J. AMER. SOC. HORT. SCI. 117(1):75-79. 1992.

Foliar Absorption of Urea, Ammonium, and Nitrate by Perennial Ryegrass Turf

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Additional index words. Lolium perenne, nitrogen nutrition, nitrogen assimilation

Abstract. **The absorption and assimilation of ^{15}N-labeled urea, $(NH4)_2SO_4$, and KNO_3 applied to the foliage of perennial ryegrass *(Lolium perenne* L.) turf were examined under a controlled environment. Each source of N was dissolved in deionized water to a final concentration of 25 g N/liter and spray-applied at a rate of 5 g N/m^2. Absorption of the fertilizer-N over 48 hours, as measured by ^{15}N analysis of tissue digests, amounted to 35%, 39%, and 40% for the urea, $(NH_4)_2SO_4$, and KNO_3, respectively. Absorption was also estimated by a washing procedure that measured the urea remaining on the foliage and by the increase in total N in the ryegrass tissue. There were no significant differences between the three methods for absorption of $(NH_4)2SO_4$ and KNO_3. The washing method, however, significantly overestimated absorption of urea. Partitioning of the absorbed N between tissues was similar at 48 hours for all three N sources, averaging 32% in new leaves, 52% in old leaves and shoot tissue, and 16% in the roots. Most of the absorbed urea- and NH_4-N was assimilated by 48 hours, whereas only half of the NO_3-N was reduced during that period.**

The potential for fertilizing plants using foliar sprays has been recognized for many years. Numerous studies conducted during the 1950s clearly demonstrated that urea is rapidly absorbed by the leaves of numerous species (Cain, 1956; Cook and Boynton, 1952; Freiberg and Payne, 1957; Impey and Jones, 1960). Today the practice is generally limited to horticultural crops, such as fruit trees and turfgrass. The commercial home lawn care industry, for example, often uses foliar applications of soluble N fertilizers (Wesely et al., 1986).

Urea is one of the most common N sources used for foliar applications because it is highly soluble, inexpensive, and has a relatively low potential for injuring foliage. Wittwer et al. (1963) have suggested that urea is absorbed more rapidly by leaves than either NO_3^- or NH_4^+, presumably because nonpolar substances, such as urea, diffuse through the cuticle more readily. As a result, most investigations of the foliar absorption of N have evaluated urea as the only source of N.

Considerably fewer studies have examined the foliar application of other N fertilizers. Weinbaum and Neumann (1977) reported that NO_3-N is absorbed, assimilated, and transported by prune leaves. Tomato leaves were also found capable of absorbing both NO_3^- and NH_4^+, but in insufficient amounts for optimum growth (Magalhaes and Wilcox, 1983). Although it is apparent from these studies that inorganic N salts are absorbed by leaves, quantitative data on the extent and pattern of foliar uptake of NO_3^- and NH_4^+ are lacking. Additionally, we are unaware of studies comparing foliar uptake of urea, NO_3^-, and NH_4^+.

This study was undertaken to compare the absorption of N, supplied as either urea, $(NH_4)2SO_4$, or KNO_3, by the foliage of perennial ryegrass turf. Three methods of estimating foliar absorption were compared. First, N uptake was measured directly as ^{15}N enrichment of tissue N following application of ^{15}N-labeled urea, $(NH_4)_2SO_4$, or KNO_3. Uptake was also estimated by a) the difference between applied N and N remaining on the foliage over time, as measured by a washing procedure, and b) a Kjeldahl procedure to determine the increase in N content of the tissue.

Materials and Methods

Perennial 'Manhattan II' ryegrass was grown from seed in 1.0-liter round plastic pots filled with 1000 g of medium fine sand. Four hundred milligrams of seed per pot (≈ 325 kg•ha^{-1}) was sown in Feb. 1986. Following germination, the turf was grown for 6 months under natural light in a greenhouse operated at 20/13C (day/night). The pots were irrigated with half-strength Hoagland's nutrient solution (Hoagland and Arnon, 1950) every 2 to 3 days and mowed as needed at 3 cm. The final mowing occurred 6 days before treatments were applied.

