LONG-TERM TRENDS IN LOBLOLLY PINE PRODUCTIVITY AND STAND CHARACTERISTICS IN RESPONSE TO STAND DENSITY AND FERTILIZATION IN THE WESTERN GULF REGION

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Two levels each of fertilization and stand density were established to create four environments in a 7-year-old loblolly pine plantation on a N and P deficient western Gulf Coastal Plain site in Louisiana. Levels of fertilization were no fertilization and application of 120 lb N and 134 lb P/ac. Levels of stand density were the original stocking (1,210 trees/ac), and row thinning for a residual stocking of 303 trees/ac. Six years later (age 13), basal areas and relative stand densities on the non-thinned (NT) and thinned (T) plots were 176 and 79 ft^2/ac and 90 and 37 percent, respectively. At age 14, 178 lb N, 45 lb P and 45 lb K/ac were broadcast on the previously fertilized (F) plots and a second thinning was conducted on the previously thinned plots to a residual relative density of 31 percent of maximum, which corresponded to 67 ft^2/ac. Long-term measurements of climate, growth, leaf area dynamics and foliar nutrition were initiated at age 11. The objectives of this paper are to describe stand productivity between age 11 and 17 and offer ecophysiological explanations for these growth trends.

Fertilization increased basal area 8 and 9 percent, and stem volume 15 and 20 percent at age 11 and 17, respectively. At age 11, basal areas on the NT and T plots were 161 and 62 ft^2/ac, respectively. After removal of 12 ft^2/ac with the second thinning at age 14, basal areas increased on the NT and T plots, reaching 191 and 87 ft^2/ac and relative densities of 98 and 41 percent, respectively, by age 17. Similar stem volume responses to thinning were observed between age 11 and 17.

Interaction between light and water availability, and subsequent leaf area responses appeared to control mortality, current annual increment (CAI), growth efficiency (GE), and diameter class distribution. On the NT plots, for example, relative densities were within the self-thinning range of 60 to 100 percent of maximum stand density (81 to 98 percent) between age 11 and 17. During this period, peak leaf area index (LAI) increased between age 11 and 14, and began to decline at age 15 with the onset of water deficit and mortality. Specifically, annual soil water deficits at age 11 through 17 were 3.6, 7.3, 7.0, 4.7, 12.0, 10.6 and 15.9 in, respectively. Mortality for the entire period between age 11 and 15 was 5.5 percent; while mortality at age 16 alone was 7.0 percent. Water deficit at age 15 may have increased the rate of fascicle senescence, created a shortage of assimilate and increased self-thinning. Persistence of a high relative density and the simultaneous occurrence of water deficit and accelerated mortality after age 14 suggests that tree survival on the NT plots was dependent on a delicate balance between leaf area and assimilate supply.

In contrast to the NT plots, the T plots exhibited a positive curvilinear relationship between LAI and CAI ($R^2 = 0.4549$). This relationship improved with exclusion of data collected after age 14 when annual soil water deficits increased ($R^2 = 0.7235$). Variation associated with CAI on the T plots after age 14 may be attributed to the variable ability of individual plots to maintain normal levels of C fixation and growth when water deficit occurred. Below a LAI of approximately 3.25, this relationship was linear, but at LAI values greater than 3.25, a lower rate of CAI per unit LAI was observed both before and after the onset of water deficit. At our site, a LAI value of 3.25 may represent the point at which shading led to reduced lower crown light availability and less whole-crown C fixation, or the fraction of C allocated to sinks other than stem growth increased.

Growth efficiency (GE) between age 12 and 16 was expressed as the ratio of CAI and peak LAI. Year and stand density, but not fertilization affected GE. Average GE was 98 ft^3/ac/year at age 12. GE decreased to 30 and 86 ft^3/ac/year on the NT and T plots, respectively, at age 15, and increased to 78 and 91 ft^3/ac/year on the NT and T plots, respectively, at age 16. Declines in GE between age 12 and 15 may have been caused by temporary imbalances between CAI and peak LAI caused by self-thinning on the NT plots and operational thinning on the T plots. At age 16, the GE of the NT and T plots increased to 80 and 92 percent of that observed at age 12. It is likely that these gains in GE were caused by shoot and fascicle growth into canopy gaps created by self-thinning or operational thinning and subsequent increases in C fixation and volume growth.

In addition to volume increment, the diameter distribution of wood volume produced on the T plots changed over time in response to fertilization. Immediately before re-thinning at age 14, the majority of volume was in diameter classes less than 9 inches with the remaining 6 and 18 percent in the 9 to 12-inch diameter classes on the thinned, non-fertilized (TNF) and thinned, fertilized plots (TF), respectively. Three years later at age 17, 44 and 83 percent of the volume was in the 9 to 12-inch diameter classes on the TNF and TF plots, respectively. By age 17, fertilization on

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Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

the T plots not only produced a 19 percent increase in volume but added 89 percent more volume to the 9 to 12-inch diameter classes than to the diameter classes less than 9 inches. Following re-thinning, LAI equilibrated to pre-treatment levels after two years on the TNF plots and one year on the TF plots. Thus, when thinning and fertilization were applied together, fertilization increased the rate at which LAI was re-established. In addition to an increase in LAI, rapid equilibration of LAI may have hastened movement of volume into the 9 to 12-inch diameter classes on the TF plots when compared to the TNF plots between age 14 and 17.

At age 14 through 16, nutrient use efficiencies were calculated as the ratio of CAI and foliar N and P content (N NUE and P NUE). Nutrient use efficiencies were affected by year but not stand density or fertilization and averaged 1.9 and 26.1 ft^3/lb of foliar N and P, respectively, at age 14 and 15. At age 16, N NUE and P NUE increased to 3.2 and 42.5 ft^3/lb, respectively. Increases in N NUE and P NUE at age 16 occurred simultaneously with increases in GE and may have been associated with re-establishment of leaf area in canopy gaps caused by self-thinning and operational thinning. Although foliar concentrations of N and P were increased, nutrient use efficiencies were unaffected by fertilization. Thus, positive effects of fertilization on stand growth were likely caused by changes in leaf area, rather than nutrition enhancement of physiological responses.

In summary, between age 11 and 17 the productivity of plantation loblolly pine in four environments created by thinning and fertilization in central Louisiana appeared to be controlled by interaction among light, water and leaf area. Mechanisms of control differed by stand density, and effects of fertilization were manifested through leaf area responses.