ph.D., (Cornell, 2003 bioproducts comparison trial) conducted a trial from June through November comparing the Emerald Isle seaplant extract greens nutrition program to a standard water-soluble synthetic spoon-feeding program. The standard program plots received 0.1 pound of nitrogen per 1,000 square feet every seven days plus granular fertility, while the seaplant extract based foliar program plots received 0.1 pound of nitrogen every 14 days: a 77 percent nitrogen reduction during the season on this Penn G2 green mowed at 0.100 inch. In spite of the significant difference in nutrient inputs, equivalent quality was maintained with the foliar program.

Mike Richardson, Ph.D., (Arkansas, reduced

Sea plant extract is linked to stress tolerance because it contains cytokinin, which increases a plant's pool of antioxidants, boosting its immune system. Photo: Nick Seaver

summer nutrient input study on a four-year-old sand-based Crenshaw bentgrass green) compared a four-pound nitrogen program (standard slow-release synthetic and natural organic sources) with a 1.5-pound nitrogen seaplant extract based Emerald Isle foliar nutrition program. Quality was high for both programs with no significant difference between the two. However, clipping yields and thatch accumulation were reduced with the Emerald Isle programs, which is typically correlated with better putting conditions.

SEAPLANT EXTRACT DATA

Before 2004, we published numerous studies documenting increased antioxidant content and, subsequently, greater drought or heat tolerance due to prestress foliar applications of seaplant extract (see references online). However, we had yet to tie antioxidant increases to increased leaf tissue cytokinin levels. In 2004, we published the results of a creeping bentgrass (L-93, Penncross and Penn G-2) drought experiment that provided evidence supporting our supposition that cytokinins in the seaplant extract will result in greater leaf tissue cytokinins, antioxidants and quality under drought.

The seaplant extract used in the study on page 87 contained 70 micrograms per gram cytokinins (zeatin riboside plus isopenteyl adenosine). Leaf tissue levels are 10^{-3} lower than that present in the extract spray solution. Hormones act in minute concentrations (a nanogram equals 10^{-9}), and it takes only a slight increase to have an effect of metabolic significance.

We have quantified the level of the predominant cytokinin, zeatin riboside, present in the product used (CPR) on two occasions. Those levels were: 90.2 and 127.1 micrograms per gram. We measured a zeatin riboside level of 80.0 nanograms per gram in greens-height bentgrass leaf tissue following six summer 2003 applications. No heat or drought stress occurred during this field trial, so we didn't get to observe whether this elevated cytokinin level would have provided greater stress resistance. However, it appears the leaf tissue was primed for action.

In a study completed in 2003, we also quantified the difference in levels in leaf tissue cytokinins between a standard soluble fertility program and the Emerald Isle seaplant extract based foliar nutrition program. With comparable levels of nitrogen inputs (.09 pound of nitrogen per 1,000 square feet every 14 days), the Emerald Isle program produced significantly greater cytokinin levels (zeatin riboside) in late July and August.

CYTOKININS AND STRESS TOLERANCE

Hormones are defined as plant-synthesized compounds that, in very low concentrations, cause a physiological response or regulate growth and development. In other words, hormones are one of the necessary compounds that must be present in a specific tissue, at the right concentration, to allow a certain metabolic (or growth) event to occur. Additionally, each hormone doesn't operate in a vacuum, as it's the concentration ratio of one hormone class relative to another that determines which developmental or metabolic event occurs.

For example, auxin and cytokinins induce cells to divide so new roots and shoots can be initiated, but their ratio determines priority. Thus, it's well documented that a higher ratio of cytokinins to auxin in meristematic (crown) regions promotes tillering (or shoot development), while root initiation lags behind. However, a higher ratio of auxin to cytokinins in the same tissue will result in greater root initiation at the expense of tiller formation.

The key moment in all this comes when we consider where in the plant each of these hormones are produced primarily: Cytokinins are produced in new, viable root tips, while auxin is produced in new shoots. Thus, if the plant has enough healthy roots, enough cytokinins will translocate from the root tips to the crown and shoot tissue and serve as the signal to say: "We're doing OK down here, so go ahead and use some energy to increase shoot density."

Correspondingly, if enough healthy new shoots are being produced, more auxin will translocate to the crown and serve as the signal to say, "We're doing OK up here, but we need to use some of our energy (photosynthate) to initiate and grow some roots to continue supporting this growth."

