Growth, Dry Weight and Nitrogen Distribution of Red Oak and 'Autumn Flame' Red Maple Under Different Fertility Levels[1]

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Abstract

Red oak (*Quercus rubra* L.) seedlings and 'Autumn Flame' red maple (*Acer rubrum* L.) rooted cuttings were grown under different fertility levels: 0, 25, 50, 100, 200 or 400 mg/liter N from 20N–8.6P–17K water soluble fertilizer applied daily in two, 45-minute irrigation events. At one-month intervals from June to October, seedlings were harvested, and dry weights and N content of leaves, stems and roots determined. In October, red oak dry weight increased up to 400 mg N/liter fertigation. Red maple dry weight was greatest between 200 and 400 mg N/liter fertigation. For both species, as N fertigation level increased, relative stem dry weight increased while relative root dry weight decreased. There was little change in relative leaf dry weight. For both species, percent N in leaf, stem and root tissues increased with increasing N fertigation. N distribution in leaf, stem and root tissues was similar to relative dry weight accumulation. Red maple plants had greater morphological adjustment to increasing N fertigation than did red oak plants. At the highest fertigation levels, red maple plants could be N loaded, increasing N tissue concentrations without an increase in plant dry weight. Red oak plants did not exhibit N loading.

Index words: *Acer rubrum*, *Quercus rubra*, mineral nutrition, stress tolerator species, competitor species, nursery production, container production.

Significance to the Nursery Industry

In N rich environments, 'Autumn Flame' red maple rapidly redistributed growth to stem and leaf tissue and less to root tissue in response to high fertility levels than did red oak seedlings. Although 'Autumn Flame' red maple increased growth in response to increased fertility, plant quality (based on shoot:root ratio) was reduced. Red oak was slower growing than 'Autumn Flame' red maple. It did not redistribute growth to the same degree that red maple plants did in response to increased fertility. In October, more grams of N were contained in red oak roots than in stems or leaves. In December, 82% of the total plant N was contained in the root system. For red maple plants, more N was contained in leaves and stems than in the roots. In December, 66% of the plant's total N was contained in the root system. These results demonstrate that the roots of dormant plants represent the major N storage organ. Also, as slower growing plants, red oak invests more resources in roots than in leaves and shoots, which in part explains their reduced growth rate.

Introduction

Nitrogen efficiency, dry matter produced per unit N applied, and N productivity, dry matter produced per unit N and time, are in opposition (16). For example, red oak and blackgum seedlings at the lowest N application rate had the greatest N efficiency, but produced the smallest plants while, high N application rates were associated with low N efficiency, but rapid growth (30).

High fertility levels increase shoot:root ratios (11), potentially lowering plant quality. Under high fertility, plants redi-

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rect proportionally more resources from the root system to the above ground portions of the plants (6). Growth models indicate that leaf and shoot development are most responsible for the increased growth (10, 22).

In addition to altering shoot:root ratios, high fertility also reduces the concentration of defensive compounds thus increasing pest susceptibility (12). In a nursery environment the reduction in defensive compounds is not of great concern; managers use pesticides as surrogates for plant-produced defensive compounds. A concern with nursery stock produced in high N environments is the effect of high shoot:root ratios and lower concentrations of defensive compounds on performance after transplanting to environments more stressful than the nursery production environment.

Conifer seedlings raised under high fertility have higher nutrient concentrations than seedlings raised under low fertility (14, 23, 24, 26, 32). This practice is termed nutrient loading, and is defined as an increase in the concentration of mineral nutrients in plant tissue without a significant increase in plant dry weight (23). Nutrient loaded seedlings performed better than conventionally produced seedlings when out planted, especially in nutrient poor sites (23, 24 32). Planting nutrient loaded seedlings was a more effective method of stimulating growth after out planting than post-transplanting fertilizer applications (32).

Shortening rotation time by maintaining high fertility is a common method of increasing nursery productivity as nitrogen is a relatively inexpensive input that greatly stimulates growth. However, high N application rates have environmental consequences. Many nurseries have installed collection systems to capture and reapply irrigation water and leached nutrients from their container nurseries.

A second step towards reducing the environmental impact and increasing fertilizer efficiency is to match either nutrient application rates of water soluble fertilizers, or release profiles of controlled release fertilizers with crop uptake potential. Nutrient application rates or crop nutrient uptake potential can be determined empirically for each species or cultivar by growing it under several fertilizer rates, harvesting the plants at regular intervals, determining dry weights and plant tissue(s) nutrient contents. Nutrient uptake potential for a given time interval is calculated as the difference between the tissues' previous and current mineral nutrient content. This approach is straight forward, but expensive. General principles of plant response to nutrient application and the resulting effects on plant quality and health need to be established so nursery managers can, without having to conduct extensive empirical studies, identify production environments for woody plant taxa that maximize growth and maintain high plant quality (34).

