Exponential Nutrient Loading as a Means to Optimize Bareroot Nursery Fertility of Oak Species

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Abstract: Conventional fertilization in nursery culture of hardwoods may involve supply of equal fertilizer doses at regularly spaced intervals during the growing season, which may create a surplus of available nutrients in the beginning and a deficiency in nutrient availability by the end of the growing season. A method of fertilization termed "exponential nutrient loading" has been successfully used in propagation of several conifer species, but this technique has not been tested in hardwood culture. By supplying fertilizer nutrients in an exponential manner, nutrient supply more closely matches plant nutrient demand, which may improve fertilizer uptake and use efficiency. The amount of fertilizer needed to maximize nutrient reserves and growth before inducing toxicity is termed the "optimum" nutrient loading level. Because optimum levels have not been established for hardwoods, we examined the response of northern red oak *(Quercus rubra*) and white oak (*Q. alba)* to a range of nutrient loading treatments at a bareroot nursery in Indiana. Ammonium nitrate was applied at rates ranging from 0X to 4X the current conventional rate. Seedling morphological and nutritional parameters exhibited responses consistent with the conceptual model for nutrient loading depicting points of deficiency, sufficiency, luxury consumption, and toxicity. Maximum seedling biomass production occurred at 1.0X the current seasonal rate, establishing the sufficiency level. Maximum nitrogen (N) content in seedling tissues peaked at 2.0X the current seasonal rate reflecting the optimum loading rate. Toxicity occurred at 3.0X the current seasonal rate and above, which increased tissue N concentration, but reduced dry mass and N content. This type of analysis may assist nurseries in refining fertilization practices and producing high quality seedlings for outplanting.

Keywords: seedling quality, nutrient loading, exponential fertilization, *Quercus rubra,Quercus alba*

Introduction

Suecess of natural regeneration oloak species (*Quercus* spp.) in the forests of the Central Hardwood Region has been redueed in recent years. This is the result of changes in disturbance patterns, such as fire, that traditionally favored development of oaks. Forest management practiees, such as single and group tree seleetions for harvesting hardwoods, have further redueed the suceess of oak regeneration beeause they do not create sufficient canopy openings to allow oak seedlings to compete with shade tolerant species sueh as maple *(Acer* spp.) and beeeh (Fagus grandifolia) (Larsen and Johnson 1998; Rogers and Johnson 1998; Clatterbuek and others 1999).

Conservation tree plantations are a viable option to maintain a sustainable supply of oak species in the Central Hardwood Region. Many of these plantations are established on abandoned agricultural fields or mine reclamation sites where soil conditions are limiting to tree growth. In Indiana, a recent survey indicated that the overall survival rate for these plantations is 66 pereent; only 33 and 53 percent of northern red oak *(Quercus rubra)* and white oak *(Quercus alba),* respeetively, were consider free-to-grow at age five (Jacobs and others 2004). This suggests the need for new silvicultural techniques that may improve survival and growth of outplanted seedlings.

Exponential Fertilization

Enhancing potential for field survival and growth of oak seedlings begins in the nursery. Most oaks are produced in bareroot nurseries in the Central Hardwood Region. Traditional nursery culture in these nurseries involves the supply of fertilizer in equal doses at regularly spaced intervals over the growing season. This may create a surplus of available nutrients in the beginning when the seedlings are small and a deficiency by the end of the growing season due to growth dilution (Imo and Timmer 1992). A method of exponential fertilization, termed "nutrient loading," may be used to help mateh nutrient supply with the growth rate of cultured seedlings (Ingestad 1979; Imo and Timmer 1992; Timmer and Aidelbaum 1996; McAlister and Timmer 1998). Closely synchronizing nutrient supply with seedling demand improves fertilizer uptake and use efficiency. Seedlings are not only able to grow to the maximum morphological standards set by the nursery industry, but may uptake extra nutrientsat the luxury consumption level and store these nutrients as reserves in seedling tissues for use once outplanted. Figure 1 is a proposed eonceptual model illustrating the relationship between plant growth, nutrient concentration, and nutrient content with increased fertilization (Timmer 1997; Salifu and Timmer 2003b). It is divided into three sections to demonstrate points of nutrient deficiency, luxury consumption, and toxicity with increased nutrient supply. Seedlings exhibit maximum growth at the sufficiency level. The optimum point is reached when growth and nutrient uptake are both maximized, whieh oceurs during luxury consumption. When fertilized at the optimum level (just prior to toxicity), the seedling is able to store maximum nutrients in its stem and root tissues for later utilization.

