Nitrogen, Phosphorus and Potassium Recovery of Container-Grown Red Oak and Blackgum Seedlings Under Different Fertilizer Application Methods[1]

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Abstract

Red oak (*Quercus rubra* L.) and blackgum (*Nyssa sylvatica* L.) seedlings were grown under five fertilizer application methods: 60 or 30 g slow release fertilizer (21N–1.8P–8.3K: Woodace 21–4–10) with a daily application of 3.8 liters of 25 mg/liter N from a water soluble fertilizer (15N–6.9P–14.1K: 15–16–17 Peter's) or not, or 3.8 liters daily application of 25 mg/liter N from a water soluble fertilizer. The largest red oak and blackgum seedlings were grown under a combination of water soluble plus 60 g slow release fertilizer. Red oak N, P and K recovery rates ranged from 4.1 to 8.6%, 4.5 to 8.8% and 4.2 to 16.5%, respectively. Blackgum N, P and K recovery rates ranged from 12.1 to 19.2%, 15.5 to 23.6% and 13.7 to 37.8%. Plant growth (both dry weight and height) was more highly correlated with total plant nutrient content (mg N/plant) than with whole plant nutrient concentration (mg N/g dry weight), except for K in blackgum seedlings. The results suggest that red oak and blackgum seedling N and P nutritional status is more accurately predicted by plant height or dry weight than by tissue concentration.

Index words: water soluble fertilizer, slow release fertilizer, electrical conductivity, nutrient recovery.

Significance to the Nursery Industry

Red oak and blackgum seedlings were fertilized by five treatments: at one, four tablespoons or a split application of two tablespoons 21–4–10 (21N–6.9P–14.1K) Woodace slow release fertilizer per container, the same slow release fertilizer treatments combined with daily 3.8 liters (one gal) 25 mg/liter N fertigation from 15–16–17 Peter's water soluble fertilizer or 25 g/liter N fertigation only. The largest seedlings were produced at the highest fertilizer rate, a combination of slow release fertilizer and fertigation. Plant N, P and K recovery by both species under all treatments was low, typically ranging between 4 and 38% of the total amount applied. The most efficient fertilizer application methods resulted in the smallest seedlings. Plant tissue N–P–K ratios were approximately 3–1–1 to 3–1–2, suggesting that fertilizer use efficiency would be increased by matching fertilizer N–P–K ratios with plant tissue N–P–K ratios. Red oak and blackgum plant dry weights were highly correlated with total plant N and K contents, suggesting that N and K nutrition for these species can be mannaged by measuring plant height or dry weight rather than by analyzing plant tissue N and K concentrations.

Introduction

Information on nutrient losses from container nurseries is needed so that environmental quality can be maintained. Studies have shown that under a range of fertilizer application methods and irrigation practices, run-off from nurseries has met current water quality standards (2, 15). However, in one study nitrate-N concentrations in leachate periodically exceeded 10 mg/liter even though slow release forms of fertilizer were used (16). There is little information on the nutrient losses (the difference between amount of nutrient(s) applied and the amount recovered by the plant) under current production practices.

Typically, woody plant nutrition studies measure plant growth and/or foliar nutrient concentrations while monitoring container leachate under different nutrient application rates, methods of application or timing of applications (3, 5, 6, 9). Only a few studies have determined whole plant nutrient recovery or nutrient partitioning within the plant (4, 7, 13). Whole plant nutrient recovery can be estimated by multiplying tissue nutrient concentration by total plant dry weight. An understanding of whole plant nutrient accumulation would allow refinement of nutrient application methods and rates, and a decrease in nutrient losses. This paper describes growth and N, P and K recovery by two species, red oak and blackgum, under five different slow release and water soluble fertilizer treatment combinations.

Materials and Methods

Red oak acorns and blackgum fruit were collected from a single tree of each species; the acorns from a tree on The Ohio State University campus, the blackgum fruit from a tree at Dawes Arboretum, Newark, OH. Acorns were picked from the mother tree in September, placed in plastic bags and put in a 2C (38F) walk-in cooler until sown in February. Blackgum seeds were handled similarly, except that the flesh was removed from the fruit before the seeds were placed in moist peat moss at 2C (38F).

