FERTILIZATION AND POST-DROUGHT RECOVERY GROWTH HELP COMPENSATE FOR 9 YEARS OF PRECIPITATION REDUCTION IN A MID-ROTATION *PINUS TAEDA* PLANTATION IN THE WESTERN GULF REGION, USA

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EXTENDED ABSTRACT

Climate change induced drought will likely decrease forest growth (Vose and others 2018). Reduced soil moisture typically decreases aboveground stem production in loblolly pine (*Pinus taeda*) plantations (Shephard and others 2021a). Drought effects on loblolly pine production is of concern due to its commercial importance in the Southern United States. Anticipated drought effects are likely to occur first on loblolly pine's drier, western commercial edge in Texas and Oklahoma. Silvicultural practices like fertilization (Maggard and others 2017) and thinning (D'Amato and others 2013) could counterbalance decreased stem production from drought. In prior studies, interactions of throughfall reduction and fertilization (Maggard and others 2017) and fertilization and thinning (Sayer and others 2004) were examined in loblolly pine. The three-way interaction of throughfall reduction and fertilization and thinning has yet to be studied in North American forestry.

To understand if intensive silviculture could remediate reduced soil moisture, we studied a mid-rotation loblolly pine stand in southeastern Oklahoma from 2012 (age 5) to 2020 (age 13). A 2 x 2 factorial of 30 percent throughfall reduction and fertilization was initiated in the spring of 2012 and replicated four times (16 plots). We hypothesized that (1) throughfall reduction would reduce volume production, (2) mid-rotation fertilization would compensate for throughfall reduction, in that ambient plots would have similar volume production as would fertilization and throughfall reduced plots, and (3) the negative effects of throughfall reduction would be less for thinned plots.

Throughfall was captured by excluder troughs that covered approximately 30 percent of each plot and diverted throughfall off-plot. Fertilizer was hand applied at 224 kg N ha^{-1}, 28 kg P ha^{-1}, and 56 kg K ha^{-1}, plus micronutrients (Will and others 2015). A split-plot treatment of thinning was applied to each plot in the spring of 2017 (age 10, 32 plots) via girdling and an injection of herbicide above the girdle. At this time, fertilizer treatments were reapplied. Diameter at breast height (DBH) and height were measured at the end of each growing season from 2012 to 2020 (age 5 to age 13).

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From 2011 to 2013, the site experienced drought conditions and precipitation was below the normal 1300 mm: 1207 mm in 2011, 1023 mm in 2012, and 1260 mm in 2013. Precipitation was close to average in 2014, above average from 2015 to 2016 and 2019 to 2020, and mild drought occurred in 2017. The net effect after 9 years of treatment (age 13) was that fertilization increased DBH by 4 percent ($p=0.004$) and thinning increased DBH by 7 percent ($p<0.0001$). By age 13 only throughfall reduction significantly (-4 percent, $p=0.01$) decreased height. Related to height, throughfall reduction decreased site index at base age 25 from 20.9 m (ambient throughfall) to 20.4 m (throughfall reduction). The DBH and height trends were reflected in total gross volume current annual increment (CAI). Throughfall reduction decreased total CAI by 7 percent ($p=0.03$), fertilization increased total CAI by 8 percent ($p=0.02$) and thinning decreased total CAI by 17 percent ($p<0.0001$). Treatments were generally dependent on annual conditions. Throughfall reduction usually had stronger negative effects on CAI in dry years and following dry years (2013, 2014, 2018), and fertilization had stronger positive CAI effects immediately following fertilization (2012, 2017). Thinning did not significantly interact with throughfall reduction or fertilization for height, diameter, or CAI. Somewhat surprisingly, throughfall reduced plots showed greater relative basal area growth once wetter conditions returned following periods of meteorological drought than non-throughfall reduced plots (Shephard and others 2021a). This increased the basal area increment in the drought plots and likely indicates "recovery growth".

Similar to other studies (Maggard and others 2016, 2017), our two hypotheses that drought would decrease CAI and mid-rotation fertilization would counteract reduced soil moisture were supported. Our study emphasizes the importance of treatment timing on stand production. After 9 years of soil moisture reduction, throughfall reduction decreased the height-diameter relationships. Throughfall reduction showed a modest 7-percent decrease in volume and 0.5 m reduction in site index. Water stress has changed other DBH-height relationships of tree species as well (Fortin and others 2018). This production decline could increase rotation age and decrease landowner profits (Shephard and others 2021b).

Fertilization results mimicked previous studies (Maggard and others 2017) and showed greater increases in diameter than height (Allen and others 2005). Positive fertilization effects on CAI were realized shortly after application and only affected DBH. Throughfall and fertilization treatments were additive in terms of CAI (i.e., no interactions) and opposed one another: fertilization +7 percent, throughfall reduction -8 percent.

Our third hypothesis that thinning would mitigate throughfall reduction was not supported. However, increased relative basal area increment occurred in throughfall reduced plots post-meteorological drought, termed recovery growth, and may indicate resilience to drought conditions, perhaps due to increased carbohydrate storage during dry conditions (Hallgren and others 1991) that is then used for growth during wetter periods.

Our study showed possible production outcomes under a moisture-limited climate. Throughfall reduction marginally reduced, -7 percent, volume production. Mid-rotation fertilization compensated for dry conditions. Throughfall reduced plots showed recovery growth when wet conditions returned. Results from our study provide support for continued site-intensive silviculture in a future that is likely to be drier.

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