UNIVERSITY OF GEORGIA
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Publication WSFNR-21-72A

September 2021

Longleaf pine wood yields response to midrotation fertilization on two old-field sites

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INTRODUCTION

Longleaf pine (*Pinus palustris*) is frequently planted by private landowners on former agricultural fields or pasture sites throughout the Coastal Plain of Georgia through enrollment in government cost-share programs such as the United States Department of Agriculture's Farm Service Agency's Conservation Reserve Program. Cost-share programs partially cover costs associated with afforestation including: site preparation, seedling purchase, seedling planting costs, post-establishment herbaceous weed control, and periodic prescribed burns. Some programs may also have yearly rental payments for the duration of the contract. These programs have been very successful for restoration of longleaf pine in Georgia and as of 2020 over 227,000 acres had been planted since longleaf pine cost-share programs began (Weaver 2011, Phillips 2020). These cost-share programs have aided tremendously with restoration of longleaf pine on private lands throughout the southern half of the state.

Old-field sites, or site that have previously been in row crop agriculture or pasture one timber rotation or less prior to planting with trees, have altered soil physical and chemical properties as compared to soils on sites that have always been forested or maintained with native vegetation. Past agricultural activities can potentially homogenize, compact, or aerate upper soil horizons. In addition, nutrient losses on these sites from soil can be increased because of leaching, erosion, or volatilization. Fertilizer amendments such as inorganic fertilizer or manure can alter soil pH, nitrogen (N) and phosphorus (P) levels, but persistence and magnitude of fertilization impacts can vary considerably with soil type, time since fertilizer application, number of previous fertilizer applications, climate, and vegetation characteristics. In general, Coastal Plain sites that were previously in row crop agriculture or used as pasture land have improved soil fertility (especially P), altered soil tilth (upper soil horizons), and higher soil pH than sites never converted to agricultural uses or converted to forests in the distant past. Longleaf pine is adapted to low fertility, droughty, eroded and sandy soils of the Coastal Plain region. It is one of the few pine species capable of sustained growth on sites with deep, excessively well-drained sandy textured soils (Brendemuehl 1981, Boyer 1990). The species also has lower foliar nutrient threshold levels than other southern pine species such as loblolly (*Pinus taeda*) and slash pines (*Pinus elliottii*) further indicating its low nutrient requirements (Dickens et al. 2003).

Midrotation fertilization merchantable volume gains are well-documented in loblolly and slash pine stands on responsive sites (Albaugh et al. 2003, Albaugh et al. 2012, Finto et al. 2009, Jokela and Stearns-Smith 1993, Liechty and Fristoe 2013). Benefits of midrotation fertilization improve when competing woody vegetation is controlled or its influence is minimized. Some sites with woody vegetation problems and low soil nutrient levels have shown benefits of vegetation control and midrotation fertilization, and these operations have been noted as additive in terms of wood growth in some studies (e.g. Albaugh et al. 2012). Midrotation fertilizer applications are usually made in conjunction with thinning (before or after) with either N and P or P alone being the most common fertilizer prescriptions. Minimal research has been published on the impacts of longleaf pine midrotation fertilization when applied to old-field longleaf pine stands. Information on potential wood volume growth additions associated with midrotation fertilization might assist with landowner and manager decisions to incorporate fertilizer applications into management activities.

The objectives of this study were (1) to determine the long-term growth and stem quality of old-field planted longleaf pine, and (2) to quantify the possible benefits of fertilizing longleaf pine prior to thinning at midrotation on old-field sites with single and split dose applications of nitrogen, phosphorus and potassium.

METHODS

Study Sites

Study areas were located on two privately owned properties in Tift and Screven County, Georgia (Figure 1). Sites were located 131 miles apart but were both within the Middle Coastal Plain physiographic region and specifically the Tifton Upland, which forms a 30-50-mile-wide strip oriented from southwest to northeast across this region. Soils at both sites were mapped by an NRCS soil mapper. The soil series at the Tift County site consisted of Albany and Leefield. Albany soils are characterized as somewhat poorly drained, sandy Aquic Arenic Paleudults while the Leefield series is a somewhat poorly drained, loamy sand Plinthaquic Paleudult. The Screven County site soil series are Blanton and Bonneau. Blanton soils are well-drained, fine sand Grossarenic Paleudults while the Bonneau series is a well-drained, loamy sand Arenic Paleudult. Both study areas were located on upland sites suitable for longleaf pine management. Soil pH ranges from 4.8 to 5.8 at these sites.