Seedlings were produced according to Ohio Production System procedures (12); seeds were germinated in mid-February, transplanted in mid-March to Spinout-treated (Griffin Corp, Valdosta, GA) square plastic containers (250 XL Classic Nursery Supplies, PA) using Metro Mix 360 (O.M. Scotts and Son, Marysville, OH) growing medium. Plants were grown in a heated greenhouse until mid-May, when they were transferred outdoors to 70% shade for one week. All plants were repotted in to Spinout-treated No. 3 round

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black plastic containers (filled volume of 1325 cm^3, Custom black containers, Nursery Supplies, Fairless Hills, PA) by June 1. Seedlings were potted in a 2:2:1 (by vol) sand:Comtil (composted municipal sewage sludge, City of Columbus, OH):Isolite (porous ceramic product, Sumitomo Corp. of America, Denver, CO) medium. This medium supported vigorous growth and could be easily removed from the root systems (Struve, unpublished data), thus allowing for root system dry weight and nutrient analysis measurements.

There were five water soluble-slow release fertilizer treatment combinations per species. The plants received either a split application of two, 15 g (the '30 gm slow release treatment' [2 tablespoons]), or one, 60 g (4 tablespoons) application of 21N–1.8P–8.3K (21–4–10 Woodace Vigoro Industries, Inc., Winter Haven, FL) slow release fertilizer per container on June 6. The second 15 g application was made on July 15. The 30 g slow release fertilizer treatment was chosen because red oak and blackgum seedlings grown at that rate had similar dry weights and heights as seedlings given one 60 g slow release fertilizer treatment (Struve, unpublished data). However, unknown was if the mineral nutrient contents of the seedlings were similar. Half of the seedlings treated with slow release fertilizer also received daily fertigation with 3.8 liters (1 gal) of 25 mg/liter N from 15N–6.9P–14.1K (15–16–17, Peter's, O.M. Scotts and Son, Co. Marysville, OH) water soluble fertilizer applied from June 1 to September 30. The fifth fertilizer application method was a daily 3.8 liter (1 gal) application of 25 mg/liter from the same water soluble fertilizer as before from June 1 to September 30. All plants received the same volume of irrigation water, 3.8 liters (1 gal) per day.

Beginning on June 28 and continuing at two week intervals until September30, leachate analyses were conducted on the same three plants within each species and fertilizer application method. Leachate was collected using the pour-through method of Wright (14). Columbus, OH, tap water was used for the leachate extractions. Electrical conductivity was measured using a Cardi C–173 (Horiba Instruments, Inc. Irvine, CA) compact conductivity meter. Nitrate-N was measured using a Cardi C–141 nitrate-N compact ion meter. Parts per million nitrate-N were converted to mg/liter N by multiplying the nitrate-N value by 0.226. At each sampling, the electrical conductivity and nitrate N of Columbus tap water were determined.

Plant heights were measured on June 10, August 20 and October 10. On July 15 (just before the second slow-release fertilizer application) and October 10, three ramdomly selected seedlings from each treatment were harvested. The medium was washed from the root systems, leaves removed and the roots severed from the stem by pruning at the root collar. All plant parts were oven dried and weighed. Plant parts were combined and ground to pass through a 20 mesh screen. A tissue sub-sample was analyzed for N, P and K concentration at the Research and Extension Analytical Laboratory, Ohio Research and Development Center, Wooster, OH. Total plant nutrient recovery was estimated by multiplying total plant dry weight by the tissue nutrient concentration.

Total nutrient loading per container (on an elemental basis) for each fertilizer treatment was calculated by summing the grams of N, P or K in each fertilizer source. The amount of nitrogen and phosphorus from Comtil was calculated by determining the volume of Comtil in a container (40% of 1325 cm^3 of medium volume per container), multiplying by the bulk density of Comtil (0.32 g cm^3) and the nutrient analysis (2N–1.3P–0K [2–3–0]).

For each species, seedlings were placed in a randomized complete block design with two 10-plant replications. Data were analyzed, by species, using the Oneway and ANOVA procedures (8). Within a species and harvest date, the Student-Newman-Kuels procedure was used to declare means significantly different at the $\alpha = 0.05$ level. Correlations between mean plant dry weight and mean nutrient concentration and estimated total plant nutrient content were developed using the Regression procedure in QuatroPro 4.0 (1).

