THE EFFECTS OF DECREASED WATER AVAILABILITY ON LOBLOLLY PINE (*PINUS TAEDA* L.) PRODUCTIVITY AND THE INTERACTION BETWEEN FERTILIZER AND DROUGHT

Adam O. Maggard, Rodney E. Will, Duncan S. Wilson, and Cassandra R. Meek[1]

Abstract—As part of the regional PINEMAP (Pine Integrated Network: Education, Mitigation, and Adaptation project) funded by the NIFA - USDA, we established a factorial study in McCurtain County, OK near Broken Bow. This study examined the effects of fertilization and ~30 percent reduction in throughfall on an seven-year-old loblolly pine (*Pinus taeda* L.) plantation. The objective of this study was to determine effects of decreased water availability and fertilization on tree growth. We measured tree and stand development as well as a suite of ecophysiological variables. Tree growth was reduced in throughfall exclusion treatments and increased in fertilizer treatments. At various times during the measurement period, throughfall exclusion reduced net photosynthesis, stomatal conductance, and mid-day leaf water potential. These results indicate that lower availability of soil moisture reduces leaf gas exchange and slows growth.

INTRODUCTION

Over the last half century, increases in pine plantation productivity and management in the southeastern United States has enabled these forests to produce more wood than any other region in the country (Fox and others 2007, Cubbage and others 2007). Loblolly pine have a greater growth rate than other commercially important southern pines and consist of over 50 percent of pine plantations across the Southeast are loblolly pine (*Pinus taeda* L.), thus making it the most commercially important tree species and a large driver of commercial timber production and habitat for numerous wildlife species (Baker and Langdon 1990, Dipesh and others 2015). Across the Southeast it is predicted that a shift towards a warmer and drier climate will likely occur. Increasing temperatures and decreasing or more variable precipitation is expected to impact forests productivity in the Southeast (IPCC 2007). More specifically, larger precipitation events with longer drying periods are predicted to lead to an increased intensity and duration of drought (Easterling and others 2000, Walsh and others 2014).

As part of the regional PINEMAP (Pine Integrated Network: Education, Mitigation, and Adaptation project) funded by the NIFA – USDA, this study examined the effects of fertilization and ~30 percent reduction in throughfall on a loblolly pine plantation over 2012, 2013, and 2014 growing seasons. The objective of this study was to determine effects of decreased water availability and fertilization on leaf gas exchange and tree growth. We hypothesized that fertilizer added to a water stressed loblolly pine plantation will lead to tree growth similar to that of an unfertilized, non-water stressed loblolly pine plantation.

SITE

This study was conducted on a privately owned loblolly pine plantation near Broken Bow in southeastern OK planted in January 2008. Planting density for the site was 2 by 3 m (~1650 trees ha^{-1}) Elevation for the site was 150 m. Soil consisted of Ruston fine sandy loam with 3 to 8 percent slopes, very deep, and well drained (U.S Department of Agriculture 2015). Depth to the water table is greater than 2000 mm. Precipitation over the three years was 1026 mm in 2012, 1312 mm in 2013, and 1289 mm in 2014. Average temperature was 15.4 °C with average maximum and minimum temperatures of 22.6 and 8.8 °C (Mesonet Weather 2015).

PROCEDURES

Experimental Design

The study consisted of four blocks (16 plots). Each block consisted of four treatment plots designed as a two by two factorial combination of fertilization and throughfall reduction. Plots had a 0.03 ha measurement plot for tree growth and yield within a 0.10 ha treatment plot. For leaf gas exchange, each plot had five measurement trees (80 total). Treatments include fertilization (optimum nutrition), ~30 percent reduction in throughfall, fertilization plus ~30 percent reduction in throughfall, and control with ambient throughfall and no fertilization. The elemental fertilization treatment

[1]Ph.D. Student, Professor of Forestry, Assistant Professor of Forestry, Research Specialist, Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, Oklahoma 74078

Citation for proceedings: Schweitzer, Callie J.; Clatterbuck, Wayne K.; Oswalt, Christopher M., eds. 2016. Proceedings of the 18th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–212. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

consisted of common operational applications of 224 kg ha^{-1} nitrogen, 27 kg ha^{-1} phosphorus, and 56 kg ha^{-1} potassium. Nitrogen was applied as 432 kg ha^{-1} urea, phosphorus was applied as 140 kg ha^{-1} DAP, and potassium was applied as 112 kg ha^{-1} potash. To prevent micronutrient deficiency, granular oxysulfate micronutrient mix (Southeast Mix, Cameron Chemicals, Inc., Virginia Beach VA) was applied at a rate of 22.4 kg ha^{-1}. Throughfall reduction treatments consisted of precipitation throughfall exclusion troughs placed between tree rows designed to cover 30 percent plot ground area. Exclusion troughs were installed in late spring/early summer 2012 and were built of lumber and covered with clear U.V. stabilized plastic sheeting consisting of two layers co-extruded polyethylene and one layer of high strength polyester string (Tuff-Scrimm™ Poly 12, Americover Inc., Escondido, CA).