All pots were transferred to a walk-in controlled environment growth chamber 48 h before N treatment. The chamber was maintained at 23/14C (day/night), ≈ 8090 relative humidity, with a 14-h photoperiod and a light intensity of 400 µmol•m^{-2}•s^{-1} at plant height. The pots were thoroughly leached with deionized water 24 h before N application to remove inorganic N from the leaves and sand. The turf in each pot was then clipped to a uniform height of 6 cm. This resulted in a canopy consisting of an upper 3-cm layer of new leaves above the normal mowing height and a lower 3-cm layer of older leaves and shoot material between the soil and the normal mowing height.

One hour after the start of the photoperiod, all pots were removed from the growth chamber. The pots were positioned within a marked area measuring 60 cm square on centers ≈ 14 cm, with the foliage canopy edge to edge. The appropriate N solution was applied by uniformly spraying the entire 0.36-m^2 area using a hand-held spray bottle. Solutions of unlabeled N as urea, NH_4^+, or NO_3^- were spray-applied to 12 pots each at a rate of 78 mg N per pot (5 g N/m^2, based on the turf canopy diameter of 14.1 cm) in the equivalent of 200 ml deionized water plus 0.1% (v/v) Triton X-100 surfactant/m^2. Four additional pots for each N source were designated for harvest at 48 h. These were sprayed separately with identical solutions, but containing ^{15}N-labeled urea, $(NH_4)_2SO_4$, or KNO_3 with ^{15}N en-

Received for publication 17 Dec. 1990. This research was supported by Isotope Services, Inc. (Los Alamos, N.M.). The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

richments of 9.90%, 13.9390, and 12.91%, respectively. All pots were then returned to the growth chamber and were subirrigated daily with 80 ml minus-N Hoagland's solution.

Four replicate pots from each N treatment were harvested at O, 12, 24, and 48 h, with the last set being the ^{15}N-treated pots. At each harvest, the turf was excised by layer into new leaves, old leaves plus shoot material, and roots. Nitrogen remaining on the leaves and shoots was washed off and analyzed as described by Bowman and Paul (1989). Roots were separated from the sand by gentle washing in a stream of water. In the case of the time O samples, N spray reaching the sand was extracted in 1 liter of water, during which time the roots were separated. Tissues were dried at 65C for 24 h and ground.

Urea-N, NH_4-N, and NO_3-N in the washing solutions were determined by the rapid diffusion method (Carlson, 1986); urea was first hydrolyzed to NH_4^+ with jackbean urease (Sigma, St. Louis). Urea-N, NH_4-N, and NO_3-N in the tissue were determined in an aqueous extract using 50 mg of tissue in 15 ml deionized water. Reduced N in the tissue was measured using a micro-Kjeldahl procedure (Carlson, 1978). ^{15}N-enrichment of the tissue N was determined by mass spectrometry. The experiment was conducted using a completely randomized split-plot design with N source as the main plot and method of estimating absorption as the subplot, with four replicates per treatment. Initial positioning of the applied N and uptake data from the final harvest were analyzed by analysis of variance and means separated by least significant difference.

Results

The distribution of N between new leaves, old leaves, and soil following spray application was very similar for the three forms of N (Table 1). Most of the N was located on the new and old leaves, in about equal amounts. Very little N reached the soil. Total recovery of the fertilizer N at time O, as determined by washing, averaged 77.3 ± 3.6 mg N per pot across the three sources of N. By comparison, the calculated application, based on a 14. l-cm canopy diameter, was 78 mg N per pot.

Application of $(NH_4)_2SO_4$ and KNO_3 caused moderate tissue damage characterized by an overall desiccation of some of the leaves by 12 h. No damage was noted with the urea spray until 24 h, when a collapse and bleaching of the cut leaf tips, ≈1 cm long, was noted. Unlike the desiccation caused by the two salts, urea damage had worsened by 48 h.