Results and Discussion

Seedling height. On October 10, red oaks given a combination of 30 g slow release and water soluble fertilizer were significantly taller than those given only water soluble fertilizer or those given only slow release fertilizer (Table 1). There were no significant differences in red oak height on either June 10 or August 20.

On August 20, blackgum seedlings given a combination of water soluble and one 60-g application of slow release fertilizer were significantly taller than those given 30 g slow release fertilizer application (Table 1). On October 10, blackgum seedlings given a combination of 60 g slow release fertilizer and water soluble fertilizer were significantly taller than those given only slow release fertilizer. There was no difference in growth between blackgum seedlings given either 30 or 60 g slow release fertilizer. Shiflett, et al. (10) found similar results.

Seedling dry weight. There were no significant differences in red oak seedling total plant dry weight or in dry weight allocation at either the July or October sampling dates (Table 2). Total plant dry weight ranged from 55.3 to 100.7 g (water soluble only vs water soluble plus 60 g slow release fertilizer) at the October 10 harvest).

Table 1. Height of red oak and blackgum plants grown under five fertilizer treatments on three dates.

Species	Fertilizer treatment	Height (cm) June 10	August 20	October 10
Red oak	WS[z]	17.4a[x]	31.9a	33.5b
	WS + 60 g SR[y]	23.1a	55.3a	62.0ab
	WS + 30 g SR	23.7a	52.1a	63.2a
	60 g SR	20.4a	36.9a	40.4b
	30 g SR	22.6a	37.7a	40.4b
Blackgum	WS	18.9a	90.6ab	128.8ab
	WS + 60 g SR	19.1a	99.4a	141.9a
	WS + 30 g SR	15.1a	80.6ab	116.8ab
	60 g SR	15.3a	81.6ab	100.3b
	30 g SR	14.2b	66.1b	80.6b

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/liter N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

[x]Means within a column and species followed by different letters are statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test.

Table 2. **Red oak and blackgum dry weight distribution on two dates. Plants of each species were grown under five fertilizer treatments. Each value is the mean of three plants per species and sampling date.**

		July 15 Dry weight (g)				October 4 Dry weight (g)			
Species	Fertilizer treatment	Root	Shoot	Leaves	Total plant	Root	Shoot	Leaves	Total plant
Red oak	WS[z]	3.9	2.4	5.5	11.8	37.2	9.5	8.7	55.3
	WS + 60 g SR[y]	7.0	5.3	9.7	22.0	66.0	20.0	14.7	100.7
	WS + 30 g SR	8.4	5.0	9.1	22.5	40.4	21.7	17.0	79.1
	60 g SR	7.9	3.9	7.0	18.8	45.4	13.5	12.2	70.1
	30 g SR	8.6	12.3	18.9	39.8	45.7	15.2	11.2	72.1
Blackgum	WS	12.5	16.1	29.4a[x]	58.0a	110.2	56.4	45.6ab	212.2ab
	WS + 60 g SR	17.1	17.3	30.3a	64.7a	130.2	75.8	52.2ab	258.2a
	WS + 30 g SR	9.9	12.4	21.5ab	48.8ab	103.2	63.6	74.4a	241.2ab
	60 g SR	5.4	4.8	9.2b	19.4b	66.4	33.8	22.4b	123.1ab
	30 g SR	5.5	4.4	9.1b	19.0b	56.7	28.5	20.4b	105.4b

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/liter N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

[x]Means within a column and species followed by different letters are statistically different from each other at the a = 0.05 level, using the Student-Newman-Kuels test. Means within a column where no letter occurs are not statistically different from each other at the a = 0.05 level, using the Student-Newman-Kuels test.

In July, blackgum leaf and total plant dry weights for the water soluble only and water soluble plus 60 g slow release fertilizer treatments were significantly greater than either slow release only fertilizer treatments (Table 2). In October, blackgum total plant dry weight under a combination of water soluble and 60 g slow release fertilizer was significantly greater than under the 30 g slow release fertilizer application.

Nutrient loading. Through July 15, N loading ranged from 6.6 g (30 g slow release only, Table 3) to 20.3 g (water soluble plus 60 g slow release fertilizer). An estimated 3.4 g N was attributed to Comtil. Comtil is a slow release form of N, so all 3.4 g N in Comtil would not have been released by July or October harvests. However, Comtil N is included to account for all potential nutrient sources. By September 30, cumulative N loading ranged from 9.7 g to 27.6 g N (Table 3).

