

Nutrient Release from Controlled-release Fertilizers in Acid Substrate in a Greenhouse Environment: II. Leachate Calcium, Magnesium, Iron, Manganese, Zinc, Copper, and Molybdenum Concentrations

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Abstract. Leachate from containerized substrate containing one of four different controlled-release fertilizers (Osmocote, Nutricote, Polyon, or Multicote) were monitored for concentrations of Ca, Mg, Fe, Mn, Zn, Cu, and Mo during a 47-week period. Environmental and cultural practices simulated an unheated greenhouse production program typically used for low-nutrient-requiring crops such as azalea and camellia. Leachate concentrations of all nutrients were relatively high during the first 10 to 20 weeks of the study, and then gradually decreased during the remaining portion of the experiment. Few differences were observed among fertilizer types. Of the elements monitored, only Fe and Mn leachate concentrations were above critical levels specified in the Clean Water Act by the U.S. EPA.

The Clean Water Act (U.S. Environmental Protection Agency, 1994) includes guidelines concerning nitrate (NO_3^-) and elemental phosphorus (P), two well-known pollutants, as well as the essential plant micronutrients: boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). Although not receiving as much attention as NO_3^- and P, these micronutrients are widely used by the nursery industry and, therefore, are at risk of being regulated by state agencies. The likelihood of micronutrient contamination of surface waters from nursery runoff is unknown. This research seeks to understand the movement of these nutrients in nursery production systems so that the nursery industry is aware of any potential problems associated with micronutrient fertilization and can develop Best Management Practices (BMPs) to reduce nutrient loss through irrigation runoff.

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Controlled-release fertilizers (CRFs) are commonly used in the nursery industry and, if used with proper cultural programs, can reduce the amount of nutrients in runoff. However, little information is available regarding leaching of plant essential nutrients other than N and P. In the following study, the nutrient release patterns of four types of CRFs, when blended into a substrate, were measured during an 11-month period in an unheated greenhouse environment to determine characteristics of nutrient release under a typical production scenario. Plants were not included in the study so that nutrient release characteristics of the CRFs could be measured through leachate analyses without the influence of nutrient uptake into plants.

Materials and Methods

The methodology of the experiment has been described in the first manuscript of this series (Merhaut et al., 2006). Therefore, methods are briefly described here, with emphasis on application, measurement and analyses of calcium (Ca), magnesium (Mg), Fe, Mn, Zn, Cu, and Mo.

Substrate. Substrate consisted of 5 sphagnum peatmoss (Premier Horticulture Inc., Red Hill, Pa.): 4 pine bark (6.4 to 9.5 mm): 1 washed builders sand (by volume). Substrate was amended with dolomite 65 (Chemical Lime Co., Scottsdale, Ariz.) at a rate of 0.59 $\text{kg}\cdot\text{m}^{-3}$ and ultrafine

calcium sulfate (Western Mining and Minerals, Apex, Nev.) at a rate of 0.59 $\text{kg}\cdot\text{m}^{-3}$. Substrate and amendments were blended together using a Model MB20L5 Batch Mixer (Measured Marketing, Kankakee, Ill.). Substrates were analyzed for nutrient concentrations prior to incorporation of CRFs. Substrates were air-dried and ground to 0.420 mm with a Wiley Mill (model #3; Arthur H. Thomas Co., Philadelphia). The ground samples were extracted using the 1:2 dilution method as described by Lang (1996) where 50 ml volume of ground substrate was diluted with 100 ml deionized water, mixed, allowed to equilibrate for 30 min, and gravity filtered through Whatman 41 filter paper (Whatman Int., Ltd., Maidstone, England). Nutrient concentrations in extracts were quantitatively determined using an inductively coupled plasma–optical emission spectrometer (ICP–OES) (model IRIS 1000 HR; Thermo Electron Corp., Franklin, Mass.). Substrate nutrient concentrations prior to incorporation of CRFs were as follows ($\text{mg}\cdot\text{L}^{-1}$): 13.06 Ca, 10.19 Mg, 2.62 Fe, 0.59 Mn, 0.75 Zn, 0.11 Cu, 0.01 Mo.

Fertilizer treatments. Treatments consisted of four different types of CRFs: Osmocote 24–4–9 (Scott-Sierra Horticultural Products Co., Marysville, Ohio), Nutricote 18–6–8 Total (Chisso-Asahi Fertilizer Co., Tokyo), Multicote 17–5–11 + minors (Haifa Chemicals, Ltd., Haifa Bay, Israel), and Polyon 17–5–11 + micros (Pursell Technologies, Inc., Sylacauga, Ala.). All four fertilizers release nutrients based on water diffusion into prills, the rate of which is regulated by temperature. Osmocote did not contain micronutrients; therefore, micronutrients were provided by the incorporation of Micromax (Scott-Sierra Horticultural Products Co., Marysville, Ohio). All CRFs were 365-d release formulations. However, release rates of the different products are based on different temperature regimes: 27 °C for Osmocote and Polyon, 21 °C for Multicote, and 21 to 27 °C for Nutricote. Element concentrations and the compounds used in each fertilizer were different (Table 1). Since the percentage of nutrients contained in the different fertilizers varied, the amount of fertilizer added was calculated so that all treatments contained 3.11 g N/container, which is equal to 1.17 $\text{kg}\cdot\text{m}^{-3}$, an average rate which the four fertilizer manufacturers recommended for slow-growing woody ornamentals. While N content for all CRF treatments were the same, the content of other nutrients varied (Table 2). The CRF prills were incorporated throughout the substrate using a portable cement mixer. Substrate with CRF were placed in #1 black polyethylene containers (2.4 L; 157 mm top diameter, 127 mm bottom diameter, 178 mm tall; Farrand Enterprises, Chino, Calif.) with side and bottom drainage holes. Each container represented one replication. There were five replications of each treatment for each month of leachate monitoring. Containers were placed in a randomized complete block design.

