



Longleaf Pine Midrotation Fertilization Response for Stands Growing on Cutover Sites in the Lower Coastal Plain

David Clabo and David Dickens, *UGA Warnell School of Forestry and Natural Resources*

INTRODUCTION

Longleaf pine management is ecologically, aesthetically, recreationally and economically important on privately owned properties throughout Georgia and the Southeast. Government and NGO initiatives as well as cost-share programs to restore longleaf pine across its former 91-million-acre range have been successful in increasing acres planted (more than 1.9 million acres since 2008) on private and public lands (Jose et al. 2006, Americas Longleaf Restoration Initiative 2021). Through these programs and initiatives, longleaf pine is planted on a variety of upland sites with varying former land uses and soil productivities.

Forest productivity can be heavily impacted by prior land use or disturbance history. In the Coastal Plain region of the southeastern United States, old-field sites that were used for either grazing or row crop agriculture can have dramatically different vegetation as well as soil physical and chemical properties than sites that have been forested for one or more timber rotations (Ostertag and Robertson 2007, Clabo et al. 2020) (Figure 1). Soil nutrients such as phosphorus that are immobile in the soil may be present at elevated levels for many decades (e.g., Campbell and Morris 2018). Longleaf pine growing on old-field sites with these soil conditions do not significantly respond to nutrient amendments (see Clabo et al. 2020) as longleaf has low nutrient requirements compared to other southern pine species such as loblolly pine (Brendemuehl 1981). Cutover sites that have not been in agriculture for 50 to 100 years or longer or had one or more timber rotations often have low soil fertility, especially phosphorus. Soil phosphorus below the 3 to 5 mg/kg threshold for adequate southern pine stand health and growth can regularly be found on some Coastal Plain soil series (Wells et al. 1973). Some of these soils have soil horizons with clay accumulations deeper than 60 inches within the soil profile and are moderately well to excessively well drained. In the University of Florida's Cooperative Research in Forest Fertilization (CRIFF) soil classification system, these soils would be classified as CRIFF F or G soils (Fox 2004).

Midrotation fertilization impacts on wood growth are best on responsive sites (i.e. poor soil fertility and/or drainage) within a couple of years after thinning, and when performed with vegetation management additive benefits have been documented for loblolly and slash pine (e.g. Albaugh et al. 2012). Soil amendments such as inorganic fertilizer (usually N+P or P alone, but K can be added if deficiencies occur) or poultry litter have the potential to maintain or increase wood volume growth (e.g., Chastain and Rollins 2007) and pine straw yields for pine straw raking. With longleaf pine, results from past studies have not always shown a significant fertilization effect and straw gains usually last less than a few years (Haywood 2009, Ludovici et al. 2018).



Figure 1: *Similar age (approximately one years apart) old-field (left photo) and cutover, planted longleaf pine stands. Note the difference in understory vegetation and development (crown closure) of these stands.*

The objectives of this trial were (1) to determine the magnitude and duration of improved longleaf pine diameter, height and volume growth (if any) following midrotation fertilization on cutover sites with well drained, sandy soils, and (2) to assess any potential improvements in pine straw yields following midrotation fertilization.

METHODS

Study Areas

Trials were established in three cutover stands located in Colleton County, South Carolina (Figure 2). Stands were assigned identification numbers (12, 16 and 17) based on their map units for this privately-owned property. The soil profile descriptions, common and taxonomic name and CRIFF soil group are found in Table 1 for each study area. Based on inventory data from this study, site index at base-age 25 years for stand 12 was 47 ft, stand 16 was 53 ft and stand 17 was 61 ft. Site index estimates are based on control treatment plots only. Stands 12 and 17 were machine planted during January 1994, while stand 16 was also machine planted but was three years younger (January 1997 planting). All three stands were planted at 6 x 10 ft spacing with 1-0 stock longleaf pine seedlings.