There was relatively good agreement between the three methods for estimating N uptake from $(NH_4)_2SO_4$ and KNO_3 (Table 2). However, assuming the ^{15}N data accurately represent N absorption, the washing method significantly overestimated uptake of urea. There was no difference in total N absorbed among the three N sources as determined by either the tissue N (Kjeldahl) or the ^{15}N method, with uptake averaging ≈40% of applied N. The partitioning of absorbed ^{15}N between new leaves, old leaves, and roots at 48 h was also very similar among the three sources of N (Table 3), with the old leaves containing half of the absorbed N. Roughly 15% of the N was found in the roots even though only 2% of the applied N was located in the soil following application (Table 1).

Table 1. The initial position and recovery of urea-N, NH_4-N, and NO_3-N on perennial ryegrass 10 min following application at 5 g N/m^2.

	Recovery of applied N (g N/m²)			
	Leaves			
N Source	New	Old	Soil	Total
Urea	2.15[z]	2.85	0.09	5.09
$(NH_4)_2SO_4$	2.39	2.24	0.06	4.69
KNO_3	2.44	2.49	0.16	5.09
$LSD_{0.05}$	NS	0.42	0.03	NS

[z]Values are means of four samples.
[NS]Nonsignificant (P > 0.05).

Table 2. Absorption of urea-N, NH_4-N, and NO_3-N by perennial ryegrass after 48 h as estimated by a) measuring N remaining on foliage with a washing procedure, b) measuring increase in total N in tissue by Kjeldahl analysis, and c) ^{15}N analysis of tissue.

	N absorption		
Method	Urea	$(NH_4)_2SO_4$	KNO_3
Washing	66.9[z]	47.7	45.5
Kjeldahl	38.4	40.7	46.5
^{15}N analysis	34.9	38.9	40.4

[z]Values are means of four samples; LSD between method of analysis values = 10.3 (P = 0.05); LSD between N source values = 11.0 (P = 0.05).

Table 3. The distribution of absorbed urea-N, NH_4-N, and NO_3-N in the new and old leaves and in roots of perennial ryegrass, determined by ^{15}N content of the tissue 48 h after application.

	Absorbed ^{15}N in tissue (%)		
	Leaves		
N Source	New	Old	Roots
Urea	30.3[z]	53.1	16.6
$(NH_4)_2SO_4$	30.8	52.6	16.6
KNO_3	34.8	51.4	13.8
$LSD_{0.05}$	NS	NS	1.5

[z]Values are means of four samples.
[NS]Nonsignificant (P > 0.05).

Based on the data in Table 2, the disappearance of applied N from the foliage, as determined by the washing procedure, may be assumed to approximate the pattern of absorption of NO_3-N and NH_4-N, but not urea. This argument is based on the fact that the washing method was similar in accuracy to the ^{15}N method for estimating absorption of NO_3-N and NH_4-N, and again assumes the ^{15}N data accurately represent N absorption. Absorption of these two forms of N (Fig. 1) was most rapid during the first 12 h, averaging 0.52 g N/m^2 (canopy area basis) for the new leaves and 0.94 g N/m^2 for the old leaves. Nitrate disappeared more slowly than either urea or NH_4^+ through 24 h. However, there was a slight increase in NH_4^+ on the tissue between 24 and 48 h while NO_3^- continued to decrease, such that by 48 h there was no difference in the amounts of NO_3-N and NH_4-N remaining on the plant surface.