Cultural Practices. Substrate and fertilizer treatments were prepared on 1 Aug. 2001. The experiment was conducted from 1 Aug. 2001 through 27 June 2002. Containers were placed in an unheated, poly-covered greenhouse on the University of California, Riverside campus (lat.

Table 1. Sources and amount (% by weight) of magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), zinc (Zn), and copper (Cu) in Polyon 17–5–11 + micros, Multicote 17–5–11 + minors, Nutricote 18–6–8 total, Osmocote 24–4–9, and Micromax.

Fertilizer type	Mg	Ca	Fe	Mn	B	Mo	Zn	Cu
Osmocote ^z	0.00	0.00	0.00	0.00	0.00	0.02	0.015	0.00
Polyon ^y	0.90	1.10	0.44	0.18	NA	0.009	0.050	NA
Multicote ^x	0.60	0.00	0.20	0.06	0.25	0.01	0.060	0.06
Nutricote ^w	1.20	0.00	0.20	0.06	0.02	0.02	0.015	0.05
Micromax ^v	3.00	5.00	16.00	2.50	0.10	0.05	1.000	1.00

^zOsmocote 24–4–9. Nutrients are derived from calcium phosphate.

^yPolyon 17–5–11. Nutrients are derived from magnesium sulfate, iron sulfate, manganese sulfate, zinc sulfate, molybdic oxide, and calcium phosphate.

^xMulticote 17–5–11 + minors. Nutrients are derived from, calcium phosphate, magnesium oxide, sodium borate, copper sulfate, iron EDTA, manganese sulfate, sodium molybdate, and zinc sulfate.

^wNutricote 18–6–8 total. Nutrients are derived from, calcium phosphate, copper sulfate, Fe EDTA, magnesium sulfate, manganese sulfate, sodium borate, sodium molybdate, and zinc sulfate.

^vMicromax. Nutrients are derived from dolomite, ferrous sulfate, manganese sulfate, zinc sulfate, copper sulfate, sodium borate, and sodium molybdate.

Table 2. Amount (g) of magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), zinc (Zn), and copper (Cu) added to each #1 container (2.4 L) of substrate for four controlled-release fertilizer treatments. Fertilizer rates were normalized for the same amount of nitrogen (3.11 g/#1 container) since different brands of fertilizers contained different ratios of nutrients.

Treatment (fertilizer)	Mg ^y	Ca ^y	Fe	Mn	B	Mo	Zn	Cu
Osmocote + Micromax ^z	0.04	0.07	0.224	0.035	0.001	0.001	0.014	0.014
Polyon	0.16	0.20	0.080	0.033	0.000	0.002	0.009	0.000
Multicote	0.11	0.00	0.037	0.011	0.005	0.002	0.011	0.011
Nutricote	0.21	0.00	0.035	0.010	0.003	0.003	0.003	0.009

^zMicromax (0.53 kg·m⁻³) was added to the Osmocote fertilizer treatment only, since Osmocote 24–4–9 contains no Mg, Ca or micronutrients.

^yAn additional 0.81 g of calcium and 0.18 g of magnesium were included in each #1 container through the incorporation of 0.59 kg·m⁻³ of dolomite and 0.59 kg·m⁻³ of calcium sulfate into the substrate prior to preparation of the four controlled-release fertilizer treatments.

33°53'30"N, long. 117°15'00"W). Containers were irrigated with municipal tap water, which contained an average of (mg·L⁻¹): 64.3 Ca, 9.48 Mg, 0.01 Fe, 0.00 Mn, 0.00 Cu, 0.004 Zn, and 0.003 Mo. Irrigation water was distributed uniformly over the surface of the substrate using DRT4-36 ring drippers (Dramm Corporation, Manitowoc, Wis.). Containers were irrigated about every 2 d, providing an average irrigation volume of about 1 L/week and an average leachate volume of about 750 mL/week. This irrigation regime reflected the water requirement of an adjacent azalea crop being grown during the same time period in the same greenhouse.

Leachate collection. All leachate was captured from each container, collected twice per week, and volumes from each collection bucket were combined so that there was one leachate sample per container per week. 2 mL of 2 N sulfuric acid were added to each collection bucket to chemically stabilize the leachate.

Leachate analysis. Total leachate volume from each container was measured at the end of each week. A 70 mL aliquot was taken and frozen until analysis. Solutions were analyzed for Ca, Mg, Fe, Mn, Zn, Cu, and Mo by ICP spectrometry (Thermo Electron Corp., model IRIS 1000 HR, Franklin, Mass.).

