Fertilizer Research **37**: 43–50, 1994.

Nitrogen leaching and plant uptake from controlled-release fertilizers

R. L. Mikkelsen [1], H. M. Williams [2] and A. D. Behel Jr. [2]
[1]*Department of Soil Science, North Carolina State University, Raleigh, NC 27695, USA and* [2]*National Fertilizer and Environmental Research Center, Tennessee Valley Authority, Muscle Shoals, AL 35660, USA*

Received 20 July 1993; accepted in revised form 10 November 1993

Key words: *Euonymus patens* Rehd., isobutylidene diurea, Osmocote, oxamide, Prokote Plus, sulfur-coated urea, urea formaldehyde

Abstract

Controlled-release N fertilizers are commonly used in the production of container-grown ornamental crops, yet the relative effects of various nutrient sources on N leaching are not well known. A 27–week experiment was conducted to evaluate N leaching loss and plant growth following two applications of six controlled-release N fertilizers and one soluble N fertilizer to container-grown *Euonymus patens* Rehd. The controlled-release fertilizers evaluated were (noncoated) isobutylidene diurea, oxamide, urea formaldehyde, and (coated) Osmocote, Prokote Plus, and sulfur-coated urea. Of the fertilizers tested, the coated fertilizers generally out-performed the noncoated fertilizers in reducing N leaching losses, stimulating plant growth, and increasing tissue N concentrations. Low N concentrations in the leachate of some treatments indicated efficient nutrient use by the plant. In other treatments, low N concentrations in the leachate merely reflected incomplete N release from the fertilizer. A daily application of NH_4NO_3 resulted in a constant rate of N loss but was not the most effective in promoting growth. Plant growth, tissue N concentrations, and N leaching losses were all increased by doubling the fertilizer application rate from 1 kg N m^{-3} to 2 kg N m^{-3}. *

Introduction

Growers in the ornamental and greenhouse industry often use high fertilizer application rates which may result in unintentionally high losses of nutrients to the environment (Hershey and Paul, 1982; Skima, 1986). Heightened concern about nutrient management and water quality has caused a re-examination of current practices and fertilizer materials in light of the effort to improve fertilizer recovery (Marconi and Nelson, 1984; Shaviv and Mikkelsen, 1993). The use of controlled-release N fertilizers may allow nutrients to be used more efficiently by plants than soluble N sources by reducing N leaching losses and providing a constant supply of nutrients to the roots (Hauck, 1985; Mikkelsen *et al.*, 1993). The extended period of nutrient release may also reduce the need for frequent fertilizer applications, thus reducing labor expenses (Maynard and Lorenz, 1979). Fertilizer-induced salt damage to plants may also be reduced by using a slowly released nutrient source (Allen, 1984).

* Reference to commercial names or companies is for information purposes only and does not imply endorsement of these products or companies over other products or companies.

Controlled-release N fertilizers are generally classified into four major groups: i) encapsulated soluble fertilizers [e.g. Prokote Plus, Osmocote, sulfur-coated urea], ii) low-solubility inorganic salts [e.g. magnesium ammonium phosphate], iii) low-solubility organic compounds which chemically and microbially decompose [e.g. oxamide, ureaformaldehyde, isobutylidene diurea], and iv) water-soluble materials that gradually decompose [e.g. guanylurea]. Since the mechanism of regulating nutrient release is varied among these four groups, their suitability for diverse conditions also may vary depending on factors such as temperature, moisture, biological activity, and wetting and drying cycles (Shaviv and Mikkelsen, 1993).

Information regarding the nutrient release patterns from controlled-release fertilizers is often difficult to interpret due to the differences in methodology used by various manufacturers and investigators (e.g. Ruter, 1992). Additionally, although many studies have been conducted to compare the effectiveness of various controlled-release fertilizer sources for plant growth [e.g. Sharma and Patel, 1978; Sartain and Ingram, 1984), their effect on leachate N concentrations has largely been ignored (Worral *et al.*, 1987). The objective of this study was to examine N leaching loss patterns from six types of controlled-release N fertilizers applied at two concentrations to container-grown *Euonymus patens*. The effects of nutrient source and application rate on plant growth and tissue composition were also examined.