Management History

The Tift County site was a former Virginia Runner peanut field prior to the establishment of the current study in December 1986, while the Screven County site was in row crop agriculture from the early 1800s to early 1950s when it was planted with loblolly pine. That stand was harvested in the early 1980s and the site was subsequently returned to row crop agriculture for three years prior to establishment of the present study in December 1986. Neither study area was enrolled in government cost-share programs.

Site preparation at Tift County and Screven County only included mechanical site preparation, and site preparation was catered to soil and vegetation conditions on these sites. At

Figure 1: *Location of the Tift and Screven County, Georgia old-field midrotation fertilization longleaf pine study areas.*

Tift County, chisel plowing was used to fracture potential hardpans or plowpans from past cultivation, while at Screven County site preparation consisted of terracing and subsoiling to also address agriculture-related hardpans. The Tift County site was planted with 1-0 stock bareroot seedlings purchased from the Georgia Forestry Commission (GFC). Seedlings were planted at a 6 x 12 ft spacing (605 trees per acre). Half the Screven County site was planted with 1-0 stock bareroot seedlings and half with 1-0 stock containerized seedlings. Seedlings were planted at an 8 x 9 ft spacing (605 trees per acre). The bare-root seedlings at the Screven County site were purchased from GFC, while the containerized seedlings purchased from GFC, called "speedlings" were four-inch plugs.

The Tift County site received first and second year banded, chemical herbaceous weed control and periodic prescribed burning (two to three-year return interval) starting at age two until pine straw raking began at age seven (Figures 2 and 3). Herbaceous weed control at the Screven County site consisted of mowing twice per year between rows for the first five years after stand establishment. The Screven County site was burned at ages five and eight before pine straw raking began at age eight.

At age 21 prior to thinning, survival was 50% at both sites. The first thinning occurred at the Tift County site occurred during 2011 at stand age 25-years. Prior to thinning, stand basal area average 139.5 $ft^2\ ac^{-1}$. A fifth row plus select combination thinning was used that favored removal of small-diameter suppressed or intermediate crown class stems. Preferred residual stems had at least one clear 16 ft log. The thinning operation removed an average of 56 $ft^2\ ac^{-1}$ of basal area (Figure 4). Within two years after thinning, one experimental unit, the unit with the

Figure 2: ***The Tift County site during the second or third growing season following herbaceous weed control applications.*** Photo: Dave Moorhead

Figure 3: ***The Tift County site at age 10, three years after pine straw raking began.*** Photo: Dave Moorhead

Figure 4: ***Tift (left photo) and Screven County sites shortly after a fifth row plus select combination thinning at stand ages 25 years (Tift County) and 23 years (Screven County) for the midrotation old-field longleaf pine fertilization study. Logging machinery operators were asked to retain trees lacking visible defects in the first 16-foot log.***

highest pre-thin trees per acre and basal area, was lost to bark beetle infestation. The Screven County site was thinned during 2009 at age 23-years with similar thinning methodology and goals. Stand basal area averaged 146 ft^2 ac^{-1} prior to thinning. Stand basal area was reduced by an average of 54 ft^2 ac^{-1} (Figure 4).

Treatment Application

Before and after fertilizer treatment application, baseline soil and foliage nutrient samples were gathered at each site. Tift County pre-fertilization samples were collected during February 2004, while samples at Screven County were gathered during December 2003. Pre-treatment soil P levels (Mehlich I extraction procedure)) were above sufficiency (6 to 10 lb ac^{-1}) for adequate southern pine growth (Wells et al. 1973) across all treatments at the Tift County site, while soil P was within the minimum threshold range for the Full NPK treatment at the Screven County site (Table 1). Longleaf pine foliar nutrient thresholds (N, P, and K) are 0.95%, 0.08%, and 0.3%, respectively (Blevins et al. 1996, Dickens et al. 2017). Foliar N levels were below sufficiency across treatments prior to study establishment at the Tift County site, while P was above the minimum threshold. Foliar nutrient concentrations were above sufficiency for all nutrients and treatments at the Screven County site prior to treatment establishment (Table 2). Post-treatment soil and foliage nutrients were above sufficiency at each site prior to the second NPK split-dose application, except for foliar N in the control and half NPK treatment at the Tift County site (Tables 1 and 2).