Statistical analysis. Preliminary analysis of the data was conducted by regressing each of the dependent variables (concentrations of individual nutrients) against time (weeks), along with the qualitative treatment and blocking factors, using a general linear model (PROC GLM). Preliminary results (not presented) indicated strong interaction between time and treatments, along with higher-level polynomial terms for the regression component of the model. To facilitate a useful interpretation of the experimental results, data were subsequently analyzed by modeling the dependent variables against only the qualitative treatment and blocking factors, with separate analyses for each week, permitting comparisons among CRF treatments

at specific times during the 11-month period. Multiple comparisons among CRF treatments within a specific week were made using Tukey's studentized range test with an experimentwise

α -level of 0.10 covering all six simultaneous pairwise comparisons. Statistical analyses were conducted using SAS Version 9.1 (SAS Institute, Cary, N.C.).

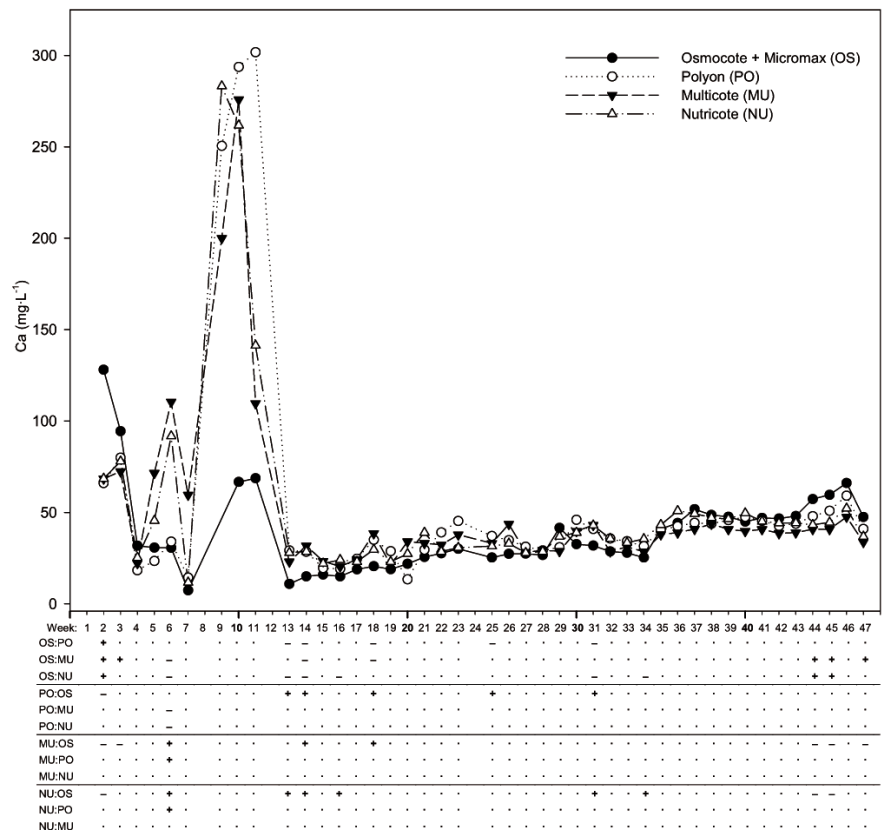
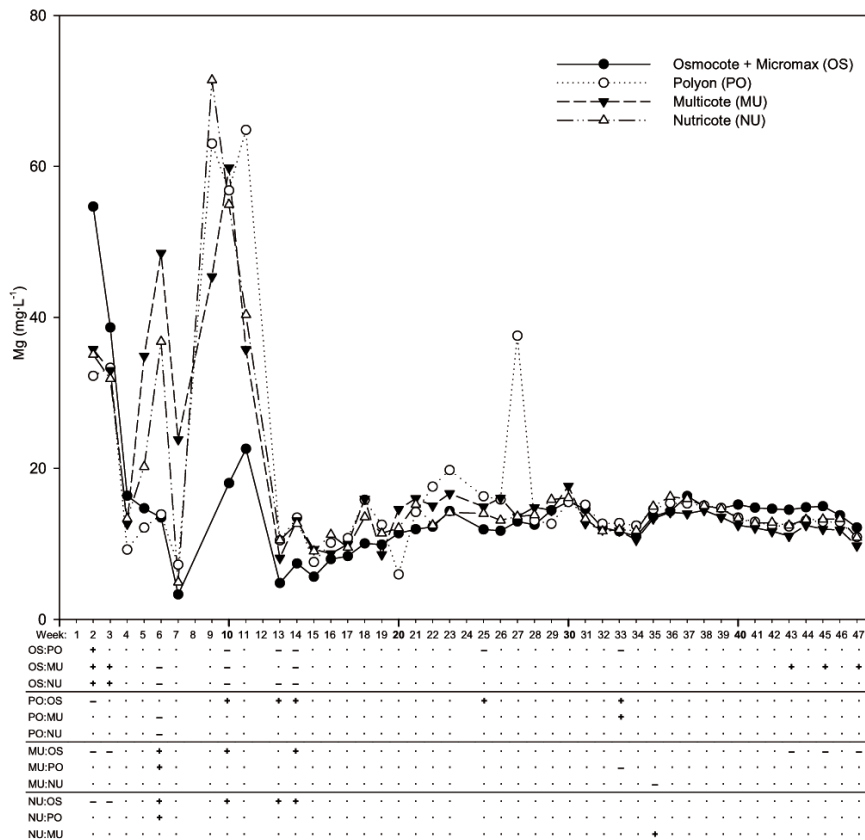


Fig. 1. Concentration of Ca (mg·L⁻¹) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (top) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (bottom) are indicated with the first treatment listed in each pair being greater than (+), less than (-), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.



