Seasonal Patterns of Nutrient and Dry Weight Accumulation in Freeman Maple

Mary Ann Rose¹ and Barbara Biernacka²

Department of Horticulture and Crop Science, The Ohio State University, Columbus, OH 43210-1086

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Abstract. Seasonal patterns of N, P, and K accumulation and remobilization in Freeman maple (*Acer ×freemanii* E. Murr. ‘Jeffersred’) were studied to guide future improvements in fertilization efficiency. Leaves, stems, and roots of container-grown trees were harvested over a 12-month period (June to June) in each of two experiments. Plants were fertilized from June to October with three rates of soluble fertilizer (50, 100, and 200 mg·L⁻¹ N). Fertilizer rate had linear and quadratic effects on dry weight and nutrient contents, but did not affect seasonal accumulation patterns. Whole-plant nutrient contents and dry weights increased until mid-October, prior to leaf abscission. The largest fractions of nutrients and dry weight were allocated to leaves until early September. Between September and October, the most rapid accumulation of N, P, and dry weight occurred in root tissue. Highest nitrogen recovery efficiency occurred in late summer (Expt. 2) or early fall (Expt. 1). There was no statistically significant evidence for N, P, or K resorption in the fall, but evidence of N (not of P or K) remobilization in the spring was very strong. Whole plant dry weight doubled between April and June, while ≈50% of the N stored in woody tissues was translocated to new shoots.

The potential for environmental legislation that would prohibit runoff from field and container nurseries justifies a reevaluation of current fertilization practices. Eliminating runoff may be difficult for many nurseries that cannot afford costly containment facilities. Fertilization regimes that increase recovery efficiency (the proportion of applied fertilizer used by the plant) could offer a solution to this problem. Reported N recovery efficiencies for woody plants vary from 1% to 9% in the field (Mugasha and Pluth, 1994; Throop and Hanson, 1997; Weinbaum et al., 1994) and from 4% to 60% in containers (Pang, 1985; Struve, 1995).

One approach to increasing nutrient efficiency is to identify minimum fertilizer rates for producing high quality plants (Henry et al., 1992; Jull et al., 1994). A problem with that approach is that minimal rates are species- and cultivar-specific (Gilliam and Wright, 1977) and are influenced by environmental conditions (M.A. Rose, unpublished). Another approach is to optimize the timing of fertilization. Some plants produce multiple flushes of shoot growth during the course of a growing season, with root growth occurring between the flushes (Mertens and Wright, 1978). Application of nutrients during periods of active

root growth holds promise for increasing N uptake efficiency (Gilliam and Wright, 1978; Yeager et al., 1980).

Root growth in woody plants is believed to be biphasic in nature, with peaks in spring or early summer and fall, but work by Harris et al. (1995) suggests that this concept is oversimplified. Root growth patterns varied among four tree species and also with the methods used to assess root growth. However, the highest rates of root growth occurred in early to mid-summer, from approximately early June to mid-July in Ithaca, N.Y., regardless of species or method.

Fertilizer recommendations for field-grown or landscape ornamentals are firmly based on the biphasic root growth model. Many extension bulletins (e.g., Smith, 1989; Swanson and Rosen, 1989) suggest that spring and late fall fertilization are optimal for woody ornamentals, with late-summer and early fall to be avoided because of potential delays in cold-acclimation.

The objectives of our research were to investigate the seasonal patterns of growth and nutrient accumulation in Freeman maple, and to determine whether these patterns were influenced by the rate of soluble fertilizer applied. Since woody plants have distinct seasonal patterns of nutrient remobilization (Brinkman and Boerner, 1994; McGrant and McArthur, 1990), nutrient use was examined for a full year in two separate experiments to observe the impact of nutrient remobilization on nutrient accumulation. Our goal was to provide initial information for future development of more efficient fertilization programs and more efficient slow-release fertilizers for woody plants.

Nutrient-use patterns were studied in Expt. 1 (June 1995 to June 1996) and Expt. 2 (June 1996 to June 1997). At the beginning of each experiment, rooted cuttings of Freeman maple, ≈20 cm in length, were potted in 3.8-L containers (22 May 1995 and 1 June 1996 in Expts. 1 and 2, respectively). The media contained 6 pine bark : 3 peat : 1 sand (by volume) amended with 3.8 kg·m⁻³ dolomitic limestone, 0.8 kg·m⁻³ iron sulfate, and 1.1 kg·m⁻³ slow release microelements (Micromax; The Scotts Co., Marysville, Ohio). Plants were placed in a container growing facility in Columbus, Ohio.

