MORPHOLOGICAL AND PHYSIOLOGICAL RESPONSES OF HARDWOOD TREES TO PLANTATION THINNING

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Abstract—A mixed hardwood plantation in Indiana was selected as a pilot study to investigate physiological and morphological responses of northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and black walnut (*Juglans nigra* L.) to thinning. Trends from the first growing season after harvest suggest average daily soil water content and soil temperature were higher in thinned plots when compared to control plots. All three species showed higher net photosynthesis rates in thinned plots. Increased production of photosynthate allowed trees in thinned plots to allocate more resources toward secondary growth as shown by increased diameter growth. Thinning, however, did not appear to increase soil nutrients, leaf water potential, crown surface area or height growth in a single growing season. Results suggest some variables responded to thinning during the first growing season after harvest, while others did not. Morphological parameters will be monitored to determine if current trends continue in subsequent years.

INTRODUCTION

In the Central Hardwood Forest Region of the United States, pure and mixed hardwood plantations have great economic potential. Intermediate silvicultural treatments such as thinnings have long been recognized as techniques to increase tree growth and quality. The increase in diameter growth and improvement in residual tree quality following thinning has been well documented in the past (Cutter and others 1991, Dale 1968, Hilt 1979, Oliver and Larson 1996). Changes occurring at the physiological level, however, are not well documented for deciduous forest tree species. To improve our ability to better predict responses after thinning and adjust silvicultural guidelines accordingly, there is a need to understand the nature and magnitude of hardwood tree responses to a change in available growing space. A pilot study was established in a mixed hardwood plantation to investigate morphological and physiological responses of northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and black walnut (*Juglans nigra* L.) during the first growing season after thinning. When compared to unthinned control plots, we hypothesized that thinned plots would have (1) increased soil water content, soil temperature, and soil nutrients; (2) trees with higher photosynthesis rates and leaf water potential; and (3) trees with higher mean diameter growth, height growth, and crown expansion.

METHODS

Study Area and Treatments

The mixed hardwood plantation is located in Colburn, IN (40°23’ N, 86°56’ W). The plantation was established in 1994 and appears to be at the beginning of the stem exclusion stage (Oliver and Larson 1996). Mean annual temperature, precipitation, and frost-free intervals are 10.1 °C, 937 mm, and 233 days, respectively (National Climatic Data Center 2004). Kalamazoo loam is the dominant soil type on this former agricultural land; it is characterized by deep, well drained soils formed in loamy outwash overlying sand or loamy sand (National Resources Conservation Service 2007). Northern red oak, white oak, black walnut, and black cherry (*Prunus serotina* Ehrh.) bareroot seedlings (1+0) were planted at 2.4 by 2.4 m spacing by the Indiana Department of Natural Resources. Mean (± SE) diameter at breast height (d.b.h.) for each species was 5.3 ± 0.3, 7.0 ± 0.2, 7.7 ± 0.3, and 11.9 ± 0.6 cm, respectively. Mean height for each species was 6.0 ± 0.2, 6.1 ± 0.1, 6.7 ± 0.2, and 8.7 ± 0.4 m. All species had 80 percent or more survival except for northern red oak with 56 percent. Four 400 m^2 square plots were established in a randomized complete block design. Two plots were thinned to 55 percent residual density while dormant based on guidelines for black walnut (Anonymous 1981) and oak (Gingrich 1971) and two plots were left as control plots. Each plot consisted of 8 by 8 rows (20 by 20 m) for a potential total of 64 trees. Black cherry had poor form, likely due to heavy browse damage; it was removed first (eight trees per plot). Smaller and less vigorous trees of all other species were cut until the required amount of trees per plot (34) was attained. On average, the number of trees cut per plot for northern red oak, white oak, and black walnut was 2, 3, and 7, respectively. The number of trees left for each species was 7, 13, and 14. The remaining ten trees were lost to mortality. One buffer row was established around each plot and treated in the same manner as the plot. A minimum of 20 m was left between each plot. Slash and debris from thinned trees were moved outside plot boundaries. Plots were mowed twice per month to reduce confounding effects from understory vegetation.