Materials and methods

The study was designed as a two (N rates) × seven (N sources) factorial experiment with four replications. Fifty-six uniform one-year old *Euonymus patens* Rehd. plants were transplanted into 3.8–L plastic pots containing a pine bark–based potting medium (50% pine bark, 40% peat, and 10% perlite by volume). Nitrogen from six controlled-release fertilizers was mixed thoroughly with the potting medium immediately prior to transplanting. The total fertilizer N added during the entire experiment supplied either 1 or 2 kg N m^{-3} (3.8 or 7.6 g N/pot). One half of the N was added at transplanting (April 20). The remaining portion was applied to the surface of the pots 15 weeks after the initial fertilizer applications (Aug 3). The Prokote Plus treatment received all of the N at the time of transplanting since its release rate extends for 6 to 8 months. Each pot received an application of 6 g Micromax controlled-release micronutrient blend, 6 g single superphosphate, and 4 g K_2SO_4, which was mixed with the potting medium at the time of transplanting. The P and K fertilizers were reapplied to the surface of the medium at the time of the second N application. The quantity of P and K provided by the Prokote Plus was subtracted from the P and K fertilizers added to these treatments.

The six controlled-release fertilizers used in this study included:

Isobutylidene Diurea (IBDU); 31% N, "fine" particles with a 2 to 3–month release rate (Mitsubishi Kasei);

Osmocote; 40% N, urea coated with multiple organic polymer layers, 3 to 4–month release period (Grace–Sierra);

Oxamide; 31% N, diamide of oxalic acid, 2 to 3–month release period (Enichem Inc.);

Prokote Plus; 20% N, 1% P, 8% K, combination of polyolefin resin-coated N with methylene urea (see urea formaldehyde), 6 to 8–month release period (O. M. Scott Co.);

Sulfur-coated urea (SCU); 36% N, 3–month release period (Tennessee Valley Authority);

Urea formaldehyde; 38% N, reaction product of urea with formaldehyde with a 4 to 6–month release period (NorAm Chemical Co.).

Two additional treatments received no N at planting, but received a daily application of NH_4NO_3 with the irrigation water to supply either 20 or 40 mg N/day. This quantity was calculated to supply the same amount of N as the controlled-release sources if they released N at a constant rate over the duration of the 27–week experiment. Although the actual NH_4NO_3 concentration in the irrigation solution varied according to the water demand of the plants, the total amount of N applied daily remained constant.

Table 1. Summary of analysis of variance test of significance for N fertilizer rates and source

Source of Variation	Degree of Freedom	Leaf Yield	Stem Yield	Leaf N	Stem N
Harvest 1					
Replication	3				
N Rate	1	*[1]	**	*	*
N Source	6	*	*	*	*
Rate * Source	6	**	**	**	**
Error	39				
Harvest 2					
Replication	3				
N Rate	1	**	**	**	**
N Source	6	**	**	**	**
Rate * Source	6	**	**	**	**
Error	39				

[1] * and ** represent 5% and 1% significance level respectively.

The plants were placed in an outdoor screened area which was covered overhead with transparent fiberglass panels which allowed adequate light penetration for good plant growth (80% of full sunlight). This arrangement allowed the plants to be exposed to daily fluctuations in temperature and humidity but protected from leaching due to rainfall. A plastic funnel was attached to the bottom of each pot and then the pots were set in a rack which suspended the tip of the funnel inside a 2–L plastic bottle to collect the leachate draining from the pots. One mL of Ag_2SO_4 solution (which when diluted resulted in a minimum concentration of 1 μg mL^{-1}) was added to each bottle to inhibit microbial activity. Black plastic sheets were draped below the racks to shield the collection bottles from sunlight. The four replicates of each treatment were arranged in a randomized complete block design.

Irrigation water was added to supply the moisture requirement of the plants and to produce approximately 80 – 100 mL of leachate each day. The actual amount of irrigation water added to the pots changed throughout the experiment depending on the growing conditions which influenced transpiration and water use. The volume of leachate was measured weekly and a subsample taken for colorimetric analysis of NO_3, NH_4, and urea using a Technicon Autoanalyzer.