Fertilization and irrigation. From June to late October, plants were fertilized with soluble fertilizer (The Scotts Co.) via a drip irrigation system. The fertilizer analysis was 20N–8.7P–16.6K in Expt. 1, and 24N–3.5P–13.3K in Expt. 2. The latter was used because it helped maintain optimal medium pH without the need for periodic adjustment. This ratio also more closely reflected nutrient ratios in plant tissues (M.A. Rose, unpublished). Three rates of N were used in both experiments: 50, 100, and 200 mg·L⁻¹. Irrigation decisions were based on daily inspections. Total irrigation volumes applied during the fertilization periods in Expts. 1 and 2 were 21.5 and 21 L, respectively. In both experiments, each plant received, over the entire growing season, ≈1, 2, or 4 g of N for the 50, 100, and 200 mg·L⁻¹ treatments, respectively. Plants were stored in a single layer polyhouse from November through April and were supplied only with water from late October through final harvest in June.

Harvest procedures. In each experiment, four representative plants were harvested in early June before fertilization began. Subsequently, four plants from each fertilizer treatment were harvested every 6 weeks (mid-July, early September, mid-October) throughout the season of active growth. Leaves harvested in October showed only initial signs of coloration. Plants also were harvested when dormant (mid-December), at bud-swell in early spring (mid-April), and during active growth (early June). In Expt. 2, leaves that abscised were collected at 2-d intervals in late October.

At each harvest, stems, leaves, and washed roots were dried at 70 °C for ≈72 h and weighed. Tissue samples were ground to pass through a 40-mesh screen and sent to the Ohio State Univ. Research Extension Analytical Laboratory (R.E.A.L.) for dry combustion analysis of N (Macro-N Elemental Analysis system, Hanau, Germany). For P and K analysis (Expt. 2 only) plant tissue digests were prepared for inductively coupled argon plasma spectrophotometry (Fison Instruments, Dearborn, Mich.) by a modification of procedures reviewed by Jones and Case (1990). Tissue samples (0.5 g) were dry-ashed for 4 h in a muffle furnace at 500 °C, cooled, then dissolved in 2.4 N nitric acid and brought up to 25 mL total volume. There was not enough tissue to analyze initial P and K status of plants in June. Nutrient contents of leaves, stems, and roots were calculated by multiplying the dry weight by nutrient concentrations.

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¹Assistant Professor.

²Graduate Student.

Experimental design and statistical analysis. In both experiments, a randomized complete block design with four replications was used. Statistical software (SAS Institute, Cary, N.C.) was used for analysis of variance, regression, and mean separation ($P < 0.05$).

Results and Discussion

The effects of fertilizer rate on plant appearance, dry weight, and whole-plant nutrient contents. Plants grew continuously throughout both summers and formed terminal buds in late September. Trees fertilized with the lowest rate (50 mg·L⁻¹ N) were slightly chlorotic in appearance in both experiments; they also had the earliest and most vivid red fall color, ≈2 weeks before the 200 mg·L⁻¹ N treatment. At final harvests (June), dry weight and nutrient content were significantly affected by fertilizer rate (Table 1). Quadratic and linear responses to fertilizer rate were evident in Expts. 1 and 2, respectively. Whole-plant dry weight was a good predictor of whole-plant nutrient content at all harvests; at final harvest in Expt. 2, r^2 values exceeded 0.90 for the regression of dry weight on N, P, and K contents. In Expt. 1, the r^2 for the regression of dry weight on N content was lower (0.60) in June, but exceeded 0.78 on other dates.

Fertilization rate clearly influenced dry weight and nutrient content as well as shoot/root ratio (Table 1). Although the interaction (data not shown) between harvest date and fertilizer rate was significant (the dry weight or N content response might be linear on one date, quadratic on another), fertilizer rate did not affect accumulation trends over the course of the year. For example, rate did not affect the time of maximum or minimum accumulation. Seasonal accumulation trends are the key focus of this paper, and to simplify the discussion, only the data for the 100 mg·L⁻¹ N treatment are used for illustration of accumulation patterns; however, the following discussion reflects observations from all treatments.

