Plant Growth and Leachate Electrical Conductivity and pH as Influenced by Controlled-release Fertilizer Blends and Coating Technologies

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SUMMARY. Although controlled-release fertilizers (CRFs) have been used in container-grown ornamental plants for decades, new coating technologies and blends of fertilizers coated for specific release rates are being employed to customize fertility for specific environments and crops. A study was conducted in the transitional climate of Kentucky to determine the nutrient release rates of three controlled-release blends of 8- to 9-month release and growth response of 'Double Play Pink' Japanese spirea (*Spiraea japonica*) and 'Smaragd' arbovitae (*Thuja occidentalis*). Fertilizer 1 (16N-3.5P-8.3K-1.8Mg + trace elements) and Fertilizer 2 (18N-3.1P-8.3K-1.8Mg + trace elements) were prototype blends with different experimental polymer coatings. Fertilizer 3 was a blend of 18N-2.2P-6.6K-1.1Ca-1.4Mg-5.8S + trace elements, which combined 100% resin-coated prills with a polymer coating. Fertilizer 4 was commercially available 15N-3.9P-10K-1.3Mg-6S + trace elements. Fertilizer 3 released its nutrients earlier in the 12-week study than the other three fertilizers and resulted in lower shoot dry weight in both species. The new polymer coating technologies show promise for delivering a predicted release rate and are appropriate for container production of these woody shrubs in Kentucky. An interesting side note of this experiment was that leachate pH measurements across treatments averaged 1.2 units lower for arbovitae (6.3) than for Japanese spirea (7.5) at week 12. It was assumed that chemical and/or biological reactions at the root/substrate interface in arbovitae moderated pH increases over the study.

Proper plant nutrition remains one of the most important topics for growers of nursery container stock. While some substrates have a starter charge of fertilizer incorporated, the pine (*Pinus* sp.) bark-based substrates commonly used by nursery growers contain little nutrient value. With the investment in plants, substrate, containers, water, and labor, growers need to be sure that they are using the correct fertilizer regimen for their production system.

CRFs are part of common fertilization strategies in container production systems. These products are usually applied to the substrate surface after potting, or are incorporated into the substrate before potting.

These CRFs are resin or polymer coated to slowly release their nutrients over the course of a growing season. The composition and thickness of the coating dictate release rate and longevity, typically measured in months (Goertz, 1993; Yeager and Cashion, 1993). However, these longevities are subject to change based on temperature. As substrate temperature in containers vary significantly with location, so do these longevities which differ with local climate (Cabrera, 1997). A commonly used CRF (Osmocote® Plus 15N-3.9P-10K; ICL Specialty Fertilizers, Dublin, OH), may be rated at 5- to 6-month longevity at 70 °F, but is only rated 4-5 months at an average 80 °F temperature. At a cooler 60 °F average, this

product is rated for 6-7 months of release. Research has shown that, while product labels often reflect a change in longevity with temperature variation, CRF longevity is often shorter than what is listed on the label (Meadows and Fuller, 1983). One study indicated that release rates vary for many CRFs on the market, including Nutricote® (Arysta LifeScience America, New York, NY), Apex Gold® (JR Simplot Co., Bosie, ID), Osmocote®, and Macracote® (Fetrol, Dandenong South, Victoria, Australia) (Huett and Gogel, 2000). Some formulations were observed to reach maximum release rate after 2-3 weeks, while others reached maximum release between 7 and 13 weeks. Blends of release patterns have been customized for specific applications based on release patterns (Medina et al., 2008). New polymer technologies for coating the fertilizers are resulting in CRF with a wider range of release rate. The objective of this study was to determine the effects of four formulations of CRF, including two with new polymer coating technology, on leachate pH and electrical conductivity (EC), and plant growth of two species of woody plants, across three application rates.

Materials and methods

Two species ('Double Play Pink' Japanese spirea and 'Smaragd' arbovitae) were provided by Spring Meadow Nursery, Grand Haven, MI, and transplanted from 2.25-inch liners to #2 containers. Plants were grown on a gravel bed in full sun under overhead irrigation in Lexington, KY. The irrigation water was from a municipal source with a pH of 7.1-7.8 and alkalinity of 64-102 mg·L⁻¹ during the experiment. Transplanting took place on 1 June 2016 for the arbovitae and 21 June 2016 for the Japanese spirea. Plants were grown in a substrate consisting of pine bark, peat, and sand (Morton's Nursery Mix; Morton's Horticultural Products,

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
1	mmho·cm ⁻¹	mS·cm ⁻¹	1
18.2495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