Phosphorus loading ranged from 2.5 g (30 g slow release fertilizer, Table 3) to 4.0 g (water soluble plus 60 g slow release fertilizer) and from 2.8 g to 5.3 g by September 30. Potassium loading ranged from 1.2 g (30 g slow release,

Table 3. **N, P and K sources and cumulative amounts applied per container between June 1 and September 30.**

	Source and amount of nutrient applied (g per container)							
	June 1 to July 15				June 1 to September 30			
Fertilizer treatment	Comtil	WS	SR	Total	Comtil	WS	SR	Total
				Nitrogen				
WS[z]	3.4	4.3	0.0	7.7	3.4	11.6	0.0	15.0
WS + 60 g SR[y]	3.4	4.3	12.6	20.3	3.4	11.6	12.6	27.6
WS + 30 g SR	3.4	4.3	3.2	10.8	3.4	11.6	6.3	21.3
60 g SR	3.4	0.0	12.6	16.0	3.4	0.0	12.6	16.0
30 g SR	3.4	0.0	3.2	6.6	3.4	0.0	6.3	9.7
				Phosphorus				
WS	2.2	0.7	0.0	2.9	2.2	2.0	0.0	4.2
WS + 60 g SR	2.2	0.7	1.1	4.0	2.2	2.0	1.1	5.3
WS + 30 g SR	2.2	0.7	0.3	3.2	2.2	2.0	0.6	4.7
60 g SR	2.2	0.0	1.1	3.3	2.2	0.0	1.1	3.3
30 g SR	2.2	0.0	0.3	2.5	2.2	0.0	0.6	2.8
				Potassium				
WS	0	2.9	0.0	2.9	0	7.7	0.0	7.7
WS + 60 g SR	0	2.9	4.9	7.8	0	7.7	4.9	12.7
WS + 30 g SR	0	2.9	1.2	4.1	0	7.7	2.5	10.2
60 g SR	0	0.0	4.9	4.9	0	0.0	4.9	4.9
30 g SR	0	0.0	1.2	1.2	0	0.0	2.5	2.5

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/liter N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

Table 4. **Electrical conductivity (mS/cm) and ppm nitrate-nitrogen in leachate collected from red oak and blackgum seedlings grown under five different fertilizer regimes. The leachate was collected by the pour-through method using Columbus, OH, tap water (Control readings).**

		Leachate collection date									
		June 28		July 15		August 1		August 15		August 30	
Species	Fertilizer treatment	EC (mS/cm)	$N\text{-}NO_3$ (mg/liter)	EC (mS/cm)	$N\text{-}NO_3$ (mg/liter)	EC (mS/cm)	$N\text{-}NO_3$ (mg/liter)	EC (mS/cm)	$N\text{-}NO_3$ (mg/liter)	EC (mS/cm)	$N\text{-}NO_3$ (mg/liter)
Red oak	WS	1.8	40ab	1.1	22b[z]	1.0	18c	1.2	37	1.2	15
	WS + 60 g SR	2.1	49ab	0.8	20b	0.7	57a	0.8	20	0.8	13
	WS + 30 g SR	2.5	65a	0.8	23b	0.6	39b	0.5	53	0.5	11
	60 g SR	0.9	45ab	0.8	34a	0.8	38b	0.7	17	0.7	14
	30 g SR	0.5	27b	0.8	28ab	1.2	27a	0.7	36	0.7	12
Blackgum	WS	0.7	33	0.7	23	0.6	27b	0.3	19	0.3b	11
	WS + 60 g SR	0.8	31	1.0	25	1.0	18b	0.5	57	0.5ab	12
	WS + 30 g SR	0.7	33	0.7	22	0.8	37ab	0.8	52	0.8a	17
	60 g SR	0.7	29	0.5	19	0.6	57b	0.5	69	0.5ab	12
	30 g SR	0.7	28	0.7	20	1.0	74a	0.5	36	0.6ab	11
Columbus tap water		0.2	3.0	0.2	0.5	0.2	0.0	0.3	0.0	0.3	0.4

[z]Means within a column and species followed by different letters are statistically different from each other at the a = 0.05 level, using the Student-Newman-Kuels test. Means within a column where no letters occurs are not statistically different from each other at the a = 0.05 level, using the Student-Newman-Kuels test.