A generalized plant response to mineral nutrient application may be applied from the ecological literature. Ecologists have classified species as stress tolerators or competitors, reflecting their adaption and response to different habitat types (8). Stress tolerator-species tend to be long-lived, later successional species with relatively slower growth rates, reduced morphological response to environmental changes and deeper root systems (which impart drought resistance) than competitor-species (2, 8). In contrast, competitor-species have shorter life cycles, are early successional species which rapidly adjust growth in response to changes in environmental conditons. Competitor-species tend to be those that first colonize a site following disturbance. They must maximize shoot growth to avoid being overtopped by adjacent plants as they are shade intolerant. Stress-tolerators tend to be shade tolerant and thus their long term survival is not dependent on exposure to full sun. Red oak (*Quercus rubra* L.) is an example of a stress-tolerator species; red maple (*Acer rubrum* L.) is an example of a competitor-species. Studying the response of these two species to a range of fertilizer rates may reveal general principles of plant response to nutrient application. Therefore, this study was conducted to describe growth, seasonal dry weight, N uptake and distribution patterns under different fertility regimes for a stress-tolerator species and a competitor-species and to determine if nutrient loading can be accomplished for these two species.

Materials and Methods

Red oak acorns were collected on The Ohio State University campus in late September, placed in plastic bags and stratified at 7C (45F) in a walk-in cooler. In February, acorns were removed, sown in deep propagation flats and germinated in a greenhouse under natural photoperiods. Metro Mix 510 (The Scotts Co., Marysville, OH) was used as the germination medium. Greenhouse temperatures were set at 24/18C (75/65F) on a 12 hour cycle.

When seedlings emerged, they were lifted from the flat, the tap root pruned to 8 cm (3 in) length and transplanted to 13 cm (5 in) square, 16 cm (6.5 in), deep plastic containers (250 Classic, Nursery Supplies, Chambersburg, PA). Metro Mix 510 was used as the growing medium. The seedlings were grown under similar greenhouse conditions as the acorns were germinated. One month after potting, seedlings were fertilized weekly with 100 mg/liter N from 20N–8.6P–17K (20–20–20 Peters Fertilizer, The Scotts Co., Marysville, OH).

On May 15, seedlings were moved from the greenhouse to 70% shade outdoors for a two-week acclimation period. Seedlings received no fertilizer during the acclimation period. Seedlings were then potted in No. 3 round nursery containers (1000 Classic, Nursery Supplies, Chambersburg, PA [25 cm dia × 23 cm deep, 10 × 9 in]) using a pine bark:peat:sand (3:1:1 by vol) medium. The medium was amended with 2.2 kg/m (6 lbs/cu yard) dolomite and 0.4 kg/cu m (1 lb/cu yard) gypsum. Seedlings were placed on a gravel pad at a 0.45 m (18 in) within row, 1.2 m (48 in) between row spacing. Seedlings were irrigated twice daily for 45 minutes using one, 1.9 liters/hr (0.5 gal/hr) trickle emitter per container; thus each container received 2.9 liters (0.75 gal) of water per day.

Fertigation treatments were begun on June 28 when 2.9 liters of 0, 25, 50, 100, 200 or 400 mg/liter 20N–8.6P–17K water soluble fertilizer was applied daily in two, 45-minute irrigation events. Fertigation treatments were applied by individual Dosatron DI 16 injectors (Dosatron International, Inc., Clearwater, FL). Fertigation treatments continued through late October. Containers were arranged in a randomized complete block design with two replications of 25 seedlings per fertilizer treatment, a total of 300 red oak seedlings.

Also on June 28, 10 additional red oak seedlings were harvested to estimate initial seedling size. Individual seedling heights were measured and leaf area determined with a LI-3100 Area Meter (Li-Cor, Inc., Lincoln, NE). Individual seedling leaves, stems and roots were oven dried for 96 hr at 70C (158F) and dry weights of leaves, stems and roots were determined. The dry weights of leaves, stems and roots of individual seedlings were summed to determine total plant dry weight. Relative percent leaf, stem and root dry weight were calculated by dividing individual seedling leaf, stem and root dry weight by total plant dry weight and multiplying by 100.

Leaf, stem and root tissue of individual seedlings were ground in a Wiley mill to pass through a 20 mesh screen. Because of small plant size, there was insufficient material for individual seedling nutrient analysis, so leaf, stem and root tissues from the individual plants were combined and analyzed for N, P and K concentrations (mg/g plant tissue) at The Ohio State University Research Extension and Analytical Laboratory, Wooster.

Ten additional seedlings per treatment were randomly selected from the two replications for analysis on July 21, August 18, September 15, October 12 and December 15. Individual seedling heights, leaf areas and dry weights were determined and plant tissue prepared for nutrient analysis as before. However, tissue samples were not combined, but leaf, stem and root tissue from three randomly selected seedlings within each treatment were analyzed for N concentration (g N/g tissue dry weight).

Leaf, stem and root nutrient contents for the three seedlings per treatment were determined by multiplying the nutrient concentration in the plant sample by the dry weight of the respective plant part. Total seedling nutrient content was determined by summing the nutrient contents of an individual seedling's leaves, stems and roots. Relative nutrient contents of leaves, stems and roots were determined similar to the relative dry weight of leaves, stems and roots.

