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# Performance of Nutrient-Loaded Red Oak and White Oak Seedlings on Mine Lands in Southern Indiana

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## **ABSTRACT**

Exponential nutrient loading was used to build nutrient reserves in northern red oak (*Quercus rubra*) and white oak (*Q. alba*) seedlings during standard bareroot nursery culture at the Vallonia State Nursery, Indiana. Nursery grown seedlings were outplanted the following year onto a mine reclamation site in southern Indiana to evaluate effects of prior nursery treatments on field performance. At the nursery stage, exponential nutrient loading improved plant dry mass production. Nutrient loading increased nitrogen uptake 40% in red oak and 35% in white oak when compared to controls. When outplanted, exponential nutrient loading enhanced shoot height and root collar diameter response in the studied species. White oak seedling survival was 92%, compared with 83% for red oak in year 1. Survival decreased to about 74% for white oak and 65% for red oak in year 2. Results suggest exponential nutrient loading has potential to promote seedling performance on harsh site conditions, and are significant for reclamation efforts in Indiana and across the US.

## **KEY WORDS**

biodiversity, forest restoration, nitrogen, *Quercus alba*, *Quercus rubra*, reclamation, seedling quality

## Introduction

Successful forest restoration on abandoned surface-mined lands can yield multiple benefits, such as provision of timber, high quality water, wildlife habitats, and aesthetic landscapes. However, poor site fertility (Bussler and others 1984; Walker 2002), soil compaction (Unger and Cassel 1991), competition from herbaceous plants (Andersen and others 1989; Casselman and others 2006), animal browse (Tripler and others 2002), and poor seedling quality (Clark and others 2000; Ward and others 2000; Jacobs and others 2004) are key factors that may limit early establishment success of newly outplanted hardwood seedlings on degraded landscapes in the Central Hardwood Forest Region of the US.

Fertilization at planting, in combination with weed control with herbicides, can alleviate poor site fertility, reduce competition, and enhance seedling field survival and growth (Jacobs and others 2005). However, there is public sentiment against herbicide use in forests owing to potential negative impacts on the environment and on biodiversity (Thompson and Pitt 2003). Thus, storing nutrients in seedlings during nursery culture to reduce competitive effects provides a better rationale than field fertilization that may stimulate growth of competing vegetation. Moreover, studies have shown that the nutritional status of a plant is a better indicator of quality and field success (Timmer and Munson 1991; Malik and Timmer 1996). Therefore, appropriate nursery nutrient management can lead to the production of high quality seedlings with greater internal nutrient reserves to reduce competitive effects and enhance field performance (Malik and Timmer 1996; Thompson and Pitt 2003).

Several fertilization methods, such as conventional, exponential, or nutrient-loading models, can be used to nutritionally pre-condition plants at the nursery stage for outplanting. Conventional fertilization involves application of equal fertilizer doses at regularly spaced intervals throughout the growing season. This approach creates a surplus of nutrients to young seedlings

early in the growth phase, but may cause a deficiency in larger seedlings by the end of the growing season (Imo and Timmer 1992). This occurs because nutrient requirements vary at different stages of seedling development throughout the growing season. Exponential fertilization closely matches nutrient supply with seedling growth demand during the exponential growth phase (Ingestad and Lund 1986; Timmer and Aidelbaum 1996), and enhances fertilizer uptake efficiency and minimizes potential leaching losses. Nutrient loading involves extra high fertilization to induce luxury uptake and build reserves in seedlings to benefit outplanting (Figure 1), and is more compatible with exponential fertilization. Thus, with exponential nutrient loading, nutrients are applied at exponentially increasing rates in excess of growth demand to induce luxury uptake, which builds seedling nutrient reserves to reduce competitive effects and benefit outplanting.

