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Nursery response of container *Pinus palustris* seedlings to nitrogen supply and subsequent effects on outplanting performance

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ABSTRACT

Container longleaf pine (*Pinus palustris*) seedlings often survive and grow better after outplanting than bareroot seedlings. Because of this, most longleaf pine are now produced in containers. Little is known about nursery fertilization effects on the quality of container longleaf pine seedlings and how that influences outplanting performance. We compared various fertilization rates (0.5, 1, 2, 3, or 4 mg nitrogen (N) per week for 20 weeks) for two crops (2004 and 2005) of container longleaf pine, grown inside a fully-controlled greenhouse (2004 and 2005) or in an outdoor compound (2005). Seedlings grew larger in the nursery with increasing amounts of N. After 20 weeks of fertilizer treatment, seedlings received two additional fertigations at the same treatment rate to promote hardening, N concentrations declined sharply, and seedlings shifted biomass production toward roots. Overall, shoots showed more plasticity to N rate than did roots. Survival of either crop after outplanting was unaffected by nursery N rate. For both crops, no seedlings emerged from the grass stage during the first year after outplanting, and during the second year, more seedlings exited the grass stage and were taller as N rate increased up to 3 mg per week. By the third field season, nearly all seedlings in the 2004 crop had exited the grass stage, whereas 44% of 2005 crop grown at 1 mg N had yet to initiate height growth, either because of differences in seed source between the two crop years or because of droughty conditions. Our data suggests that an application rate of about 3 mg N per week for 20 weeks plus two additional applications during hardening yields satisfactory nursery growth as well as field response for the container type we used. The potential for improving field performance by using more robust fall fertilization during nursery production should be investigated.

1. Introduction

The longleaf pine (*Pinus palustris* Mill.) ecosystem once dominated the southeastern United States, occupying more than 36 million hectares. Longleaf pine features a stemless grass stage to ensure its seedlings survive the frequent, low-intensity surface fires characteristic of their fire-adapted ecosystem (Barnett, 1999). For decades, foresters discriminated against planting longleaf pine. Low seedling survival due to poor seedling quality, grass stage persistence for several years, and faster initial growth from other southern conifer species led to the reluctance to plant longleaf pine (Croker, 1990; Barnett, 2002). In addition, intense harvesting during the past century reduced this forest type by nearly 98% and caused many other terrestrial species to become threatened and endangered (Noss et al., 1995; Outcalt, 2000; Barnett, 2002; Jose et al., 2006).

Two recent shifts in focus have brought attention to the production of longleaf pine for restoration and reforestation. First, federal incentive programs have encouraged restoration of longleaf pine ecosystems (Hainds, 2002), and second, land managers are moving from pulpwood to sawtimber production because of higher economic returns (Kush et al., 2004). To meet this demand, use of container longleaf pine has increased dramatically because survival and growth often exceeds bareroot stock (Boyer, 1989; Barnett and McGilvary, 1997; South et al., 2005). In 2008, 84% of the 76 million longleaf seedlings produced were grown in containers (Dumroese et al., 2009). Despite high demand for container longleaf pine seedlings, detailed research is lacking concerning its production and an absence of standards has caused subsequent variation in stock quality (Hainds, 2004). Based on the limited research, Barnett et al. (2002a,b) published interim guidelines for producing container longleaf pine, and these standards were recently updated (Dumroese et al., 2009). Although a target seedling is described, no fertilizer regimes to obtain that target are provided.

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Proper fertilization is critical during production of reforestation stock; fertilization influences the quality and quantity of plant growth within the container (Landis, 1989). Proper seedling nutrient levels can be linked to improved drought tolerance, cold hardiness, survival, competitive advantage, and growth, and reduced transplant shock (van den Driessche, 1991; Grossnickle, 2000). Excessive fertilizer during nursery production, however, can reduce growth because of salt accumulation (Jacobs and Timmer, 2005) as well as cause seedlings to grow too large for their containers and consequently perform poorly after outplanting, as exemplified by longleaf pine (South and Mitchell, 2006). Thus, finding an optimum fertility target for reforestation stock is fundamental (Salifu and Jacobs, 2006). Although this optimum fertility and subsequent stock quality can be described in the nursery, seedling performance after outplanting is paramount (Landis and Dumroese, 2006). Unfortunately, the field response of longleaf pine seedlings has yet to be related to specific nutrient rates, especially nitrogen (N), used in container nurseries (Dumroese, 2003; Jackson, 2006).

Therefore, our null hypothesis was that nursery N rate used to produce container longleaf pine would have no effect on outplanting survival, growth, and/or time spent in the grass stage. To test the hypothesis, we grew two crops in subsequent years under a variety of nursery N treatments and outplanted them to monitor survival and growth of individual seedlings for three field seasons.

2. Materials and methods

2.1. Nursery

Longleaf pine seedlings were grown at the USDA Forest Service, Southern Research Station facility in Pineville, Louisiana (latitude 31.3, longitude −92.4) inside a double polycarbonate-coved, fully-controlled greenhouse (2004 and 2005), and in a nearby (within 20 m) outdoor compound (2005) where seedlings were exposed to ambient conditions. We filled Ropak® Multi-Pot containers, commonly used to grow longleaf, with a 1:1 (v:v) Sphagnum peat moss:vermiculite medium. Each plastic Multi-Pot (61 cm long × 36 cm wide) consisted of 96 cavities (441 cavities m^{-2}) having 98 ml volume (3.8 cm diameter × 12 cm deep). Seeds were sown in early April and each year we used a different Florida seed source that was appropriate for outplanting in Louisiana. Three weeks after sowing, we thinned cavities having two seedlings by gentle pulling the extra seedling out. Frequency of irrigation or fertigation (irrigation with soluble fertilizer added) was determined gravimetrically; after irrigating containers to field capacity and allowing them to drain for 1 h, we measured the field capacity mass of the containers. When container mass reached 75% of field capacity, seedlings were fertigated or irrigated as required.