McMinnville, TN), with a lime rate of 10 lb/yard³. The containers were top dressed with two rates of four different blends of CRF (31 and 47 g per #2 container; corresponding to the low and medium manufacturer recommended rates), plus a control treatment (0 g) for total of nine treatments on each of the two species. Fertilizer 1 (ICL503034; ICL Specialty Fertilizers) and Fertilizer 2 (ICL503037; ICL Specialty Fertilizers) were prototype blends with different experimental polymer coatings. Fertilizer 1 was 16N–3.5P–8.3K–1.8Mg + trace elements with N sources of 7.1% nitrate and 8.9% ammoniacal N. Fertilizer 2 was 18N–3.1P–8.3K–1.8Mg + trace elements with N sources of 5.0% nitrate N, 8.0% ammoniacal N, and 5.0% urea. Fertilizer 3 was 18N–2.2P–6.6K–1.1Ca–1.4Mg–5.8S + trace elements, which combined 100% resin coated prills with E-max Release Technology (ICL Specialty Fertilizers) polymer coating, and the N consisting of 5.1% nitrate N, 6.1% ammoniacal N, and 6.8% urea. Fertilizer 4 was 15N–3.9P–10K–1.3Mg–6S + trace elements with N sources of 6.6% nitrate N and 8.4% ammoniacal N (Osmocote® Plus; ICL Specialty Fertilizers), a commonly used blend in the nursery industry. Each of the fertilizers has a targeted release over an 8- to 9-month period at 70 °F.

Ten single-plant replications were placed in a randomized complete block design with a factorial combination of fertilizer and rate

treatments. Substrate EC and pH were recorded using the pour-through leachate extraction technique (LeBude and Bilderback, 2009). This technique is performed 30 min to 2 h after irrigation by placing the containers into collection trays, adding 350 mL of water evenly over the surface of the #2 container and collecting ≈50 mL of water from the bottom of the container. This water was collected in the trays for EC and pH measurements, and EC readings were adjusted for EC of irrigation water used for the pour-through. In container production, these salts reflect the levels of fertilizer present in the substrate. Industry guidelines for container-grown plants recommend that these readings should be between 0.5 and 1.0 mS·cm⁻¹, and pH should range from 4.5 to 6.5 (Southern Nursery Association, 2013). Pour-through measurements took place on 20 June, 11 July, 1 Aug., and 23 Aug. 2016 for the arbovitae; and 7 July, 25 July, 15 Aug., and 8 Sept. for the japanese spirea.

The experiment was concluded 18 Oct. 2016 and aboveground shoots of both test plants were harvested, dried, and weighted. The arbovitae roots were harvested, cleaned, dried, and weighed. The nature of japanese spirea roots did not allow effective separation from the substrate for dry weight determination. Shoots and roots of japanese spirea received a visual rating for salability from 1 to 5, with 5 being the highest rating to capture

information about the visual differences observed and the difficulty of cleaning japanese spirea roots. Root to shoot dry weight ratio was calculated and analyzed for treatment effects for arbovitae. Plant growth data were subjected to analysis of variance (Proc GLM) to determine statistical differences for main effects and interactions and Duncan's multiple range test ($\alpha = 0.05$) to separate treatment means (SAS version 9.1; SAS Institute, Cary, NC). Repeated measures analysis (Proc Glimmix) was conducted to elucidate leachate EC and pH differences due to treatment over time.

Results and discussion

JAPANESE SPIREA. There were no interactions between fertilizer and rate on measured variables. At the conclusion of the experiment, only the no-fertilizer control plants were not saleable. Japanese spirea shoot dry weights were greatest for Fertilizers 1 and 2 and lowest for Fertilizer 3 and 4 (Table 1). Shoot dry weight for the two higher application rates was similar, but greater than plants treated with the zero rate. Quality ratings for aboveground growth were similar between Fertilizers 1, 2, and 4 and all were higher than for Fertilizer 3. Although both Fertilizer 3 and 4 resulted in a lower shoot dry weights, the shoot visual rating for Fertilizer 4 was higher relative to Fertilizer 3. Root visual ratings were highest for Fertilizer 3 and similar for Fertilizer 1, 2, and 4. Visual rating of shoots was not different between Rates 2 and 3

Table 1. The effects of controlled-release fertilizer products and rates on growth of 'Double Play Pink' japanese spirea and 'Smaragd' arbovitae.

Treatment	Japanese spirea			Arbovitae	
	Shoot dry wt (g) ^z	Shoot visual rating (1 to 5) ^y	Root visual rating (1 to 5) ^y	Shoot dry wt (g)	Root dry wt (g)
Fertilizer ^x					
1	59.26 a ^w	2.65 a	2.90 b	49.70 a	21.09 b
2	63.64 a	2.70 a	3.25 b	50.75 a	23.15 b
3	53.47 b	2.30 b	3.65 a	46.00 a	33.06 a
4	53.61 b	2.85 a	3.25 b	40.75 b	22.51 b
Rate (g) ^z					
0	7.00 b	1.00 b	1.40 c	18.76 c	16.50 b
31	58.09 a	2.50 a	3.53 a	44.00 b	25.72 a
47	56.09 a	2.75 a	3.00 b	49.62 a	24.18 a

^z1 g = 0.0353 oz.