Exponential nutrient loading has been sueeessfully used with a variety of conifer species (Timmer 1997; McAlister and Timmer 1998; Salifu and Timmer 2003b). Many studies of exponential fertilization have reported improved outplanting performance of exponentially cultured seedlings that may be associated with the use of stored excess N that is retranslocated to support new growth (Malik and Timmer 1995; Salifu and Timmer 2001, 2003a). Rapid growing exponentially eultured seedlings may better compete with natural vegetation, reducing the need for herhicide application, promoting rapid height growth to free-to-grow status, and possibly helping to minimize deer browse damage.

Given the improved performance of eonifer seedlings eultured using exponential fertilization, we suspected that this technique may also be useful for bareroot nursery propagation of oak seedlings, Thus, we established an experiment to 1) compare conventional nursery fertilization praetices to: exponential methods; 2) determine the

suffieiency level (maximum growth) and the optimal loading level (highest

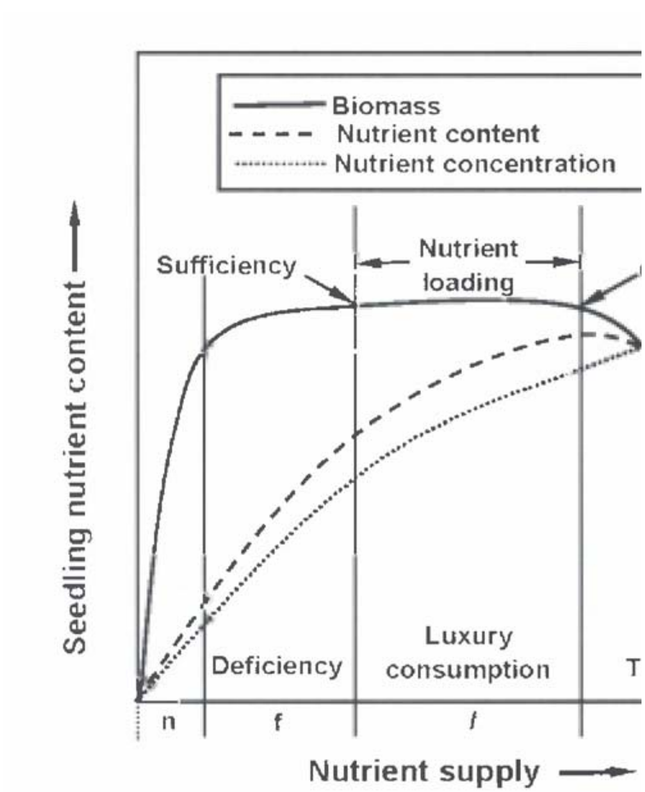

Figure 1—Relationships between nutrient supply with plant growth, tissue nutrient content, and concentration. Fertilizer (*l*) is added to supplement native fertility *(n)* to prevent nutrient deficiency and maximize growth to the sufficiency level. Optimum nutrient loading is achieved by adding fertilizer *(l)*

level of luxury consumption before toxicity is reached) by fertilizing at eight levels using the exponential method; and 3) analyze elemental N content in struetural plant tissues at various stages of growth during the first year.