Results

Calcium concentration. During the first 13 weeks of the experiment, Ca concentrations in

leachates from all treatments fluctuated, with concentrations reaching as high as 300 mg·L⁻¹ (Fig. 1). During the last 30 weeks of the study, Ca concentrations in leachates ranged between

Fig. 2. Concentration of Mg (mg·L⁻¹) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (-), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

25 and 50 mg·L⁻¹, with few differences among treatments. While there were some weeks in which certain treatments were significantly different from others, there did not appear to be any discernable pattern or trend in these differences. The lack of differences among treatments was expected since most of the Ca in all treatments was derived from calcium sulfate and dolomite that were blended into the substrate in addition to Ca present in the municipal tap water. The changes in Ca concentrations throughout the study may also be attributed to fluctuations in Ca levels in the municipal tap water. Ca concentrations observed in the present study are similar to leachate readings observed in simulated production systems (Chen et al., 2003), where Ca concentrations ranged from 12 to 42 mg·L⁻¹. In shorter-term (1 to 2.5 months) studies (Huett, 1997b; Huett and Morris, 1999), the greatest loss of Ca occurred during the first week with Osmocote and Nutricote.

It does not appear that Ca would have been limiting to plant growth during any period of the study. In several other studies (Dunham and Tatnall, 1961; Edwards and Horton, 1981; Starr and, 1984; Wright, 1984), optimum plant growth was obtained with a Ca leachate concentration of 10 to 15 mg·L⁻¹. If similar uptake kinetics and Ca requirements can be generalized for most woody ornamentals, then under the fertilization regime described, sufficient Ca should be available throughout the production period.

There are no federal guidelines established for Ca. Significant Ca runoff may indirectly contribute to elevated electrical conductivity and pH. However, EPA criterion for salinity is 250 mg·L⁻¹ and is based only on chloride and sulfates (U.S. EPA, 1976), not Ca or any other element. Present

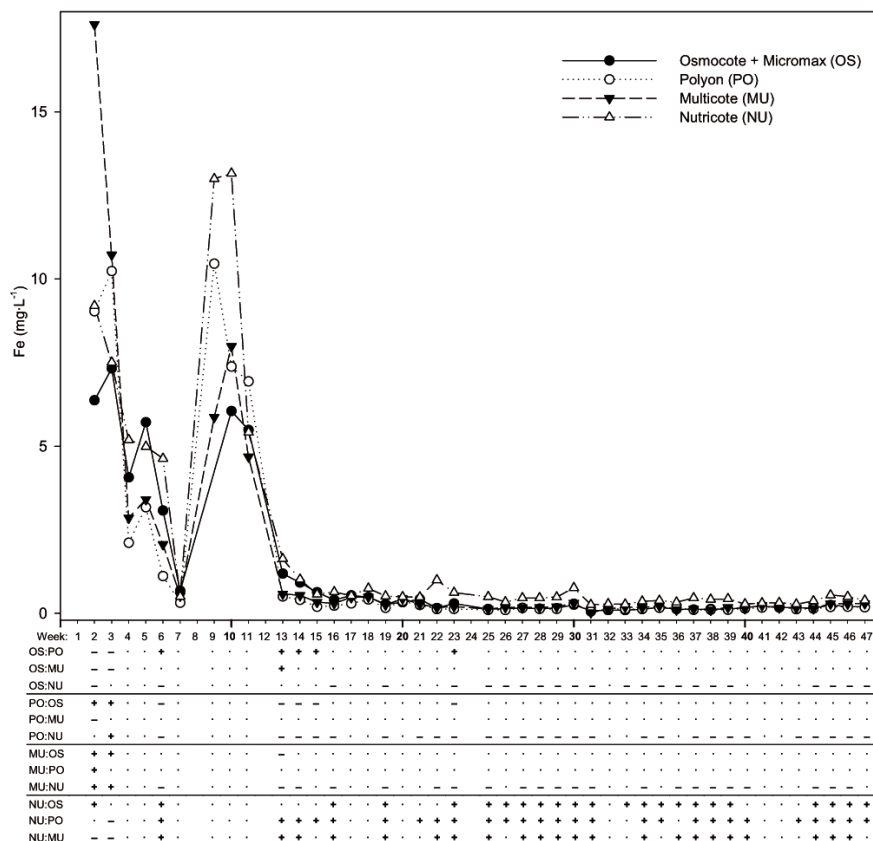


Fig. 3. Concentration of Fe (mg·L⁻¹) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (-), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

