

Nutrient Uptake, Partitioning and Leaching Losses from Container-Nursery Production Systems

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Abstract

A three-year study was initiated in 1999 to gather long-term data on nitrogen (N) and phosphorus (P) movement from container-nursery operations. The overall objectives of this study were to quantify N and P application, partitioning and leaching losses for *Ilex cornuta* x *regosa* var. 'China Girl' (holly, a 'high' nutrient-use species) and *Rhododendron* var. 'Karen' (azalea, a 'low' nutrient-use species), using two irrigation methods (drip vs. overhead sprinkler). Nutrients were applied at industry-recommended rates, with incorporated and top dressed controlled release fertilizer averaging 4.3g N and 6.12g N • plant⁻¹, respectively). Supplemental soluble fertilizer (averaging 2.3g N • plant⁻¹) was applied over the first 14 months of the study period. During this period, irrigation method did not affect N uptake within species, although total runoff was over three times higher (averaging 2.50g N vs. 0.74g N) for sprinkler vs. drip blocks. Plant N-uptake efficiencies during this period were between 17.9 and 24.0% for both species. Total N recoveries (plant, substrate and leachate) were between 24.8 and 45.6% for both species and irrigation methods. In a subsequent 12-week azalea study under controlled greenhouse conditions, plant N-uptake efficiencies averaged 15% for plants fertilized with a similar N / P rate (250 mg N • week⁻¹; 25 mg P • week⁻¹). Large fractions of the total N applied were not accounted for by either study, indicating that, while plant N uptake-efficiencies in container production are very low, there may be significant microbial competition for available N in these systems even over short periods of time.

INTRODUCTION

Recent state and federal nutrient management regulations (Maryland Dept. of Agric., 2000; Lea-Cox and Ross, 2001) are making us reexamine the efficiency of water and nutrient applications in the United States, particularly when plants are grown in intensive, out-of-ground container-nursery and greenhouse operations. Water that is applied through overhead or drip irrigation systems may either fall between, and/or leach from the container, and may contribute to non-point source nutrient runoff (Environmental Protection Agency, 2000). The quantity and quality of water used by intensive agriculture is a topic of national interest (Lea-Cox et al., 2002), as clean water is a critical requirement for sustaining natural and managed terrestrial and aquatic ecosystems. The economic, environmental and social aspects of improving and protecting water sources are substantial. There is thus a need to accurately quantify water and nutrient use for these farming operations, ensure that these data integrate the major production factors, and examine the nutrient use efficiencies of nursery crops.

Concerns with water use and nutrient runoff have forced many nurseries to search for "Best Management Practices" (BMP's) to improve irrigation and nutrient application efficiency. Best management practices can be defined as schedules of activities, prohibitions, maintenance procedures and structural or other management practices found to be the most effective and practical to prevent or reduce the discharge of pollutants (Yeager et al., 1997). The problem is that published BMP recommendations (Yeager et

al., 1997) are necessarily general, and are designed to give common-sense guidelines for nurseries to upgrade irrigation and nutrient management rather than provide information on specific practices. These recommendations are based on a number of research studies that have been done with a small number of indicator species, mostly in the greenhouse (e.g. Argo and Biernbaum, 1995; Fare et al., 1994; Niemiera and Leda, 1993; Yelanich and Biernbaum, 1993). Few of these studies, however, provide more than a limited N, P or electrical conductivity (EC) leachate dataset, from which we must extrapolate yearly leaching N and P data for large multi-species operations. Since an effective nutrient management strategy is dependent on the interactions between substrate use, fertilization and irrigation strategies, combined with an overall stormwater management strategy, few quantitative data exist for container-production systems, which constitute the highest-risk nursery and greenhouse production situations (Lea-Cox and Ross, 2001). This is especially true for phosphorus data. There is a real need to rigorously quantify nutrient use and leaching data from intensive plant-production systems. This paper describes initial results from two studies that investigate both water application and nutrient use efficiencies, using two model woody ornamentals species that are widely grown in the ornamental nursery industry.