Table 3) to 7.8 g by July (water soluble plus 60 g slow release fertilizer, Table 3) and from 2.5 g to 12.7 g by September 30.

Leachate electrical conductivity and nitrate-nitrogen concentration. On June 28th, red oak leachate EC ranged from 2.5 to 0.5 mS/cm (Table 4). Electrical conductivity for the water soluble plus slow release fertilizer treatments decreased by over 250% between June 28 and July 15 (from 2.1 to 0.8 mS sq cm) indicating that the slow release fertilizer had released a significant amount of fertilizer salts. Other researchers have found similar rapid release of slow release fertilizers (5, 10). Leachate EC from the 30 g slow release fertilizer treatments increased from 0.8 to 1.2 mS/cm between July 15 and August 1, reflecting the second 15 g application (on July 15) of slow release fertilizer. There was no corresponding increase in leachate EC after the second slow release application in the 30 g slow release plus water soluble fertilizer treatment; electrical conductivity was 0.8 mS/cm on July 15 and 0.6 on August 1. Electrical conductivity remained relatively constant in the other treatments after July 15.

On June 28, red oak leachate nitrate-N was significantly lower in the 30 g slow release fertilizer only treatment than in the 30 g slow release plus water soluble fertilizer treatment (Table 4). During July 15 and August 1 leachate from the water soluble fertilizer treatment had the lowest nitrate-N levels; after August 15 there were no statistical differences in nitrate-N levels among the fertilizer treatments.

There were few statistical differences in EC and nitrate-N levels in blackgum leachate. On August 1, nitrate-N levels were significantly greater in the 30 g slow release fertil-

Table 5. **Whole plant nitrogen concentration (mg/g) and total g N/plant (estimated by multiplying plant dry weight by tissue nitrogen concentration, g/plant) at two harvest times for red oak and blackgum seedlings grown under five fertilizer application methods. Percent nitrogen recovery is the ratio between the total amount of nitrogen in the plant tissue to the total amount of nitrogen applied as reported in Table 3.**

		July 15			October 10		
Species	Fertilizer treatment	mg/g	total (g)	Plant recovery (%)	mg/g	total (g)	Plant recovery (%)
Red oak	WS[z]	170	0.20	2.6	110	0.61b[x]	4.1
	WS + 60 g SR[y]	187	0.41	2.0	119	1.20a	4.3
	WS + 30 g SR	177	0.39	3.7	126	1.00ab	4.7
	60 g SR	170	0.32	2.0	114	0.80ab	5.0
	30 g SR	158	0.62	9.5	116	0.84ab	8.6
Blackgum	WS	172	1.00a	13.0	112b	2.37b	15.8
	WS + 60 g SR	172	1.11a	5.5	153ab	3.95a	14.3
	WS + 30 g SR	185	0.90ab	8.4	126bc	3.03ab	14.3
	60 g SR	190	0.36b	2.3	157ab	1.93b	12.1
	30 g SR	175	0.33b	5.0	177a	1.87b	19.2

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/liter N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

[x]Means within a column and species followed by different letters are statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test. Means within a column where no letters occurs are not statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test.

izer treatment than in the other treatments, reflecting the addition of the second 15 g slow release fertilizer application made two weeks earlier. On August 30, EC was greater in the water soluble plus 60 g slow release fertilizer treatment combination than in the water soluble fertilizer treatment only. Throughout the growing season, Columbus tap water contributed little to either the nitrate-N or EC readings of the leachate samples (Table 4).

Plant nutrient concentration and total plant nutrient recovery: nitrogen. Red oak whole plant N concentrations ranged from 158 to 187 mg/g on July 15, and from 110 to 126 mg/g on October 10 (Table 5). Whole plant N concentrations were low compared to suggested sufficient foliar N levels (11). Red oak foliar N concentrations are higher than root and stem N concentrations (Larimer and Struve, unpublished data), thus whole plant N concentration would be less than foliar N concentrations. There were no statistical differences in whole plant N concentrations at the July and October harvests (Table 5).

