CONTROLLED-RELEASE NITROGEN IN TREE NURSERIES[1/]

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Introduction

Nitrogen management in nursery systems faces two challenges: improving seedling quality and reducing environmental impacts on adjacent ecosystems. Nursery management is generally based on the concept of "bigger seedlings are good seedlings." Guidelines for seedling quality have been developed based on seedling size and other physical features (Thompson and Schultz, 1995; Dey and Parker, 1997; Kormanik et al., 1998; Jacobs et al., 2005). Seedling performance after outplanting suggests that soil management under conditions of luxury consumption will improve chemical seedling-quality (Timmer, 1997). Maintaining large plant-available nitrogen pools in nursery soils requires large amounts of nitrogen fertilizer over a growing season because of the complexity of the soil nitrogen cycle, the sandy soil texture, and intensive irrigation events typical of tree nursery systems. Thus, maintaining luxury-consumption conditions with nitrogen fertilizer could generate excessive soil nitrogen levels in nursery systems, which may lead to nitrate groundwater contamination.

Using organic fertilizers (slow-release fertilizer) or matching seedling demand with timing of fertilizer applications (i.e., exponential fertilization) are potential solutions for conservation nitrogen-fertilizer management. Slow-release fertilizer strategies are popular in public opinion, however the contribution of nitrogen (N) from slow-release fertilizer varies by field condition, climate, and cropping system (Kirchmann and Bergstrom, 2001; Borken et al., 2004; Jaber et al., 2005). Exponential fertilization works by applying small amounts of nitrogen fertilizer when seedlings are small and larger amounts of nitrogen during later growth stages (Imo and Timmer, 1992; Timmer, 1997; Birge et al., 2006). Exponential fertilization increases nutrient use efficiency, resulting in significantly greater (up to 260 %) biomass production in oak and pine seedlings relative to multiple even-rate fertilizer applications (Salifu and Timmer, 2003; Birge et al., 2006). However, as with slow-release fertilizers, exponential fertilization has higher associated costs, as this strategy requires increased gas, labor, and machine maintenance.

Controlled-release fertilizer (CRF) has been recently considered as a third alternative to minimize excessive N leaching from nursery ecosystems (Alva, 1992; Juntunen et al., 2003). Even though the nitrogen release pattern from CRF differs by product due to differences in the coating material, the general release pattern starts with an exponential application and ends with decadal release after the contained nitrogen becomes lower than its solubility (Shaviv, 2001). The effects of CRF application on crop production appear in fruit production, often with higher nutrient use efficiency (Broschat and Moore, 2001; He et al., 2003; Alva et al., 2003; Alva et al., 2006). Theoretically, CRF should be able to reduce the amount of fertilizer input without sacrificing seedling quality. However, few studies on hardwood species have examined nitrogen leaching and seedling production under the different patterns of nitrogen inputs in bare-root nursery conditions.

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In this project, we test the hypothesis that equal amounts of nitrogen supplied by CRF application will produce greater seedling biomass and nitrogen uptake relative to conventional fertilizer because of the closer matching of nitrogen supply and seedling demand.

Materials and Methods

Experiments were established in two Wisconsin state nurseries: Hayward State Nursery (Hayward, WI. N 46°0', W 91°5') and F.G. Wilson State Nursery (Boscobel, WI. N 43°1', W 90°7'). Prior to setting up the experiment, soil at all sites was fumigated with methyl bromide for ten days. The acorns of northern red oak (*Quercus Rubra* L.) were seeded with an average density of 100 acorns m^{-2} on November 2004. Liquid mulch was applied two weeks after seeding to reduce wind erosion and acorn movement during the winter period.

Conventional fertilizer (CONV), ammonium sulfate (21-0-0), and CRF were applied in three replicated rows (1.2 m by 167 m) during the 2005 growing season. CONV was applied eight times from May to August with the rate of 114 kg ha^{-1}, totaling 914 kg ha^{-1} (192 kg N ha^{-1}) during a growing season. CRF was applied twice (450 kg ha^{-1} in November 2004 and 462 kg ha^{-1} in May 2005) totaling 914 kg ha^{-1} (192 kg N ha^{-1}). Soil samples were taken every other week from May to October to evaluate the dynamics of nitrogen in bare-root nursery systems.

Biomass samples (i.e., red oak seedlings) were separated into leaf, stem, and root and air-dried (65°C) for 2 weeks. The samples were weighed (±0.01 g) and ground using Wiley-mill with #60 mesh screen. Total biomass nitrogen in samples was measured by semi-micro Kjeldahl digestion with titration analysis (±0.01%). The rates of net-nitrogen mineralization were measured by resin-bag method (Brye, 1999). Nitrogen leaching was estimated using mass-balance equations.

Results

The amount of released nitrogen from CRF granules was approximately 85% of applied amount of nitrogen at the end of the growing season of 2005, based on the daily mean soil surface temperature and moisture (Fujinuma, unpublished data). Thus, the nitrogen input from fertilizer under CRF management was estimated as 163 kg N ha^{-1} during the 2005 growing season. The coating membrane shells on the soil surface were easily recognized in the beginning of the 2006 growing season (Fujinuma, field observation).