Similar growing and harvest procedures were followed for red maple plants. However, instead of seedlings, un-rooted micro-cuttings of *Acer rubrum* 'Autumn Flame' (Microplant Nurseries, Gervis, OR) were rooted under mist in February and transplanted to 250 Classic containers in March. There were two, 15-plant replications per fertilizer treatment, a total of 186 plants. At each harvest, three randomly selected individuals from each treatment were selected for analysis. Harvest procedures for the red maples were similar to the red oaks.

Because of unequal sample sizes, growth data (height, and dry weights) were analyzed by species. Data was subject to ANOVA using SPSS for the personal computer. Replication effects for red oak were not significant, so data was analyzed as single-plant replications. Similarly, the red maple analyses were done using three individual plant replications. Nutrient analyses for both species were analyzed as three, single-plant replications. Regression equations for plant growth (height, dry weight and relative dry weight distribution) and N content and concentration were developed using SPSS for the personal computer.

Results and Discussion

To simplify the presentation of results, only the data from the October harvest is presented.

Height. Red oak initial height averaged 27.4 cm (10.8 in). By mid-September, shoot elongation had stopped. In October, red oak seedling heights ranged from 57.5 cm (22.6 in) to 29 cm (11.4 in) for plants grown under the 400 and 50 mg/liter N treatments, respectively. 'Autumn Flame' red maple initial height averaged 24 cm (9.4 in); by October 12 heights ranged from 122.5 cm (48 in) to 33 cm (12.9) for plants grown

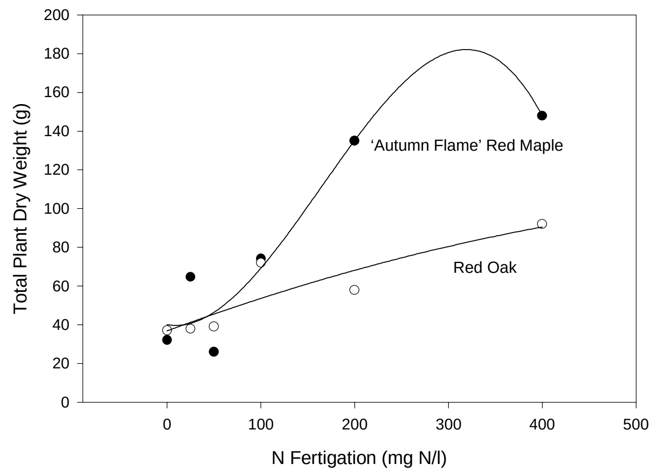

Fig. 1. 'Autumn Flame' red maple and red oak total plant October dry weight when grown under various N fertigation rates. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Red maple dry weight = 0.00000798 (rate)^3 – 0.00548 ((rate)^2 + 1.096 (rate) + 45.496, R^2 = 0.94; red oak dry weight = – 1.084 (rate)^2 + 0.1665 (rate) + 30.016, R^2 = 0.87.

under the 100 and 0 mg/liter N fertigation treatments, respectively.

Dry weight. Red oak October dry weight, as affected by N fertigation, was best described by a quadratic equation, while red maple dry weight was best described by a cubic equation (Fig. 1). The regression equation predicted optimum red maple dry weight to be achieved at approximately 300 mg N/liter fertigatioin. Rose et al. (28) found the optimum N

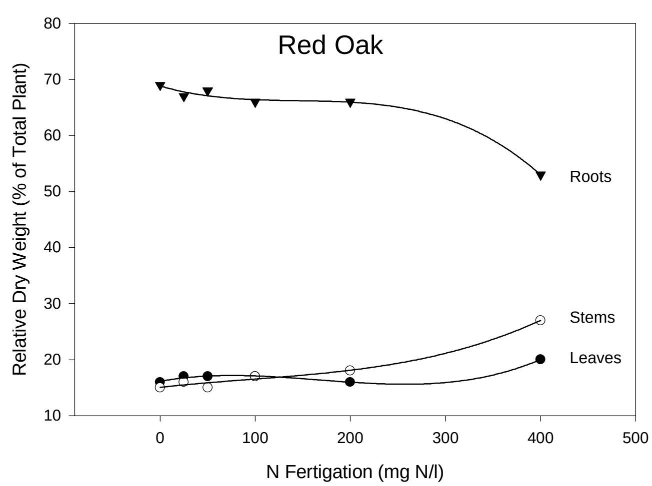

Fig. 2. Relative dry weight of red oak leaves, stems and roots in October when grown under various N fertigation rates. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Relative % leaf dry weight = 0.00000197 (rate)^3 – 0.00109 (rate)^2 + 0.136 (rate) + 30.316, R^2=0.42, relative % stem dry weight = –0.000000353 (rate)^3 + 0.000208 (rate)^2 – 0.0307 (rate) + 12.529, R^2= 0.46, relative % root dry weight = –0.00000161 (rate)^3 + 0.000879 (rate)^2 – 0.106 (rate) + 57.155, R^2=0.30.