Patterns of dry weight and N accumulation in Expts. 1 and 2. During the first season, whole plant dry weight (Fig. 1) and nitrogen content (Expt. 1, Fig. 2) increased steadily after planting to a maximum in mid-October, prior to leaf coloration. Although in Expt. 2 the difference in whole-plant N content was not significant between September and October, the difference in root N content was. From July through September, roughly half of plant N and dry weight was allocated to the foliage. Between early September and mid-October, accumulation rates were greatest in roots; for all treatments, between 45% and 85% of the N gained was allocated to roots. During this period both root dry weight and N content more than doubled.

Between October and December, the substantial decrease in whole-plant N and dry weight represented losses from leaf abscission (Figs. 1 and 2). Concentrations of N in abscised leaves (Expt. 2, data not shown) averaged 41% lower than in leaves collected in early October, suggesting that some N had been remobilized to woody organs; however, no corre-

Table 1. Effect of fertilizer rate on whole-plant dry weight; N, P, K contents; and shoot/root ratios of Freeman maple trees at final harvest (June).

Fertilizer rate (mg·L ⁻¹ N)	Dry weight (g)	Content (g/plant) of:			Shoot/root dry weight ratio
		N	P ^z	K	
Expt. 1					
50	40.3	0.32	---	---	1.3
100	78.3	0.57	---	---	2.1
200	66.8	0.50	---	---	2.0
Linear	*	NS	---	---	*
Quadratic	**	*	---	---	*
Expt. 2					
50	31.6	0.31	0.04	0.21	1.5
100	53.7	0.54	0.07	0.37	2.2
200	64.6	0.81	0.12	0.53	2.7
Linear	**	***	**	**	***
Quadratic	NS	NS	NS	NS	*

^aPlant tissue analyzed for P and K in Expt. 2 only.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Fig. 1. Dry weights of leaves, stems, and roots for each harvest date in the 100 mg·L⁻¹ N treatment. Upper and lower case letters indicate mean separation for whole plant and component dry weights, respectively (LSD₀₅). The column on far left (June) indicates weights before treatments began.

sponding increase in N content (Fig. 2) of stems and roots was observed in the following harvest. Other authors have reported resorption of N from leaves as high as 68% (Brinkman and Boerner, 1994). We cannot account for the decrease in foliar N; perhaps our methods (i.e., destructive harvests of separate groups of plants) were not sensitive enough to detect N remobilization from leaves to stems and roots.

Between October and April harvests, there

was little evidence of N or dry weight accumulation. Since fertilization ended about 2 weeks after the October harvest, N accumulation was not expected during this period.

Growth resumed between April and June. Whole-plant N content did not change (Fig. 2), while whole plant dry weight approximately doubled (Fig. 1). New leaf growth represented more than 50% of dry weight gain during this period. Stem dry weight significantly increased

in all treatments, whereas root dry weight did not, with the exception of the 200 mg·L⁻¹ N treatment in Expt. 2 (data not shown). Because no N was applied in the spring, new shoot growth was sustained by N stored in the fall. As N was remobilized from woody tissues, its concentration in stems and roots fell by ≈ 50% or more in all treatments.

Nitrogen accumulation relative to the size of the plant, June to October. Nitrogen and dry weight accumulation patterns suggested that as plants increased in size (dry weight) they took up correspondingly greater amounts of N. To separate N uptake from the size effect, N content gains during the three 6-week periods between June and October were divided by initial dry weight. This revealed that N accumulation relative to size was much lower during the September to October period (Fig. 3). Maximum accumulation probably occurred from July to September, although it was not significantly different from the June to July period in some cases. Highest relative N uptake rates occurred in the summer when leaf growth was dominant, with lower rates in early fall when root growth was dominant. Leaves always had higher N concentrations than roots (data not shown) and thus a higher N demand relative to dry weight.

Phosphorus and potassium accumulation in Expt. 2. Phosphorus and K contents increased steadily through October (Fig. 4), closely resembling patterns of N accumulation (Fig. 2). The decrease in whole-plant P and K contents during leaf abscission paralleled N losses, although the decrease in P was not statistically significant. However, after growth resumed in spring, an increase in K content was observed despite the fact that fertilization had ceased in October. Residual K in the growing media could account for K accumulation between April and June; K and P concentrations were not measured during this time. However, related studies (M.A. Rose, unpublished) have suggested that P and K are retained longer than is N in soilless media.

The P and K contents did not provide evidence of fall or spring remobilization of nutrients. No increase in nutrient content was observed in woody stems and roots in the fall, nor any decrease in the spring that would suggest N translocation from/to leaves.