Table 1: Soil nutrient levels pre and post-treatment application at the Tift and Screven County longleaf pine midrotation fertilization study areas. Values are for the first 6 in of surface soil. Available nutrient status levels are reported in lbs ac-1. Underlined values are considered below sufficiency.

Tift County

Date	Treatment	pH	P	K	Ca	Mg
Feb 2004	Across All Treatments	4.8	18	–	–	–
Feb 2006*	Control	4.9	<u>7</u>	26	94	10
	1/2+1/2 NPK	4.8	11	32	138	16
	Full NPK	4.7	28	28	90	12

Screven County

Date	Treatment	pH	P	K	Ca	Mg
Feb 2003	Control	5.7	14	30	296	34
	1/2+1/2 NPK	5.8	12	30	312	34
	Full NPK	5.8	<u>8</u>	24	214	28
Jan 2006*	Control	5.2	17	40	322	40
	1/2+1/2 NPK	5.2	24	44	308	40
	Full NPK	4.9	42	56	204	24
Minimum sufficiency levels			6-10 lbs ac^{-1}	–	–	–

* Assessed before second NPK half dose.
** Adapted from Wells et al. (1973).

Table 2: Foliar nutrient levels pre- and post-treatment application at the Tift and Screven longleaf pine midrotation fertilization study areas. Underlined values are considered at or below sufficiency.

Tift County

Date	Treatment	N	P	K	Ca	Mg
Feb 2004	Across All Treatments	0.91	0.095	0.37	–	–
Feb 2007*	Control	0.95	0.087	0.28	0.24	0.063
	1/2+1/2 NPK	0.92	0.093	0.34	0.21	0.073
	Full NPK	0.98	0.087	0.29	0.19	0.043

Screven County

Date	Treatment	N	P	K	Ca	Mg
Feb 2002	Control	1.3	0.11	0.43	0.21	0.12
	1/2+1/2 NPK	1.04	0.092	0.45	0.15	0.11
	Full NPK	1.06	0.095	0.42	0.15	0.1
Feb 2005*	Control	1.2	0.11	0.43	0.21	0.13
	1/2+1/2 NPK	1.5	0.095	0.45	0.18	0.1
	Full NPK	1.5	0.11	0.54	0.23	0.11
Minimum sufficiency levels		0.95	0.08	0.3	0.1	0.06

*Assessed before second NPK half dose.
**Adapted from Blevins et al. (1996) and Dickens et al. (2017).

The Tift County site consisted of nine plots, giving three replications of three treatments, while the Screven County site was comprised of 12 plots giving four replications of three treatments. Plots were square and 0.25 ac in size. Square internal measurement plots (0.1 ac) were established within each gross treatment plot. Treatments were (1) control, (2) a full dose of diammonium phosphate (DAP) + urea + muriate of potash; 50 lb ac^{-1} elemental P, 150 lb ac^{-1} N, and 50 lb ac^{-1} elemental K applied during mid-February 2004 (treatment referred to as full NPK treatment), and (3) a split (half and half) dose of DAP + urea + muriate of potash; 25 lb ac^{-1} elemental phosphorus, 75 lb ac^{-1} N, and 25 lb ac^{-1} elemental K hereafter referred to as 'half NPK treatment'. The first half of this treatment was applied during mid-February 2004 (stand age 17-years) and the second half was applied during February 2007 at stand age 20-years. Fertilizer applications were applied using a calibrated 40 lb hand crank spreader.