^y1 to 5 scale with 5 being the highest.

^xFertilizer 1 (16N–3.5P–8.3K–1.8Mg + trace elements) and Fertilizer 2 (18N–3.1P–8.3K–1.8Mg + trace elements) were prototype blends with different experimental polymer coatings. Fertilizer 3 was a blend of 18N–2.2P–6.6K–1.1Ca–1.4Mg–5.8S + trace elements, which combined 100% resin-coated prills with a polymer coating. Fertilizer 4 was commercially available 15N–3.9P–10K–1.3Mg–6S + trace elements.

^wMeans with the same letter within shoot and root ratings are not statistically different (5% level).

but both were higher than the 0-g rate. Root visual rating was highest for Rate 2. Rate 3 root rating was also significantly higher than for the control.

The repeated measures analysis revealed differences in leachate EC and pH over time for fertilizers and rate. At the leachate analysis 2 weeks after treatment, EC averaged 1.49 $\text{mS}\cdot\text{cm}^{-1}$ across all fertilizers and rates. However, the highest EC was 2.14 $\text{mS}\cdot\text{cm}^{-1}$ measured in plants receiving Fertilizer 3, whereas all other treatments were not different from each other (Fig. 1A). By week 5, the EC associated with all the fertilizer treatments was similar. By the week 8, EC readings for plants receiving Fertilizers 1, 2, and 4 were all similar, but higher than plants receiving Fertilizer 3. EC for plants receiving Fertilizer 3 had the greatest change over the experiment when compared with the other fertilizers. At week 12, EC readings

associated with Fertilizers 2 and 4 were higher than for Fertilizer 3 with EC from Fertilizer 1 being intermediate. EC readings generally increased with rate increases across all fertilizer formulations, except for readings taken in week 5 when the EC readings for the two highest rates were similar (Fig. 1B).

At week 2, the average leachate pH was 6.32. The pH readings increased throughout the experiment, with an average of 7.51 at week 12 when all treatment means were above 7.4 (Fig. 1C). Fertilizer 3 had the lowest pH at weeks 2 and 5, with no difference at weeks 8 or 12. Nitrogen from ammoniacal and nitrate sources were similar between fertilizers but urea (6.8% of product) was present only in Fertilizers 2 and 3. The lower pH at weeks 2 and 5 corresponds to the quicker nutrient release rate as measured by pour-through EC. Average readings for pH were highest in

the 0-g rate throughout all measurement dates. Readings for pH decreased as fertilizer rate increased, except in week 5 when there was no difference between the two higher rates (Fig. 1D).

Fertilizer 3 applications resulted in higher EC early on and higher visual rating of roots at the end of the experiment, but lower weights for aboveground growth after 17 weeks. This could relate to having high N availability early, with lower N:K ratios favoring root growth later, but this should be confirmed with tissue or leachate mineral composition.

ARBOVITAE. At the conclusion of the experiment, only the no-fertilizer control arbovitae plants were not saleable. There were no interactions between fertilizer and rate treatments on measured variables. Dry weights of aboveground growth were similar after 20 weeks for Fertilizers 1, 2, and 3, and all were higher than shoot dry

Fig. 1. Leachate electrical conductivity (EC) and pH in 'Double Play Pink' Japanese spirea as affected by controlled-release fertilizers (A and B) and fertilizer rates (C and D). Fertilizer 1 (16N-3.5P-8.3K-1.8Mg + trace elements) and Fertilizer 2 (18N-3.1P-8.3K-1.8Mg + trace elements) were prototype blends with different experimental polymer coatings. Fertilizer 3 was a blend of 18N-2.2P-6.6K-1.1Ca-1.4Mg-5.8S + trace elements, which combined 100% resin-coated prills with a polymer coating. Fertilizer 4 was commercially available 15N-3.9P-10K-1.3Mg-6S + trace elements. Error bars about each mean are SE; 1 g = 0.0353 oz, 1 $\text{mS}\cdot\text{cm}^{-1}$ = 1 $\text{mmho}\cdot\text{cm}^{-1}$.

weights for plants receiving Fertilizer 4 (Table 1). Dry weight of roots for plants treated with Fertilizer 3 was the highest, with other treatments resulting in similar growth.

Higher fertilizer application rates resulted in higher aboveground growth (Table 1). The 31- and 47-g rates resulted in similar root dry weight and both were higher than plants receiving 0 g. Root-to-shoot ratio was lowest for Rate 3 (0.49) with Rate 2 (0.59) being lower than for control plants (1.10). It appears that increasing fertilizer rate favored shoot growth over root growth in arbovitae.