Soil and Tree Measurements

A soil moisture probe and temperature probe (Decagon Devices Inc., Pullman, WA) connected to a data logger (Onset Computer Corp., Bourne, MA) were installed in each plot for the months of July and August. Each probe was located within a 2-m radius of one tree selected for physiological measurements. The soil moisture probe measured volumetric water content (m^3/m^3) for the first 20 cm of the soil horizon; the temperature probe measured to a depth of 5 cm. Three soil samples were collected in the upper 10 cm of the mineral horizon of each plot in April, June, and August to determine N, P, and K content based on methods for the North Central Region (Brown 1998). Samples were sent to a professional laboratory for analysis (A&L Great Lakes Laboratories Inc., Fort Wayne, IN). Net photosynthesis rates (*A*) were measured twice per month between 9:00

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and 10:30 from June to August. Two trees of each species were sampled in each plot for a total of 24 trees. Two fully expanded leaves from the middle of the canopy (about 3 m in height) were chosen from each measurement tree. Photosynthesis measurements were conducted with a portable photosynthesis system (LI-6400, Li-Cor Biosciences Inc., Lincoln, NE). A light level of 1,200 μmol/m²/s¹ and ambient [CO_2] of 380 μmol/ mol¹ were specified in the chamber of the infrared gas exchange analyzer. Predawn and midday leaf water potential (Ψ) were measured on half of the trees selected for photosynthesis measurements using a pressure chamber (PMS Instruments Co., Albany, OR). Height, d.b.h., and crown surface area were measured prior to thinning and at the end of the first growing season. Crown surface area was calculated based on formulas from Brack (1999).

Statistical Analysis

Statistical analysis for this pilot study was descriptive in nature. The planting pattern was not uniform and did not allow us to establish more than four plots. With the plot as the experimental unit, sample size (n=4) did not allow for t-test or analysis of variance. For the first objective, data were plotted and descriptive statistics were used to compare means and associated variation. For the second and third objectives, data from trees measured over the course of the growing season were used to generate box charts for each measured variable. This approach identified general trends in the data.

RESULTS

Mean daily soil water content was 0.19 ± 0.01 m³/m³ in thinned plots compared to 0.13 ± 0.01 m³/m³ in control plots. Mean daily soil temperature was 26.3 ± 0.3 °C in thinned plots compared to 22.9 ± 0.2 °C in control plots (fig. 1). Thinning did not measurably alter soil nutrient content within a single growing season following the thinning treatment. Box charts showed a trend toward higher net photosynthesis rates for trees in thinned plots for all three species (fig. 2). No clear trend was detected in predawn or midday leaf water potential measurements. A tendency toward higher diameter growth was found in thinned plots for all three species (fig. 3), but height growth appeared to be higher in control plots for all species as well. Thinning did not alter crown surface area.

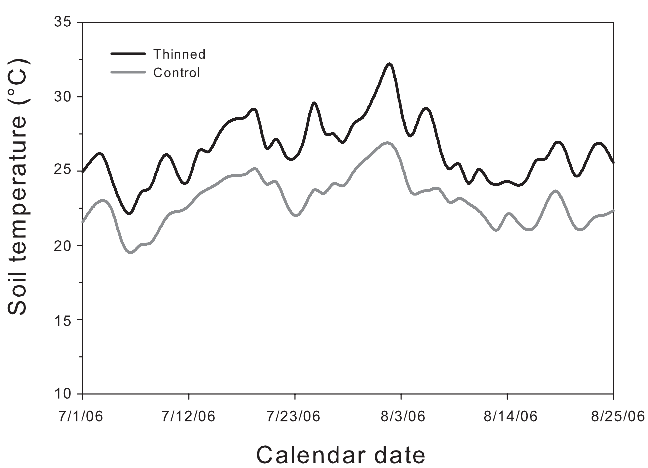

Figure 1—Mean daily soil temperature in thinned and control plots during the first growing season after thinning.