Measurements and Analysis

Volumetric soil water content (VWC) was measured every 4 to 6 weeks at 0 to12 cm with a HydroSense Soil Water Measurement System (Campbell Scientific, Inc, Logan, UT). Tree height and diameter growth was measured in January 2012 before treatments were implemented and in December following each growing season. Height growth was measured initially using a height pole. Once trees were taller than the height pole, tree height was measured with a hypsometer (Laser Technology, Inc., Centennial, CO, USA). Diameter growth was measured at DBH by averaging two caliper measurements taken at right angles. Similar to height growth, once trees outgrew the use of calipers, diameter tape was used. Total height and diameter growth was analyzed as a two by two factorial combination ($n = 4$). Leaf gas exchange was measured every 4 to 6 weeks from October 2012 through September 2014 on two fascicles taken from the upper third of tree using a portable photosynthesis system (LiCor 6400, LiCor Inc., Lincoln, NE). Mid-day leaf water potential was measured using a pressure chamber (PMS, Instrument Corp., Corvallis, OR) and coincided with leaf gas exchange measurements. Leaf gas exchange measurements and mid-day leaf water potential measurements were analyzed using a repeated measures analysis with an AR1 covariance structure ($n = 4$).

RESULTS AND DISCUSSION

Soil Moisture

Throughfall reduction reduced VWC. Ambient precipitation plus fertilizer treatments maintained greater VWC than control treatments. Across all plots, VWC at 0 to12 cm was reduced from 10.8 to 8.5 percent by throughfall excluders.

Growth

Fertilizer increased tree growth and throughfall reduction decreased tree growth. Throughfall reduction decreased total height growth over 2012, 2013, and 2014 growing seasons ($p < 0.0001$) compared with ambient precipitation treatments (fig. 1A). Throughfall reduction decreased total diameter growth over 2012, 2013, and 2014 growing seasons ($p = 0.0009$) and fertilization increased total diameter growth ($p = 0.0003$), compared with ambient precipitation and non-fertilized treatments, respectively (fig. 1B). Fertilization compensated for drier conditions in diameter growth, where throughfall reduction plus fertilization had similar growth as control treatments (fig. 1B).

Leaf Gas Exchange

Throughfall reduction decreased net photosynthesis and stomatal conductance ($p < 0.0001$). Fertilization decreased stomatal conductance ($p = 0.006$) and had no effect on net photosynthesis. Throughfall reduction caused increasingly negative mid-day leaf water potentials ($p < 0.0001$) and fertilization caused less negative mid-day leaf water potentials ($p = 0.02$).

Effects of Fertilization and Reduced Precipitation

These results indicate that lower availability of soil moisture reduces leaf gas exchange and slows growth. However, it was shown that fertilization can compensate for throughfall reduction. Tree growth was increased by fertilization and decreased by throughfall reduction. Additive effects of throughfall reduction and fertilization indicate that positive effects of fertilization are not eliminated when growth is reduced by throughfall reduction. Differences between the two responses determined whether volume growth decreased or increased when responses were combined, thus determining the net effect on growth. Throughfall reduction decreased net photosynthesis and stomatal conductance. These changes are related to increasingly negative mid-day leaf water potential and higher degree of tree water stress. Fertilizer decreased stomatal conductance and led to less negative mid-day leaf water potential, indicating how fertilization can be beneficial in loblolly pine plantations experiencing reduced water availability.