MATERIALS AND METHODS

Field Study

A three-year study was initiated in 1999 to gather long-term N and P application, plant uptake-efficiency and leaching data using two irrigation methods (drip vs. overhead) for two 'model' plant species, since few systematic data exist in the literature. *Ilex cornuta* x *regosa* var. 'China Girl' (holly) and *Rhododendron* var. 'Karen' (azalea) were chosen for their different growth rates and because they are widely grown in the industry. The experimental site is described in detail in Ristvey et al. (2001). Briefly, the site consists of two replicated greenhouse structures with eight, 9m wide x 8m long blocks per house, with an impervious surface to collect leachate and irrigation water runoff from each block. All irrigation and fertilization application volumes to each block are measured by digital flow-meters (Great Plains Industries, KS). All runoff is diverted into a central furrow and is collected by a sub-surface 170 L polyethylene barrel at the end of every block. The runoff is then continuously pumped from this sub-surface barrel through another flow-meter into an above-ground collection barrel, where a fraction is collected for N and P analysis. The rest is diverted to a lined 100KL containment pond. The runoff water is sampled whenever necessary (2-3 times per week), acidified and frozen until analyzed for $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. Leachates from fertigation events are collected the same day after a fertigation event. Leachates from irrigations and rainfall events are collected before fertigation events and include any rain events between fertigations.

In the first year of the study, 448 plants of each species were randomly assigned to one of the four growing partitions within each house, with two blocks of each species under drip or overhead sprinkler irrigation in an offset pot-to-pot configuration. In this arrangement, plants took up approximately 38% of each blocks' area. Holly plants were grown in 11.7 L (Classic #3) plastic containers in a commercial hardwood-based substrate, that had been amended with 1.82 kg m^{-3} Osmocote 19-5-9, 1.3 kg dolomitic lime, 0.22 kg iron sulfate and 0.68 kg micromax per m^3 , respectively. Azalea plants were grown 11.7 L plastic containers in a commercial pine-bark substrate, similarly amended, but with only 1.36 kg m^{-3} Osmocote 19-5-9. From four weeks after transplanting, all plants were fertilized once or twice weekly during the production season with a soluble formulation that provided, on average, 150 mg $\text{N} \cdot \text{L}^{-1}$ and 6 mg $\text{P} \cdot \text{L}^{-1}$ during spring (April – May) and 75 mg $\text{N} \cdot \text{L}^{-1}$ and 6 mg $\text{P} \cdot \text{L}^{-1}$ from June through October. This rate can be translated to between 2.22 and 2.44 g N applied in soluble form to each plant via fertigation. An additional controlled release N application totaling 6.12 g N was applied to each plant in winter.

Eight plants from each treatment (n= 32) were harvested at four times during the

study period. Details of the plant harvest, partitioning and subsequent tissue analysis are detailed in Ristvey et al., 2001. Fertilization and runoff water samples were colorimetrically analyzed for $\text{NH}_4\text{-N}$ (phenolic method), $\text{NO}_3\text{-N}$ (cadmium method) and the soluble P fraction, orthophosphate (ascorbic acid method) using an Alpkem Flow 3000 system (Cleseri et al., 1989; Ristvey et al., 2001). Azalea and holly plants were pruned two and three times, respectively, during the 14-month study period. Leaf and branch tissue dry weights were taken and the tissue analyzed similarly to the other harvest tissues. Total N leachate amounts were calculated by multiplying the $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ concentrations by the volume of the water collected at each collection time. A saturated paste extract analysis was performed by Scotts Testing Laboratories (Allentown, PA); substrate N contents were calculated by multiplying the substrate $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ concentrations by the total volume of each substrate (measured at sampling).

Greenhouse Study

A three-month greenhouse experiment was conducted over a 12-week period to investigate the uptake and partitioning of N and P by azalea from March to May 2001. Five replicates of six treatments in a completely randomized 2 x 3 factorial design provided limiting and luxurious rates of N (i.e. 25 and 250 mg N per week, respectively) combined with limiting, sufficient and luxurious rates of P (0, 5 and 25 mg P per week, respectively). Eight-month-old *Rhododendron* var. 'Karen' in 7.2-L plastic containers were transplanted into a composted pine bark media, amended only with dolomitic lime and a micronutrient fertilizer in late February, 2001. These plants were not fertilized over the winter (dormancy) period prior to onset of this study, so that the plants and substrate were slightly N and P-deficient. Plants received a weekly application of N and P in an otherwise balanced liquid fertilizer solution (at the rates specified above) for each treatment throughout the experimental period. The fertilizer was applied to each plant in approximately 250 ml aliquots once a week. In addition, all plants were deficit irrigated (by hand), but were all watered to excess the day prior to fertilization, which leached the excess soluble N and P in the substrate remaining in the substrate from the previous week. The replicate plants designated for the final harvest were placed above catchment saucers to retain the leachate. Leachate volumes were recorded the same day, and samples were taken for N and P analysis as described above. The first harvest was performed prior to the onset of the study to provide baseline dry mass and nutrient content data. Five plant harvests were thereafter conducted every two weeks to provide sequential N and P uptake, partitioning and use-efficiency data. Harvest methods and tissue analysis are described above. All sample data were analyzed using a factorial analysis of variance using a PROC MIXED routine (SAS Institute, NC).