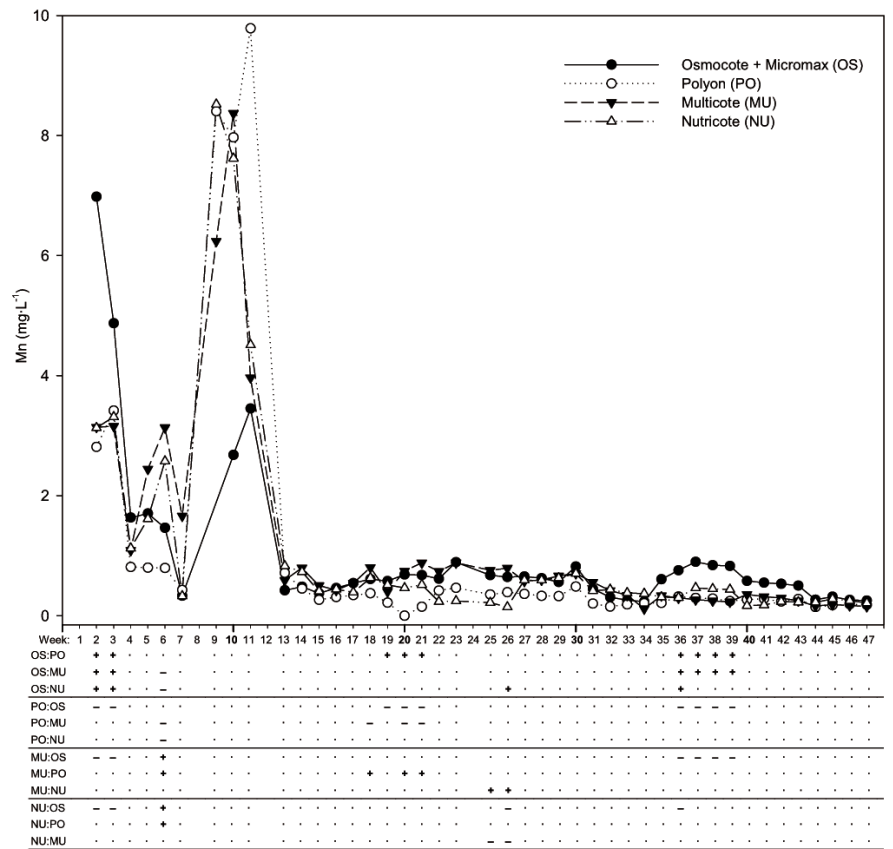
Fig. 4. Concentration of Mn ($\text{mg}\cdot\text{L}^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (–), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

EPA criteria for pH are 5.0 to 9.0 (domestic water supply), 6.5 to 9.0 (freshwater aquatic life), and 6.5 to 8.5 (marine aquatic life) (U.S. EPA, 1976). The other water quality criterion associated with Ca is alkalinity, which is not to exceed $20 \text{ mg}\cdot\text{L}^{-1}$ of calcium carbonate (CaCO_3) for freshwater aquatic life, "except where natural concentrations are less". (U.S. EPA, 1976).

Magnesium concentrations. Leachate concentrations of Mg fluctuated during the first 12 weeks of the study, with concentrations as low as $4 \text{ mg}\cdot\text{L}^{-1}$ for Osmocote (week 7) and as high as $70 \text{ mg}\cdot\text{L}^{-1}$ for Nutricote (week 9) (Fig. 2). However, from week 13 to the conclusion of the experiment, Mg concentrations were relatively stable, falling within the range of 10 to $20 \text{ mg}\cdot\text{L}^{-1}$. The range of Mg concentrations observed in the present study is similar to concentrations measured in simulated container-production systems (Chen et al., 2003). In shorter-term studies (Huett, 1997b; Huett and Morris, 1999), Mg leaching was also greatest during the first week of the experiment. Other studies noted that Mg in the form of sulfates solubilized and leached from substrate more quickly than Mg derived from oxides and carbonates (Broschat and Donselman, 1985).

Based on plant requirements for Mg that have been established in other studies (Mankin and Fynn, 1996; Starr and Wright, 1984; Wright, 1984), it appears that Mg availability would be sufficient for plant growth in the production scenario studied. In hydroponically grown herbaceous plants, the maximum Mg uptake rate was achieved at a concentration of $30 \text{ mg}\cdot\text{L}^{-1}$ (Mankin and Fynn, 1996). In other studies (Starr and Wright, 1984; Wright, 1984), optimum plant growth in containerized plants was