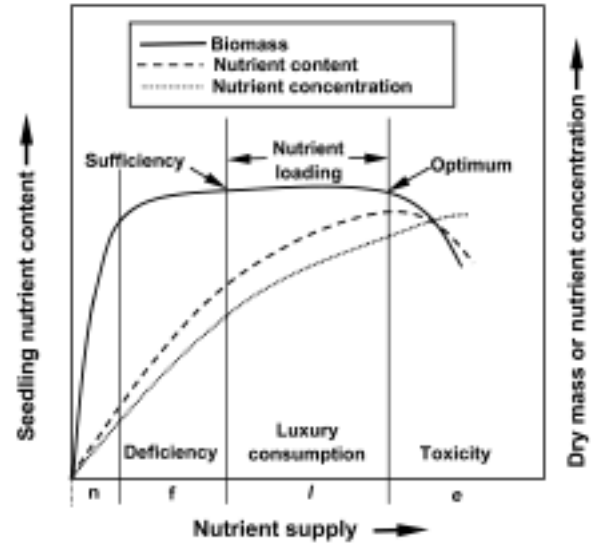
Although the above fertilization techniques may have universal application, protocols to determine optimal target rates associated with maximum growth and seedling nutrient storage are not well defined. There is apparent need to quantify target rates for each species and cultural system owing to differences in species demand for nutrients and variations in cultural conditions. An innovative approach that can help rationalize and quantify fertility targets in tree seedling culture is illustrated in Figure 1. The figure shows that the relationship between plant growth, nutrient status, and increased fertilization is curvilinear, but sectioned here into 3 phases to demonstrate points of nutrient deficiency, luxury consumption, and toxicity with increased fertility (Salifu and Timmer 2003; Salifu and Jacobs 2006). Generally, seedling growth is maximized at sufficiency. Optimum response is obtained when growth and nutrient uptake are maximized, which occurs during luxury uptake. Excessive fertilization induces toxicity, which is associated with increased tissue nutrient concentration but diminished growth (Figure 1).

Nutrient-loaded seedlings exhibit greater survival, growth, and competitiveness over non-loaded plants on a variety of habitats (Timmer and Munson 1991; Malik and Timmer 1996). The approach provides a new and useful technique to build plant nutrient reserve at the nursery stage, which has specific significance to reducing competitive effects and enhancing seedling performance on harsh outplanting environments. Birge and others (2006) tested application of exponential nutrient loading in standard bareroot red oak (*Quercus rubra*) and white oak (*Q. alba*) seedling culture to build nutrient reserves to benefit field outplanting. These nursery grown seedlings were then outplanted onto a mine reclamation site in southern Indiana to examine effects of prior nursery treatments on seedling field performance. Our objectives were to evaluate: 1) growth and nitrogen storage in exponentially fertilized seedlings compared with conventional cohorts at the end of nursery culture; and 2) survival and growth of exponentially nutrient-loaded seedlings compared with conventional cohorts planted on mined land in southern Indiana. These species were selected for the study because of their great importance to the local hardwood industry, wildlife habitat, and increased use in environmental plantings (Jacobs and others 2004).

## Materials and Methods

### Nursery Phase

Bareroot northern red oak and white oak seedlings were grown from seeds germinated in spring 2004 at Vallonia State Nursery, Indiana (38°85'N, 86°10'W). Seedlings were fertilized conventionally or exponentially using 10 fertility treatments that ranged from deficiency to toxicity (0 to 3.35 g N/plant/season). Higher fertility treatments were intended to build nutrient reserves in plants for later utilization when outplanted. Nitrogen was applied bi-weekly as ammonium nitrate in crystal form (34N:0P<sub>2</sub>O<sub>5</sub>:0K<sub>2</sub>O). Further details on the nursery study can be found in Birge and others (2006). Seedlings were mechanically lifted in December 2004 and processed for overwinter



**Figure 1.** Relationships between nutrient supply with plant growth and nutrient status. Fertilizer (*f*) 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*) that induces luxury consumption to build up plant nutrient reserves for outplanting. Excess fertilization (*e*) inhibits growth because of toxicity (adapted from Salifu and Timmer 2003).

storage in coolers (3 °C [37 °F]) at Purdue University, West Lafayette, Indiana. Plants were removed from storage in late April 2005, and sorted for the field experiment.

### Field Study

Nursery-reared seedlings were outplanted in April 2005 into an abandoned mine reclamation site in southern Indiana. The field design was a split-plot design with a 2 x 10 factorial treatment structure, and was replicated in 5 blocks. The main plot treatments were species at 2 levels and the sub-plot treatments were the 10 nursery fertility treatments. Each block measured 21 x 42 m (69 x 138 ft) and was separated from the next by 2-m (6.5-ft) buffers. Species were randomly allocated within blocks, and fertility treatments were randomly allocated within species. Each treatment consisted of 20 trees in one row within a block, and each block contained 20 rows. A total of 2500 seedlings were planted and monitored in this

experiment (10 treatments x 20 trees per treatment x 2 species x 5 replications). Trees were planted 1 x 1 m (3.3 x 3.3 ft) within rows and 2 x 2 m (6.5 x 6.5 ft) between rows. Sampling and quantification of seedling morphological and nutritional responses followed standard protocols (Salifu and Timmer 2003; Jacobs and others 2005). Growth and nutritional parameters were evaluated by analysis of variance using SAS (SAS Institute Inc, Cary, North Carolina), and treatments were declared significant at  $P < 0.05$ . Significant treatment means were ranked according to Waller-Duncan's multiple range test at  $\alpha = 0.05$ .