RESULTS

Field Study

In Table 1, plant N uptake was not affected by irrigation method for either species. However, holly plants took up significantly more N than azalea by the end of the 14 months. Less than 1% of total N applied to any treatment was recovered in the substrate at the end of the study period. Total N runoff was significantly lower for drip treatments (0.74 g N) compared to overhead treatments (2.50 g N). Total N recovery averaged 28.4% for drip treatments compared to 41.6% for overhead. Plant N uptake efficiencies averaged 18.0% for azaleas and 23.8% for hollies, and was not influenced by irrigation method.

Greenhouse Study

Nutrient uptake efficiency reflects the average nutrient amount that plants took up over the 12-week period. An initial harvest at the beginning of the experiment gave an average 90 mg N and 20 mg P per plant. The total plant N and P uptake is the difference between final tissue nutrient content after 12 weeks and the initial nutrient content (Table 2). Plant N and P uptake was highest at the N250:P25 rate. The zero P treatment

combinations had the lowest P uptake compared to all other treatments. Plant N uptake efficiencies at the high N rate were two to three times less than at the low N rate. Phosphorus uptake efficiencies increased two to four-fold between the 25P and 5P treatments. Plant tissue P in the zero P treatment also increased, despite the plants not receiving any P additions.

On average, N loss through leaching (Table 2) was between 5 and 10 times higher in high N treatments compared to low N treatments. Of the 275 mg of P applied at the highest P treatment combinations during the study, 9.1mg P was the maximum leached, representing less than 3.3% of the total P applied. Total N recoveries averaged 16.7% for high N versus 30.7% for low N treatment combinations. Total orthophosphate recovered averaged 15.9% for high P compared to 48.6% for low P treatment combinations. Zero P treatment recoveries were not calculated as no P was added.

DISCUSSION

These results summarize some of the first long-term N and P uptake, leaching, and efficiency data in the ornamental literature. Plant N uptake and uptake efficiencies were very low for both azalea and holly, irrespective of irrigation system. Total N recoveries were greater for overhead than for the drip irrigation systems, as much of the soluble N applied via overhead sprinklers missed the containers and contributed directly to higher N runoff. This was then reflected in higher total N recoveries for both species. Total N recoveries ranged from 24.8 to 45.6%, indicating that a majority of N was lost between the bottom of the container and the catchment barrel (less than 8m from the furthest container). Given the fact that fertigation runoff samples were collected immediately after application, and clear water and rainfall samples were collected within 72 hours and all samples immediately preserved and frozen, it appears that this N loss was primarily due to microbial use and denitrification.

The issue of container spacing thus appears to be an important factor in maximizing interception efficiency. The 11.7 L containers in the field study were placed side by side, which is the most efficient spacing possible. Nevertheless, the total area taken up by the containers was only 38% of the total growing area. In commercial production and in the latter years of this study, containers were spaced to maximize canopy light interception, further reducing interception efficiency. Thus, overhead irrigation systems using soluble fertigations are likely to substantially contribute to nutrient runoff. Although the total plant N uptake was no greater with drip systems, leaching and runoff totals were significantly lower, and the efficiency of these systems is likely to increase substantially when larger containers and/or greater spacings are used.

For nutrient management planning purposes, N and P applications should be calculated in $\text{kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. Given that approximately 163,200 (11.7 L) containers occupy a hectare if spaced next to each other, our overhead azalea application rate of 12.3 g of N per container per year equals 2000 kg N per hectare per year. Chen et al. (2001) cited a list of suggested N application rates for a number of species grown in containers and in several cases these rates were as much as 15 times higher than fertilization rates for agronomic field crops. The suggested rate for an azalea variety was $2,237 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (Dole and Wilkins, 1999, cited by Chen et al, 2001). Our study used 90% of that N rate, and provides plant uptake efficiency, N leaching and loss data for that rate. It is therefore apparent that we should search for more efficient ways to manage water and fertilizer applications, increase plant nutrient uptake, and reduce or contain nutrient runoff (Yeager et al., 1997).