Obviously, this is simplified, but it clearly makes the point: Lower cytokinin amounts coming to the crown serve as a direct feedback signal – don't grow new tillers at the expense of existing root viability.

Alternatively, heavy mechanical or pest damage on the surface will result in less auxin moving to the crown, thereby changing the balance to favor cytokinins, which will result

Tips for efficient foliar fertilizer uptake

- **Apply between 7 a.m. and 1 p.m. when stomates are most open.**
- **Apply to turgid or nonwater stressed leaf tissue as the intercellular solution (apoplast) will be more dilute creating a greater diffusion gradient for nutrient absorption and cuticle waxes will be thinner.**
- **Do not water in as this will wash the minerals from the leaf surface.**

Antioxidants reaction sequence

1. $O_2^- + O_2^- + 2H^+ \xrightarrow{SOD} H_2O_2 + O_2$
2. $H_2O_2 \xrightarrow{catalase} H_2O + \frac{1}{2} O_2$

or

3. $H_2O_2 + \text{ascorbate} \xrightarrow{APX} 2H_2O + \text{dehydroascorbate}$

in more tiller initiation to replace those tillers being lost.

There are other important points about cytokinin function. Cytokinins have been shown to operate not only as chemical signals to allow or disallow certain developmental events, but to act directly as antioxidant and antisenescence chemicals. The stress resistance message here is that higher leaf tissue levels of cytokinins are overwhelmingly correlated with longer maintenance of functioning (photosynthesizing) green leaves that contain higher levels of antioxidant vitamins (E and C) and antioxidant enzymes (SOD, CAT, APX) when subjected to heat and drought stress. Refereed papers in Crop Science and HortScience authored independently by Bingru Huang and me provide replicated data that confirm the above statements.

OK, what does all of this have to do with summer stress? A brief walk-through of the oxidative stress cycle that occurs in response to summer heat, drought, mechanical and disease stresses should provide some answers. Plants possess antioxidant defense systems that function to protect cells against damage. This system needs to be operating under all conditions, stressful or not.

A natural consequence of radiant (light) energy hitting leaf surfaces is that some of this energy will be absorbed by chlorophyll and excite an electron to move through the photosystems and serve as the fuel for turning light energy into chemical energy. Other excited electrons won't be transferred in this manner and will react with oxygen in the chloroplast to produce reactive oxygen species (or free oxy-radicals) such as superoxide (O_2^-).

A robust pool of antioxidants in the chloroplast are always required to deactivate free radicals such as superoxide and hydrogen peroxide (H_2O_2) or else membranes and other essential organic molecules will begin to be destroyed. The antioxidants required for protection and their reaction sequence are listed above.

Superoxide dismutase (SOD) – as shown in equation one – is required to turn superoxide radicals into hydrogen peroxide and ground-state oxygen (equals good or nonreactive oxygen). However, hydrogen peroxide (bleach), as we know, is quite a dangerous, reactive substance. The plant has two antioxidant enzyme systems to deal with hydrogen peroxide. Catalase – as shown is equation two – will convert some to water and oxygen, while ascorbate (or vitamin C) will react with some and, with the help

Demand for fast and firm drives foliar feeding

BY PAT JONES

Ask any low-handicapper what kind of conditions he wants at his club or regular course, and the response is predictable: fast and firm.

Fast and firm have become buzzwords among avid golfers. They usually can't define what they mean by the term, but they know they want it. It's like art: They don't know much about it, but they know what they like.

As superintendents strive to meet that vague but compelling demand for fast and firm, they've increasingly sought to reduce the amount of nitrogen they use to eliminate puffiness and other side effects of traditional N-based fertility programs. Thus, foliar feeding – which just a decade or so ago was considered by many to be tantamount to snake oil – has emerged as a huge trend in the business.

Foliar feeding is rarely a one-shot deal, although foliar products are often used as tank-mix supplements for plant growth regulators or fungicides. Instead, foliar nutrition products usually are packaged in programs based on needs determined by soil testing and local conditions. Some programs require careful calculation and measurement. Others, like the one described in the above article, have simplified the process to help reduce the possibility of misapplication by packaging product in premeasured doses.

