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

Daniel C. Bowman
Department of Plant Science, University of Nevada, Reno, NV 89557

Jack L. Paul
Department of Environmental Horticulture, University of California, Davis, CA 95616

Abstract. The absorption and assimilation of \(^{15}\)N-labeled urea, \((\text{NH}_4)_2\text{SO}_4\), and \(\text{KNO}_3\), 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, \((\text{NH}_4)_2\text{SO}_4\), and \(\text{KNO}_3\), 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 \((\text{NH}_4)_2\text{SO}_4\) and \(\text{KNO}_3\). 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 \(\text{NH}_4\)-N was assimilated by 48 hours, whereas only half of the \(\text{NO}_3\)-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; Impy 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 \(\text{NO}_3\) or \(\text{NH}_4^+\) 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 absorption of other N fertilizers. Weinbaum and Neumann (1977) reported that \(\text{NO}_3\)-N is absorbed, assimilated, and transported by prune leaves. Tomato leaves were also found capable of absorbing both \(\text{NO}_3\) and \(\text{NH}_4^+\), 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 \(\text{NO}_3\) and \(\text{NH}_4\) are lacking. Additionally, we are unaware of studies comparing foliar uptake of urea, \(\text{NO}_3\), and \(\text{NH}_4\).

This study was undertaken to compare the absorption of N, supplied as either urea, \((\text{NH}_4)_2\text{SO}_4\), or \(\text{KNO}_3\), 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, \((\text{NH}_4)_2\text{SO}_4\), or \(\text{KNO}_3\). 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), 80% 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, \(\text{NH}_4\), or \(\text{NO}_3\) 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, \((\text{NH}_4)_2\text{SO}_4\), or \(\text{KNO}_3\), with \(^{15}\)N en-
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 0, as 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.

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$^2$.

| N Source | Leaves | New | Old | Soil | Total |
|----------|--------|------|-----|------|-------|
| Urea     | 2.15$^*$ | 2.85 | 0.09 | 5.09 |
| (NH$_4$)$_2$SO$_4$ | 2.59 | 2.24 | 0.06 | 4.89 |
| KNO$_3$  | 2.44 | 2.49 | 0.16 | 5.09 |
| LSD$_{0.05}$ | NS | 0.42 | 0.03 | NS |

$^*$Values are means of four samples.
$^{**}$Non-significant (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.

| Method     | Urea   | (NH$_4$)$_2$SO$_4$ | KNO$_3$ |
|------------|--------|--------------------|---------|
| Washing    | 66.9$^*$| 47.7               | 45.5    |
| Kjeldahl   | 38.4   | 40.7               | 46.5    |
| $^{15}$N analysis | 34.9 | 38.9               | 40.4    |

$^*$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.

| N Source | Leaves | New | Old | Roots |
|----------|--------|-----|-----|-------|
| Urea     | 30.3$^*$ | 53.1 | 16.6 |
| (NH$_4$)$_2$SO$_4$ | 30.8 | 52.6 | 16.6 |
| KNO$_3$  | 34.8 | 51.4 | 13.8 |
| LSD$_{0.05}$ | NS | NS | 1.5 |

$^*$Values are means of four samples.
$^{**}$Non-significant (P > 0.05).
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, $\approx 30\%$ 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$_4$)$_2$SO$_4$ 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$_4$)$_2$SO$_4$ 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$_3$-, 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 $\mu$g-g$^{-1}$ dry wt | NO$_3$-N $\mu$g-g$^{-1}$ dry wt | Urea-N $\mu$g-g$^{-1}$ dry wt | Absorbed N unassimilated$^a$ (%) |
|-------------------------------|----------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| New leaves                    |                      |                               |                               |                               |                               |
| 0                             | 4.21 ± 0.03*         | 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                         |                               |

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.

$^a$Values are means of four samples ± sd.
Table 5. Concentrations of reduced-N, NH$_3$-N, and NO$_3$-N in perennial ryegrass tissue at various times following application of (NH$_4$)$_2$SO$_4$.

| Type of tissue and interval (h) | Reduced-N (%) dry wt | NH$_3$-N $\mu$g g$^{-1}$ dry wt | NO$_3$-N (%) dry wt | Absorbed N unassimilated$^a$ (%) |
|-------------------------------|----------------------|---------------------------------|--------------------|-------------------------------|
| New leaves                    |                      |                                 |                    |                               |
| 0                             | 4.09 ± 0.04$^a$      | 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 ± 12                       | 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          |                               |

The percent absorbed N unassimilated at 48 h is calculated as the ratio of the NH$_3$-N content in the tissue divided by the $^{15}$N content of the turf. 
$^a$Values are means of four samples ± SD.

Table 6. The concentrations of reduced-N, NH$_3$-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$_3$-N $\mu$g g$^{-1}$ dry wt | NO$_3$-N (%) dry wt | Absorbed N unassimilated$^a$ (%) |
|-------------------------------|----------------------|---------------------------------|--------------------|-------------------------------|
| New leaves                    |                      |                                 |                    |                               |
| 0                             | 4.23 ± 0.12$^a$      | 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                            | 1.51 ± 0.03          | 26 ± 2                         | 566 ± 109         |                               |

$^a$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. 
$^a$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 $\approx 15\%$, is identical to that for Kentucky bluegrass (Bowman and Paul, 1989) and similar to the 10% to 12% reported for olive (Klein and Weinbaum, 1984) following foliar application of urea. These values are in contrast to the $\leq 2\%$ recovered in the roots of soybean (Morris and Weaver, 1983; Vasilas et al., 1980) and tea (Karayuasa 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 $\approx 8\%$ 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$_3$ production measured in the 12-h samples indicates a very rapid initial hydrolysis of absorbed urea by leaf tissue. Application of (NH$_4$)$_2$SO$_4$ steadily increased tissue NH$_3$ levels in new and old leaves over the entire 48 h (Table 5). The NH$_3$ 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$_3$, and thus perpetuate the high NH$_3$ concentrations. Possibly, leaf desiccation due to the spray disrupted normal cellular function, allowing NH$_3$ 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$_4$)$_2$SO$_4$. 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$_3$ treatments.

We conclude from this study that perennial ryegrass absorbs foliar-applied urea, KNO$_3$, and (NH$_4$)$_2$SO$_4$ equally well. Uptake of each N form is greatest during the first 12 h, decreases thereafter, with total absorption after 48 h being $\approx 40\%$ of that applied. However, (NH$_4$)$_2$SO$_4$ 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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