Study Procedure

This study was conducted at Vallonia State Nursery south of Indianapolis, IN. Soil texture class was sandy loam with 65 pereent sand, 23 percent silt, and 12 percent elay. Seeds of northern red and white oak were obtained from local sourees and mechanically sown in the fall of 2003 in high densities (9 to 10/ft^2 [97 to 108/m^2]) to obtain about 6 seedlings/ft^2 (65 seedlings/m^2) after germination. Once the seedlings had germinated, plots were thinned to 120 seedlings per plot to allow for more uniform densities. The seedlings were grown as bareroot stock for one season.

Standard nursery practices were followed for all seedlings except for the fertilization treatments. Treatment plots were 4 by 5 ft (1.2 by 1.5 m) to allow a density of 6 seedlings/ft^2 (65 seedlings/m^2). There were four beds with each of the 10 treatments represented to provide 480 seedlings per treatment per species. A buffer of 2 ft (0.6 m) between treatment plots was installed and a randomized complete block design was used for assigning the treatments. An additional bed to either side of the study and 25 ft (7.6 no in front of the plots and 15 ft (4.6 m) after the plots were left unfertilized as buffers to prevent fertilizer drift from other nursery operations. Thestudy was established as a randomized complete block design, and each species was designated as an independent experiment.

Ammonium nitrate (34N:0P$_2$O$_5$:0K2$_O$) fertilizer in a solid crystal form was broadcast manually on the individual treatment plots. A regime that followed the nursery's current application rate of 206 lb/ac (231 kg/ha) in seven equal applications every 2 weeks (1,444 lb/season [655 kg/season] was the conventional treatment. A treatment that received no fertilizer (0 lbs) represented a control to examine the effect of the indigenous soil fertility on seedling growth. Eight treatments were based on the modified exponential method of fertilization to mateh nutrient supply with seedling growth. Seasonal dose rates were 0.5X, 1.0X, 1.5X, 2.0X, 2.5X, 3.0X, 3.5X, and 4.0X the current seasonal rate (see totals in table 1). Table 2 shows how some of these fertilizer treatments (exponential method at the 0.5X, 1.0X, 1.5X, and 2.0X rates) might be applied on a per acre basis at a nursery.

Fertilizer treatment amounts were divided across seven applications and applied bi-weekly, which started shortly after the first full flush of leaves. The application schedule followed procedures described in detail by Salifu and Timmer (2003b) and Timmer and Aidelbaum (1996). A modified version of exponential fertilization was used as per Imo and Timmer (1992).

Once the seedlings emerged and had developed their first flush ofleaves (representing the baseline), five seedlings per plot (20 per treatment) were removed from the soil to preserve all the root parts possible and placed in coolers for

Table 1-Bi-weekly fertilization schedule for northern red oak (amounts given are grams of N per plant).

Time Treatment	0 wks 1	2 wks 2	4 wks 3	6 wks 4	8 wks 5	10 wks 6	12 wks 7	Total
Zero	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conventional	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.84
0.5 Exp	0.031	0.033	0.039	0.051	0.066	0.100	0.100	0.42
1.0 Exp	0.078	0.065	0.068	0.089	0.124	0.207	0.207	0.84
1.5 Exp	0.138	0.098	0.093	0.121	0.179	0.315	0.315	1.26
2.0 Exp	0.209	0.132	0.115	0.149	0.230	0.423	0.423	1.68
2.5 Exp	0.287	0.165	0,136	0.174	0.279	0.529	0.529	2.10
3.0 Exp	0.369	0.198	0.154	0.197	0.325	0.633	0.633	2.51
3.5 Exp	0.459	0.231	0.172	0.220	0.371	0.738	0.738	2.93
4.0 Exp	0.554	0.264	0.188	0.240	0.416	0.843	0.843	3.35

Table 2-Proposed fertilization schedule to implement exponential fertilization techniques in nursery operations. given as lbs ammonium nitrate (34N:0P$_2$O$_5$:0K$_2$O) per acre (1 lb/ac = 1.12 kg/ha). All exponential seasonal rates are based on conventional season rates, so 0.5X, 1.0X. 1.5X and 2.0X are stated (totals). These rates have been tested in northern red oak and white oak nursery production systems as discussed in this study. The 1.0X rate was the sufficiency amount and the 2.0X rate was the optimum amount.

