A Metabolic Approach

Improving nitrogen use efficiency in turfgrasses

by RICHARD J. HULL and JOHN T. BUSHOVEN

NITROGEN (N) is the most important mineral nutrient for the maintenance of high quality turf. Few turf managers would disagree with this statement, but one could easily question why this is true. Certainly on greens and intensively managed fairways where clippings are removed, two to three pounds of N can be lost per thousand square feet each year. That can be equivalent to 70% of the N applied each year, and such losses surely must be returned in the form of fertilizer. However, if clippings are not removed, N applications normally can be reduced by only 30% (Starr & DeRoo, 1981). Other routes of N loss (runoff, nitrate leaching and denitrification, and ammonia volatilization) are not very large from well-managed turf and have been estimated collectively not to exceed 15% of that applied (Petrovic, 1990).

Where Does the Nitrogen Go?

If N is not lost from turf in appreciable amounts, what then happens to it? A survey of variously aged turf sites led Porter *et al.* (1980) to conclude that turf is a substantial sink for N. They found that the top four inches of soil from mature turf can contain between 1,000 to 4,000 lbs. N/acre. Most of this N is in the form of soil organic matter that is relatively resistant to decomposition, so mineralization of its N is slow and represents an annual release of about 4% or 40 to 160 lbs. N/year. This amount should be sufficient N to meet the needs of turf, and it would be if its release occurred in early spring when turf is most in need of N. Since N mineralization depends on microbial activity, which is greatest when soils are warm, most N release from soil organic matter occurs in summer when cool-season grasses are suffering from heat stress (Huang *et al.*, 2000) and roots often are dying.

One answer to this dilemma is to manage turf so as to promote maximum root growth that would allow turf to absorb N when it is available and store enough to meet its needs when soil sources are limited. Turf managers are already doing this as best they can, given the management constraints of a golf course environment. However, research at Rhode Island has demonstrated that many turfgrasses do not cooperate with this effort.

Variation of root growth can be observed between two perennial ryegrass cultivars grown 246 days in sand ('Linn' on left, 'Secretariat' on right).

We compared nine cultivars each of perennial ryegrass and creeping bentgrass, measuring their rates of nitrate uptake and the rates and location of nitrate metabolism within the grass plants. Cultivars were chosen to represent a broad performance range as demonstrated in the National Turfgrass Evaluation Program field trials at Kingston, R.I. (Table 1).

Assessing Nitrate Uptake

Nitrate uptake was measured using solution-grown turfgrass cultures obtained from seed. Perennial ryegrass and creeping bentgrass cultures were grown in nutrient solution for 60 and 90 days, respectively. Nitrate uptake was determined by measuring nitrate depletion during a 24-hour period from solutions containing 14 ppm NO_3-N. (This concentration should saturate the major nitrate mechanism of grass roots, and the uptake rates so determined represent the grass's capacity for nitrate uptake under ideal conditions.) Differences in nitrate uptake rate were observed among cultivars of both turfgrasses (Table 1).

The total root fresh weight of perennial rygrass and creeping bentgrass averaged 0.88 and 2.00 grams, respectively. This was reflected in the root: shoot weight ratio of creeping bentgrass being more than twice that of perennial ryegrass (Table 1). There also were substantial differences in root fresh weight among cultivars of both grass species.

Nitrate metabolism was measured by monitoring the rates of tissue nitrate reductase activity (NRA) for roots and leaves of each cultivar. Nitrate reductase is the enzyme that catalyzes the reduction of nitrate to nitrite, and it is the first step in nitrate metabolism. It is measured by determining the amount of nitrite produced by plant tissue when nitrate is abundant but conditions are such that nitrite is not further reduced to ammonium. NRA is generally thought to be the rate-limiting step in nitrate utilization by plants (Lillo, 1984), so its measurement pretty much determines the extent that nitrate is being utilized by a plant organ.

In our study, shoots exhibited 3 to 7 times more NRA than did roots (Table 2). While shoot NRA in perennial ryegrass was more than twice that of creeping bentgrass, root NRA did not differ between the two turfgrass species. If the tissue-specific NRA of roots and shoots is multiplied by their respective weights, the total NRA for each plant part can be estimated. We found that the root:shoot ratio of NRA in creeping bentgrass was four times greater than that in perennial ryegrass.

Although the NRA per unit of root weight did not differ between the two grass species, the fact that creeping bentgrass had more than two times more root mass than perennial ryegrass meant that the bentgrass could metabolize more than twice as much nitrate in its roots. Consider also that each gram of perennial ryegrass roots absorbed at least two times more nitrate than did the same root mass of creeping bentgrass (Table 1). It then becomes likely that the NRA of perennial ryegrass roots was saturated, leaving more nitrate free to be transported to the shoots. NRA in plant tissues is induced by the presence of nitrate, so the greater transport of nitrate to the shoots of perennial ryegrass probably explains why its shoot-specific NRA was so much greater than that of creeping bentgrass (Table 2).