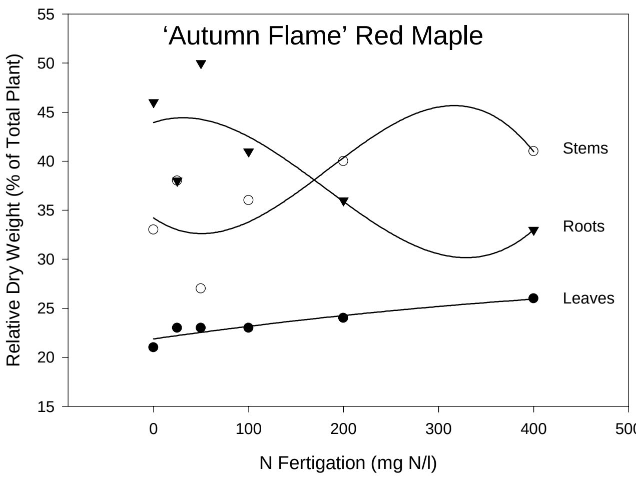

Fig. 3. Relative dry weight of 'Autumn Flame' red maple leaves, stems and roots in October when grown under various N fertigation rates. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Relative % leaf dry weight = 0.0293 (rate) + 29.723, R^2=0.98, relative % stem dry weight = –0.00000136 $(rate)^3$ + 0.000764 $(rate)^2$ – 0.0870 (rate) + 24.149, R^2=0.61, relative % root dry weight = 0.00000133 $(rate)^3$ – 0.000715 $(rate)^2$ + 0.0434 (rate) + 46.689, R^2=0.92.

concentration for Freeman maple growth was between 100 and 200 mg N/liter. However, the predicted optimum N fertilizer rate needs to be confirmed by growing red maple plants at several fertigation rates between 200 and 400 mg N/liter. The rate of N fertigation that maximized red oak dry weight was greater than 400 mg N/liter.

Relative dry weight distribution. In October, the relative dry weight of red oak roots decreased (from 69 to 53%) while the relative dry weight of the stems increased (from 15 to 27%) as the N fertigation levels increased from 0 to 400 mg N/liter (Fig. 2). The relative percent of leaf tissue dry weight ranged from 15 to 27%. In general, the equations predicting red oak relative leaf, stem and root dry weights had low R^2 values, meaning much of the variation in the relative percent dry weights of these tissues is unexplained by the regression equations.

For 'Autumn Flame' red maple, the relative percentage of root dry weight decreased (from 50 to 33%) as the N fertigation rate increased (Fig. 3). Stem and leaf relative dry weights increased (from 21 to 26% and 27 to 41%, respectively). The regression equations for red maple relative dry weights had higher R^2 values than those for red oak.

Nitrogen concentration. Nitrogen concentration in red oak leaf, stem and root tissue increased up to 200 mg N/liter fertigation and decreased slightly at 400 mg N/liter (Fig. 4). Leaf N concentration was approximately twice that of stem and root tissue. Red oak foliar N concentrations ranged from 2.0 to 2.7%. For 'Autumn Flame' red maple, N concentration in all tissues increased with increasing N fertigation rates (Fig. 5). Similar to red oak, red maple leaves had the highest N concentration. Red maple foliar N concentrations ranged from 1.8 to 3.0%. Jones et al. (17) found the average red maple foliar N concentration to be 2.61% although typical values can vary greatly. For instance foliar N levels ranged from 0.1 to 4.3% achieved under 5 and 100 mg/liter N fertilization (6). Foliar N levels (2.0 to 3.2% N) in this study were similar to Rose et al. (28) although they used lower (50 and 200 mg/liter N) fertilizer rates.

Tissue N content and relative N distribution. Grams of N in red oak leaf, stem and root tissue and in the whole plant increased up to 200 mg N/liter fertigation (Fig. 6). For red maple, the greatest N content of plant tissues and in the whole

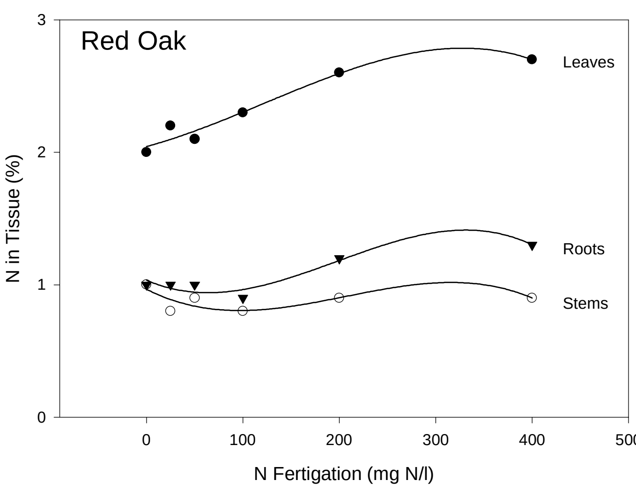

Fig. 4. Nitrogen concentrations in red oak leaf, stem and root tissue in October when grown under various N fertigation rates. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Leaf N % = –0.0000000239 $(rate)^3$ + 0.00000877 $(rate)^2$ + 0.00196 (rate) + 2.043, R^2 = 0.96, stem N % = –0.0000000403 $(rate)^3$ + 0.00000249 $(rate)^2$ – 0.00392 (rate) + 0.966, R^2=0.55, root N % = –0.0000000497 $(rate)^3$ + 0.000530 $(rate)^2$ – 0.00316 (rate) + 1.035, R^2=0.91.