Reduced N in the tissue increased in the new and old leaves following foliar application of urea (Table 4) and $(NH_4)_2S0_4$ (Table 5) but not KNO_3 (Table 6). Following application of urea, the concentration of free urea and NH_4^+ in the tissue increased substantially by 12 h, with elevated levels being maintained through 48 h. Similarly, with the application of $(NH_4)_2SO_4$, NH: in the tissue increased up to 13-fold in the old leaves, from 53 to 672 µg·g^{-1}, and up to nearly 100-fold in the new leaves, from 29 to 2850 µg·g^{-1}. Nitrate levels rose from 1900 and 1700 to as high as 7100 and 3100 µg·g^{-1} in the new and old leaves, respectively, in response to KNO_3 application. There was thus substantial accumulation of nonmetabolized fertilizer

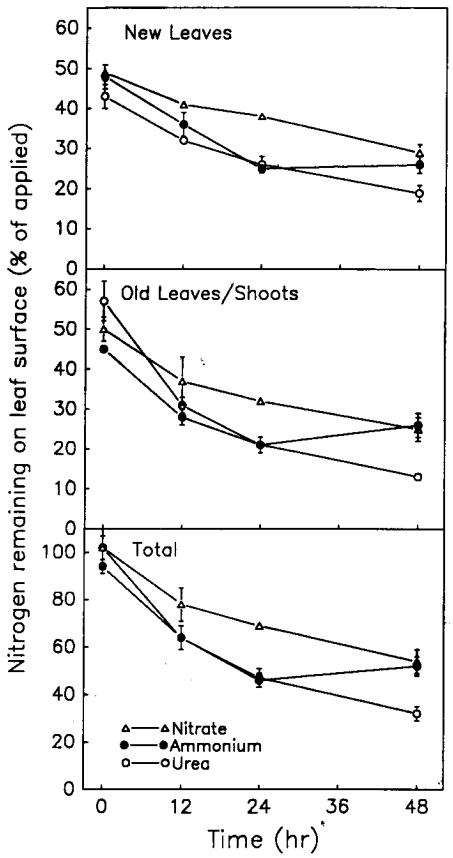

Fig. 1. Loss of urea-N, NH_4-N, and NO_3-N from the new and old leaves of perennial ryegrass as determined by a washing procedure. Values are means of four samples ± SD, where larger than the symbol.

N in the tissue that amounted to 13%, 16%, and 49% of the absorbed urea, $(NH_4)_2SO_4$, and KNO_3, respectively, based on uptake determined by ^{15}N analysis. No changes were apparent in the levels of reduced N, NH_4-N^+, NO_3^-, or urea in the roots.

Discussion

A previous study on the foliar uptake of urea by Kentucky bluegrass reported that both a washing and tissue N procedure gave estimates of absorption inconsistent with uptake determined by ^{15}N analysis (Bowman and Paul, 1989). We suggested that the washing procedure overestimated uptake due to loss of applied urea through volatilization. Assuming that the difference between uptake estimated by washing and ^{15}N analysis in the present study is due to volatilization, ≈ 30% of the applied urea-N was lost as NH_3. That there was no statistical difference between the methods for estimating absorption of either $(NH_4)_2SO_4$ or KNO_3 suggests that losses due to either volatilization or denitrification from these N sources was insignificant.

The absorption of urea by foliage is reportedly much greater than that of fertilizer salts (Wittwer et al., 1963). Therefore, we were surprised that the three N sources were absorbed to the same degree (Table 2) by perennial ryegrass. Likewise, Morris and Weaver (1983) reported that there was no significant difference in absorption between urea and $(NH_4)_2SO_4$ by the foliage of soybeans. This similarity in response to the N forms may indicate that absorption is by a common mechanism, independent of charge, such as simple diffusion through regions high in ectodesmata (Franke, 1967) or low in resistance. The considerable amount of the applied N remaining on the turf after 48 h implies that absorption may not be uniform across the leaf surface. For example, urea uptake is much more rapid by young leaves (Cain, 1956; Klein and Weinbaum, 1984) or by the underside of leaves for several species (Cain, 1956; Cook and Boynton, 1952; Freiberg and Payne, 1957; Impey and Jones, 1960).