Sampling and Measurements

Trees within each plot were aluminum tagged shortly before fertilizer treatments were applied at stand age 17-years so that repeat measurements could be made on individual trees through time. Tagged trees were measured for diameter at breast height (dbh) and total height, and defect type and height of defect were noted on each tree. Assessments of dbh and total height were conducted during the winters of 2008 (stand age 21-years), 2009–10 (age 23-years), 2013–14 (age 27-years), 2017 (age 30-years), and 2019 (age 32-years). Stem defects including forks, ramicorn branches (high-angle, large-diameter branches that are partly suppressed by the more dominant stem), fusiform rust (*Cronartium quercuum*) cankers, broken tops, branch whorls (≥5 branches originating from a specific height on the stem), and sweep greater than 3 in from vertical in any 10 ft stem section to a three-inch top were noted in the 2019 inventory. Planted longleaf pine weight equations by Baldwin and Saucier (1983) for total tree wood plus bark were used to calculate green weight values. Separate equations were used for trees ≥5 in dbh and <5 in dbh at each assessment. Statistically significant results are reported as well as age 32-years average dbh, total height and green weight per acre results. Average periodic increment was calculated for dbh, height and green weight per tree across the different sampling dates (pre- and post-thinning). Information on statistical analyses and significance tests can be referenced in Clabo et al. (2020).

RESULTS

No site and treatment differences were detected for dbh, total height and green weight per acre at stand age 32-years (Table 3). As expected, average dbh, height and green weight per acre differed by stand age and by stand age and site (age x site interaction) (Table 4). Average dbh increased 2 in from age 21 to 32-years at Screven County, while over the same period at Tift County average dbh growth was only 1.7 in. At both sites average dbh increased the most from ages 27 to 30-years which was 2 to 6.5 years post-thinning. Height increased by an average of 17.2 ft from stand age 21 to 32-years at the Screven County site and by 12.2 ft at the Tift County site over the same period. Similar to dbh, average height increment was greatest during the period just after thinning (ages 27 to 30 years). At age 21-years, green tons per acre were greater at the Tift County site but averaged less than Screven County at age 23-years prior to thinning and remained less than Screven County post-thinning. The drop in average green tons per acre across treatments at the Tift County site can be explained by the loss of an entire plot to pine bark beetles just after thinning (Table 4).

Table 3: Age 32-years average diameter, total height and green weight per acre across the two study sites for the old-field longleaf pine midrotation fertilization study.

Treatment	DBH(in)	Height (ft)	Weight (t ac^{-1})
Control	10.9 ± 0.5	75.4 ± 1.1	141.8 ± 6.6
Full NPK	11.1 ± 0.5	74.8 ± 0.8	140.9 ± 16.8
Half NPK	11.1 ± 0.4	74.3 ± 0.9	131.4 ± 6.9

Table 4: Results for dbh, height and green tons per acre by age and site for the old-field longleaf pine midrotation fertilization study.

Diameter at Breast Height (in)

Tift		Screven	
Age	Estimate (± standard error)	Age	Estimate (± standard error)
21	8.9 ± 0.2	21	9.4 ± 0.2
23	9.1 ± 0.2	23	9.8 ± 0.2
27	9.6 ± 0.2	27	10.4 ± 0.2
30	10.3 ± 0.2	30	11.3 ± 0.3
32	10.6 ± 0.2	32	11.4 ± 0.3

Total Height (ft)

Tift		Screven	
Age	Estimate (± standard error)	Age	Estimate (± standard error)
21	60.7 ± 0.5	21	59.8 ± 0.5
23	62.0 ± 0.7	23	62.1 ± 0.5
27	66.7 ± 0.8	27	68.5 ± 0.7
30	70.4 ± 0.6	30	75.2 ± 0.7
32	72.9 ± 0.7	32	77.0 ± 0.7

Green Weight Tons Per Acre

Tift		Screven	
Age	Estimate (± standard error)	Age	Estimate (± standard error)
21	144.3 ± 15.3	21	136.2 ± 13.4
23	148.0 ± 19.1	23	155.9 ± 14.1
27	96.2 ± 9.5	27	110.2 ± 13.0
30	110.1 ± 9.9	30	145.3 ± 13.2
32	119.0 ± 7.0	32	157.0 ± 13.2

Mean periodic increment for dbh, height and green weight per acre did not differ by treatment for any age increment (21-23, 23-27, 27-30, and 30-32). Average dbh increment was greatest from ages 27 to 30, but decreased rapidly between ages 30 and 32 (Figure 5). Across all treatments, average height increment was greatest between ages 23 to 27 and lowest from ages 21 to 23 and 30 to 32 (Figure 6). Average green weight periodic increment reached a peak from ages 27 to 30 and was at its lowest just prior to thinning at ages 21 to 23 (Figure 7).