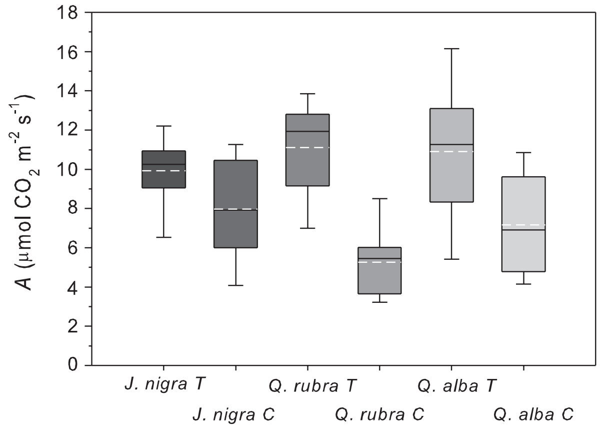

Figure 2—Box chart of net photosynthesis rates for each species and treatment (T = thinned, C = control) for the first growing season after thinning. Mean is shown by dashed line and median is shown by solid line, boxes represent one standard deviation from the mean, and whisker caps indicate 5th and 95th percentiles.

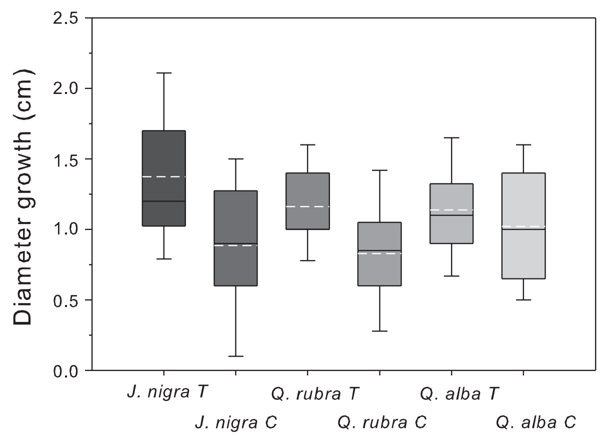

Figure 3—Box chart of diameter growth for each species and treatment (T = thinned, C = control) one growing season after thinning. Mean is shown by dashed line and median is shown by solid line, boxes represent one standard deviation from the mean, and whisker caps indicate 5th and 95th percentiles.

DISCUSSION

Results suggest some parameters responded immediately to thinning while others did not. Thinning increased soil water content, soil temperature, and net photosynthesis rates of residual trees of all three species. This was expected and is in agreement with previous thinning studies of conifers (Aussenac 2000, Sala and others 2005, Skov and others 2004). Diameter growth is mainly determined by environmental conditions from the current growing season, and increased production of photosynthate allowed trees in thinned plots to allocate more resources toward secondary growth. Height growth, however, is a function of the conditions from the previous growing season, at least for determinate growth species like black walnut. This may help explain the lack of response in height and crown surface area. Many oak species such as northern red oak can have additional flushes of shoot growth if conditions are favorable, but morphological responses to thinning may be delayed by two years or more with this species (Ward 2002).

Other variables also failed to respond to thinning. More time appears necessary to detect any changes in soil processes and nutrient content resulting from the increase in water content and temperature, albeit our sampling scheme may not have been extensive enough to detect actual trends. First and second year responses to thinning in mature sessile oak (*Q. petraea* (Matt.) Liebl.) stands in France showed increased predawn leaf water potential due to higher extractable water in the soil (Bréda and others 1995). Annual precipitation in 2006 was much higher than the long-term average in Indiana; this could have significantly lowered any potential water stress that might have occurred during a normal year. The lack of response of morphological parameters such as height and crown surface area may change over the next few growing seasons. They will be monitored to determine if current trends continue. This pilot study served as a template for additional experiments aimed at determining how plantation-grown hardwood trees respond to thinning in terms of photosynthetic activity and leaf morphology.

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