Nutrient uptake:

Some turfgrasses do it better than others

By Richard J. Hull and Haibo Liu

There has been a lot of discussion within the turfgrass community about reducing the material inputs required to maintain high quality turf. Environmental concerns, economic realities and shifting priorities in the allocation of scarce resources are all pressing turf managers to do their job more efficiently. It is estimated that as early as the next century, much of the fertilizer, water and pesticide currently used to grow turf will no longer be available.

Quality scores* Cultivar	Rhode Island	All of US
Kentucky bluegrass (1986-90)		
Blacksburg	7.4	6.3
Eclipse	7.2	6.0
Bristol	6.6	5.9
Liberty	6.7	5.7
Kenblue	5.4	5.0
Joy	5.2	5.0
Perennial ryegrass (1987-90)		
Repell	6.8	6.1
Tara	6.5	5.9
Derby	6.2	5.7
J207	6.4	5.2
J208	6.1	5.2
Linn	4.2	3.7
Tall fescue (1988-91)		
Rebel II	6.5	5.9
Apache	5.8	5.8
Jaguar	6.2	5.7
Arid	5.7	5.7
Falcon	5.4	5.5
KY31	4.1	4.7

* Quality scores: 9 = Excellent turf; 1 = Dead turf or bare ground

Table 1. Turfgrasses evaluated and quality scores at Rhode Island and nationally (NTEP data).

Responses to the problem of limited resources

The US Golf Association and the Golf Course Superintendents Association of America have invested several million dollars in research intended to reduce by fifty percent the fertilizer, water and pesticides needed to grow turf of high quality. This effort was launched about ten years ago and has involved turfgrass researchers all across the country.

State agricultural experiment stations have been conducting research on integrated pest management (IPM) strategies to reduce pesticide use. They have also been evaluating various organic fertilizer materials in an effort to recycle wastes and minimize nutrient losses.

The National Turfgrass Evaluation Program (NTEP) has been comparing the quality of turfgrasses grown under low maintenance conditions with those grown under more conventional practices (see TGT, September/October 1992 and April 1995). This program is aimed at identifying turfgrass cultivars which are more efficient in their use of resources and will produce good turf with reduced material inputs.

Field Editor's Note

By Christopher Sann
Re: Article by Drs. Hull and Liu on nutrient uptake

I strongly recommend the article on turfgrass nutrient uptake by Drs. Hull and Liu to all of our subscribers. The research that they are reporting to us in this article is revolutionary. For the first time, turfgrass researchers have been able to accurately measure nutrient uptake for multiple cultivars of multiple species of turfgrass and begin to relate these measurements to results in the field.

The implications for future turfgrass managers' ability to tailor their cultivar choices precisely to their site and soil environments, and to manage nutrient and soil chemistry strategies, are spectacular.

So, don't be put off by the apparent technicalities of the discussion. It's very straightforward, and will give you a good look at what the future appears to hold in store for cultivar breeding and cultivar and nutrient management in the field.

