Nutrient use patterns in woody perennials: implications for increasing fertilizer efficiency in field-grown and landscape ornamentals

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SUMMARY. Timing nutrient application to periods of high nutrient demand could increase nutrient use efficiency and reduce the potential for fertilizer leaching or runoff. However, current recommendations for field nursery and landscape ornamentals (extension publications) suggest fertilizing in late fall and early spring despite research with perennial fruit crops that demonstrates low uptake potential during those times. Research is needed to resolve this apparent conflict. Application rates for woody ornamentals, established in the 1960s and 1970s, also need reexamination in the light of environmental concerns.

In 1990, the ASHS Nursery Crops working group held a workshop that addressed the impact of runoff water quality on the future of nursery production. In the published proceedings, Wright (1992) challenged researchers to come to a greater understanding of plant nutrient needs as they change during the growing season to maximize nutrient use efficiency and reduce fertilizer runoff from nurseries. Now, at the end of the 1990s, we are still challenged to accomplish that goal. The objective of this article is to examine fertilizer recommendations based on what is known about nutrient uptake patterns of woody plants.

NUTRIENT USE PATTERNS IN NURSERY CROPS. Several container studies in the 1960s (Good and Tukey, 1969; Meyer and Tukey, 1967) established that roots of woody plants grow at lower temperatures than shoots, and that when shoots are dormant, roots can take up nutrients that contribute to the spring flush of growth. These studies profoundly affected field fertilization practice (E.M. Smith, personal communication) by suggesting that late fall applications of fertilizer made to dormant plants could be as effective as spring applications.

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There are several possible advantages to late season fertilization: 1) soil temperatures in mid to late fall are higher than in early spring, thus promoting root activity and presumably uptake; 2) precipitation is usually adequate at that time to move nutrients into the root zone; 3) the primary nursery activities of digging and planting have subsided.

More recent nutrient use studies with container nursery crops (late 1970s through 1990s) have focused on a few species with episodic growth patterns [e.g., Japanese holly (*Ilex crenata* Thunb.), Japanese euonymus (*Euonymus japonica* Thunb.), rose (*Rosa hybrida* L.)]. Episodic growth is characterized by alternating phases of shoot growth and budset throughout the growing season. In these episodic species, greatest N accumulation occurred between the shoot flushes (Evans et al., 1992; Gilliam and Wright, 1978; Hershey and Paul, 1983), when root growth was most active (Mertens and Wright, 1978). Compared to regular, weekly fertilization, timing fertilization to occur between the shoot flushes increased uptake efficiency in Japanese holly (Yeager et al., 1980).

NUTRIENT USE PATTERNS IN FRUIT CROPS. The uptake studies with episodic nursery plants had important implications for increasing fertilizer efficiency in those species, but do not support an assumption that active shoot growth and nutrient uptake are mutually exclusive. Citrus [*Citrus sinensis* (L.) Osb.] has episodic growth patterns; however maximum N uptake and substantial root growth both occurred during shoot elongation (Maust and Williamson, 1994). Weinbaum et al. (1978) observed no difference in uptake efficiencies of container plum trees (*Prunus domestica* L.) when fertilizer applications were made during or after active shoot elongation periods.

Research tracking nutrient uptake patterns over one or more growing seasons has been conducted on container fruit trees: plum (Weinbaum et al., 1978); peach [*Prunus persica* L. (Munoz et al., 1993)], field-grown grapes [*Vitus labrusca* L. (Hanson and Howell, 1995)], and field-grown blueberries [*Vaccinium corymbosum* L. (Throop and Hanson, 1997)]. These studies suggest that nutrient and biomass accumulation are linked; thus, greatest nutrient uptake will occur with rapid growth and / or fruit development. In all studies, nutrient uptake efficiencies were lowest at budbreak in the spring, and during or after leaf abscission in the fall. Highest efficiencies were observed from late spring through middle or late summer, when plants were fully in leaf.