Table 1. Soil descriptions for the three cutover, planted longleaf pine stands in Colleton County, South Carolina.

| Depth to Soil profile descriptions (inches) | Stand # 12 | Stand #16 | Stand #17 |
|---|---|----------------------------|-------------------|
| A horizon | 0-5 | 0-3 | 0-4 |
| Top of argillic (Bt) | 42 | NA (clay lamellae @ 50) | 33 |
| Depth to season high water table | 70 | 50 | 51 |
| Depth to redox depletions | 70 | 50 | 51 |
| Soil drainage class | Somewhat excessively to moderately well drained | Excessively drained | Well drained |
| CRIF soil group | F | G | F |
| Soil series name | Blanton | Alpin | Bonneau |
| Taxonomic name | Grossarenic Paleudults | Lammellic Quartzipsamments | Arenic Paleudults |

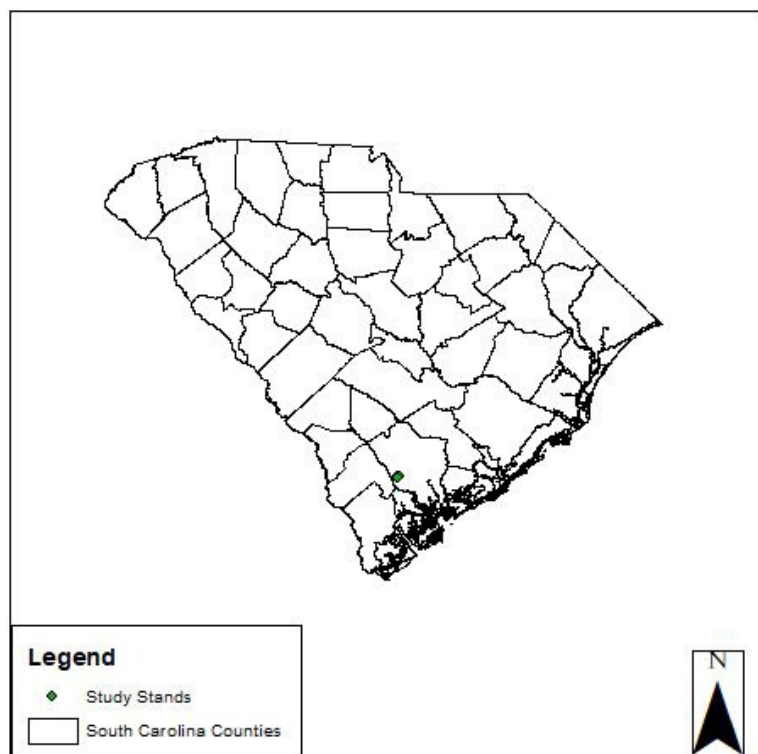


Figure 2: Location of trial areas in Colleton County, South Carolina.

CRIFF Forest Soil Classification

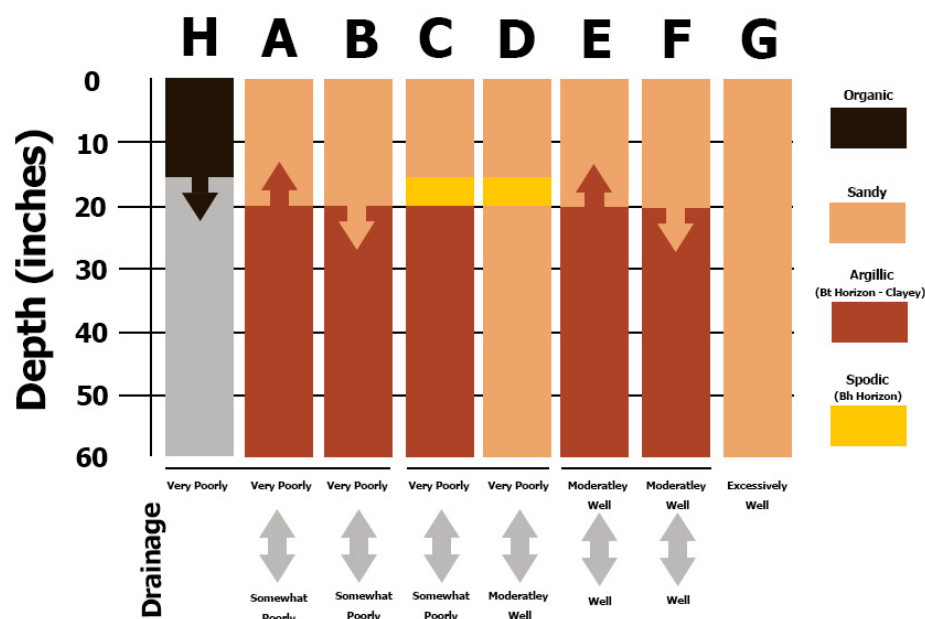


Figure 3: *The University of Florida's Cooperative Research in Forest Fertilization (CRIFF) forest soils classification system (Fox 2004).*