ACKNOWLEDGMENTS

The Pine Integrated Network: Education, Mitigation, and Adaptation project (PINEMAP) is a Coordinated Agricultural Project funded by the USDA National Institute of Food and Agriculture, Award #2011-68002-30185. We would like thank Bob Heinemann and the staff of the Kiamichi Forestry Research Station for installation, data collection, and field work. Special thanks to Mr. Ed Hurliman for generously allowing us to use his property for this study. We thank Brittany

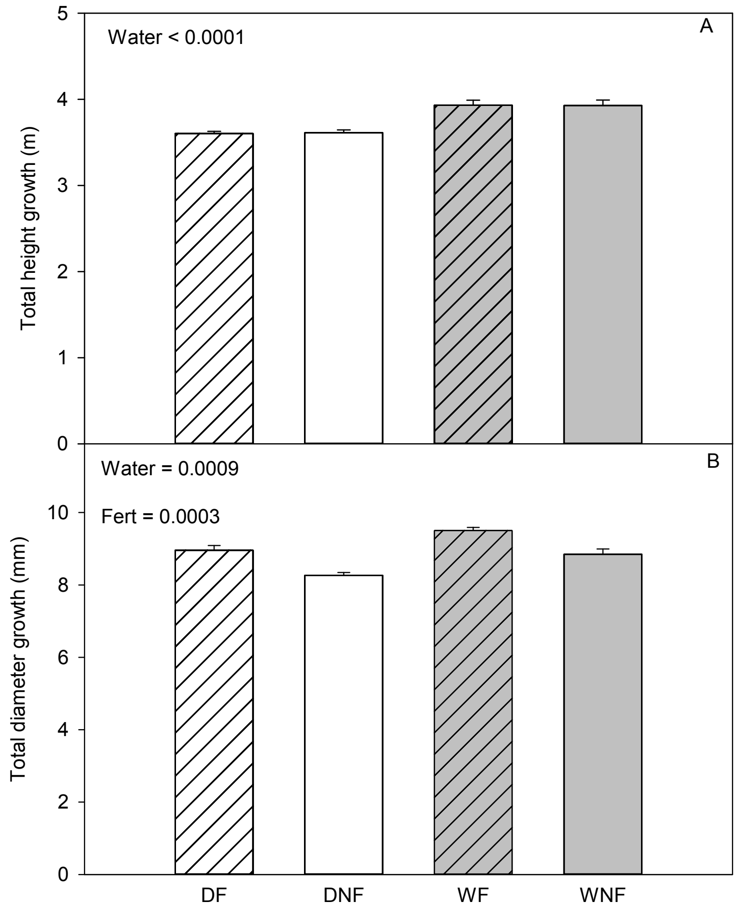

Figure 1—Total height growth (A) and diameter growth (B) by treatment over three growing seasons. DF = 30 percent throughfall reduction plus fertilization, DNF = 30 percent throughfall precipitation reduction with no fertilization, WF = ambient precipitation plus fertilization, and WNF = ambient precipitation with no fertilization.

Baggott and Alex Hardison as part of the PINEMAP undergraduate fellowship program for their technical assistance and dedication to this project.

LITERATURE CITED

Baker, J.B.; Langdon, O.G. 1990. *Pinus taeda* L.-Loblolly Pine. In: Burns, R.M.; Honkala, B.H., tech. cords. Silvics of North America, Vol. 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 497-512.

Cubbage, F.; Donagh, P.M.; Sawinski, J. [and others]. 2007. Timber investment returns for selected plantations and native forests in South America and the southern United States. New Forests. 33: 237-255.

Dipesh, K.C.; Will, R.E.; Lynch, T.B. [and others]. 2015. Comparison of loblolly, shortleaf, and pitch X loblolly pine plantations growing in Oklahoma. Forest Science. 61(3): 540-547.

Easterling, D.R.; Meehl, G.A.; Parmesan, C.; Changnon, S. 2000. Climate extremes: observations, modeling, and impacts. Science. 289: 2068-2074.

Fox, T.R.; Jokela, E.J.; Allen, H.L. 2007. The development of pine plantation silviculture in the southern United States. Journal of Forestry. 105: 337-347.

IPCC, 2007: Summary for policymakers. In: Climate change 2007: The physical science basis. Solomon, S.; Qin, D.; Manning, M. [and others]. eds. Contribution of working group I to the 4th assessment report of the intergovernmental panel of climate change. New York: Cambridge University Press: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spm.html [Date accessed: May 7, 2015].

Mesonet Weather. 2015. Daily data retrieval. http://www.mesonet.org/index.php/weather/daily_data_retrieval [Date accessed: May 7, 2015].

U.S. Department of Agriculture. 2015. Official series description-Ruston series. https://soilseries.sc.egov.usda.gov/OSD_Docs/R/RUSTON.html [Date accessed: May 1, 2015].

Walsh, J.; Wuebbles, D.; Hayhoe, K. [and others]. 2014. Ch.2 Our changing climate. In: Melillo, J.M.; Richmond, T.C. and Yohe, G.W., eds. Climate change impacts in the United States: The 3rd National Climate Assessment. Washington, DC: U.S. Global Change Research Program: 19-67.