Total biomass of northern red oak seedlings tends to be greater under CONV management than CRF management regardless the site differences although there is a slight interaction of site difference and fertilizer types (Table 1). Total biomass is 40% less under CRF management relative to CONV management at Wilson, but only 5% less in CRF management relative to CONV management at Hayward. The interaction between site difference and fertilizer type shows that the fertilizer type influences the root-shoot ratio differently by site. The root-shoot ratio at Wilson shows 50% higher ratio ($p < 0.10$) in CRF management relative to the ratio in CONV management. However, there is no significant difference between the treatments at Hayward (Table 1).

Total seedling nitrogen uptake in this experiment shows no significant influence from either site difference or fertilizer type (Table 1). However, there is a significant interaction ($p < 0.10$) of site difference and fertilizer type on the allocation of seedling nitrogen, which is expressed as root-shoot ratio of seedling nitrogen (Table 1). This interaction suggests the influence of fertilizer type on the allocation of seedling nitrogen depends on site difference. The seedlings allocate 75% more nitrogen to root under CRF management than under CONV management at Wilson. Alternatively, the oak seedlings allocate 33% less nitrogen to roots under CRF management than under CONV management at Hayward.

Table 1. Biomass and nitrogen uptake of northern red oak seedlings by conventional fertilizer management (CONV) and controlled-release fertilizer management (CRF) in bare-root nurseries Wilson and Hayward. The values in parentheses show standard error.

Site	Fertilizer type	Total Biomass	root/shoot	Total seedling nitrogen	Seedling nitrogen root/shoot
		g $seedling^{-1}$	g g^{-1}	g $seedling^{-1}$	g g^{-1}
Wilson	CONV	21.01 (2.73)	2.14* (0.33)	0.19 (0.03)	2.39** (0.21)
	CRF	14.61 (3.40)	3.19* (0.28)	0.19 (0.04)	4.27** (0.44)
Hayward	CONV	9.83 (1.27)	3.41 (0.13)	0.19 (0.04)	5.47 (1.61)
	CRF	9.34 (0.38)	3.22 (0.37)	0.16 (0.01)	3.44 (0.47)

* statistical significance at 0.1 within each site

** statistical significance at 0.05 within each site

Fertilizer nitrogen and net-nitrogen mineralization compose the majority of nitrogen input to plant-available nitrogen in the bare-root nursery soil (Table 2). Net-nitrogen mineralization shows a trend of less net mineralization under CRF management than under CONV management by approximately 60% regardless of site difference. Similarly, nitrogen leaching from the bare-root nursery system is mainly influenced by fertilizer type regardless of site difference. CRF management reduces N leaching by 70% at Wilson and by 40% at Hayward.

Table 2. Nitrogen budget analysis of conventional fertilizer management (CONV) and controlled-release fertilizer management (CRF) at bare-root tree nursery systems in Wilson and Hayward, Wisconsin during the 2005 growing season (May through October).

Site	Fertilizer type	Input			Output	
		Precipitation / irrigation	Fertilizer nitrogen	Net nitrogen mineralization	Seedling nitrogen uptake	Nitrogen leaching
		kgN ha^{-1} $year^{-1}$				
Wilson	CONV	8	192	166	180	186
	CRF	8	163	59	180	50
Hayward	CONV	16	192	55	180	83
	CRF	16	163	20	150	49

Discussion

Oak seedlings use plant available nitrogen in soil more effectively under CRF management than CONV management. CRF management resulted in less fertilizer nitrogen input during a growing season yet produced similar seedling biomass as CONV management in this experiment. Similar effective nutrient use in plant growth under CRF management has been reported for several tree species at container-grown tree nurseries (Irino et al., 2004; Sandrock et al., 2005) and agricultural fields (Shoji and Kanno, 1994; Guertal, 2000; Shoji et al., 2001).

CRF management produces higher quality seedlings than CONV management if the field receives sufficient precipitation or irrigation. Although the size of seedling is similar, more nutrients in the root system should improve post-transplant growth (Malik and Timmer, 1995; Salifu and Timmer, 2003; Birge et al., 2006). This experiment shows the higher nitrogen accumulation in roots at the Hayward nursery, but this is presumably caused by a severe drought in the Hayward area from July through early September 2005. Even though the Hayward nursery had an intense irrigation schedule during that time, the seedlings at Hayward still grew under water stress (data not shown). In this drought condition, it appears there was insufficient water to leach plant-available nitrogen from soil profile under CONV management, even though the soil texture is very sandy. Therefore, the seasonal dynamics of plant-available nitrogen in soil under CONV management at the Hayward could be similar dynamics with the CRF management.

CRF management reduced nitrogen leaching regardless of site difference, likely due to less input of fertilizer nitrogen and net-nitrogen mineralization during the growing season and better timing of nitrogen application than CONV management. Less nitrogen leaching under CRF management has been reported for container-grown nurseries (Cox, 1993; Cabrera, 1997; Fernandez-Escobar et al., 2004) and agricultural fields (Shoji et al., 2001; Morita et al., 2002; Zvomuya et al., 2003) due to the better matching of fertilizer nitrogen input and plant demands. The less net-nitrogen mineralization under CRF management indicates greater soil microbial activity than CONV management. Nitrification activity under CRF management is less than CONV management for a short time period, but sustains at the activity rate for a longer time period than CONV (Chu et al., 2005). Although this study could not reveal the detailed fate of fertilizer-nitrogen in the bare-root nursery soils, it seems dynamic relationships occur among differences of fertilizer inputs, soil plant-available nitrogen-pool, and net-nitrogen mineralization.

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