## Results and Discussion

### Nursery Phase

Growth and nutritional data sampled at the end of nursery culture (Birge and others 2006) conformed closely to trends shown in Figure 1, which demonstrates suitability of the model for application in hardwood culture. Exponential nutrient loading increased plant biomass 113% to 260% for red oak, and 49% to 144% for white oak when compared with nonfertilized plants. Similarly, nutrient loading stimulated N uptake 40% in red oak and 35% in white oak relative to controls. The greater nutrient reserves in loaded seedlings may serve as critical nutrient resources to reduce competitive effects and promote rapid growth under field conditions (Crow 1988; Dickson 1989; Tagliavini and others 1998). We recommend the use of balanced fertilizers to avoid potential antagonistic interactions associated with only N-based fertilizers in the nutrient loading process. Frequent fertilizer additions will make nutrients readily available to plants, which increases uptake efficiency and minimizes potential leaching losses associated with heavy and less frequent applications.

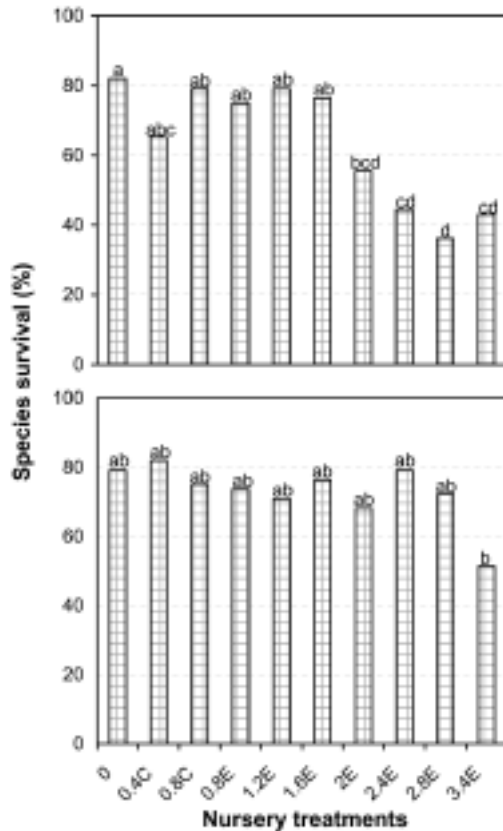
### Field Response

Generally, field survival was high in year 1 (Figure 2), but decreased by year 2 (Figure 3). First year field survival for exponentially cultured seedlings ranged from 83% to 92%, which is higher than the 66% (Figure 3) observed for con-

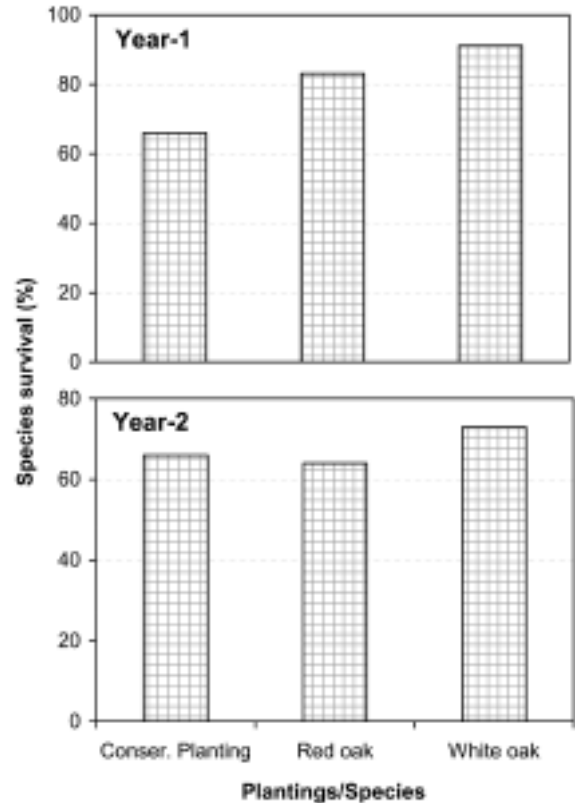
servation tree plantings in Indiana (Jacobs and others 2004). Year 1 survival for white oak was 92%, which was higher than survival of red oak at 83% (Figure 2). Survival decreased to 74% for white oak and 65% for red oak in year 2. Exponential nutrient loading promoted seedling height and root collar diameter growth for red oak (Figure 4, top) and white oak (Figure 4, bottom). High survival and rapid early growth may allow the plants to reach free-to-grow status sooner, which may minimize animal browse and/or the need for vegetation control with herbicides. Results of our current study suggest that exponential nutrient loading provides a new and useful management technique which has specific significance to improving seedling performance on mine reclamation sites and reclamation success in Indiana. We anticipate improved performance in subsequent years because of the potential to exploit greater nutrient resources stored in roots to support ongoing growth demand. We suggest further testing of exponential nutrient loading to build nutrient reserves in plants at the nursery stage to improve performance on harsh site conditions. Other innovative approaches, such as the use of controlled-release fertilizers at planting (Jacobs and others 2005), different stocktypes (Dixon and others 1983; Davis and Jacobs 2004), and mycorrhizal inoculation (Zhou and Sharik 1997) have been found to promote seedling field performance. The potential of these new approaches to improve seedling field response needs further testing and refinement.