On Aug. 3, all shoots from the main stem were uniformly pruned to a length of 30 cm. After the leaves were removed from the pruned stems, all the harvested plant tissue was dried, weighed, ground, and analyzed for total Kjeldahl N. The plants were similarly sampled on Oct. 26 at the conclusion of the experiment.

Results and discussion

Plant growth

The analysis of variance of the data revealed that the rate of fertilizer application, the N source, and their interaction had statistically significant effects on the yield of leaves and stems at both sampling dates (Table 1). These differences among sources and rates were also evident through visual observation. In general, the coated fertilizers were more effective in increasing yields of stems and leaves than the noncoated fertilizers (Table 2 and 3). Increasing the N application rate

Table 2. The effect of N fertilizer source and N application rate on leaf yield of *Euonymus patens* Rehd.

N Source	Application rate (kg N mm^{-3}) 1 — Harvest 1[1] —	2	1 — Harvest 2 —	2
	Leaf Yield (g)			
NH_4NO_3	15.2 D[2]	21.5 B	20.8 BC	27.4 B
IBDU	15.1 D	20.1 BC	26.8 A	34.6 A
Osmocote	20.4 AB	22.5 AB	24.8 A	35.8 A
Oxamide	19.1 BC	18.9 C	25.5 A	30.4 B
Prokote	24.1 A	25.2 A	22.1 B	36.4 A
SCU	15.8 CD	25.8 A	21.6 B	35.6 A
Urea formaldehyde	14.9 D	21.1 B	16.1 C	30.1 B

[1]Harvest 1 and 2 occurred 15 and 27 weeks after commencement of leaching, respectively;
[2]Mean separation within a column by DMRT at the 5% level.

Table 3. The effect of N fertilizer source and N application rate on stem yield of *Euonymus patens* Rehd.

N Source	Application rate (kg N m^{-3}) 1 — Harvest 1[1] —	2	1 — Harvest 2 —	2
	Stem Yield (g)			
NH_4NO_3	14.1 C[2]	19.2 AB	13.7 BC	18.8 B
IBDU	13.3 C	16.9 B	18.0 A	21.2 AB
Osmocote	18.7 AB	19.4 AB	20.1 A	24.5 A
Oxamide	15.6 BC	16.7 B	14.3 BC	18.6 B
Prokote	21.6 A	22.5 A	15.9 B	25.5 A
SCU	13.1 C	21.7 A	10.9 C	22.1 A
Urea formaldehyde	12.5 C	17.5 AB	9.0 C	19.9 AB

[1]Harvest 1 and 2 occurred 15 and 27 weeks after commencement of leaching, respectively;
[2]Mean separation within a column by DMRT at the 5% level.

from 1 kg N m^{-3} to 2 kg N m^{-3} resulted in significantly increased plant growth. In order of their overall effectiveness in promoting plant growth (averaged over both N application rates for the entire experiment), the fertilizers may be generally ranked as follows: Prokote Plus > Osmocote > SCU > IBDU > Oxamide > NH_4NO_3 > Urea formaldehyde.

Tissue N concentrations

Both the N application rate and the N fertilizer source had significant effects on the N concentration of stems and leaves (Table 1). Tissue N concentrations were consistently increased by doubling the N application rate from 1 kg N m^{-3} to 2 kg N m^{-3} (Tables 4 and 5). When averaged over both application rates for the entire experiment,

Table 4. The effect of N fertilizer source and N application rate on leaf N concentration of *Euonymus patens* Rehd.

N Source	Application rate (kg N m^{-3}) 1	2	1	2
	— Harvest 1[1] —		— Harvest 2 —	
	Leaf N (%)			
NH_4NO_3	1.43 A[2]	1.84 A	1.35 AB	1.90 A
IBDU	0.98 C	1.24 D	1.45 A	1.87 A
Osmocote	1.29 B	1.53 B	1.47 A	1.81 AB
Oxamide	1.03 C	1.10 E	1.31 AB	1.61 C
Prokote	1.42 A	1.78 A	1.22 B	1.54 C
SCU	1.08 C	1.42 C	1.35 AB	1.90 A
Urea formaldehyde	1.06 C	1.40 C	1.21 B	1.65 BC

[1]Harvest 1 and 2 occurred 15 and 27 weeks after commencement of leaching, respectively;
[2]Mean separation within a column by DMRT at the 5% level.