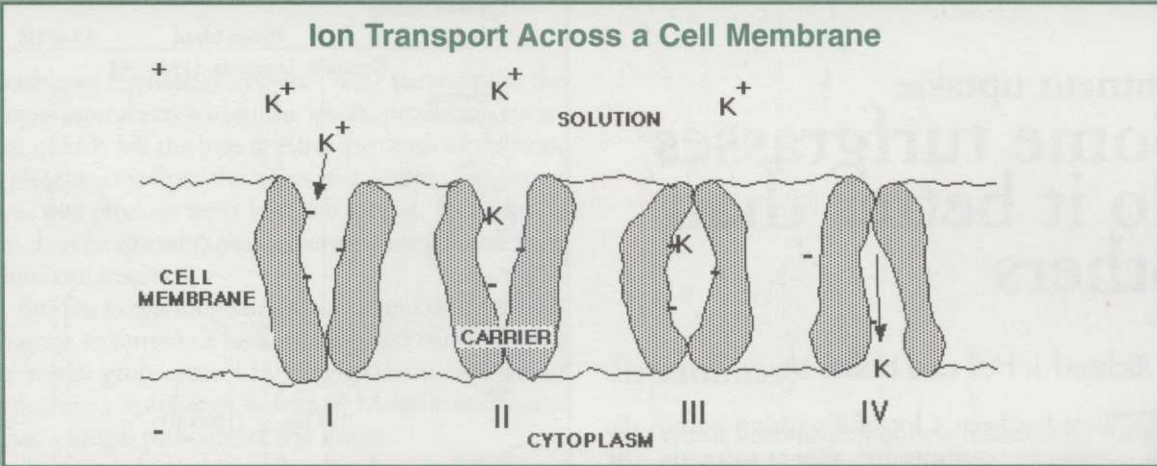

Figure 1. Function of potassium carrier transporting K+ across a cell membrane. I. K+ being attracted by site on carrier protein. II. K+ binding to carrier protein. III. Conformational change in protein enclosing K+ within membrane. IV. Further conformational change and carrier releasing K+ into cytoplasm of cell. The energy driving K+ from the solution into the cell is the electrical gradient spanning the membrane; outside solution positive (+) and inside cytoplasm negative (-). This gradient is produced by a membrane protein which consumes ATP and in the process pumps H+ from the cytoplasm into the external solution (see TGT September 1994). While the potassium carrier shown here provides the channel for K+ transport into the cell, the electrical gradient does the work.

Has all this research resulted in a noticeable decrease in the amount of materials used to maintain turf? An honest answer to that question probably should be "not really."

Many turf managers are actually using fewer materials to grow grass than they did twenty years ago. However, this is more a result of socioeconomic pressures to use less, and pollute less, and because products have been removed from the market without effective replacements being made available at the same (or lower) cost. On top of that, quality standards for general utility turf may be a little lower than they were in the 1950s and 60s. In any event, until now, all this effort to increase the material efficiency of turf management has had little practical impact.

Why is this? In the first place, ten years is not a long time for research to be designed and conducted, the results validated and interpreted, follow-up studies performed, results translated into new management practices or new grass cultivars, and these developments introduced into, and accepted by, the turf profession. Although the close working relationship between university researchers and turf management professionals insures that information transfer is rapid, the process still takes time.

Also, much of this research into turf management efficiency has been conducted at a time of shrinking budgets for university research. Lack of funds has created an atmosphere favoring short-term, externally-funded, practical studies, designed to generate quick answers to immediate problems rather than long-term, basic research on underlying issues like plant efficiency. As a result, our fundamental understanding of what constitutes efficiency in turfgrasses' use of nutrients and water has not advanced very far.

Having said that, we would like to tell you about some research conducted recently at the University of Rhode Island which demonstrates that cultivars of the major cool-season turfgrass species differ in their ability to absorb nutrients from the soil, and suggests why this is so. This information may not be of use to you today, but it is likely to have a profound influence on the development of the turfgrass cultivars you will be using in the not-so-distant future, so you should be aware of it.

Linking turf quality with resource use efficiency

Before describing our research, it is important to understand what efficiency in turfgrass management means. How is efficiency measured? How is quality measured? How are the two linked?

In general, the efficiency of a process can be thought of as the number of units of product made from each unit of a resource invested in its production. For example, the number of bushels of corn harvested per pound of nitrogen fertilizer applied is a measure of the efficiency of the corn's use of nitrogen.

The problem in evaluating turf management efficiently is that its product is not harvested and is therefore not easily measured. The "product" of turf management that most closely resembles a "crop" is turf quality. Quality scores are commonly used to evaluate turf performance in response to experimental treatments. Developing quality scores involves making judgements about characteristics, and combining those judgements into a single value. Needless to say, that involves a lot of subjectivity.

High quality turf has good color and a dense texture, is free of weeds, disease, and insect damage, and is uniform in appearance. Each of those characteristics can be measured individually, but judging turf quality involves integrating all of them into a conclusion about utility and aesthetics. The problem researchers must overcome is finding a way to relate resource use by turf with this illusive property we know as "quality."

One way of making this connection is to measure a particular efficiency characteristic for several different turfgrasses in the laboratory, then relate that characteristic to the quality of turf produced by those grasses when grown in the field under normal management practices. We have several statistical procedures which allow us to quantify the relationship between two properties of the same subject. These procedures give us a measure of how closely, for example, the rate of nutrient uptake is linked with turf quality. As one characteristic increases, how much does the other also increase or decrease?