Nursery N treatments began 4 weeks after sowing (early May) and continued once per week for 19 weeks (mid-September; 20 applications total). In 2004, greenhouse seedlings received one of five nursery N treatments: 0.5, 1.0, 2.0, 3.0, or 4.0 mg N $seedling^{-1}$ $week^{-1}$ (hereafter simply mg N). Based on 2004 observations, greenhouse and outdoor grown seedlings in 2005 received one of three nursery N treatments: 1.0, 2.0, or 3.0 mg N. In both years, during the hardening phase, seedlings received two additional applications, at the same treatment rates, 3 and 6 weeks after weekly fertigation ceased (mid-October and mid-November, respectively). Therefore, seedlings in the 0.5, 1.0, 2.0, 3.0, or 4.0 mg N $seedling^{-1}$ $week^{-1}$ treatments received 11, 22, 44, 66, and 88 mg N total. We mixed the appropriate amount of fertilizer (Peters Professional® 20-19-18 [20N:19P_2O_5:18K_2O; The Scotts Company, Marysville, OH, USA]) into the volume of water required to return each replicate within each nursery N treatment to field capacity, and seedlings were hand-fertigated. Given the average field capacity mass (7.6 kg) and a target irrigation mass of 75% field capacity mass (i.e., 5.7 kg), each container received approximately 1.9 L per irrigation, or 20 ml per seedling. Thus, our weekly fertigation solutions for the 0.5, 1, 2, 3, and 4 mg N rates were approximately 25, 50, 100, 150, and 200 ppm N, respectively; the proportion of nutrients was constant: 100N (27NO_3^-; 20NH_4^+; 54urea): 42P: 75K: 0.75Mg: 0.1B: 0.05Cu: 0.05Fe: 0.28Mn: 0.05Mo: 0.08Zn. The applied ppm of N (25–200), P (10–80), and K (20–158) were similar to those reported by Landis (1989) for general seedling production.

Each nursery N rate included three Ropak® Multi-Pot containers that served as replicates. In 2004, we had 288 seedlings per nursery N treatment (1440 total). In 2005, we grew 288 seedlings per nursery N treatment per growing area (1728 total).

Beginning 9 weeks after sowing (5 weeks after initiation of nursery N treatments; early June) and continuing at 5-week intervals for 25 weeks (mid-November), we randomly measured 10 seedlings per replicate (30 per treatment; 6 sample times total). The fourth sample occurred 1 week after the weekly fertigation ceased and the final (sixth) sample occurred 1 week after the final fertigation (just prior to outplanting). Root-collar diameter (RCD) was measured twice at perpendicular angles at ground-line and the mean recorded. We measured the longest needle (either primary or secondary), and determined biomass after carefully washing the roots, segregating seedlings into shoots (needles, buds) and roots (basipetal from the cotyledon scar), and oven-drying at 60 °C to constant mass. Shoots and roots were subsequently ground and analyzed for N concentration using a LECO-2000 (LECO Corp., St. Joseph, MI, USA).

2.2. Outplanting

Immediately prior to outplanting, we removed seedlings from either the greenhouse or outdoor compound, extracted them from their containers by nursery N treatment, pooled them by replication and subsequently randomly re-allocated them into 4 replications (2005 seedlings remained segregated by growing location), left needles unclipped, and outplanted them (mid-November) on a mowed site within the Palustris Experimental Forest (latitude 31.0, longitude −92.6) near McNary, Rapides Parish, Louisiana. The area is gently sloping (1–3%) with a moderately drained and slowly permeable Beauregard silt-loam (fine-silty, thermic Plinthaquic Paleudult); this soil develops a perched water table during prolonged wet periods during winter and can be droughty during summer (Kerr et al., 1980). In 2004, 25 seedlings from each nursery N treatment were dibble-planted within a row at 60-cm spacing. Each row was 1 m apart. Each treatment was randomly assigned within each of 4 replicates (400 seedlings total). In 2005, 16 seedlings from each nursery N × nursery type (greenhouse or outdoor compound) combination were dibble-planted in a similar manner (384 seedlings total). Seedlings were outplanted with their buds at ground level and care was taken to ensure treatments were not confounded by planter technique.

At outplanting, we measured RCD of each seedling as described above. For three consecutive growing seasons, we re-measured seedling survival, RCD, and height (ground-line to tip of terminal bud). Seedlings were deemed to exit the grass stage when RCD ⩾ 25 mm and height ⩾ 10 cm (Wahlenberg, 1946). Accord™ herbicide (glyphosate *N*-(phosphonomethyl) glycine, isopropylamine salt; Dow AgroSciences, Indianapolis, IN, USA) was applied at 1.25 kg ai ha^{-1}on May 2005 to reduce weed competition. A wildfire burned the plots on 21 March 2007.

Rapides Parish weather data (Southern Regional Climate Center; http://www.srcc.lsu.edu/) proximate to the outplanting site was recorded at Oakdale (latitude 30.8, longitude −92.7; precipitation) and the Louisiana State University Dean Lee Research Station (latitude