Red oak total plant N content (the product of plant dry weight and tissue N concentration) ranged from 0.20 to 0.62 g at the July harvest to 0.61 to 1.20 g N at the October harvest (Table 5). At the October harvest, red oak given a combination of water soluble fertilizer with one, 60 g application of slow release fertilizer contained significantly more N than red oak given only water soluble fertilizer.

The percent N recovery for red oak seedlings, the ratio between plant N content at a harvest date and the total amount of N applied, ranged form 2.0 to 9.5% at the July harvest to 4.1 to 8.6% at the October harvest (Table 5). The estimates of percent plant N recovery are low because of the inclusion of Comtil-N, a slow release N form. However, Comtil N was at most 1/3 of the total amount applied, so plant recovery would not increase significantly if omitted. A N budget was beyond to scope of this project, therefore the amount of N lost to leaching, de-nitrification or remaining in the medium is unknown. The most efficient method of N application, a split application of 30 g slow release fertilizer without liquid feed, resulted in smaller plants than the least efficient N application method: water soluble only. However, N recovery was low for all fertilization methods. To adopt the most efficient fertilizer application method identified in this study would not be justified; the small increase in percent N recovery would not off set the corresponding reduction in plant growth.

Blackgum seedling N concentrations ranged from 172 to 190 mg/g in July to 112 to 177 mg/g in October (Table 5). In October, blackgum seedlings given a 30 g application of slow release fertilizer had a significantly greater N concentration than seedlings given only water soluble fertilizer or water soluble plus a 30 g application of slow release fertilizer.

Total plant N content ranged from 0.33 to 1.11 g N in July to 1.87 to 3.95 g N in October (Table 5). At both harvest dates seedlings grown under a combination of water soluble plus one 60 g slow release fertilizer application had significantly greater N content than those grown under either slow release only application methods.

Percent plant N recovery ranged from 2.3 to 13% in July to 12.1 to 19.2% in October (Table 5). As with the red oak N recovery values, the blackgum values are low because Comtil N content is included in the N loading value.

The shortest blackgum seedlings (and the shortest red oak seedlings) were produced under the fertilizer application method (30 g slow release fertilizer) with the most efficient plant N recovery. However, unlike red oak, the tallest blackgum seedlings were produced with a relatively high percent plant N recovery of 14 to 16%, in contrast to the 4% N recovery of red oak. The difference in percent plant N recovery between species is attributed to greater growth of blackgum than red oak seedlings. The inference is that N uptake and growth are correlated. The relationship between plant dry weight and N concentration and content will be discussed in a later section.

Phosphorus. There were no significant differences in P concentrations or total plant phosphorus contents within either harvest date for red oak seedlings (Table 6). Percent plant P recovery rates ranged from 1.4 to 3.7% on July 15, to 6.2 to 8.8% on October 10 harvests (Table 6). Comtil was

Table 6. Whole plant phosphorus concentration (ug/g) and amount (estimated by multiplying plant dry weight by tissue phosphorus concentration, ug/plant) at two harvest times for red oak and blackgum seedlings grown under five fertilizer application methods. Percent phosphorus recovery is the ratio between the total amount of nitrogen in the plant tissue to the total amount of phosphorus applied as reported in Table 3.

		July 15			October 10		
Species	Fertilizer treatment	ug/g	Total (g)	Plant recovery (%)	ug/g	Total (g)	Plant recovery (%)
Red oak	WS[z]	3484	0.041	1.4	3484	0.192	4.5
	WS + 60 g SR[y]	3628	0.080	2.0	4277	0.431	8.1
	WS + 30 g SR	2627	0.059	1.8	3741	0.295	6.2
	60 g SR	2644	0.049	1.5	3083	0.216	6.5
	30 g SR	2330	0.093	3.7	3400	0.245	8.8
Blackgum	WS	5395	0.313	10.8	4679	0.993a[x]	23.6
	WS + 60 g SR	4623	0.299	7.4	3181	0.821ab	15.5
	WS + 30 g SR	5227	0.255	8.0	3882	0.936ab	19.9
	60 g SR	7479	0.145	4.4	5188	0.639ab	19.4
	30 g SR	6634	0.126	5.0	5492	0.579b	20.7

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/liter N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

[x]Means within a column and species followed by different letters are statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test. Means within a column where no letters occurs are not statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test.