The repeated measures analysis revealed differences in leachate EC and pH over time for fertilizers and rate. At week 3, leachate EC averaged $1.63 \text{ mS}\cdot\text{cm}^{-1}$ across fertilizer and rate; however, the EC from plants receiving Fertilizer 3 ($2.46 \text{ mS}\cdot\text{cm}^{-1}$)

was higher than for plants receiving Fertilizers 1, 2, and 4, which were similar at that time (Fig. 2A). At week 6, the EC due to Fertilizer 1 was still lower than Fertilizer 3 while the effect of Fertilizer 2 and 4 were intermediate and similar to each other. By week 12, plants with Fertilizer 3 had the lowest EC, and Fertilizer 1 had the highest EC, with EC due to Fertilizers 2 and 4 being intermediate to those treatments but similar to each other. As was true for spirea, the EC for arbovitae receiving Fertilizer 3 changed the most over the length of the experiment compared with the other fertilizers. EC was higher with increasing rate at each measurement date (Fig. 2B).

Leachate pH generally decreased from week 3 through week 9 for Fertilizers 1, 2, and 4 (Fig. 2C). Leachate pH for Fertilizer 3 was lower than the other fertilizers at

weeks 3 and 9 but was similar to Fertilizers 2 and 4 at week 9 when the pH from plants receiving Fertilizer 1 was lowest. At week 12, only Fertilizer 1 resulted in a lower pH compared with the other fertilizer treatments.

The pH averaged 6.48 at week 3 and 6.32 by week 12 across rate and was highest in plants receiving the 0-g rate at each measurement date (Fig. 2D). The pH due to the two higher rates was similar to each other and lower than the 0-g rate at all dates.

It was concluded that Fertilizers 1 and 2 produced the highest shoot dry weight in Japanese spirea and arbovitae, with Fertilizer 3 being equal to Fertilizer 1 and 2 only in arbovitae. With Japanese spirea, Fertilizers 1 and 2 were observed to produce a deeper green foliage and higher shoot dry weight when compared with Fertilizers 3 and 4.

Fig. 2. Leachate electrical conductivity (EC) and pH in 'Smaragd' arbovitae as affected by controlled-release fertilizers (A and B) and fertilizer rates (C and D). Fertilizer 1 (16N-3.5P-8.3K-1.8Mg + trace elements) and Fertilizer 2 (18N-3.1P-8.3K-1.8Mg + trace elements) were prototype blends with different experimental polymer coatings. Fertilizer 3 was a blend of 18N-2.2P-6.6K-1.1Ca-1.4Mg-5.8S + trace elements, which combined 100% resin-coated prills with a polymer coating. Fertilizer 4 was commercially available 15N-3.9P-10K-1.3Mg-6S + trace elements. Error bars about each mean are SE; 1 g = 0.0353 oz, 1 $\text{mS}\cdot\text{cm}^{-1}$ = 1 $\text{mmho}\cdot\text{cm}^{-1}$.

Fertilizers 1 and 2 were prototype blends with experimental polymer coatings and, based on these data, have potential for use in Kentucky.

Fertilizer 3 was found to produce a higher visual rating of roots in japanese spirea but relatively lower shoot dry weight. Fertilizers 1, 2, and 3 produced equivalent shoot dry weight in arbovitae but Fertilizer 3 also produced the highest root dry weight.

Fertilizer 3 resulted in the highest EC at the first pour-through and was the lowest (below $1.0 \text{ mS}\cdot\text{cm}^{-1}$) by the third pour-through in both species. EC was higher as rate increased in both species. Rate also impacted shoot dry weight in both species. There was no incremental increase in japanese spirea shoot dry weight between Rates 2 and 3; however, arbovitae shoot dry weight increased with increasing rate.

Although the experiment was not designed to determine differences between species, mean leachate pH was 6.3 for arbovitae and 6.5 for japanese spirea at 2–3 weeks after treatment. At the last pour-through (week 12), the pH in arbovitae averaged 6.3 while pH of japanese spirea averaged 7.5. Alteration of rhizosphere pH has been reported in several crop plants, including floral crops, and has been explained by the differential uptake of cations/anions and the proportional efflux of hydrogen ions (Dickson et al., 2016; Huang et al., 2001; Johnson et al., 2013; Taylor et al., 2010). Fertilizer had a significant impact on pH in

arbovitae, especially in the first 9 weeks, but Fertilizer 3 resulted in a lower pH at the first two pour-through dates for both species which corresponds to the highest release rate during the time period. The impact of Fertilizer 3 on leachate pH was likely because of the release rate pattern, but having a portion of the N supplied by urea could have had an impact. pH rise, which was probably due to the relatively high pH and moderate alkalinity of the irrigation water, was buffered somewhat by fertilizer treatment in both species as the highest pH was in control plants which received no fertilizer.

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