Percent defect rates did not differ across treatments or sites. At stand age 32, defect rates ranged from 29.9% in the half NPK treatment to 35.2% in the full NPK treatment with the control having an average defect rate of 34.9%. When defects were assessed for the entire stem, forks and ramicorn branches were the most common defect types (16.7% and 12.8%, respectively), whereas sweep (2.2%) and broken tops (2.2%) were the least common defect types. No first log defect rate differences by treatment were observed, and first log defect rates ranged from 26.9% to 38.5% across treatments and sites. Fusiform rust cankers (53.9%), forks (26.9%) and ramicorn branches (19.2%) were the only observed first log defects. In addition, no differences in defect rates by treatment were observed in the second log (17.1 to 33 ft assuming a 1 ft stump height). Forks (42.9%) and ramicorn branches (39.3%) constituted most second log defects observed across treatments and sites.

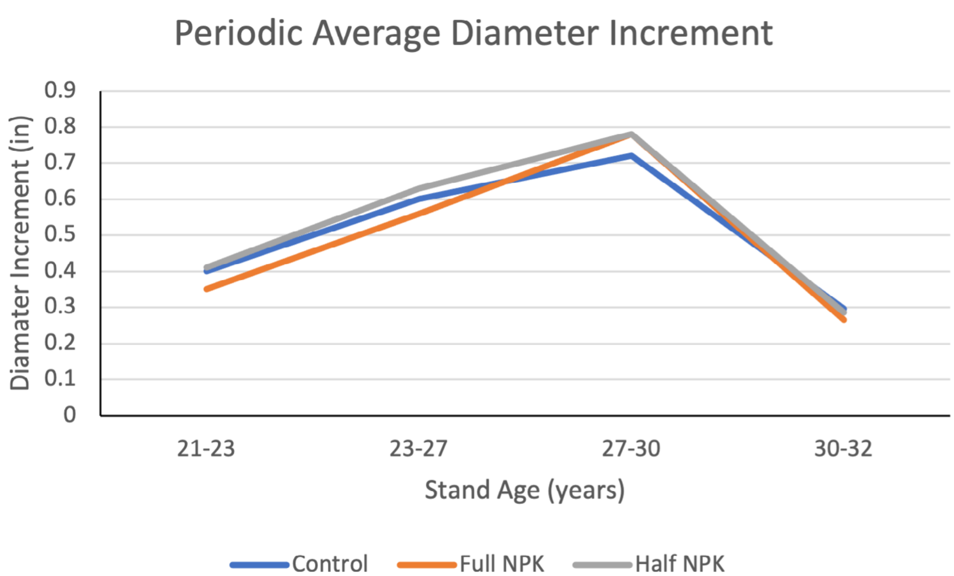

Figure 5: *Average periodic diameter at breast height increment by stand age for the old-field longleaf pine midrotation fertilization study. Note that fertilization occurred at age 17 (full and split dose) and age 21 (split dose only). Thinning occurred at either age 23 or 25 years.*