The azaleas and hollies in the field study were given approximately 200 mg N and 28 mg P per plant per week over the 14-month period. The highest rate for the greenhouse study was 250 mg N and 25 mg P per plant per week. In the greenhouse study, nutrient uptake efficiency was greatly affected by the total amount of nutrient applied. Supplying the azaleas with high N and P treatments increased nutrient loss through leaching, and decreased the plant uptake efficiency. The plants given the 250N:25P rate used only 15.8% of the N and 15.2% of the P applied which was remarkably similar to the azalea

drip plant N uptake efficiency of 18.2% in the field study. Thus, even in a carefully controlled greenhouse environment we could not achieve substantially higher N uptake efficiencies using carefully applied N applications. Note that a single application of 250 mg of N per week is equivalent to twice daily applications of 36 ppm N in equal volumes of water. Perhaps consideration of frequent ultra-low nutrient concentrations to plants in minimal volumes would ensure continuous nutrient availability and reduce the potential leaching of nutrients.

Differences in soluble phosphorus leachates between treatments were probably not significant, given the fact that the maximal leaching loss of P was less than 3.3% of the total P applied (at the 25 mg P rate). Interestingly, there was some P leachate from the zero P treatments. This perhaps may have been due to root turnover, or release of native P by the breakdown of the pine bark substrate.

There is very little discussion of P rates for ornamentals in the literature. In this study, azaleas were treated with luxurious and insufficient treatments of N combined with luxurious, sufficient, and insufficient treatments of P, to examine the affect of N and P on root and shoot growth. Despite many publications pointing to the contrary, the belief that it is necessary to apply more than minimal quantities of P to promote root development seems to be common in the nursery industry. Many high-P ratio fertilizers claim to boost root and bloom growth. Some CRF formulations and many ready-mix soluble fertilizers supply P in molar ratios near 1N:1P, far in excess of plant P requirements. The results of this study show that N influences total growth, and insufficient quantities of both N and P increase root growth in for azalea. There was no significant difference in growth between the 5 mg P per week and the 25 mg P week treatments when sufficient N was supplied. However, the 25 mg P per plant per week treatment was still less than 20% of the standard industry rate. It appears that we could therefore lower P rates considerably and not compromise plant growth rates.

In conclusion, it is clear that an integrated water management and fertilization strategy is necessary to maximize plant uptake efficiency, and reduce nutrient loss from containerized growing systems. Many best management practices have been suggested, but maximizing plant nutrient interception efficiency, reducing soluble overhead fertilization applications and applying reduced concentrations of fertilizer more frequently during the growing period should greatly increase the efficiency of nutrient use.

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Tables

Table 1. Nitrogen budget (grams N per plant) includes N application, plant uptake (\pm standard error), substrate N, percent N recovered and plant N uptake efficiency for close-spaced Holly and Azalea plants, grown under drip and sprinkler irrigation systems from July, 1999 to September, 2000.

Treatment	Total N Applied		Plant Uptake	Substrate N	Runoff (NH ₄ + NO ₃)	N Recovered	Plant Uptake Efficiency
	CRF (g)	Soluble (g)	(g)	(g)	(g)	(%)	(%)
Azalea – Drip	9.82	2.35	2.21 (\pm 0.42)	0.12	0.69	24.8	18.2
Azalea – Overhead	9.82	2.44	2.20 (\pm 0.06)	0.00	2.41	37.6	17.9
Holly – Drip	11.06	2.22	3.12 (\pm 0.41)	0.33	0.79	31.9	23.5
Holly – Overhead	11.06	2.33	3.21 (\pm 0.20)	0.31	2.59	45.6	24.0

Table 2. Nutrient application (mg N:P • week⁻¹), plant N and P uptake, nutrient leaching and uptake efficiency after 12 weeks for azalea. Uptake efficiency represents total nutrient taken up after 11 weekly nutrient applications.

Treatment (mg • week ⁻¹)	Plant N Uptake (mg)	N Leachate (mg)	N Recovery (%)	N Uptake Efficiency (%)	Plant P Uptake (mg)	P Leachate (mg)	P Recovery (%)	P Uptake Efficiency (%)
N250:P25	433.2 (±30.1) a	84.6	18.8	15.8	41.8 (±3.4) a	5.4	17.2	15.2
N250:P5	352.9 (±51.8) b	100.1	16.5	12.8	22.4 (±3.7) b	1.9	44.2	40.7
N250:P0	304.1 (±40.4) b	106.7	14.9	11.1	0.5 (±2.8) c	2.9	--	--
N25:P25	57.6 (±8.5) d	9.8	24.5	20.9	30.7 (±5.6) b	9.1	14.5	11.2
N25:P5	63.7 (±10.1) c,d	13.9	28.2	23.2	25.2 (±2.9) b	3.9	52.9	45.9
N25:P0	128.6 (±47.0) c	22.1	34.2	31.2	7.2 (±2.0) c	2.7	--	--