Absorption of spray-applied ^{15}N by perennial ryegrass in this study was comparable to uptake of urea previously reported for Kentucky bluegrass (43%, Bowman and Paul, 1989), soybean (44% to 69%, Vasilas et al., 1980), corn (30% to 34%, Below et al., 1985), tea (44%, Karasuyama et al., 1985) and six turfgrass species (31% to 61%, Wesely et al., 1985). The similarity in partitioning of the absorbed urea-, NH_4^-, and NO_3-N between tissues over the 48-h experimental period suggests that longer term N metabolism is controlled by factors other than the source

Table 4. Concentrations of reduced-N, NH_4-N, NO_3-N, and urea-N in perennial ryegrass tissue at various times following a foliar application of urea.

Type of tissue and interval (h)	Reduced-N (% dry wt)	NH_4-N	NO_3-N	Urea-N	Absorbed N unassimilated[z] (%)
		$\mu g \cdot g^{-1}$ dry wt			
New leaves					
0	4.21 ± 0.03[y]	50 ± 3	1898 ± 964	24 ± 2	
12	4.53 ± 0.09	274 ± 53	926 ± 610	4387 ± 1105	
24	4.93 ± 0.04	291 ± 49	903 ± 311	5062 ± 996	
48	4.56 ± 0.10	226 ± 29	429 ± 217	2683 ± 435	8.6
Old leaves					
0	2.23 ± 0.03	67 ± 1	1706 ± 465	38 ± 8	
12	2.37 ± 0.07	253 ± 66	999 ± 314	339 ± 104	
24	2.43 ± 0.03	260 ± 48	934 ± 269	351 ± 41	
48	2.34 ± 0.10	224 ± 71	855 ± 355	279 ± 64	4.3
Roots					
0	1.41 ± 0.06	48 ± 14	770 ± 240	28 ± 7	
48	1.33 ± 0.13	26 ± 4	367 ± 148	6 ± 3	

[z]The percent absorbed N unassimilated at 48 h is calculated as the ratio of the urea-N content in the tissue divided by the ^{15}N content of the turf.
[y]Values are means of four samples ± SD.

Table 5. Concentrations of reduced-N, NH_4-N, and NO_3-N in perennial ryegrass tissue at various times following application of $(NH_4)_2SO_4$.

Type of tissue and interval (h)	Reduced-N (% dry wt)	NH_4-N	NO_3-N	Absorbed N unassimilated[z]
		$\mu g \cdot g^{-1}$ dry wt		(%)
New leaves				
0	4.09 ± 0.04[y]	29 ± 2	1898 ± 964	
12	4.45 ± 0.13	1280 ± 87	762 ± 366	
24	4.70 ± 0.05	2051 ± 278	653 ± 251	
48	4.82 ± 0.13	2850 ± 274	378 ± 106	8.6
Old leaves				
0	2.20 ± 0.06	53 ± 7	1706 ± 465	
12	2.39 ± 0.05	225 ± 30	1224 ± 238	
24	2.42 ± 0.04	378 ± 128	977 ± 360	
48	2.60 ± 0.08	672 ± 26	995 ± 141	7.3
Roots				
0	1.33 ± 0.16	39 ± 6	770 ± 240	
48	1.51 ± 0.03	47 ± 7	573 ± 96	

[z]The percent absorbed N unassimilated at 48 his calculated as the ratio of the NH_4-N content in the tissue divided by the ^{15}N content of the turf.

[y]Values are means of four samples ± SD.

Table 6. The concentrations of reduced-N, NH_4-N, and NO_3-N in perennial ryegrass tissue at various times following a foliar application of KNO_3.