One word of caution is needed in making correlation analyses like this. We are not measuring cause and effect relationships. We may find that turf quality increases as the rate of nutrient uptake increases, but that does not permit us to say that turf quality results from greater nutrient uptake. Establishing an association between two sets of measurements does not prove that one is the result of the other. Some "third factor" could be at work.

Theory of nutrient uptake

Before starting this research, we had to determine how we were going to measure nutrient utilization by turf. We wanted to use values which would describe the inherent ability of grass roots to absorb a nutrient from solution.

This led us to consider the kinetic description of nutrient uptake first described in the early 1960s by Emanuel Epstein of the University of California at Davis. Epstein recognized that when the rate of nutrient uptake by roots is measured over a range of nutrient concentrations, the resulting curve exhibits what is known as "saturation kinetics." That is, at

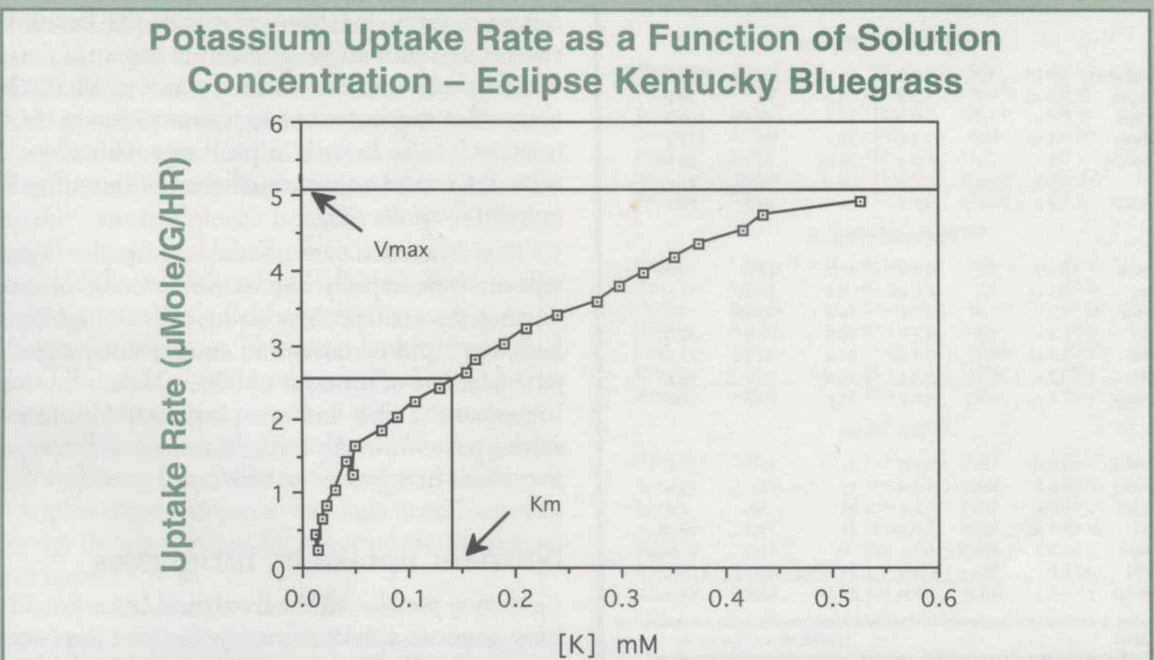

Figure 2. Potassium uptake by concentration curve showing typical saturation kinetics. The kinetic parameters Km and Vmax are identified: Km = 0.14 mM and Vmax = 5.1 µmoles/ gram fresh root/hour. Turfgrass was 'Eclipse' Kentucky bluegrass.

low nutrient concentrations, nutrient uptake increases directly as concentration increases. However, at higher nutrient concentrations, the rate of uptake begins to fall off with further increases in concentration. Eventually, a nutrient concentration is reached where additional increases in nutrient cease to affect the rate of uptake. The uptake process has become saturated.