Table 5. The effect of N fertilizer source and N application rate on stem N concentration of *Euonymus patens* Rehd.

N Source	Application rate (kg N m^{-3}) 1	2	1	2
	— Harvest 1[1] —		— Harvest 2 —	
	Stem N (%)			
NH_4NO_3	0.79 A[2]	1.25 A	0.94 B	1.41 AB
IBDU	0.65 C	0.68 D	0.98 AB	1.37 BC
Osmocote	0.75 AB	0.90 B	0.90 B	1.44 AB
Oxamide	0.63 C	0.72 CD	1.01 AB	1.20 BC
Prokote	0.79 A	1.18 A	0.83 B	1.13 C
SCU	0.71 B	0.95 B	1.15 A	1.64 A
Urea formaldehyde	0.69 BC	0.85 BC	0.85 B	1.21 BC

[1]Harvest 1 and 2 occurred 15 and 27 weeks after commencement of leaching, respectively;
[2]Mean separation within a column by DMRT at the 5% level.

plants receiving a daily application of NH_4NO_3 generally had the highest tissue N concentration, decreasing in the order: NH_4NO_3 > SCU > Osmocote > Prokote Plus > IBDU > Urea formaldehyde > Oxamide.

Among the controlled-release fertilizers tested, the three coated N sources were more effective at increasing tissue N concentrations than the noncoated N sources when averaged over the entire experiment. This was the same overall trend observed for plant growth. Other formulations of some of the noncoated N sources are available which may have performed better than the materials tested in this experiment since the dissolution of these noncoated sources can be controlled by the size and compactness of the fertilizer particle or the chemical chain length. Additionally, it is interesting the NH_4NO_3 was the most effective