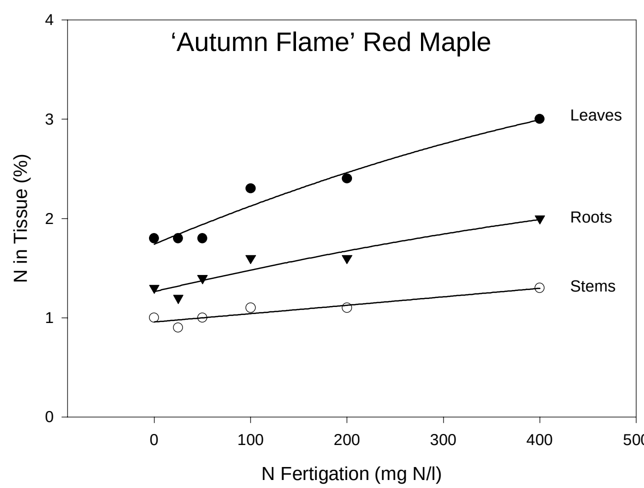

Fig. 5. Nitrogen concentrations in 'Autumn Flame' red maple leaf, stem and root tissue in October when grown under various N fertigation rates. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Leaf N % = –0.00000235 $(rate)^2$ + 0.00407 (rate) + 1.741, R^2 = 0.95, stem N % = 0.000000403 $(rate)^2$ – 0.00832 (rate) + 0.957, R^2 = 0.87, root N % = –0.0000117 $(rate)^2$ + 0.00228 (rate) + 1.263, R^2 = 0.91.

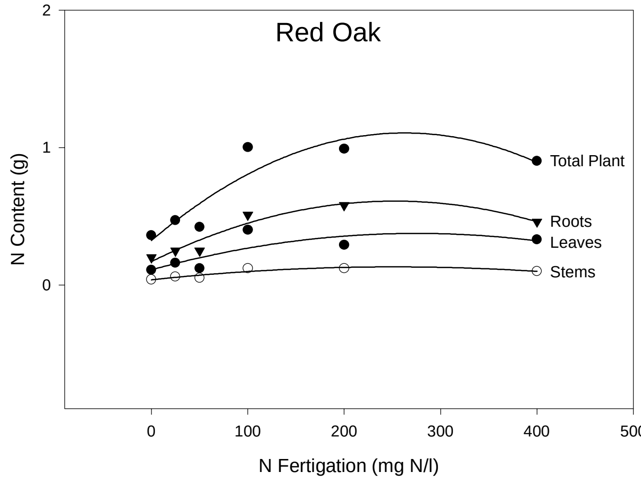

Fig. 6. Nitrogen content of red oak leaf, stem and root tissues in October after being grown under various N fertigation rate. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Grams N in leaves = 0.00000396 (rate)^2 + 0.00396 (rate) + 0.0469, R^2 = 0.97, grams N in stems = –0.00000150 (rate)^2 + 0.000751 (rate) + 0.0378, R^2 = 0.84, grams N in roots = –0.0000691 (rate)^2 + 0.00349 (rate) + 0.170, R^2 = 0.92, grams N in total plant = –0.0000113 (rate)^2 + 0.00596 (rate) + 0.323, R^2 = 0.84.

plant occurred at approximately 300 mg N/liter fertigation (Fig. 7). Red maple plants accumulated more N than red oak plants under the conditions of this experiment. The increased N accumulation of red maple, relative to red oak, results form both increased plant dry weight (Fig. 1) and higher tissue N concentrations (Figs. 4 and 5). Under the 400 mg N/liter fertigation rate, red maple plants had over twice the N content as red oak plants (2.4 vs 0.9 g).

In October, the relative % of total plant N contained in the stems of red oak was similar over all the fertigation rates (Fig. 8). Relative % N in leaves and roots varied inversely with each other over the fertigation treatments. The relative % of N in stem tissues of red maple plants was more variable than that of red oak stem tissue (Fig. 9 vs Fig. 8). Relative % total plant N in red maple leaf tissue increased with increasing fertigation rate, while that of root tissue decreased (Fig. 9).