This sort of saturation response is common in nature and can be described mathematically for the uptake of potassium (K+) by roots with the following equation:

$$V = \frac{Vmax \times [K+]}{Km + [K+]}$$

Where V= the rate or velocity of K+ uptake
Vmax = the rate of K+ uptake at saturating concentrations
[K+] = the concentration of K+ in nutrient solution
Km = the concentration of K+ which produces half the maximum uptake rate

In this equation, Vmax and Km can be considered constants. That makes it possible to calculate the rate of K+ uptake for any concentration of K+ in a nutrient or soil solution.

	VMAX			KM		
Cultivar	NO3-	H2PO4-	K+	NO3-	H2PO4-	K+
	µmole N/gram/hour			µM		
			Kentucky bluegrass			
Blacksburg	4.9 b*	1.3	4.4 bc	36 ab	30	121 a
Eclipse	5.5 ab	1.3	5.5 b	8 b	15	50 c
Bristol	5.9 a	1.2	2.0 cd	71 a	18	160 a
Liberty	5.0 ab	0.9	1.3 d	76 a	18	127 a
Kenblue	5.6 a	1.1	8.0 a	38 ab	16	62 bc
Joy	4.0 b	1.1	2.2 d	26 ab	16	57 c
Average	5.2 z	1.2 y	4.1 z	42 y	19 y	96 x
			Perennial ryegrass			
Saturn	9.0†a	1.1	6.6 b	81†a	15 b	26 ab
Tara	6.2 ab	1.1	7.0 ab	8 b	19 ab	18 b
Derby	4.1 b	1.4	5.2 b	16 b	20 ab	5 b
J207	7.8 a	1.5	4.7 b	26 b	24 a	32 ab
J208	7.0 ab	1.8	7.1 ab	24 b	16 b	21 ab
Linn	9,2 a	1.7	9.2 a	45 ab	24 a	58 a
Average	7.2 y	1.4 y	6.6 y	33 y	20 y	27 z
			Tall fescue			
Rebel II	5.2 ab	1.6	3.5 b	21	12	45 c
Apache	4.2 b	0.9	6.3+a	19	15	15+cd
Jaguar	6.9 a	1.1	6.3 a	64	9	2 d
Arid	5.1 ab	1.1	5.0 ab	21	15	10 cd
Falcon	4.0 b	1.0	6.8 a	9	11	91 b
KY31	7.0 a	1.1	6.3#a	22	12	177#a
Average	5.4 z	1.1 y	5.8 y	26 y	12 z	57 y

* Values in a column for each species followed by the same or no letter are not significantly different.
† Repell perennial ryegrass used in NO3- test.
\+ Aquara tall fescue used in K+ test.
\# Pst-5AG tall fescue used in K+ test.

Table 2. Kinetic constants for nitrate, phosphate and potassium uptake by three turfgrass species.

Vmax and Km are also the primary values which describe the relationship between K+ concentration and its rate of uptake by roots. If roots of different plants absorb K+ at different rates, the Km and Vmax values for those roots will differ accordingly. Those differences tell us something about the basic relationship between the nutrient ion being absorbed and the cell membrane protein responsible for transporting that nutrient from the soil solution into the root cells.

Ions in a soil solution may or may not enter root cells. Those which are not nutrients for plants, aluminum and silicate for example, are mostly kept out of root cells. Nutrient ions cross the cell membrane because they bind with a protein, imbedded in that membrane, that carries them across the membrane to the cytoplasm inside (Fig. 1). To do this, the nutrient ion must have an attraction or affinity for the carrier protein. This affinity between nutrient ion and carrier protein is represented by Km.

Km also represents the concentration of the nutrient ion which produces half the saturation rate (Vmax) of nutrient uptake. The lower the Km value, the stronger the affinity between nutrient and carrier protein. And the stronger that affinity, the lower the nutrient concentration it will take to begin to saturate the uptake process.

What this means in practical terms is that if we measure Km values for the absorption of a nutrient by different plants, the plant root with the lowest Km value is the one with the greatest binding attraction for that particular nutrient, and is the root which can best obtain that nutrient when its concentration in the soil solution is low. In short, a plant root with a low Km value for a nutrient is very efficient in capturing that nutrient from the soil.