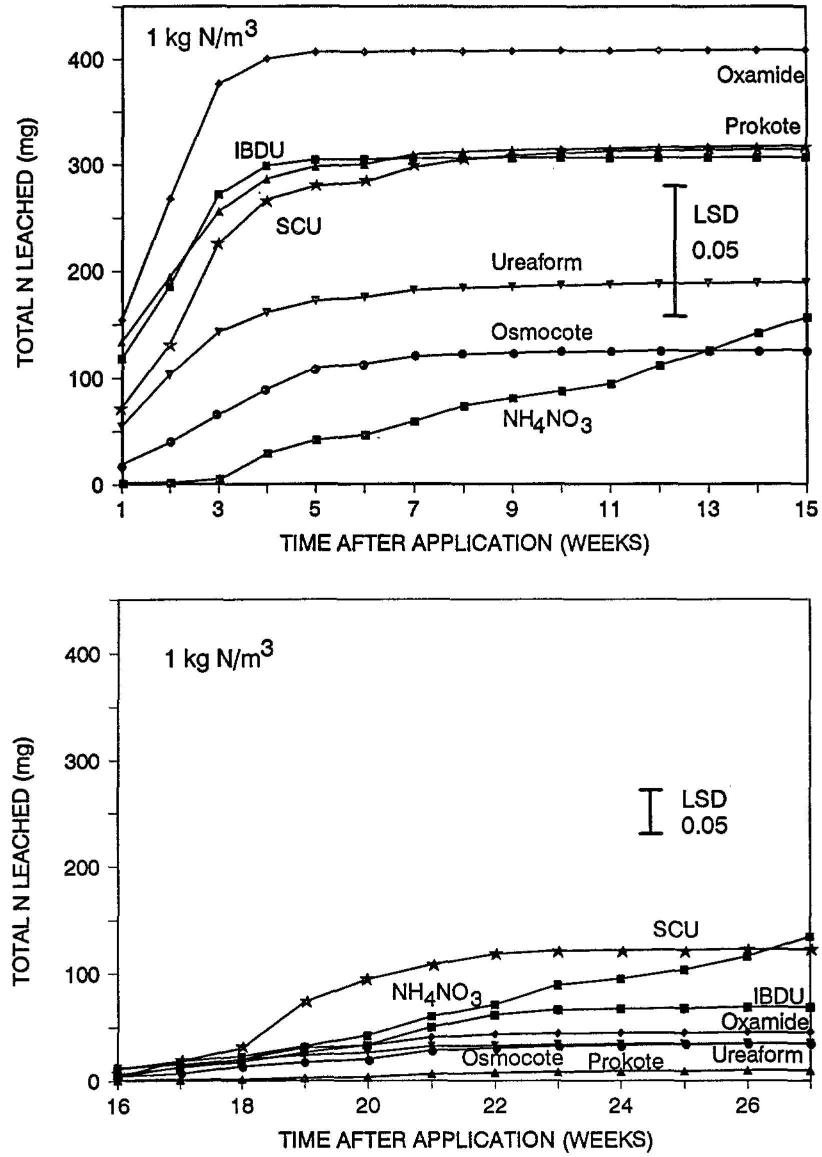

Fig. 1. Total N leaching losses following application of 1 kg N m^{-3} from various sources of controlled-release fertilizers to *Euonymus patens*. One half of the N was applied at the time of transplanting (weeks 1 to 15) and the other half was applied 15 weeks later (weeks 16–27). The NH_4NO_3 solution was added daily to supply 20 mg N day^{-1}.

N source for increasing tissue N concentrations, yet was one of the poorest for stimulating plant growth.

Nitrogen leaching losses

There were significant differences in the amount of N leached among the fertilizer sources (Figs. 1 and 2). After the first two weeks following fertilizer application, virtually all of the leached N was in the NO_3 form, so only total amounts of N leached are reported. The amount of applied N lost through leaching was not an accurate indicator of plant growth or tissue N concentrations. For example, Prokote was one of the least effective fertilizers in reducing N leaching losses during the first 15–week period, yet its application resulted in both high biomass production and tis-