Study Design and Establishment

Trials began during winter 2015 when three paired control and fertilization plots were established in each stand. Plots were 0.25 acres (gross treated). Stands had not been thinned when plots and treatments were established. Stand 17 was thinned first due to an Ips beetle infestation. Thinning was completed during February 2016 using a 5th row and logger select combination thinning. Stand 12 was thinned two years later using the same combination thinning. Stand 16 had not been thinned as of July 2023, but site preparation was not adequate at establishment necessitating hardwood control prior to study establishment. Approximately 1,500 to 2,500 scrub oaks per acre (2-4 inches in ground-line diameter) were cut, piled and stump treated with triclopyr during 2013.

Prior to fertilization treatments, foliar soil macro- and micro-nutrients were assessed. Soil tests revealed that stands 12 and 17 had soil available P (Mehlich I procedure) much less than 6 to 8 lb/ac (3-5 ppm), which is considered below sufficiency for southern pines (Wells et al. 1973, Dickens et al. 2003). Surface soil available P is considered the best indicator of site fertility in the southeastern US. Surface soil available P status shows that stand 16 had much higher P @ 12 - 17 parts per million (ppm) than stands 12 @ 0.40 - 2.0 ppm and stand 17 @ 0.70 - 1.3 ppm (Table 2) prior to fertilization in March 2015. Soil pH ranged from 4.5 to 4.7 in stand 12, 4.0 in stand 16 and 4.7 to 4.8 in stand 17 (Table 2). Foliage samples were also collected in March 2015 when the project started following foliage collection protocols by Dickens and Moorhead (2018). Results revealed foliar nitrogen (<0.95%), phosphorus (<0.08%), potassium (<0.30%) and magnesium (<0.06%-stand 16 only) were all below sufficiency for longleaf pine (Dickens et al. 2003). In retrospect, the March 2015 foliage collection time was most likely late for the best indication of longleaf nutrient needs, especially in stand 16 that had soil available P levels above sufficiency, whereas stands 12 and 17 had soil available P levels lower than the minimum sufficiency guidelines (Table 2).

Table 2. Surface (0-6”) soil pH and nutrient status range prior to the fertilizer treatments (March 2015), five years after the initial fertilizer treatment for the control (C) and fertilizer treatment (F) means (March 2020) and eight years after the study started (July 2023) means.

| Month- year | Stand # | pH | P (ppm) | K (ppm) | Ca (ppm) | Mg (ppm) |
|-------------|---------|-----------|-----------|---------|----------|----------|
| March 2015 | 12 | 4.5-4.7 | 0.4 – 2.0 | 6-8 | 54-59 | 7-8 |
| | 16 | 4 | 12-17 | 6-8 | 42-55 | 8-9 |
| | 17 | 4.6 – 4.8 | 0.7 – 1.3 | 6-7 | 61-89 | 9-10 |
| | | | | | | |
| March 2020* | 12 C | 4.6 | 1.67 | 3.8 | 34 | 6.0 |
| | 12 F | 4.4 | 2.14 | 4.9 | 38 | 6.0 |
| | | | | | | |
| | 17 C | 4.7 | 2.2 | 4.6 | 40 | 7.6 |
| | 17 F | 4.7 | 2.6 | 4.4 | 45 | 7.9 |
| | | | | | | |
| July 2023 | 12 C | 4.7 | 2.0 | 5.6 | 30 | 7.2 |
| | 12 F | 4.7 | 2.8 | 7.6 | 27 | 7.3 |
| | | | | | | |
| | 16 C | 4.5 | 17.5 | 8.5 | 29 | 7.4 |
| | 16 F | 4.4 | 15.8 | 7.6 | 26 | 8.1 |
| | | | | | | |
| | 17 C | 4.9 | 3.0 | 7.1 | 52 | 11 |
| | 17 F | 4.9 | 4.3 | 8.0 | 46 | 9.9 |

*No soil pH or nutrient status values for stand 16 in March 2020.