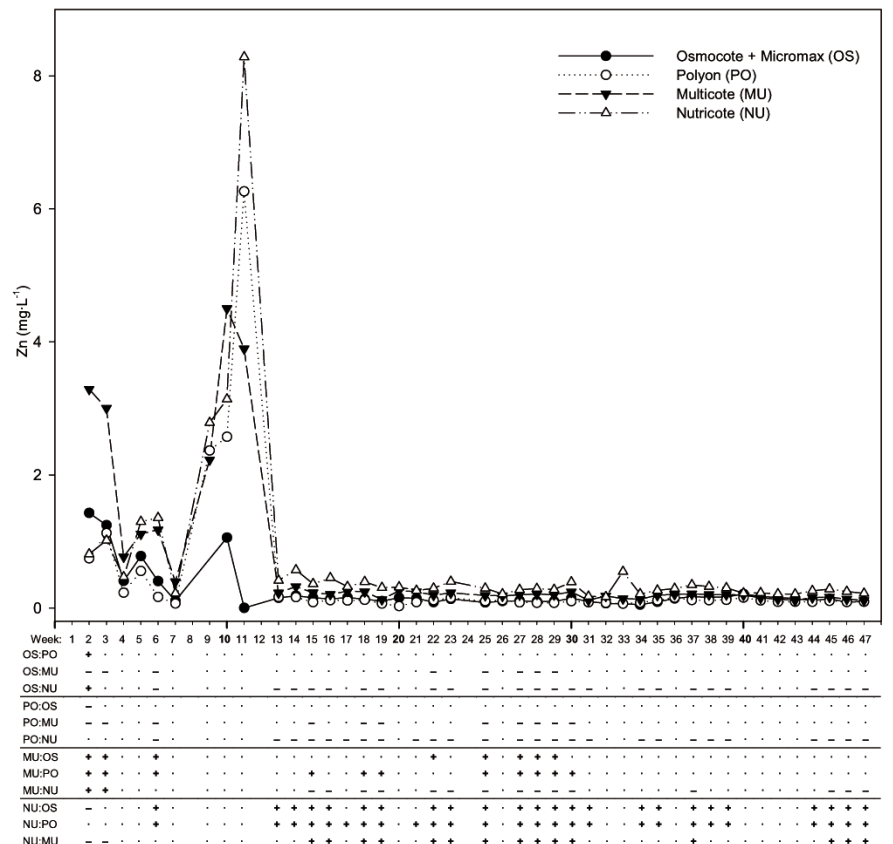
Fig. 5. Concentration of Zn ($\text{mg}\cdot\text{L}^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (–), or not different from (•) the second treatment listed in each pair according to Tukey's studentized range (HSD) test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.



achieved when leachate Mg concentrations were maintained between 10 and $15 \text{ mg}\cdot\text{L}^{-1}$. If the research by Mankin and Fynn (1996) and Wright (1984) can be applied to general containerized

production practices, Mg availability from CRFs should not be limiting during a typical 11-month plant production cycle.