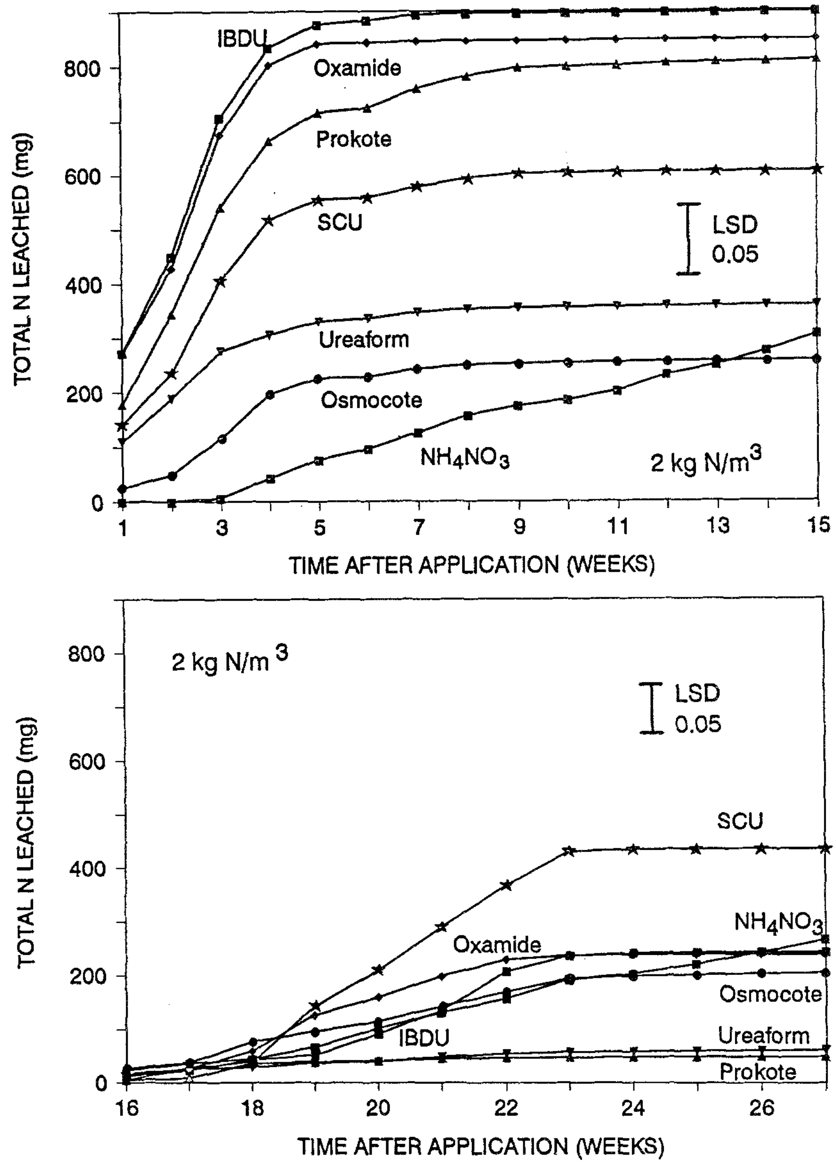

Fig. 2. Total N leaching losses following application of 2 kg N m^{-3} from various sources of controlled-release fertilizers to *Euonymus patens*. One half of the N was applied at the time of transplanting (weeks 1 to 15) and the other half was applied 15 weeks later (weeks 16–27). The NH_4NO_3 solution was added daily to supply 40 mg N day^{-1}.

sue N concentrations at the first harvest. Unlike the other CRF treatments, Prokote was applied only at the beginning of the experiment due to its stated 6–8 month release rate. However, N leaching loss and plant growth were lower for the Prokote–fertilized treatments following the first harvest, indicating a possible decline in the actual release rate. The treatments receiving oxamide also had high initial N leaching losses, yet plant growth was not as rapid as other N sources. Conversely, urea formaldehyde applications resulted in relatively little N leaching loss along with relatively poor plant growth. Osmocote applications generally resulted in both minimal N leaching losses and excellent plant growth. As expected, the application of dilute solutions of NH_4NO_3 resulted in a fairly constant rate of N leaching loss during the entire experiment.

Total N leaching losses from all sources were greater during the first 15–week period following the initial fertilizer application (as much as 24% of the applied N) than during the 11–week period following the second fertilizer application (< 11% of the applied N). This may have been caused by the difference in application methods (incorporated initially versus surface applied for the second application) or the media temperature associated with the season of the year.

This experiment indicates that the source of controlled-release N fertilizer can have a large influence on plant growth, N uptake, and N leaching losses for container-grown plants. It is important to note that due to physical, chemical, and biological differences between potting media and soil, these results are not immediately transferable to soil-based field conditions (e.g. with crops and turf), but should be restricted to container-grown plants. However, there appears to be potential for improving plant growth and avoiding undesirable N losses through the development and use of improved controlled-release fertilizers that release nutrients in synchrony with plant demand.

References

Allen SE (1984) Slow-release nitrogen fertilizers. In: Hauck RD (ed) Nitrogen in Crop Production, pp 195–206. American Society of Agronomy. Madison, WI

Hauck RD (1985) Slow-release and bioinhibitor–amended nitrogen fertilizers. In: Engelstad OP (ed) Fertilizer Technology and Use, pp 293–322. Soil Science Society of America. Madison, WI

Hershey DR and Paul JL (1982) Leaching losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Sci Hort 17: 145–152

Marconi DJ and Nelson PV (1984) Leaching of applied phosphorus in container media. Sci Hort 22: 275–285

Maynard DN and Lorenz OA (1979) Controlled-release fertilizers for horticultural crops. Hort Rev 1: 79–140

Mikkelsen RL, Behel AD Jr and Williams HM (1993) Addition of gel–forming hydrophilic polymers to nitrogen fertilizer solutions. Fert Res 36: 55–61

Ruter JM (1992) Leachate nutrient content and growth of two hollies as influenced by controlled release fertilizers. J Environ Hort 10: 162–166

Sartain JB and Ingram DL (1984) Influence of container medium, lime, and nitrogen source on growth of woody ornamentals. J Am Soc Hort Sci 109: 882–886

Sharma GC and Patel AJ (1978) Effect of nine controlled-release fertilizers on chrysanthemum growth and foliar analysis. J Am Soc Hort Sci 103: 148–150

Shaviv A and Mikkelsen RL (1993) Slow-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation – A Review. Fert Res 35: 1–12

Shima CA (1986) Recycling irrigation runoff on container ornamentals. HortScience 21: 32–34

Worral RJ, Lamont GP, O'Connell MA and Nichols PJ (1987) The growth response of container-grown woody ornamentals to controlled-release fertilizers. Sci Hort 32: 275–286