Our studies with container ornamental trees support the fruit crop research. Linden trees (*Tilia cordata* Mill. 'Greenspire') had lower N uptake efficiencies at budbreak and during leaf abscission (6% to 24%) than during the growing season when leaves were present (42% to 71%) (unpublished data). A study with container maple trees [*Acer* ×*freemanii* E. Murr. 'Jeffersred' (Rose and Biernacka, 1999)] suggested that N uptake is biomass-driven. Between potting in June and leaf abscission in October, whole-plant N contents increased steadily, reflecting increases in dry weight. Substantial N uptake and biomass accumulation in the roots were observed in early fall, after buds had set (August). Weinbaum et al. (1984) observed that the later that fertilization occurs in the season, the greater the contribution to the following season's shoot growth relative to the current season's, but once leaf abscission began, N recovery decreased as the canopy was lost. These findings suggest that early fall (before leaf abscission) may be a desirable time to fertilize to benefit growth the following year.

FERTILIZER TIMING RECOMMENDATIONS FOR LANDSCAPE AND NURSERY CROPS. The fertilizer standard (American National Standards Institute, 1998; Table 1) recently developed through the National Arborist Association provides little guidance to the timing of fertilization. This standard only suggests that nutrients should be applied when roots are growing, which is not a simple determination to make. In contrast, state nursery and landscape fertilizer recommendations vary with respect to suggested timing and rates of fertilization (Table 2). Most bulletins suggest applying fertilizer in spring, before budbreak;

Table 1. Nitrogen fertilizer recommendations from the American National Standards Institute (1998).

Fertilizer type	Maximum rate per fertilizer application lb/1000 ft^{2}[z] (lb/acre)	Maximum annual rate lb/1000 ft^{2} (lb/acre)	Comments
Slow-release (≥50% water insoluble N)	2–4 (87–174)	6 (261)	Salt-sensitive plants and new transplants should receive slow-release fertilizer only.
Quick-release	1–3 (44–131)	4 (174)	Slow-release fertilizers preferred to quick-release types.

[z]Fertilizer timing guidelines: apply fertilizer so that nutrients are available when roots are growing; 1 lb / 1000 ft^{2} = 48.8 kg·ha^{-1}, 1 lb / acre = 1.1 kg·ha^{-1}.

in fall, after the first hard frost; or split between the two seasons. Most of these recommendations conflict with the fruit crop research that shows minimal uptake at budbreak and at leaf abscission. Some bulletins distinguish between plants that produce one flush of shoot growth in the spring and those that produce multiple flushes (episodic growth). When possible, more frequent fertilization is suggested for the episodic species.

Late season fertilization. Some bulletins suggest that fertilization in late summer or early fall is beneficial (Halbrooks, 1990; Kuhns, 1985). A bulletin from Ohio (Smith, 1989) suggests avoiding fertilization at that time. The Ohio bulletin reflects concern among members of the nursery industry that early fall fertilization may retard cold acclimation, particularly in heterophyllus (indeterminate) species that are capable of producing multiple flushes of shoot growth (Davidson et al., 1994). However, Pellet and Carter (1981) extensively reviewed literature and concluded that moderate rates of fertilization applied in late summer or early fall did not reduce the cold hardiness of woody plants. Commercial tree care companies commonly fertilize in early fall before leaves abscise, and this can be considered as anecdotal evidence that early fall fertilization will not injure woody plants (T. Smiley,

Table 2. Recommended fertilization rates and timing for field-grown nursery and landscape ornamentals from state extension bulletins.

State	Author	Annual N rate for landscape or nursery in lb/acre[z] (lb/1000 ft[2 y])	Fertilizer timing suggestions
South Carolina	Halbrooks, 1990	Nursery 87–261 (2–6)	Plants with one flush of growth: fertilize in fall and / or spring, 4–6 weeks before budbreak. Plants with multiple flushes: fertilize with smaller, more frequent doses of fertilizer between flushes. Late summer, early fall fertilization ok, but use a lower rate than earlier in the season.
Ohio	Smith, 1989	Nursery 87–261 (2–6)	Plants with one flush of growth: the best time to fertilize is fall, after the first hard freeze (October to December); else fertilize in early spring, 4–6 weeks before budbreak.
		Landscape 131 (3)	Avoid fertilizing from July 1 until frost. Plants with multiple flushes: split applications between late spring / early summer after the first flush of growth (no later than 1 July) and the late fall.
Minnesota	Swanson et al., 1986	Nursery 87–261 (2–6)	No guidance on timing except for sandy soils: split the annual rate between April, May, and June.
Minnesota	Rosen, Bierman Eliason, 1998	Landscape, rapid growth 87–174 (2–4) Maintenance level 44–87 (1–2)	Fertilize in early spring, early summer, or late fall.
Pennsylvania	Kuhns, 1985	Nursery 87–261 (2–6)	Best times to fertilize: 2 weeks before budbreak and in late summer / early fall. Plants with multiple flushes will benefit from more frequent application or from slow-release fertilizers.
New York	Lieberman and Weir, 1989	Landscape 44–87 (1–2)	Fertilize in early spring when growth begins.
Virginia	Va. Coop. Ext. Serv., 1989	Landscape 44–261 (1–6)	Best time to fertilize: mid or late fall after leaf abscission begins. Or split the applications between early spring (February to April) and fall (October to December).