Nutrient recovery during the growing season. Most research suggests that nutrient recovery is lower with higher fertilizer rates (Struve, 1995; Yeager et al., 1980). This relationship was observed in Expt. 2, where cumulative N, P, and K recovery efficiencies were lowest in the 200 mg·L⁻¹ N treatment (≈12% vs. recoveries between 30% and 40% for the two lower rates). However, in Expt. 1, cumulative N recovery efficiency was lower in the 50 mg·L⁻¹ N treatment (33%) than in the 100 and 200 mg·L⁻¹ N treatments (48% and 43%, respectively).

Of greater interest are the changes observed in nutrient recovery efficiencies throughout the growing season; these were calculated for each of three 6-week periods (Fig. 5). Nitrogen recovery was lowest in the beginning of the season in two out of three

Fig. 2. Nitrogen contents of leaves, stems, and roots for each harvest date in the 100 mg·L⁻¹ N treatment. Upper and lower case letters indicate mean separation for whole plant and component nitrogen contents, respectively (LSD_{0.05}). The column on far left (June) indicates contents before treatments began.

Fig. 3. Nitrogen gains per unit initial dry weight for three growth periods in the 50, 100, and 200 mg·L⁻¹ N treatments. Letters indicate mean separation among the growth periods within each N rate (LSD_{0.05}).

treatments each year. This observation is consistent with the smaller plant size and less well-established root system after potting. The pattern of N recovery over the next two periods of growth was distinctly different between experiments. These trends were observed in all treatments, but were significant in only two of the three: maximum N recovery efficiency was observed between September and October in Expt. 1 and between July and September in Expt. 2. Records collected <1.7 km from the research site indicated that precipitation in September and October during Expt. 2 was greater (29 cm) than during Expt. 1 (16 cm). Heavier precipitation may have leached more N, accounting for lower recovery in Expt. 2. In contrast with N, there were no consistent seasonal trends in P and K recovery efficiency among treatments (data not shown).

Conclusions. Nitrogen, P, and K accumulation during the growing season was correlated with dry weight accumulation and increased steadily from potting through mid-October. Although larger, established plants would be expected to take up more nutrients, fertilizer application rates in the container nursery industry are determined by container size, not stage of growth or plant size. This work suggests that fertilizer efficiency could be increased by taking those factors into account.

Cabrera (1997) described two distinctly different patterns of N release in commercial slow-release fertilizers with 8- to 9-month formulations. One group was highly responsive to temperature and had higher release rates earlier in the season. Another group was less responsive to temperature; maximal release rates were attained by mid-July and remained high through mid-September. Release patterns of the latter group would be a closer match to the accumulation patterns observed in Freeman maple in these experiments. However, there may be an inherent difficulty in matching fertilizer release to nutrient uptake patterns: newly potted plants require lower absolute amounts of N, but are less efficient in absorption. Later in development, the reverse is true; larger, mature plants require more N, but absorb it more efficiently. Potentially the two contradictory effects cancel one another out, making it difficult to predict the most efficient pattern of nutrient release.

These container experiments also may have implications for field-grown or landscape ornamentals, although the root environment in the field may affect uptake patterns. Most field nursery stock is fertilized once or twice annually: during spring, before or after budbreak, and/or in late fall when plants are dormant. Nursery growers avoid fertilization in late summer or early fall for fear of delaying cold acclimation. In their extensive review, Pellet and Carter (1981) concluded that late summer/early fall fertilization did not prevent cold-acclimation. Some research even indicates that fertilization at this time stimulates the development of cold-hardiness (DeHayes et al., 1989). Our data suggest that applying fertilizer in late summer or early fall may be

Fig. 4. Phosphorus and K contents of leaves, stems, and roots for each harvest date in Expt. 2, 100 mg-L⁻¹ N treatment. Upper and lower case letters indicate mean separation for whole plant and component nutrient contents, respectively (LSD_{0.05}).

Fig. 5. Nitrogen recovery efficiency (NRE) for three growth periods in the 50, 100, and 200 mg-L⁻¹ N treatments. Letters indicate mean separation among the growth periods within each N rate (LSD_{0.05}).

more efficient than applying it earlier in the season. Late fall (dormant) fertilization was not investigated in these studies; however, in future work, the relative efficiencies of early vs. late fall fertilization will be examined.

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