Table 3. Longleaf foliar nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) nutrient sufficiency guidelines (Blevins and others 1996, Dickens and Moorhead 2003).

| N | P | K | Ca | Mg |
|-----------------------|------|-----------|------|------|
| percent concentration | | | | |
| 0.95 | 0.08 | 0.25-0.30 | 0.10 | 0.06 |

Fertilization treatments consisted of an initial application of NPK (stands 12 and 17) or NPKMg (stand 16) then a second N application in each stand in the fertilizer plots. The first fertilizer application was completed during March 2015. Urea, diammonium phosphate (DAP), and muriate of potash (MOP) were applied as 75 N, 25 elemental-P, and 50 elemental-K lb/ac to all stands, plus 120 lb/ac potassium magnesium sulfate, or K-Mag, was applied to stand 16. The second application of the split application was applied during 2016 to stand 17 (due to earlier thinning) and April 2018 to stands 12 and 16. Stand 17 received 75 lb/ac N (160 lb urea). Stand 12 received 75 lb/ac N (160 lb/ac urea), while stand 16 received 55 lb/ac N (120 lb urea). Stand 16 received less urea per acre for the second application than stands 12 and 17 due to smaller average stem diameters (see Dickens and others 2020b). All fertilization treatments were applied using a tractor with a power takeoff (pto) driven cyclone spreader (Figure 4). A separate stand was used to calibrate the fertilizer spreader.



Figure 4: *Cyclone spreader used to apply fertilizer treatments.*

Baseline stand and litter measurements were completed during March 2015. For individual tree measurements, a 0.1-acre sampling plot was installed in the center of the gross treated plot. Trees were tagged and numbered to allow repeat measurements. Survival, diameter at breast height (dbh), and total height were also assessed for each tree during January or February of 2018 and 2020 (stands 12 and 16). Basal area and green weight were calculated from dbh and height measurements. Whole tree green weight was calculated from equations by Harris et al. (2022). Litter weights were assessed within four 4x4 ft angle iron grids randomly located within each 0.1-acre sampling plot. Litter samples were collected and weighed during January or February (after fall needle fall) of 2015, 2016, 2017, 2020 (not stand 16), 2021, and 2022. Samples were collected before pine straw raking operations began each year. Field weight is reported for all straw yield analyses (average field to dry weight conversion was dry weight = 82.5% of field weight). Data were analyzed using analysis of variance (anova) and a randomized complete block design with replication ($p=0.05$). The fixed factor in the model was treatment (fertilization versus no fertilization) as stands were analyzed separately and by inventory year (stand age) due to differences in management practices and establishment dates. Stand and individual tree dependent variables were dbh, height, trees per acre (tpa), basal area per acre, and green weight per acre. Pine straw field weights were also analyzed by stand using anova and a randomized complete block design with replication ($p=0.05$). Fixed factors for this analysis included treatment and year. The random term was block. Results for each analysis are presented by stand.

RESULTS

Wood growth and stand density results for stand 12 indicated no significant differences between the control and NPK treatments across inventory years (stand ages), but average diameter and height growth increases at the inventory after thinning (age 24 years) were evident for both treatments (Figure 5). Age 21-years (2015 assessment) annual average dbh increment was 0.27 in/yr, while the height increment was 1.89 ft/yr. Average green weight growth per acre per year was 2.72 t/ac/yr (pre-thinning).

Stand 16 had no significantly different results for any of the wood growth variables analyzed (Figure 6). Diameter at breast height annual increment averaged 0.26" and 0.27", respectively for the control and NPK treatments, while annual height increment averaged 1.96 and 1.99 ft/yr for

Longleaf Pine Midrotation Fertilization Response for Stands Growing on Cutover Sites in the Lower Coastal Plain

the control and NPK treatments. Mean annual increment at stand age 21 years averaged 2.71 t/ac/yr (pre-thinning).