Table 7. **Whole plant potassium concentration (ug/g) and amount (estimated by multiplying plant dry weight by tissue potassium concentration, ug/plant) at two harvest times for red oak and blackgum seedlings grown under five fertilizer application methods. Percent potassium recovery is the ratio between the total amount of nitrogen in the plant tissue to the total amount of potassium applied as reported in Table 3.**

		July 15			October 10		
Species	Fertilizer treatment	ug/g	total (g)	Plant recovery (%)	ug/g	total (g)	Plant recovery (%)
Red oak	WS[z]	9350	0.110	3.8	5800	0.320	4.2
	WS + 60 g SR[y]	9997	0.219	2.8	5320	0.536	4.2
	WS + 30 g SR	8711	0.196	4.7	5753	0.455	4.5
	60 g SR	8548	0.161	3.2	6454	0.452	9.2
	30 g SR	9434	0.375	31.3	5708	0.412	16.5
Blackgum	WS	1480ab[z]	0.086	3.0	8771	1.861	24.2
	WS + 60 g SR	1299b	0.084	1.1	6736	1.739	13.7
	WS + 30 g SR	1336b	0.065	1.6	8439	2.035	20.0
	60 g SR	1645a	0.032	0.7	8412	1.035	21.1
	30 g SR	1487ab	0.028	2.4	8954	0.944	37.8

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/g N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

[x]Means within a column and species followed by different letters are statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test. Means within a column where no letters occurs are not statistically different from each other at the $\alpha = 0.05$ level, using the Student-Newman-Kuels test.

a significant source of P (Table 3). However, the release rate of P from Comtil is unknown, but included in the P loading value. A higher percent P recovery may have occurred.

There were no significant differences in P concentration or content of blackgum seedlings on the July 15 harvest. On the October 10 harvest, blackgum seedlings fertilized with water soluble fertilizer only, had significantly more total plant P than plants given a 30 g slow release fertilizer application. Percent P recovery by blackgum seedlings ranged from 4.4 to 10.8% at the July 15 harvest to 15.5 to 23.6% at the October 10 harvest (Table 6).

Potassium. There were no statistical differences in K concentration or total plant K content within either harvest date for red oak seedlings (Table 7). Percent K recovery by red oak seedlings ranged from 2.8 to 31.3% at the July harvest to 4.2 to 16.5% at the October harvest (Table 7).

Blackgum seedlings at the July 15 harvest grown under the one 60 g slow release fertilizer treatment had a significantly higher K concentration than blackgum seedlings under the either of the water soluble plus slow release fertilizer treatment combinations (Table 7). There were no statistical differences in K concentration or content at the October 10 harvest (Table 7).

Percent K recovery by blackgum seedlings ranged from 0.7 to 3.0% on the July 15 harvest, to 13.7 to 37.8% at the October harvest. Clearly, the most efficient method of K fertilization used in this study is via a water soluble fertilizer.

Correlations between plant dry weight and plant nutrient concentration and content. Whole plant tissue N concentrations for red oak and blackgum seedlings were not highly correlated with growth (plant dry weight), at either the July or October harvest dates (Table 8). However, total plant N contents for both species and harvest dates were highly correlated with plant growth: r^2 ranged from 0.84 to 0.99 (df = 13) (Table 8). Further, October plant dry weight and October plant height (Table 1) were highly correlated for both species, r^2 of 0.76 and 0.72 (df = 13) for red oak and blackgum seedlings, respectively. Thus, both plant height and dry weight, were good predictors of whole plant N content; whole plant N concentration was not. The strong correlation between plant growth and total plant N content suggest that it would be more effective to measure plant height to assess total plant N status, than to rely on foliar nutrient analysis.

Similar to whole plant N content, red oak P, and red oak and blackgum K contents were more highly correlated with plant dry weight than with P and K tissue concentrations. The data suggest that P and K nutrition can also be managed by monitoring plant growth. An exception to using plant growth to manage P nutrition is blackgum; in October, blackgum growth was more highly correlated with P tissue concentration than with whole plant P content, r^2 = 0.87 and 0.66 (df = 13) for whole plant P concentration and whole plant P content, respectively.