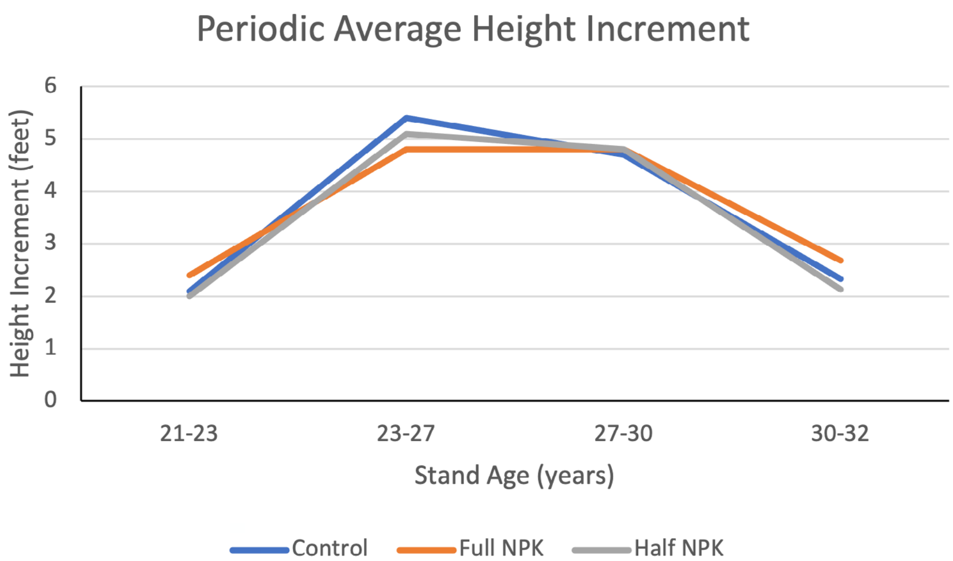

Figure 6: *Average height growth increment by stand age for the old-field longleaf pine midrotation fertilization study. Note that fertilization occurred at age 17 (full and split dose) and age 21-years (split dose only). Thinning occurred at either age 23 or 25-years.*

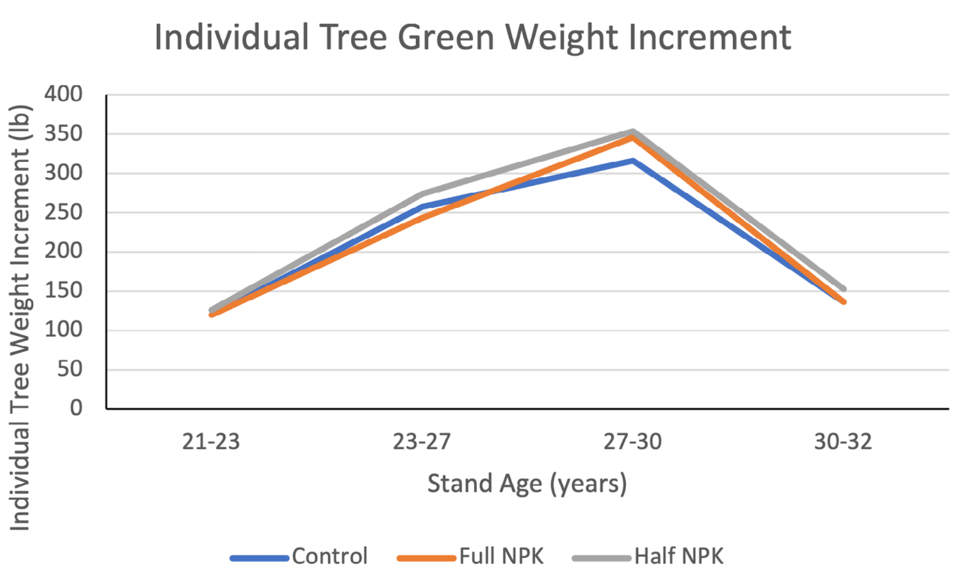

Figure 7: *Average individual green weight increment by stand age for the old-field longleaf pine midrotation fertilization study. Note that fertilization occurred at age 17 (full and split dose) and age 21-years (split dose only). Thinning occurred at either age 23 or 25-years.*