Correlations, developed by combining red oak seedlings within a harvest date, between whole plant dry weight and whole plant % N and % foliar N were not significant between July and December (Table 1). However, whole plant N content (g N per plant) and whole plant dry weight were significantly correlated for the August through December harvests. Similarly, correlations between stem height and whole plant % N and foliar % N were not significant, but were significant for total plant N content for the August through December harvests. For red maple plants, similar significant correlations were found. In addition, foliar % N was significantly correlated with whole plant dry weight and stem height in October (Table 1). Throughout the growing season, N–P–K ratios of the whole plants remained relatively constant for both species (Table 2).

A goal of this study was to determine if nutrient loading could be accomplished with these two species. Nutrient loading is expected to occur at the higher N fertigation rates; it is identified by increased N content without an increase in plant dry weight. Nitrogen loading was not achieved for red oak. Under the conditions in this study, red oak dry weight increased up to 400 mg N/liter fertigation rate (Fig. 1) but tissue N concentrations did not (Fig. 6). With ‘Autumn Flame’ red maple plants nutrient loading was achieved. Predicted maximum red maple dry weight occurred at 300 mg N/liter (Fig. 1) and N tissue concentrations were higher in plants

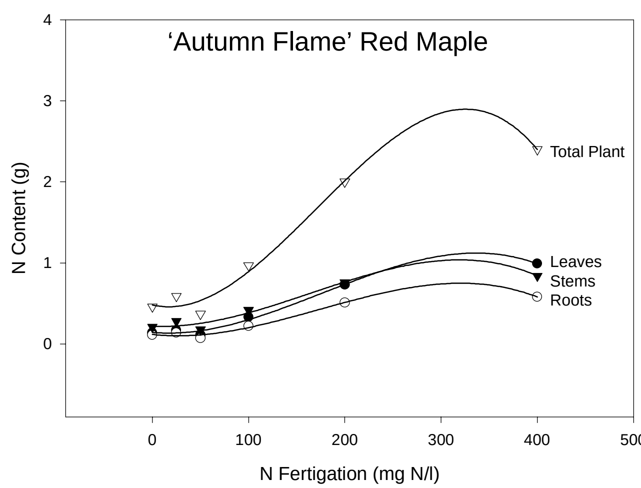

Fig. 7. Nitrogen content of ‘Autumn Flame’ red maple leaf, stem and root tissues in October after being grown under various N fertigation rate. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. Grams N in leaves = –0.000000129 (rate)^3 + 0.0000654 (rate)^2 – 0.00353 (rate) + 165, R^2 = 0.99, grams N in stems = –0.0000000982 (rate)^3 + 0.0000497 (rate)^2 – 0.00305 (rate) + 0.134, R^2 = 0.99, grams N in roots = –0.0000000188 (rate)^2 + 0.00161 (rate) + 0.200, R^2 = 0.95, grams N in total plant = –0.000000166 (rate)^3 + 0.0000854 (rate)^2 – 0.00278 (rate) + 0.483, R^2 = 0.99.

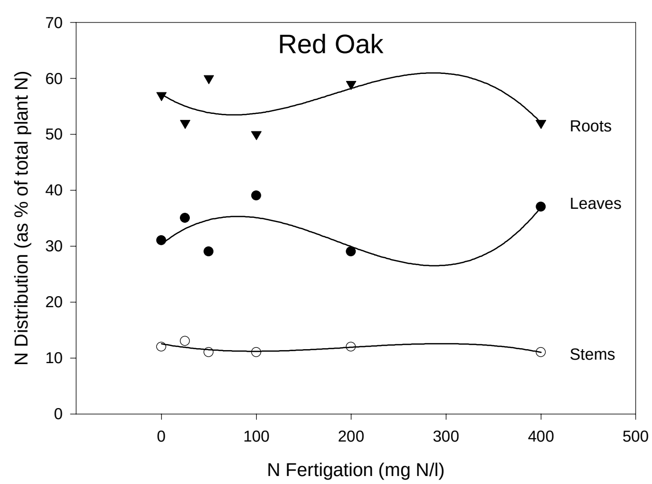

Fig. 8. Relative N distribution in red oak leaves, stem and roots, as a percentage of total plant N, in October. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. % total plant N in leaves = 1.966 (rate)^3 – 0.00109 (rate)^2 + 0.137 (rate) + 30.310, R^2 = 0.42, % total plant N in stems = –0.000000530 (rate)^3 + 0.000208 (rate)^2 – 0.0365 (rate) + 0.464, R^2 = 0.46, % total plant N in roots = –0.000000161 (rate)^3 + 0.000878 (rate)^2 – 0.106 (rate) + 57.164, R^2 = 0.30.