Similar wood growth and stand density results were observed for stand 17. No statistical differences for any of these variables were detected before or after thinning (Figure 7), but thinning increased diameter and height growth compared to pre-thin averages. Age 21-years (2015 baseline data) annual dbh increment was 0.34" in/yr, while annual height increment was 2.6 ft/yr. Green weight mean annual increment averaged 5.17 t/ac/yr at stand age 21 years (pre-thinning).

Pine straw yield results for stands 12 and 17 showed no significant difference between treatments for either site. As expected, straw production per acre did drop after thinning in stands 12 and 17 (Figures 8 and 9). Stand 12 control plots averaged 2,690 lbs/ac while the NPK plots averaged 2,731 lbs/ac (field weight) from 2015 through 2022 (Figure). Post thin, stand 17 control treatment plots averaged 1,618 lbs/ac while the NPK treatment averaged 2,256 lbs/ac (field weight) pine straw (Figure 9); a 638 lbs/ac/yr gain with NPK and N compared to the control treatment pine straw yields. Stand 16 (the unthinned stand) did have a significant difference for the NPK+N treatment compared to the control. From 2015 through 2022, the NPK treatment averaged 410 lbs/ac/yr greater pine straw yields than the control (2,828 lbs/ac/yr for the NPK+N treatment and 2,418 lbs/ac/yr for the control treatment) (Figure 10).