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Midrotation fertilization as a full or split-dose application did not significantly improve longleaf pine growth and wood yields over the control treatment. This finding can be explained by two factors: (1) longleaf pine is a low nutrient demanding species and (2) the mostly above or at sufficiency foliage and soil nutrient levels recorded on the two sites prior to treatment application. Results from at least one other midrotation fertilization longleaf pine study that occurred on a site with low-fertility, deep sands (Ailey and Lakeland series) showed no growth improvements with inorganic fertilizer or poultry litter compared to a control three years post-application (Chastain et al. 2007). Another longleaf pine midrotation fertilization study on an old-field site in South Carolina reported no improvements in tree growth following five fertilization treatments over a 15-year period (Ludovici et al. 2018). Significant growth improvements during a four-year span of the 15-year fertilizer regime were attributed to a thinning operation similar to periodic increment improvements observed in this study. By stand age 23-years, growth rates at the Tift and Screven County sites were beginning to diverge for dbh, height and green weight per acre. Excluding soil P in all treatments and foliar P in the half NPK treatment, the Screven County site had greater soil and foliar nutrient concentrations observed during pre-treatment assessments, and site index for the predominant soil series at Screven County was 2 to 7 ft greater for longleaf pine than the primary soil series at the Tift County site.

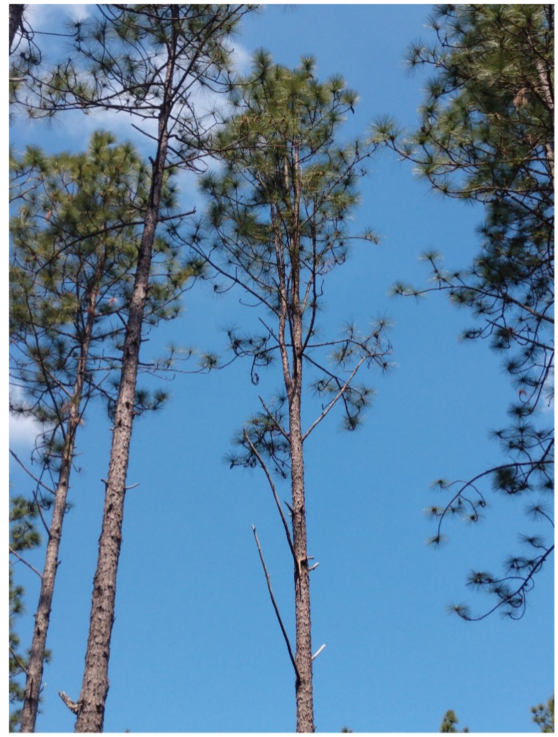

Figure 8: *Example of a fork in the second log at stand age 32 years.*

Stem quality was an issue with trees at both sites, as 29% to 35% of all stems had wood-quality degrading defects. High defect rates have been noted in other surveys of old-field longleaf pine stands throughout Georgia (Dickens et al. 2018). Treatment did not affect defect rate and defect type and rates did not differ by position in the first or second logs. Defects in southern pines are primarily a result of genetics (individual trees), but land use and management history as well as disturbances (e.g. ice storms and insect damage) can also cause high stem defect rates across entire stands (Xiong et al. 2010). Though research is limited on stem defects in longleaf pine, past work has suggested that forks and ramicorn branches (most commonly observed defects) tend to be more common in young, fast growing stands even if parent trees did not have defects (Figure 8) (Stephenson and Snyder 1969). High soil nutrient levels and management techniques such as intensive site preparation and relatively wide planting spacing have been reported as causing greater defect rates in loblolly pine stands (Eaton et al. 2006, Rowan and Steinbeck 1977, Xiong et al. 2010). Though stem defect research with longleaf pine is lacking, perhaps these phenomena also occur in that species.

Soils on old-field sites in the Coastal Plain region of the Southeast typically have improved soil nutrient levels and soil tilth compared to soils never or not recently in agricultural production. Improved longleaf pine wood growth response to midrotation fertilization should not be expected. Fertilizer cost increases and suppressed pine sawtimber prices in recent years limit the chances of attractive financial rates of return associated with longleaf pine midrotation fertilization. Even after a first thinning, stem quality was an issue with longleaf pine on the old-field sites in this study. Faster than normal longleaf pine growth rates associated with high soil nutrient levels and relatively wide planting spacings as required by USDA Farm Service Agency's Conservation Reserve Program guidelines may be contributing to greater defect rates along with a lack of longleaf pine genetic improvement as compared to other southern pine species. More narrow planting spacings may be one method to reduce the occurrence of defects. Thinning and/or competing vegetation management are better and more cost-effective options than midrotation fertilization to maintain growth rates of longleaf pine stands managed on long rotations for sawtimber or poles.

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