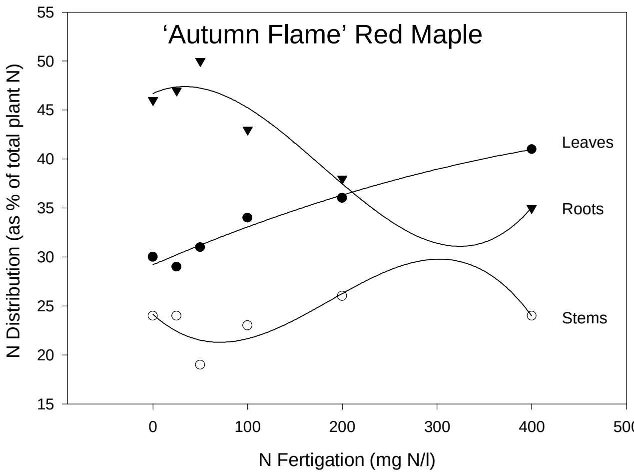

Fig. 9. Relative N distribution in 'Autumn Flame' red maple leaves, stem and roots, as a percentage of total plant N, in October. Plants were fertigated from June to October with various N concentrations from 20N–8.6P–17K water soluble fertilizer. % total plant N in leaves = –0.0000308 (rate)^2 + 0.0417 (rate) + 29.203, R^2 = 0.42, % total plant N in stems = –0.0000136 (rate)^3 + 0.000764 (rate)^2 – 0.0875 (rate) + 24.155, R^2 = 0.61, % total plant N in roots = 0.00000133 (rate)^3 – 0.000715 (rate)^2 + 0.0435 (rate) + 46.693, R^2 = 0.92.

grown under 400 than at 200 mg N/liter fertigation (Fig. 5). Conifer transplanting studies have demonstrated the benefits of nutrient loading (14, 23, 24, 26, 32). Any benefits of N loading hardwood species must be confirmed by transplanting studies. If beneficial, then nursery managers can offer customers higher quality plants — ones with reduced short-term fertilizer needs.

'Autumn Flame' red maple plants grew more rapidly than did the red oak seedlings. Although 'Autumn Flame' red maple initial dry weight was less than half that of the red oak seedlings (3.8 vs 9.3 g), red maple dry weight was greater than red oak dry weight in October (128.4 vs 92.0 g).

High N fertigation rates produced the largest red maple root systems (in October, root systems of plants fertilized with 400 mg/liter N averaged 42.4 g; under 0 mg/liter N roots averaged 13.3 g) but proportionally, the root system represented a lower percentage of total plant dry weight, 33 vs 46% of total plant dry weight for 0 and 400 mg/liter N treatments, respectively. Concomitant with a shift in relative total plant dry weight from the roots to the shoots, was a redirection of the relative proportion of total plant N from the root system to the leaves and stems, a result found by others (7, 27). 'Autumn Fame' red maple's ability to alter growth in response to differences in nutrient availability is consistent with a competitor-species growth habit (8). Competitor-species have the ability to rapidly turn over leaves and roots so as to continuously respond to environmental changes. Adjustments in relative dry weight are made to maximize growth. For instance, in a nutrient rich environment, competitor-species reduce resource allocation to roots and increase allocation to leaves and shoots. Thus, shoot growth is maximized, an important factor for shade intolerant early successional species.

Table 1. Seasonal correlation coefficients between whole plant dry weight and stem height, and whole plant N concentration and content for red oak and red maple seedlings grown under various N fertigation rates.

	July	August	September	October	December
Red oak					
	Seasonal whole plant dry weight				
Whole plant % N	0.13	0.32	0.76	0.64	0.87
Foliar % N	0.28	0.40	0.84	0.82	NA
Total plant N content	0.73	0.91+[z]	0.97++	0.98++	0.99++
	Stem height				
Whole plant % N	–0.01	0.69	0.80	0.72	0.73
Foliar % N	–0.12	0.66	0.84	0.84	NA
Total plant N content	0.46	0.99++	0.97++	0.99++	0.92+
Red maple					
	Seasonal whole plant dry weight				
Whole plant % N	NA	0.79	0.29	0.84	0.65
Foliar % N	–0.31	0.68	0.42	0.91++	NA
Total plant N content	0.86	0.96+	0.93+	0.98++	0.99++
	Stem height				
Whole plant % N	NA	0.77	0.15	0.70	0.35
Foliar % N	–0.44	0.63	0.23	0.90	NA
Total plant N content	0.69	0.91+	0.81	0.91+	0.70

[z]+ and ++ indicate significance at P < 0.05 and 0.01, respectively.

Table 2. **Seasonal whole plant N–P–K ratios of red oak and red maple seedlings grown under fertigation rates.**

Species	Harvest date	Ratio N	Ratio P	Ratio K
Red oak	June 28	4.4[z]	1	2.5
	July 21	4.4	1	2.3
	August 18	3.8	1	2.1
	September 15	3.6	1	1.9
	October 12	3.7	1	1.8
	December 15	4.1	1	1.6
Red maple	June 28	4.6	1	2.4
	July 21	4.6	1	3.0
	August 18	4.1	1	2.5
	September 15	2.3	1	1.6
	October 12	3.8	1	1.9
	December 15	5.1	1	2.0

[z]Each value is the mean of 18 plants, except the initial (June 28) harvest, which is the mean of three plants. Means for the harvests dates other than the initial have been averaged over N fertigation rates.