Conclusions

It has been shown that nitrate in leaves serves as a metabolic signal molecule that causes more photosynthetic product to be diverted from sucrose production, which would be transported to and support root growth, to the synthesis of amino acids that remain in the shoots and stimulate leaf growth (Champigny and Foyer, 1992). This explains why excess nitrogen fertilization promotes excessive turf shoot growth and clipping production. The fact that creeping bentgrass absorbs nitrate less rapidly than perennial ryegrass and is able to metabolize more of it in its roots might explain why it has a proportionally larger root system. This greater allocation of resources to root growth could also explain why creeping bentgrass can tolerate closer mowing than most other grasses.

We believe these findings could provide valuable insight as to how turfgrasses might be made more efficient in their use of fertilizer and soil-derived N. If nitrate metabolism can be concentrated in the roots with much less occurring in the shoots, turfgrasses would have a larger root system, be better able to forage for water and nutrients, and be better adapted to the stresses imposed by high temperatures and wear. This could be exploited by plant breeders to create new grass cultivars better suited to golf course conditions.

Table 1

Turf quality scores, root:shoot mass ratios and nitrate uptake rates from five cultivars each of perennial ryegrass and creeping bentgrass

Cultivar	*Quality Score#*	*Root:Shoot*	*NO$_3^-$ Uptake mol/g FW/hr*
Perennial ryegrass			
Palmer III	6.5 a*	0.20 a	7.04 ab
Secretariat	6.3 a	0.13 ab	10.80 a
Calypso II	6.3 a	0.10 b	8.63 ab
Morning Star	4.9 b	0.18 a	7.96 ab
Linn	2.9 c	0.15 ab	5.79 b
Mean†	5.2	0.15	8.29
Creeping bentgrass			
L-93	6.6 a*	0.41 ab	2.67 ab
Penn G-2	6.3 a	0.28 b	3.78 ab
PennLinks	5.2 b	0.36 ab	3.15 ab
Penncross	4.0 c	0.35 ab	4.00 a
18th Green	3.9 c	0.49 a	2.57 b
Mean†	5.1	0.37	3.24

#Scores from NTEP trials, Kingston, R.I. (1 to 9; 9 = excellent turf)

*Means in a column for each species followed by the same letter are not significantly different (P = 0.05)

†Means derived from nine cultivars

DR. RICHARD J. HULL *is Emeritus Professor of Plant Physiology and* JOHN T. BUSHOVEN *is a doctoral student studying turfgrass physiology in the Plant Sciences Department at the University of Rhode Island.*

Table 2

Nitrate reductase activity (NRA) in leaves and roots of perennial ryegrass and creeping bentgrass cultivars and the potential partitioning of NRA between roots and shoots of these grasses

Cultivar	*Nitrate Reductase Activity (NRA)*		*Root:Shoot Ratio of Total Plant NRA*
	Roots	*Shoots*	
	mol NO$_2^-$/g FW/hr		
Perennial ryegrass			
Palmer III	0.56 a*	1.95 cd	0.06 a
Secretariat	0.50 a	4.01 a	0.02 bc
Calypso II	0.39 a	3.28 ab	0.01 c
Morning Star	0.38 a	2.48 bc	0.03 bc
Linn	0.38 a	1.47 d	0.04 ab
Mean†	0.43	2.83	0.03
Creeping bentgrass			
L-93	0.48 ab*	1.45 ab	0.13 a
PennLinks	0.34 ab	0.82 b	0.15 a
SR 1020	0.69 a	1.61 a	0.16 a
Penncross	0.27 b	1.32 ab	0.07 a
18th Green	0.35 ab	0.89 ab	0.19 a
Mean†	0.45	1.22	0.14

*Means in a column for each species followed by the same letter are not significantly different (P = 0.05)

†Means derived from nine cultivars

References

Champigny, M-L, and C. Foyer. 1992. Nitrate activation of cytosolic protein kinases diverts photosynthetic carbon from sucrose to amino acid biosynthesis. Basis for a new concept. *Plant Physiol.* 100:7-12.

Huang, B., X. Liu, J. Fry, and M. P. Kenna. 2000. Burning the candle at both ends: High temperatures and low cutting heights lead to a dead end. *USGA Green Section Record.* 38(3):15-16.

Lillo, C. 1984. Diurnal variations of nitrate reductase, glutamine synthetase, glutamate synthase, alanine aminotransferase, and aspartate aminotransferase in barley leaves. *Plant Physiol.* 61:214-218.

Petrovic, A. M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. *J. Environ. Qual.* 19:1-14.

Porter, K. S., D. R. Bouldin, S. Pacenka, R. S. Kossack, C. A. Shoemaker, and A. A. Pucci, Jr. 1980. Studies to assess the fate of nitrogen applied to turf: Part I. Research project technical completion report. OWRT Project A-086-NY. Cornell Univ., Ithaca, N.Y.

Starr, J. L., and H. C. DeRoo. 1981. The fate of nitrogen applied to turfgrass. *Crop Sci.* 21:531-36.