The saturation rate of nutrient uptake (Vmax) tells us how rapidly the carrier protein is transporting the nutrient into a root cell. A high Vmax indicates rapid turnover and consequently a greater potential rate of nutrient uptake. Of course, a large Vmax could also indicate a greater number of carrier proteins in the cell membrane, which would also result in a greater uptake rate.

Nutrient uptake by turfgrasses

Having established the theoretical bases for examining nutrient uptake efficiency, the next step was to measure the Km and Vmax absorption constants for several turfgrasses. This raised the question of which grasses we should examine. We wanted to determine how much difference existed among grasses, so it seemed reasonable to compare grasses that came from diverse places, and which produced turf of differing quality. For this, we turned to the NTEP trials which were underway at Rhode Island and which included many of the turfgrass cultivars available in the United States. We concentrated on three grasses: Kentucky bluegrass, perennial ryegrass and tall fescue. For each of those species, we selected six cultivars that gave us a broad range of turf performance, under both Rhode Island and national conditions (Table 1). We also decided to determine the absorption kinetic constants for three nutrients: nitrate (NO3-), phosphate (H2PO4-) and potassium(K+).

To determine the absorption constants, we measured intact root systems' depletion of nutrients from a solution, taking samples for analysis every 15 minutes over a period of about six hours. Using the nutrient depletion curves derived from those measurements, we constructed nutrient uptake curves over the range of concentrations measured (Fig. 2). These enabled us to calculate the kinetic parameters: Km and Vmax.

The results for the six cultivars of each turfgrass species are presented in Table 2. The most important finding from all those numbers is that, in most cases, there were significant differences among the six cultivars of each turfgrass. The values for phosphate uptake showed little variation, and the differences that were observed were rarely significant; but kinetic constants for nitrate and potassium uptake showed greater variation, and here the differences usually were significant.

Differences among the six cultivars of each species generally were greater than the differences among the averages for the three turfgrass species. In fact, the differences among the three species are probably meaningless, because very different average values would have been obtained had we selected different cultivars. However, these values do appear to support field observations.

Kentucky bluegrass, with its lower Vmax and higher Km values, would be expected to be less able to capture soil nitrate and potassium than perennial ryegrass or tall fescue, which generally exhibited a greater Vmax and lower Km. Most turf managers would agree that it takes more nitrogen to maintain good Kentucky bluegrass than is required for either perennial ryegrass or tall fescue.

Next, we attempted to do what most plant physiologists dread. We tried to see if all our theory and careful laboratory measurements said anything about how these grasses actually perform in the field. To do this, we collected clippings through two growing seasons from the same grasses for which we had measured uptake kinetics. For this, we used the NTEP plots at our turf research farm. Those plots were then in their fourth and fifth seasons, but the turf quality was still reasonably good and they continued to be maintained as they had been for the NTEP program.

Clippings were harvested each week, dried, weighed, and analyzed for total nitrogen, phosphorus and potassium. From those measurements, we calculated average daily clipping production rates and daily nutrient recovery rates (Table 3). We reasoned that these values should reflect differences in basic nutrient uptake kinetics.

Again, significant differences were found among cultivars of Kentucky bluegrass and perennial ryegrass; tall fescue cultivars, on the other hand, showed little difference in anything but potassium recovery. It appears that turfgrass cultivars differ in their ability to absorb nutrients from the soil. This is an encouraging finding because it means there is genetic variability within the major turfgrasses, and this variability can be exploited to select or develop more nutrient-efficient grasses.