Environmentally, the greatest likelihood



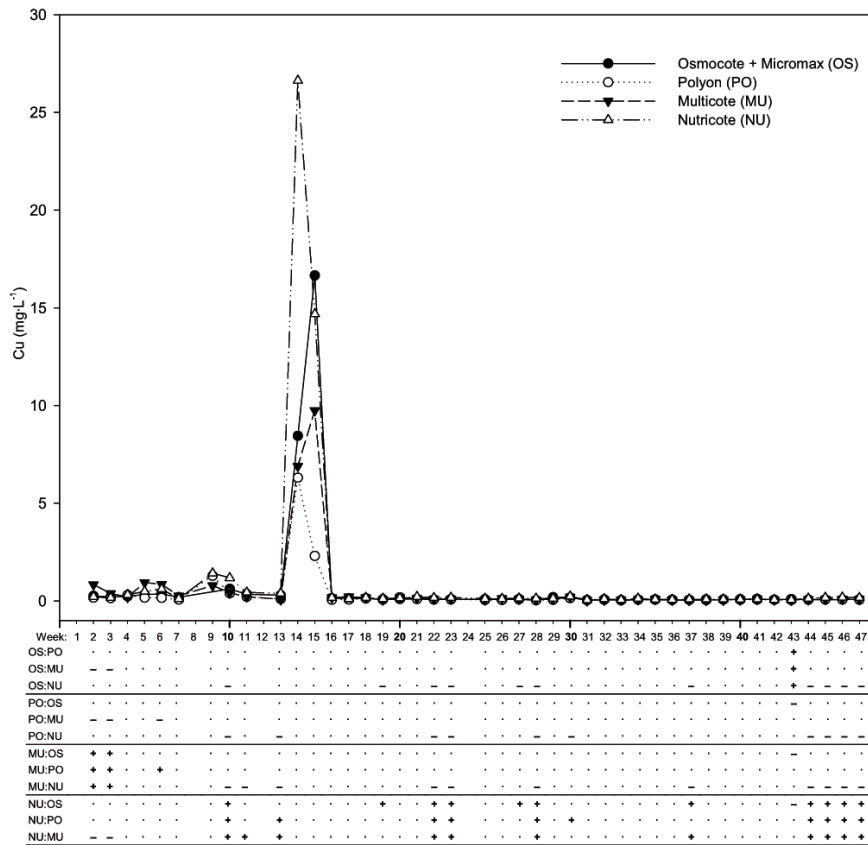


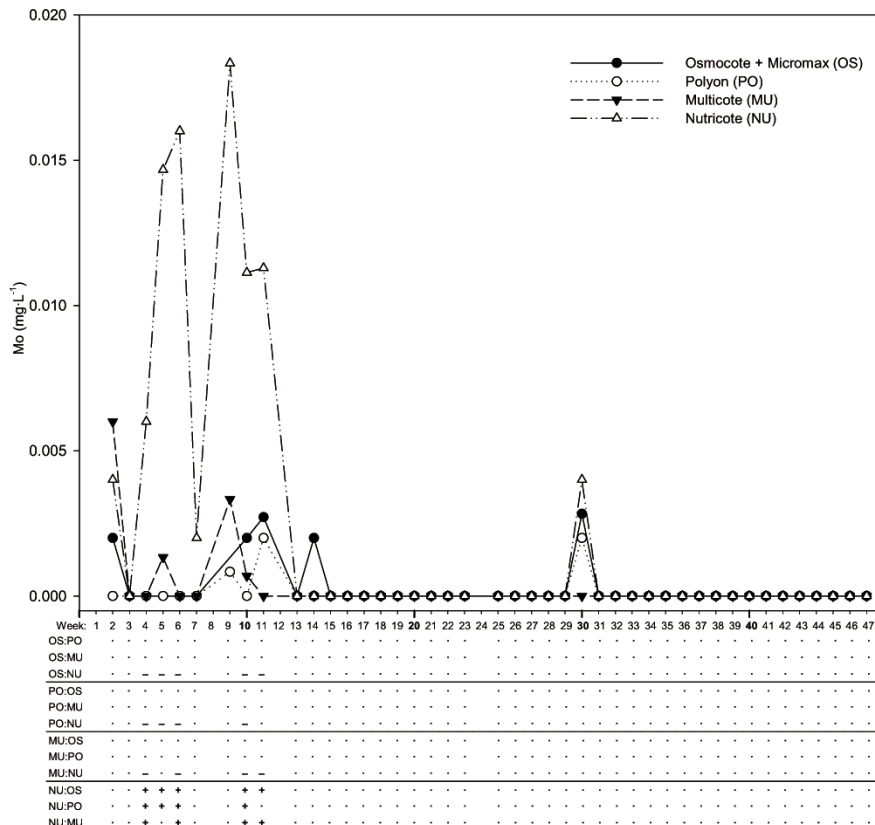
Fig. 6. Concentration of Cu ($\text{mg}\cdot\text{L}^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (-), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

Iron concentrations. Iron concentrations in leachates from all treatments were relatively high and fluctuated during the first 12 weeks of the study (Fig. 3). Fe concentrations in leachates were relatively stable during the last 30 weeks of the study, with significantly higher concentrations recovered in the leachates from the Nutricote treatment compared to the other three CRF treatments. This may be due to Fe leaching out of broken prills or, in the case of Micromax, Fe directly solubilizing from the fertilizer since Micromax is a noncoated form of micronutrient fertilizer. In other studies with uncoated granular fertilizers, a notable leaching of Fe occurred (Frost et al., 2003; Handreck, 1989) and, in some cases, the leaching rate from granular fertilizers was greater than that observed from soluble fertilizers (Frost et al., 2003). Overall, Fe concentrations measured in the present study, with the exception of the first 11 weeks, were similar to those observed in containerized production systems (Chen et al., 2003). The significant differences with Nutricote may be associated with the iron formulation, which was iron EDTA, a soluble iron form. Iron chelate was also the form of Fe used with Multicote; however, the Multicote treatment resulted in significantly greater leaching than all other CRFs during the first three weeks of the study, which may have resulted in less Fe available for release during the later part of the study. Broschat and Donselman (1985) noted that the leaching of Fe from organic-based substrate was greater with the use of chelated Fe compared to other mineral forms of Fe. It has also been determined that Fe is immobilized by organic substrate, up to $100 \text{ mg}\cdot\text{L}^{-1}$ for certain types of sawdust and bark products (Handreck, 1989).

Fig. 7. Concentration of Mo ($\text{mg}\cdot\text{L}^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug. 2001 to 27 June 2002) from a pine bark and peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Plotted points (**top**) represent least squares means for each fertilizer. Significant differences in least squares means for pairs of treatments for each week (**bottom**) are indicated with the first treatment listed in each pair being greater than (+), less than (-), or not different from (•) the second treatment listed in each pair according to Tukey's test ($P \leq 0.10$). One-gallon containers containing substrate without plants were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

of Mg leaching from containers would only be during the first 10 weeks of a production cycle; thereafter, Mg levels are low enough that most actively growing plant roots should take up all Mg (Mankin and Fynn, 1996; Starr and

Wright, 1984; Wright, 1984). However, since current federal policies (U.S. EPA, 1976) have no criterion for Mg concentration in runoff waters, Mg in runoff is not presently an environmental concern.



Based on the present study and the results of other research (Broschat and Donselman, 1985; Chen et al., 2003; Frost et al., 2003; Handreck, 1989), it appears that sufficient Fe was probably available for normal plant growth in the simulated production system studied, with the environmental risk of high Fe concentrations ($>0.3 \text{ mg}\cdot\text{L}^{-1}$) in leachates occurring during the first 20 weeks of the production cycle. The primary concern for Fe leaching would be with formulations using chelated iron, which have been found to be easily leached from organic substrates typically used in many containerized production systems. Current federal guidelines indicate Fe concentrations are not to exceed $0.3 \text{ mg}\cdot\text{L}^{-1}$ for water for domestic use and $1.0 \text{ mg}\cdot\text{L}^{-1}$ for freshwater aquatic life.