[z]1 lb / acre = 1.1 kg·ha^{-1}.
[y]1 lb / 1000 ft2 = 48.8 kg·ha^{-1}.

Table 3. Some key nitrogen (N) fertilization studies in woody ornamentals.

Literature citation	Study location[z]	Study duration	Common name	Latin name
Davidson and McCall, 1959	Field nursery	2 years	Japanese yew	*Taxus cuspidata* Siebold & Zucc.
Neely, 1980	Landscape	2 years	Norway maple	*Acer platanoides* L.
			Honey locust	*Gleditsia triacanthos* L. *var. inermis* Willd.
			Tuliptree	*Liriodendron tuliperifera* L.
			Pin oak	*Quercus palustris* Muenchh.
Smith, 1974	Field nursery	2 years	Norway maple	*Acer platanoides*
Smith, 1975	Field nursery	2 years	Chinese juniper	*Juniperus chinensis* L.
			Anglojap yew	*Taxus* ×*media* Rehd.
			Eastern arborvitae	*Thuja occidentalis* L.
Smith and Treaster, 1982	Landscape	9 years	Sugar maple	*Acer saccharum* Marsh.
			Crabapple	*Malus* 'Snowdrift' L.
			Littleleaf linden	*Tilia cordata* Mill.
van den Werken, 1981	Landscape	11 years	Sugar maple	*Acer saccharum*
			Tuliptree	*Liriodendron tuliperifera*
			Pin oak	*Quercus palustris*

[z]Trees grew in turf in all landscape studies.
[y]1 lb / 1000 ft^2 = 48.8 $kg \cdot ha^{-1}$
[x]Continued observation of these trees for 18 years (Smith and Treaster, 1990) revealed that crabapple and maple responded to fertilization only through year 12. Linden responded to fertilization through year 18, but there were no differences in growth (caliper) among the fertilized treatments at final evaluation.

personal communication). Furthermore, some research suggests that fertilization at this time may increase hardiness (DeHayes et al., 1989).

NITROGEN FERTILIZATION RATES FOR FIELD-GROWN AND LANDSCAPE ORNAMENTALS. Suggested annual N rates provided by landscape / nursery extension bulletins (Table 2) and the fertilizer standard (Table 1) vary between 44 and 261 lb / acre (48 and 287 $kg \cdot ha^{-1}$, Table 2). These rates are based on research from the 1950s through 1970s (Table 3), when maximizing fertilizer response was the primary goal. Not only does this range exceed N recommendations for agronomic crops (Vitosh et al., 1995), far less guidance for selecting a rate within the range is provided compared to agronomic fertilizer recommendations which may factor in soil test results, yield potentials, and previous crops. Some extension bulletins do specify that broadleaf evergreens, needle-leaf evergreens, and deciduous plants should receive the low, medium, and high rates, respectively, within the range. More recent recommendations (Rosen et al., 1998) are encouraging because soil organic matter content and growth expectations are factored into the N recommendation.

Conclusions

Current environmental concerns call for a reexamination of field and landscape ornamental fertilizer recommendations. Research is needed 1) to determine whether fertilization timing can be optimized to increase nutrient uptake efficiency and 2) to establish appropriate rates according to soil type, expected growth rates, and intended maintenance level. The law of diminishing returns dictates that the return will be smaller for each additional increment of fertilizer. This principle needs to be emphasized in future recommendations.

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N rates used annually unless noted otherwise (lb/1000 ft[2y])	Authors' recommended N rate based on study (lb/1000 ft^2)
0–38	1.2
2, 4, 6	No fertilizer recommended since response was minimal
0, 3, 6, 9	3
0–10	4–5
0–10	4–5
0–10	5–7
0, 3 ,6, 9 at 3-year intervals	6 at 3-year intervals[x]
0, 1.4, 2.8	2.8

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