		Daily recovery in clippings		
Cultivar	Daily clipping yield	N	P	K
	grams/sq-meter/day	mg/sq-meter/day		
		Kentucky bluegrass		
Blacksburg	1.91 c*	84 c	7.2 c	57 c
Eclipse	2.45 bc	105 bc	10.0 abc	79 ab
Bristol	2.65 ab	118 ab	10.7 ab	80 ab
Liberty	2.20 bc	94 bc	8.4 bc	66 bc
Kenblue	3.24 a	141 a	12.3 a	98 a
Joy	2.67 ab	114 ab	10.2 ab	80 ab
Average	2.52 y	110 y	9.8 yz	77 y
		Perennial ryegrass		
Saturn	2.13 ab (1.89)†	81†ab	9.8 ab	72 ab
Tara	1.50 b	62 b	7.0 b	53 b
Derby	2.02 ab	82 ab	9.7 ab	67 ab
J207	2.24 ab	92 a	10.8 a	76 a
J208	1,93 ab	79 ab	9.0 ab	64 ab
Linn	2.26 a	90 a	10.6 a	76 a
Average	2.01 z	86 z	9.5 z	68 z
		Tall fescue		
Rebel II	2.84	113	10.8	92 ab
Apache	2.76 (2.36)+	100	10.4	72+bc
Jaguar	3.01	121	11.2	97 a
Arid	2.93	115	10.8	93 ab
Falcon	3.05	118	11.3	101 a
KY31	3.11 (1.90)#	113	11.6	61#c
Average	2.95 x	113 y	11.0 y	57 y

* Values in a column for each species followed by the same or no letter are not significantly different.
† Repell perennial ryegrass used in NO_3^- test.
+ Aquara tall fescue used in K^+ test.
# Pst-5AG tall fescue used in K^+ test.

Table 3. Clipping growth rate and nutrient recovery rate from clippings for three turfgrass species grown in field plots.

Completing the story

The final step in our research was to correlate laboratory measurements of nutrient uptake with recovery of those nutrients from turfgrasses growing in the field. Not surprisingly, the results were mixed. In general, there was little relationship between the kinetic parameters of nutrient uptake and turf quality or nutrient recovery in clippings. We say this was not surprising because kinetic constants for phosphateuptake showed little variability across species, and tall fescue cultivars didn't vary in either clipping production rate or nutrient recovery.

This seriously limited our opportunity for observing connections between root properties and field performance for one of the three nutrients and one of the three grass species studied. The most significant relationships observed were for potassium uptake. Km was negatively correlated with the potassium content of clippings in Kentucky bluegrass and tall fescue. This is what we expected, since a low Km should result in more efficient nutrient recovery by roots.

Turf quality of perennial ryegrass also was correlated negatively with Km, but positively with Vmax, as we would have expected. Nitrogen did not provide such predictable relationships between root characteristics and nutrient recovery or turf quality. In tall fescue, clipping yields and daily nitrogen recovery were positively correlated with Vmax. Turf performance was not correlated with Km values, but there was little difference in turf performance within tall fescue cultivars.

We find these results very encouraging. Many initial attempts to relate basic physiological properties with crop performance in the field have come up empty. Something as basic as leaf photosynthesis often does not correlate well with crop yields. While our results were not always comprehensible, they were clear enough to demonstrate that the capacity of turfgrass roots to absorb nutrients is reflected in their performance in the field.

Our field data measured turf quality and nutrient recovery through two growing seasons. We know that turf roots take a beating during the summer, and that grasses lose half of their roots by fall. We also know that high summer temperatures place cool-season grasses under considerable heat and drought stress. It is consequently not surprising that seasonal turf performance may not be predicted by a single physiological property of grasses measured under laboratory conditions. (As noted above in discussing the inability of correlational analysis to capture means-ends relationships, "third factors" can intervene.) When we restricted our correlations to field measurements made in the spring, when grasses were growing well, uptake kinetics demonstrated a closer relationship to field performance.

Given all the problems with this type of research, we were gratified that our basic hypothesis, that turf nutrient recovery from soil can be predicted by the uptake characteristics of roots, was not rejected. We only examined six cultivars of each of three species. The NTEP trials during the 1986-91 period included 65 cultivars each of perennial ryegrass and tall fescue, and 72 cultivars of Kentucky bluegrass. In addition, there are many other genotypes which are not included in these national evaluations. A larger screening of the available turfgrass germplasm may uncover genotypes with nutrient uptake efficiency very much superior to anything we discovered. These could then be developed into commercial cultivars or their superior genes incorporated into established name varieties.

There are other efficiency traits which could be

Terms to know:

• **Absorption kinetics** - The dynamics of nutrients passing through plant tissues from a soil solution.

• **Correlation analysis** - Mathematically-based examination of the nature and strength of the relationship between two sets of measurements.