Manganese concentrations. Manganese concentrations in leachates of all fertilizer treatments were relatively high (between 1.0 and $9.0 \text{ mg}\cdot\text{L}^{-1}$), but variable during the first twelve weeks of the study (Fig. 4). During the last 30 weeks of the experiment, Mn concentrations were below $2.0 \text{ mg}\cdot\text{L}^{-1}$ for all treatments. In other studies, Mn leached from granular fertilizers, even more so than with the use of liquid fertilizers (Frost et al., 2003). The only significant differences observed were that the Osmocote treatment resulted in higher Mn concentrations in leachates compared to the other CRFs during the first 2 weeks of the study, then again from weeks 36 through 39 for Polyon and Multicote. Other differences were observed among fertilizer types throughout the experimental period, but no patterns or trends in these differences evolved. The lack of differences is not unexpected, since all fertilizer types contained manganese sulfate as their form of Mn. In other studies (Broschat and Donselman, 1985), it was shown that Mn might precipitate with other compounds at a substrate pH above 6.2; however, in the present study, the initial substrate pH was 4.5. Therefore, solubilization and possible leaching of Mn probably occurred during the beginning of the study. However, as leachate pH increased, and probably substrate pH as well, the solubilization, and therefore the leaching, of remaining Mn was minimized. Based on other research (Tinus and McDonald, 1979), a Mn concentration of $0.5 \text{ mg}\cdot\text{L}^{-1}$ is sufficient for healthy plant growth. Therefore, the Mn concentrations observed in the present study should be adequate for plant requirements. Environmentally, Mn leaching, and therefore the potential for excess Mn in runoff, was high throughout the entire study since federal guidelines indicate that Mn concentrations are not to exceed $0.050 \text{ mg}\cdot\text{L}^{-1}$ for domestic waters and $0.100 \text{ mg}\cdot\text{L}^{-1}$ "for protection of consumers of marine mollusks" (U.S. EPA, 1976), levels which are below concentrations measured in the present study.

Zinc concentrations. Leachate concentrations of Zn were relatively high and variable during the first twelve weeks of the study (Fig. 5). After week 13, Zn concentrations were below $0.5 \text{ mg}\cdot\text{L}^{-1}$, regardless of fertilizer type. These readings were higher than leachate measurements conducted in other studies (Chen et al, 2003) where Zn concentrations ranged between 0.01

and $0.04 \text{ mg}\cdot\text{L}^{-1}$. Leaching of Zn with granular micronutrients was also noted in other studies (Frost et al., 2003). Leachate Zn concentrations from the Nutricote treatment were significantly higher than with other fertilizer treatments during most of the study, despite the fact that the amount of Zn was three to four times less in the Nutricote treatment compared to the other CRF treatments. For plant growth, the Zn concentrations observed would probably be sufficient for most crops, as noted in other studies (Carroll and Loneragan, 1969; Tinus and McDonald, 1979). From an environmental perspective, Zn concentrations were usually below the critical limit of $5.000 \text{ mg}\cdot\text{L}^{-1}$ for domestic water supplies as established by the EPA.

Copper concentrations. Copper concentrations in leachates were usually below $1.00 \text{ mg}\cdot\text{L}^{-1}$, regardless of fertilizer type (Fig. 6). During weeks 14 and 15, concentrations of Cu increased for all treatments, then decreased and stabilized, indicating a likely Cu contamination of the water source during those two weeks. There were some differences among treatments, most notable being the higher Cu concentrations with Nutricote relative to the other CRFs for eight weeks out of the 47-week period. In another study (Broschat and Donselman, 1985), copper concentrations in leachates were relatively stable throughout an 18-month period. The low Cu concentrations observed in the present research and other studies may be attributed to the high affinity of Cu for organic matter (Schnitzer and Skinner, 1966). The EPA has established a Cu limit of $1.0 \text{ mg}\cdot\text{L}^{-1}$ for domestic water supplies (U.S. EPA, 1976), well above that found in our leachate data.

Molybdenum concentrations. Molybdenum concentrations were variable during the first 15 weeks of the study, with significantly greater concentrations measured in the Nutricote treatment compared to the other fertilizer types. After week 15, Mo concentrations were near $0.0 \text{ mg}\cdot\text{L}^{-1}$ for all treatments. There are currently no federal guidelines established for Mo in surface waters.

Conclusions

Concentrations of Ca, Mg, Fe, Mn, Zn, Cu, and Mo in leachates were relatively high during the first 10 to 16 weeks of the 11-month production cycle under cultural conditions typically used for low-nutrient requiring crops such as azalea and camellia. In most cases, leachate concentrations of all nutrients appeared to be at levels that would be considered sufficient for healthy plant growth. From an environmental perspective, only Fe and Mn were at concentrations that exceeded U.S. EPA guidelines, and these elevated concentrations only occurred during the first 2 months of the experiment. Based on these results, the use of Ca, Mg, Zn, Cu, and Mo in the fertilizer program tested should have little or no impact on water quality of nursery runoff. However, the use of Fe and Mn should be carefully considered, as concentrations of these nutrients may exceed federal guidelines, especially during the early phase of a typical production cycle.

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