Typical programs are based on a core product – usually a seaplant extract, amino acid or other nutrient source – plus smaller amounts minerals like magnesium, calcium or iron. Again, the recommended combination of products needs to be based on an objective analysis of turf and soil needs determined by lab testing.

Foliars once were considered to be a luxury item reserved for high-end facilities; but, over the years, pricing has declined and superintendents have recognized they can – with the right program – realize savings in terms of fungicide applications and other curative measures that might be required when low-nitrogen turf becomes stressed out.

That said, foliar programs can be a sticker shock for a facility used to relatively cost-effective traditional fertilization programs. A full foliar program can run anywhere from \$5,000 to \$30,000 a year, depending on which product is used and whether fairway applications are part of the system. Clearly, those costs have to be weighed against the agronomic benefits and potential chemical savings.

Golfers – despite the best efforts of golf organizations and superintendents – will continue to demand fast and firm conditions and wall-to-wall green color.

The right foliar program can be more expensive but can meet those expectations. The best advice: Do your homework, talk to colleagues and reps and make sure you've chosen wisely before you make the jump into foliar feeding.

SEAPLANT EXTRACT INFLUENCE

End-of-trial average creeping bentgrass responses as influenced by seaplant extract (5 grams dry weight per 1,000 square feet) under the presence or absence of drought stress.

Response	Drought stressed (5% soil moisture)		Well watered (35% soil moisture)	
	Untreated	Seaplant extract	Untreated	Seaplant extract
Quality (9=best)	4.4	5.5*	7.9	8.4*
Photosynthetic efficiency	0.23	0.30*	0.66	0.68
Shoot weight (grams)	0.96	1.46*	5.27	5.56
Root weight (grams)	0.59	0.69	0.86	0.91
Vitamin E (micrograms per gram)	10.7	14.3*	2.1	3.7*
Zeatin riboside (nanograms per gram)	18.3	28.9*	19.4	27.1*

* Indicates a significant difference from the untreated at a 95 percent level of probability.
Data compiled from Xunzhong Zhang and Erik Ervin. Crop Science 44:1737-145 (2004).

of ascorbate peroxidase (APX) – as shown in equation three – convert it to water and dehydroascorbate. The dehydroascorbate then, in a short series of reactions, cycles back to ascorbate. The production of these antioxidant enzyme proteins requires plant energy.

Heat and drought stress greatly increase free radical production. Initially, plants respond by increasing production of antioxidants to protect photosynthetic function. However, if the assault is persistent antioxidant pools will become depleted and substantial leaf senescence will occur as the plant stops all leaf growth and new root development and conserves energy reserves in the crown and surviving roots.

As mentioned earlier, cytokinins are produced in the tips of relatively new and viable roots. Given prolonged stress, root tip cytokinin production will decline sharply, resulting in little or no cytokinin xylem transfer to leaves. Adequate leaf tissue cytokinin levels signal the plant to keep producing antioxidants and resist senescence (or programmed cell death). Once leaf tissue cytokinin levels fall, antioxidant production isn't maintained and programmed cell death (and accompanying translocation of energy reserves to crown storage tissues) is allowed.

How can we intervene and forestall this decline? First, we can fine-tune our irrigation, mowing, cultivation and fertilization practices so as to produce as robust a plant as possible (within the demands of your budget and clientele) before the summer stress season. A balanced, but not overzealous, nutrition program is a must, and True Foliar nutrition appears to offer the right balance. Second, application of a university-tested biostimulant that is based upon cytokinin-containing seaplant extracts before the onset of summer stress might help forestall decline.

How? Our research-backed reasoning is that by purposefully boosting leaf tissue cytokinin levels and, in turn, increasing the plant's pool of antioxidants, the plant can fight off (or deactivate) stress-induced free radicals for a longer period of time. The result is a boosted immune system that prolongs photosynthetic efficiency, allowing for a minor amount of sustained energy production and maintenance of leaf and root tissue viability during summer stress. Of course given prolonged stress, even plants with boosted immune systems will succumb and die.

The point isn't that these programs will create a supergrass, but they might provide a little added insurance during the summer, especially during the member-guest tournaments when you're asked to double-cut at 0.095 inch, roll and not irrigate or syringe. **GCI**

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Editor's note: References for this article can be found online at www.golfcourseindustry com.