Table 8. **Coefficient of determination, r^2, for linear regression of red oak and blackgum total plant dry weight on nitrogen, phosphorus and potassium concentration or total plant nutrient content at two harvest times.**

	Coefficient of determination (r^2)			
	July 15		October 10	
Species	Conc.	Total	Conc.	Total
	Nitrogen			
Red oak	0.25	0.97	0.38	0.96
Blackgum	0.29	0.99	0.41	0.84
	Phosphorus			
Red oak	0.43	0.58	0.62	0.95
Blackgum	0.89	0.81	0.87	0.66
	Potassium			
Red oak	0.43	0.58	0.62	0.94
Blackgum	0.57	0.88	0.87	0.90

Table 9. July and October N–P–K ratios of red oak and blackgum seedlings grown under five fertilizer application methods.

Species	Fertilizer treatment	July 15			October 10		
		N	P	K	N	P	K
Red oak	WS[z]	4.8	1.0	2.7	3.2	1.0	1.7
	WS + 60 g SR[y]	5.1	1.0	2.7	2.7	1.0	1.2
	WS + 30 g SR	6.6	1.0	3.3	3.4	1.0	1.5
	60 g SR	6.5	1.0	3.3	3.7	1.0	2.1
	30 g SR	6.7	1.0	4.0	3.4	1.0	1.7
Blackgum	WS	3.2	1.0	0.3	2.5	1.0	2.0
	WS + 60 g SR	3.7	1.0	0.3	4.8	1.0	2.1
	WS + 30 g SR	3.5	1.0	0.3	3.2	1.0	2.2
	60 g SR	2.5	1.0	0.2	3.0	1.0	1.6
	30 g SR	2.6	1.0	0.2	3.2	1.0	1.6

[z]Water soluble fertilizer, 3.8 liters/day at 25 mg/g N from Peter's 15–16–17 (15N–6.9P–14.1K) water soluble fertilizer.

[y]Woodace 21–4–10 (21N–1.8P–8.3K) at either a 30-g application (two 15-g applications) or one 60-g application per container.

In July, the N–P–K ratios in red oak seedlings ranged from 4.8–1–2.7 (WS only) to 6.7–1–4.0 (30 g SR treatment, Table 9). In October, the ratios (N relative to P and K) were lower, ranging from 2.7–1–1.2 (WS + 60 g SR) to 3.7–1–2.1 (60 g SR). In general, the N–P–K ratios were similar for blackgum seedlings. The N–P–K ratio of the slow release fertilizer was 11.7–1–4.6 and the water soluble fertilizer ratio was 5.8–1–3.8. Fertilizer N–P–K ratios of 3–1–1 and 3–1–2 have been suggested for woody plants (11). The water soluble fertilizer N–P–K ratio more closely matched the red oak and blackgum tissue N–P–K ratios at the July and October harvests than did the slow release fertilizer's N–P–K ratio. The data suggest that one method of increasing fertilizer recovery would be to match the N–P–K ratios of the fertilizer with the N–P–K ratios found in plant tissue.

Unknown is why a combination of 60 g slow release plus water soluble fertilizer application resulted in the largest blackgum plants. This treatment combination applied the greatest amount of N, P and K, but there were no significant differences among the leachate EC readings within the June 28 to August 15 (nor amoung the nitrate-N readings between June 28 and August 1) sampling dates. Further, at the August 1 sampling date, the nitrate-N concentration in the leachate was lowest for the 60 g slow release plus water soluble fertilizer combination, the treatment that resulted in the largest blackgum plants. The lower leachate EC and nitrate-N are consistent with greater plant nutrient uptake.

Plant nutrient recovery for both species and all fertilizer treatments was low. The results do not suggest an efficient fertilization method. Thus, nursery managers concerned about environmental quality face a dilemna: at present, there is no way to increase fertilizer use efficiency of container-grown red oak and blackgum plants without correspondly reducing plant growth (and potential gross nursery revenue). Reducing the amount of fertilizer applied (while holding irriagtion volume constant) will reduce the amount of N, P and K in the leachate, but plant growth will also be reduced. Until a better understanding of nutrient uptake patterns by different plant species is obtained, the best method for managing nutrient loss from container production sites is through irrigation application rate and delivery methods, and by nutrient capture and recycling systems.

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