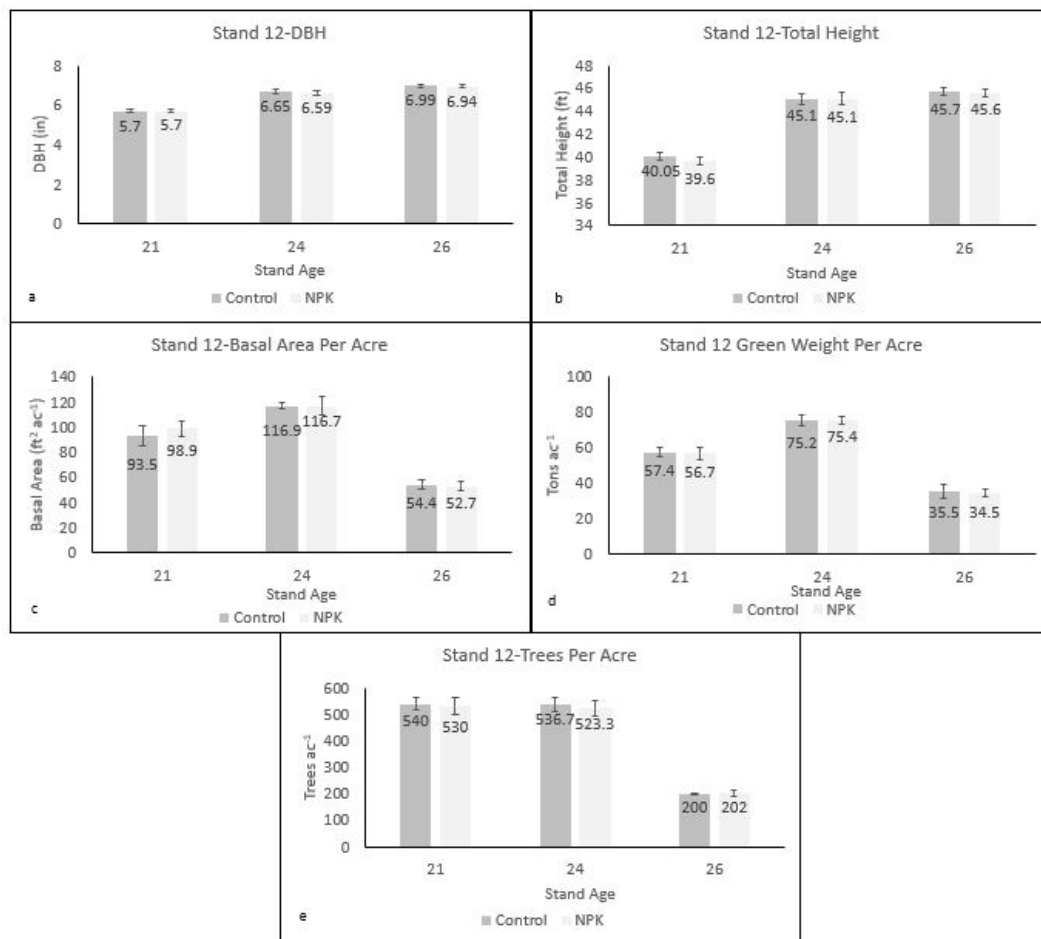


Figure 5: Wood growth averages and standard error bars for stand 12 from 2015 (age 21-yr), 2018 (age 24-yr), and 2020 (age 26-yr) inventories including dbh growth (a), height growth (b), basal area per acre (c), green weight per acre (d), and trees per acre (e). No statistical differences between the control and fertilization treatments were found for any variable or stand age.

Longleaf Pine Midrotation Fertilization Response for Stands Growing on Cutover Sites in the Lower Coastal Plain

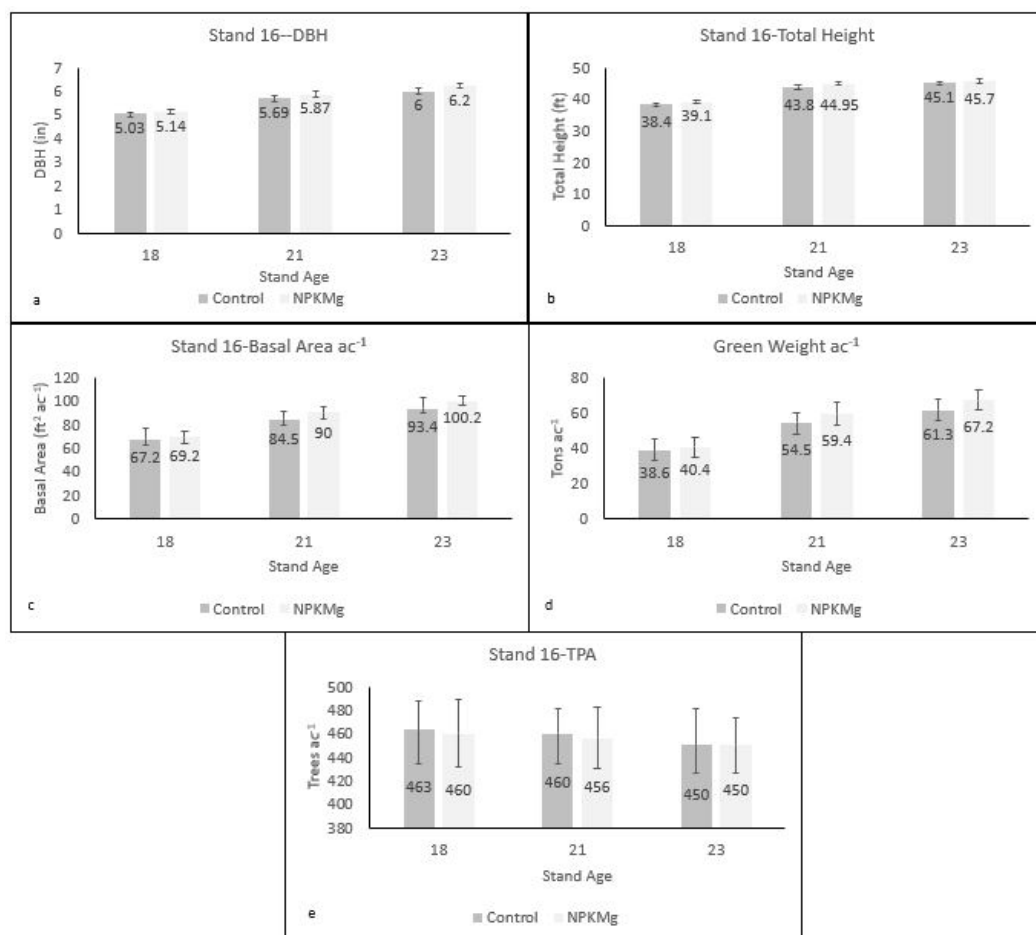


Figure 6: Wood growth averages and standard error bars for stand 16 from 2015 (age 18-yr), 2018 (age 20-yr), and 2020 (age 23-yr) inventories including dbh growth (a), height growth (b), basal area per acre (c), green weight per acre (d), and trees per acre (e). No statistical differences between the control and fertilization treatments were found for any variable or stand age.