• **Cytoplasm** - the material enclosed by the plasma membrane of a cell, but exclusive of the large central vacuole in plants (and the nucleus in animals).

• **Saturation response** - Cessation of an absorption process through high concentrations of an input material.

• **Uptake kinetics** - See absorption kinetics.

evaluated in turfgrasses. Crops research has demonstrated that root surface area, root growth rate and photosynthate partitioning to roots are all factors which contribute to greater water and nutrient recovery and overall increased efficiency.

It has long been assumed that the genetic base for many of our turfgrass species is limited, and large differences in basic physiological functions would not be found. Our results indicate this may not be the case, and suggest that future efforts at turfgrass improvement might profitably explore such differences.

For such efforts to be effective, we need to understand the basic biology underlying plant efficiency. We have explored the properties of roots which directly influence nutrient uptake from soil solutions. Once in the plant root, many other processes influence the efficiency of nutrient use. Rate of delivery into the xylem and transport to shoots, rate of incorporation into functional enzymes, turnover rate among metabolites and retention within the plant body are just a few of the factors which contribute to efficiency of nutrient use.

Dr. Richard J. Hull is a professor of Plant Science and Chairman of the Plant Sciences Department at the University of Rhode Island. He has degrees in agronomy and botany from the University of Rhode Island and the University of California at Davis. His research has concentrated on nutrient use efficiency and photosynthate partitioning in turfgrasses and woody ornamental plants. He teaches applied plant physiology and plant nutrition. His most recent contribution to *TurfGrass TRENDS* appeared in the April 1995 issue.

Dr. Haibo Liu is a Postdoctoral Research Associate in Turfgrass Science at the Department of Plant Science, Rutgers University. He has degrees in landscape architecture, horticultural science, and biological science-turf science from Beijing Forestry College, the University of Illinois and the University of Rhode Island. His research focuses on turfgrass management and physiology, emphasizing nutrient use efficiency, stress tolerance and environmental impacts of turfgrass management practices. This is his first contribution to *TurfGrass TRENDS*.

Guest Commentary

The research mill

By Richard J. Hull

My statement in the accompanying article that the ten years of research devoted to increasing the efficiency of turfgrass management has had little practical effect requires some explanation. It does not suggest criticism of the research initiatives undertaken. Quite the contrary. The organizations sponsoring such research are to be commended for their farsightedness, and the researchers involved for their imagination and persistence. It is in the nature of research that practical results are slow to emerge.

I said "ten years is not a long time for research..." I also said "our fundamental understanding of what constitutes efficient nutrient and water use by turfgrasses remains limited."

The turf research enterprise is like a mill. Basic scientific understanding is brought to bear on a practical problem, the two are processed together for a period of time and, with luck, a realistic solution to the problem emerges. The most valuable product of such research often is a deeper understanding of the problem being studied. This greater knowledge and insight makefuture problems easier to handle. The grist for this mill is basic science, without which practical problem solving is difficult if not impossible.

The weakness of basic science related to turfgrasses and their environment is a serious problem for turf researchers. The turf industry has been reluctant to support basic research which offers little prospect of immediately useful information. The federal government has for many years given research on turfgrasses and other ornamental plants a low priority for funding. Universities have not encouraged their faculties to undertake research projects with little opportunity for substantial external support. Most turf research programs are small and only a few universities have enough faculty devoted to turfgrass studies that the luxury of basic research can even be considered. Thus, the basic science grist necessary for sound turf research is often lacking, or at best very thin. This seriously limits the ability of turfgrass research to address fundamental issues like resource use efficiency, tolerance of environmental stresses or long-lasting resistance to diseases and insects.

This problem will be resolved only when turfgrass professionals recognize the importance of maintaining strength in basic research, and insist that their industry leaders commit resources to its support. Deans and other university administrators must be persuaded that basic research on turfgrasses is worth funding, and that it has the support of industry and the professions.

It comes down to investing in the future. Is the turf industry concerned only with solving immediate problems and maximizing profit margins, or does it also recognize the need for taking a broader view and committing resources to strengthening the scientific base on which turfgrass science is built? A sustainable future for the turf industry may very well depend on the answer to that question.