## Conclusions

Storing nutrients in seedlings at the nursery stage provides a better rationale to promote seedling field performance. Higher pre-plant nutrient reserves have potential to reduce competitive effects and enhance internal redistribution to support new growth soon after outplanting. High survival and growth of competitive nutrient-loaded seedlings will accelerate forest restoration success on degraded landscapes, which will help to conserve soil resources as well as provide habi-



**Figure 2.** Field survival of red oak (top) and white oak (bottom) seedlings fertilized conventionally (C) or exponentially (E) during standard bareroot nursery culture for 8 months, and then outplanted for 4 months on a mine reclamation site in southwestern Indiana.



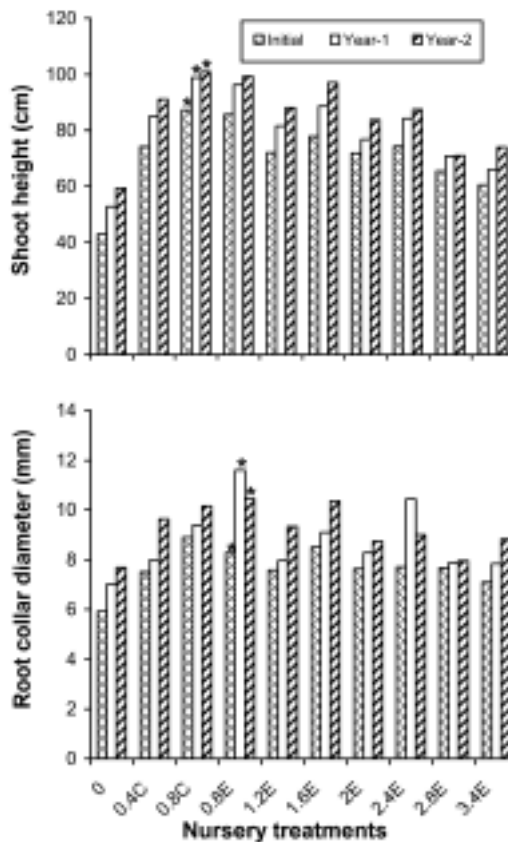
**Figure 3.** Survival of conservation tree plantations compared with overall field survival of red oak and white oak seedlings fertilized conventionally (C) or exponentially (E) during standard bareroot nursery culture for 8 months, and then outplanted for 4 months on a mine reclamation site in southwestern Indiana.

tat for wildlife. Early rapid growth will allow plants to reach free-to-grow status sooner and minimize potential for animal browse. Use of competitive nutrient-loaded seedlings will accelerate early growth and minimize the need to control competing vegetation with herbicides.

The use of balanced fertilizer is key to successful nutrient loading. Frequent and light applications will make nutrients readily available to plants. This increases uptake efficiency and minimizes potential leaching losses associated with heavy and less frequent applications.

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**Figure 4.** Shoot height and root collar diameter of red oak seedlings fertilized conventionally (C) or exponentially (E) during standard bareroot nursery culture for 8 months, and then outplanted for 4 months on a mine reclamation site in southwestern Indiana.

and R Winks during field or laboratory phase of this study.

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