Time Treatment	0 wks 1	2 wks 2	4 wks 3	6 wks 4	8 wks 5	10 wks 6	12 wks 7	Total
Conventional	206	206	206	206	206	206	206	1.444
0.5 Exp	54	56	67	88	113	172	172	722
1.0 Exp	134	112	118	153	214	357	357	1,444
1.5 Exp	238	169	161	208	307	542	542	2,167
2.0 Exp	359	226	199	256	395	727	727	2,890

further lab analysis. Samples were washed, measured (stem height and root collar diameter) and then pooled into root, shoot, and leaf parts. These were dried for 72 hours at 158°F (70 °C) and weighed for dry mass determination. Samples were ground in a Wiley mill and mixed to create a uniform powder for chemical analysis. This proeedure was repeated at weeks 0, 4, 8, 12, and 16 before application of fertilizer.

The seedlings were mechanieally lifted in early December 2004 by cutting at a depth of 10 in (25 cm) for the white oak and 12 in (31 cm) for the red oak to retain as mueh of the root mass as possible. Harvested seedlings were further processed and stored at 36 °F (2 °C).

Results and Discussion

For each species, seedling growth and nutritional responses to the different fertility rates resembled that of the eonceptual model shown in figure 1. For example, seedling growth increased with N rates in the deficiency range (< 1.0X rate), remained fairly stable in the luxury consumption range (1.0X to 2.0X rates), and began to decline at the higher N range (> 2.0X rates), suggesting toxieity. When compared to unfertilized seedlings, fertilization significantly increased plant biomass (figure 2). Similar trends were seen in shoot height growth and root collar diameter. During the growing season, five flushes were observed in the red oaks for all treatments except the eontrol. Color of the leaves between treatments was noticeably different, with the controls exhibiting chlorosis (figure 2). The exponential treatments beyond the 1.0X rate were dark green compared to the conventional treatment. Greater leaf biomass was also observed in seedlings grown in the luxury consumption range. Thus, it could be presumed that the greater leaf biomass and darker leaf color were indicative of the presence of more chlorophyll and greater photosynthetie ability. This could allow the plants to provide increased carbon and N resources for growth sinks once outplanted.

By the end of the growing season (4 months), the 1.0X and 2.0X rates (exponential) had the highest biomass in red oak regardless of tissue part. By contrast, all the exponential fertility rates in white oak, other than that in the toxic range, had higher biomass than the conventional fertilization method. Similar trends were detected for tissue N content.

Figure 2—Experimental plots of red oak showing the contrast between seedlings grown without fertilizer in buffer plots (foreground) and those grown under various conventional or exponential fertilizer schedules.

We expect to formally publish these results in a referred journal in the future.

Conclusions

This study was able to demonstrate the importance of N fertilization in nursery culture of oaks. We also found that that the prineiples of exponential nutrient loading (examined in detail by many authors for conifer species) appear to also be applicable to oak species. Luxury consumption of N was induced in these two oak species, and seedlings appeared able to store excess N in seedling tissues beyond that needed to maximize morphological growth. Increased growth and N uptake occurred with the exponential treatment even though the total N delivered over the entire growing season did not vary from current conventional practices. Exponential nutrient loading has potential to improve nursery seedling quality of oaks by maximizing morphological development and optimizing nutrient storage reserves in plant tissues. Simultaneously, the proeess has potential to improve fertilizer use efficiency, thereby decreasing fertilizer costs and leaching losses. Additional studies need to closely examine responses of nutrient loaded hardwood seedlings during outplanting, and examine performance of additional hardwood species under this fertilization technique.

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