Type of tissue and interval (h)	Reduced-N (% dry wt)	NH_4-N	NO_3-N	Absorbed N unassimilated[z]
		$\mu g \cdot g^{-1}$ dry wt		(%)
New leaves				
0	4.23 ± 0.12[y]	47 ± 10	1898 ± 964	
12	3.82 ± 0.05	34 ± 7	4516 ± 343	
24	4.07 ± 0.11	58 ± 5	7087 ± 900	
48	4.11 ± 0.04	31 ± 3	5482 ± 961	17.3
Old leaves				
0	2.18 ± 0.11	72 ± 8	1706 ± 465	
12	2.10 ± 0.03	40. ± 5	2332 ± 501	
24	2.25 ± 0.07	46 ± 11	2774 ± 982	
48	2.18 ± 0.11	50 ± 11	3126 ± 659	31.6
Roots				
0	1.31 ± 0.04	31 ± 2	770 ± 240	
48	1.31 ± 0.04	26 ± 2	565 ± 109	

[z]The percent absorbed N unassimilated at 48 h is calculated as the ratio of the NO_3-N content in the tissue divided by the ^{15}N content of the turf. The NO_3-N content is corrected by the amount of NO_3-N present in the tissues of the urea treatment.

[y]Values are means of four samples ± SD.

of N, such as the relative sink strength of the tissues. The percentage of absorbed N translocated to the roots of perennial ryegrass, averaging ≈ 15%, is identical to that for Kentucky bluegrass (Bowman and Paul, 1989) and similar to the l0% to 12% reported for olive (Klein and Weinbaum, 1984) following foliar application of urea. These values are in contrast to the ≤ 2% recovered in the roots of soybean (Morris and Weaver, 1983; Vasilas et al., 1980) and tea (Karasuyama et al., 1985).

The amount of fertilizer N associated with new leaves (both in the tissue and on the leaf surface) at 48 h was calculated as the sum of applied N remaining on the foliage, as determined by washing, plus the ^{15}N content of the new leaves. Values ranged from 28.8 to 29.9 mg N per pot for the three N sources, or ≈38% of the N applied. Consequently, more than one-third of a typical N application could be lost with subsequent mowing and disposal of leaf clippings.

The metabolism of absorbed urea-N (Table 4) followed a pattern similar to that reported for Kentucky bluegrass (Bowman and Paul, 1989). Urea concentration in new and old leaves reached a maximum at 12 to 24 h, decreasing slowly thereafter. The high level of NH_4^+ production measured in the 12-h samples indicates a very rapid initial hydrolysis of absorbed urea by leaf tissue. Application of $(NH_4)_2SO_4$ steadily increased tissue NH_4^+ levels in new and old leaves over the entire 48 h (Table 5). The NH_4^+ concentrations measured in the leaves between 12 and 48 h may have been high enough to inhibit photosynthesis (Puritch and Barker, 1967), which, in turn, would limit the synthesis of carbon substrate required to assimilate NH_4^+ and thus perpetuate the high NH_4^+ concentrations. Possibly, leaf desiccation due to the spray disrupted normal cellular function, allowing NH_4^+ to build up.

Following application of KNO_3, tissue NO_3^- increased 4-fold and 2-fold in the new and old leaves, respectively. Interestingly, reduced N in the tissues remained essentially unchanged with KNO_3 application, unlike the increases in reduced N noted following application of either urea or $(NH_4)_2SO_4$. The NO_3^- absorbed by the ryegrass foliage likely is principally stored in the vacuole. This vacuolar NO_3^- would be released slowly, as demanded for growth. Consequently, the concentration of reduced N would remain fairly constant. Metabolism of endogenous NO_3^-; was fairly similar in both the urea and NH_4^+ treatments.

We conclude from this study that perennial ryegrass absorbs foliar-applied urea, KNO_3, and $(NH_4)_2SO_4$ equally well. Uptake of each N form is most rapid during the first 12 h, decreases thereafter, with total absorption after 48 h being ≈40% of that applied. However, $(NH_4)_2SO_4$ and KNO_3 caused unacceptable foliar damage and thus would be unsuitable for foliar fertilization at the concentration used in this study. Because more than one-third of the fertilizer N is retained on or in new leaf tissue, clippings should be returned to the turf. Where clippings are removed, increased fertilizer efficiency should result from irrigating the turf after N application, but before mowing, to wash the N off the leaves and into the soil.

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