Ease of transplanting and shoot response to N fertility are two reasons why the nursery industry tends to produce early successional species. Early successional species (*Ulmus* sp., *Acer rubrum*, *Betula papyrifera*, and *Fraxinus pennsylvanica* are examples) tend to have fibrous root systems which makes transplanting easy (29). These early successional species respond to high fertility by increasing growth rate, but increasing shoot growth proportionally more than root growth. High shoot:root ratios, induced by resource rich production environments, may reduce plant quality and fitness to purpose; they may have low survival and establish slowly in nutrient poor and/or drought-prone landscape sites. High fertility rates also increased foliar N concentration. Foliar N concentrations were also increased when another early successional species, paper birch (*Betula papyrifera*), was grown under high N fertility (3, 12, 13, 15, 25, 33). High foliar N concentration increased susceptibility to defoliating insects (4, 5, 12, 20).

The practical significance to the nursery producer is that high fertility increases the shoot:root ratio. But, although the relative percentage of the root system dry weight is reduced, high fertility produced the greatest root dry weight. High fertility increased tissue N concentrations. Transplanting studies are needed to determine if the benefits of N loading (greater root mass and nutrient content) outweighs its disadvantages (increased shoot:root ratio and increased susceptibility to pests).

In contrast, red oak under high N fertigation did not alter its growth to the same degree as red maple did, a response characteristic of stress tolerator species. For example, red maple foliar concentrations ranged from 1.8 to 3.0%, red oak ranged from 1.9 to 2.7 %. Others have found red oak foliar N concentrations to be relatively stable over a range of N fertility: 1.6 to 1.9% for a range of site qualities (9); 1.1 to 1.2% under a three-fold difference in N loading (30); 0.9 to 1.6 under a two-fold difference in soil N mineralization rate (18) and 0.98 to 1.7% under a ten-fold difference in N concentrations (21). Jones et al. (17) found foliar N averaged between 1.9 to 3.0% for *Quercus* spp. One study has reported variation in foliar N concentrations similar to red maple; red oak foliar N concentrations ranged from 0.5 to 3.0% under fertility levels ranging from 5 to 100 mg/liter N (6). The results of this study agree with the stress-tolerator growth habit of red oak found by others (6, 9, 18, 19, 21). Red oak did respond to increased N fertility by increasing growth (both height and dry weight), but did so proportionally.

For both species, most height growth was completed by mid-September, even under the high N fertility rates used in this study. Rose et al. (28) demonstrated that late fall fertilization did not predispose Freeman red maple to fall freeze damage.

Shoot:root ratio for both species was highest in early summer and decreased into October (data not presented). Thus, transplanting container plants between June and August, when shoot:root ratios are highest, may result in greater plant stress than transplanting between mid-September and October. Seasonal N accumulation followed a pattern similar to dry weight accumulation; dry weight and total plant N content, and plant height and total plant N content were highly correlated (Table 1). The stress-tolerant species (red oak), which had a higher proportion of dry weight in the root system, also had a higher percentage of total plant N in the root system, relative to the competitor species, red maple.

The N distribution pattern suggests a reason other than root morphology as to why field grown red oak are more difficult to transplant than red maple. Significant root loss occurs when field grown nursery stock is harvested (31). Root loss would also significantly reduce total plant N. In December, 82% of the total N content of red oak seedlings was contained in the root system; in red maple it was 66%. Digging field-grown red oak may induce N deficiency. Container production (with appropriate root control methods (1)) of coarse-rooted species would not only reduce root loss, but would also retain most of the plant's N.

One way to increase fertilizer efficiency is to match fertilizer N–P–K ratios with seasonal plant mineral nutrient ratios. The fertilizer used in this study, 20N–8.6P–16.6K, has an N–P–K ratio of 2.3–1–1.9 when N and K contents are expressed relative to P. The N and K accumulation, relative to P, for red oak ranged from 4.4 to 3.6 for N and 2.5 to 1.6 K; for red maple they ranged from 2.3 to 5.1 N and 1.6 to 3.0 K, respectively. A fertilizer with relatively higher N and K content than the one used in this study, would have better matched red oak and red maple N–P–K whole plant ratios.

For two reasons, it is not unexpected to have non-significant correlations between N concentration and stem height and whole plant dry weight. First, in both species leaves contained 50% or less of the total plant N. Second, the fertigation treatments did not consistently affect N concentration in red oak leaves, stems and roots throughout the season.

The principles demonstrated in this study are:

- The competitor-species, red maple, had a faster growth rate than the stress-tolerator species, red oak.
- Red maple responded to a nutrient rich environment by increasing its growth rate and redirecting proportionally more dry weight and N to the stems and leaves and less to the root system.
- Red oak responded to a nutrient rich environment by increasing its growth rate, but the redistribution in dry weight and N was less than red maple. It grew proportionally larger in a nutrient rich environment.

Additional research with other stress-tolerator and competitor-species is needed to determine if the growth response to N fertilizer of these two species was species specific, or represents a generalized response of stress-tolerator and competitor-species to nutrient rich environments.

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