Longleaf Pine Midrotation Fertilization Response for Stands Growing on Cutover Sites in the Lower Coastal Plain

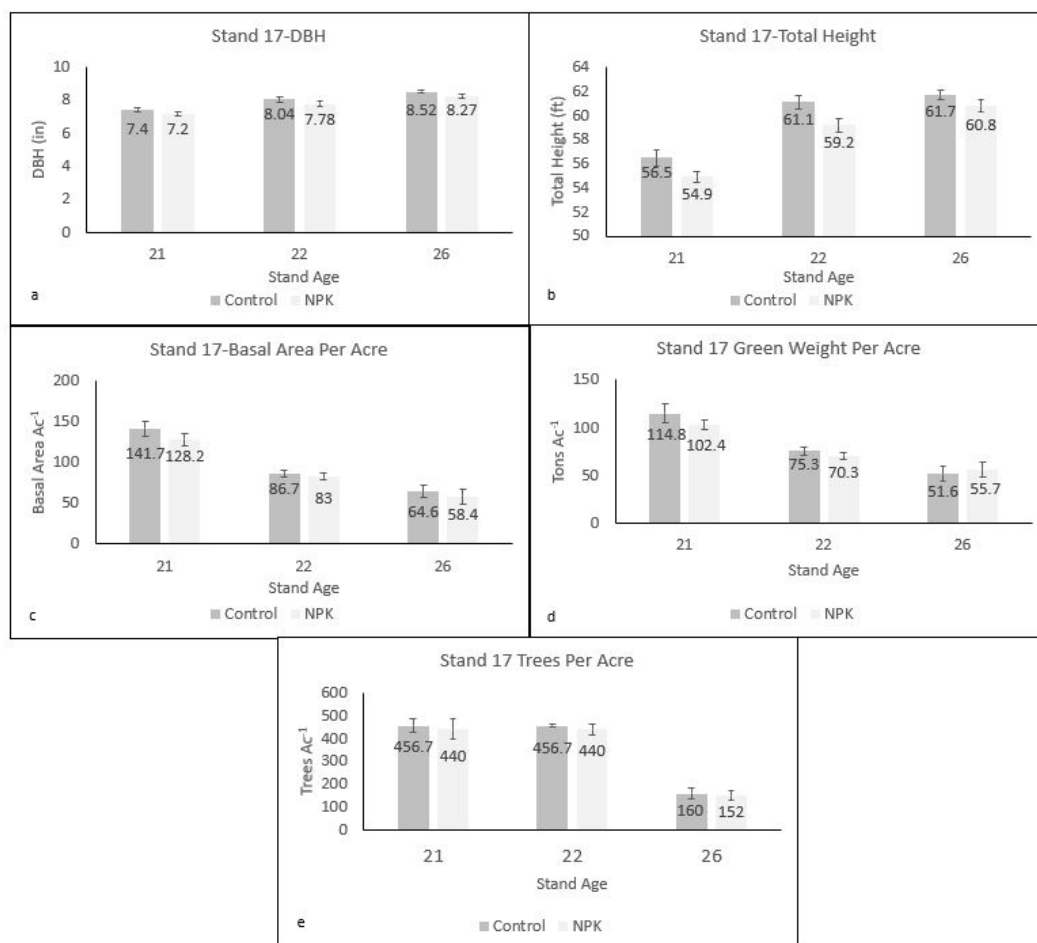


Figure 7: Wood growth averages and standard error bars for stand 17 from 2015 (age 21-yrs) , 2016 (age 22-yrs), and 2020 (age 26-yrs) inventories including dbh growth (a), height growth (b), basal area per acre (c), green weight per acre (d), and trees per acre (e). No statistical differences between the control and fertilization treatments for any variable or stand age.

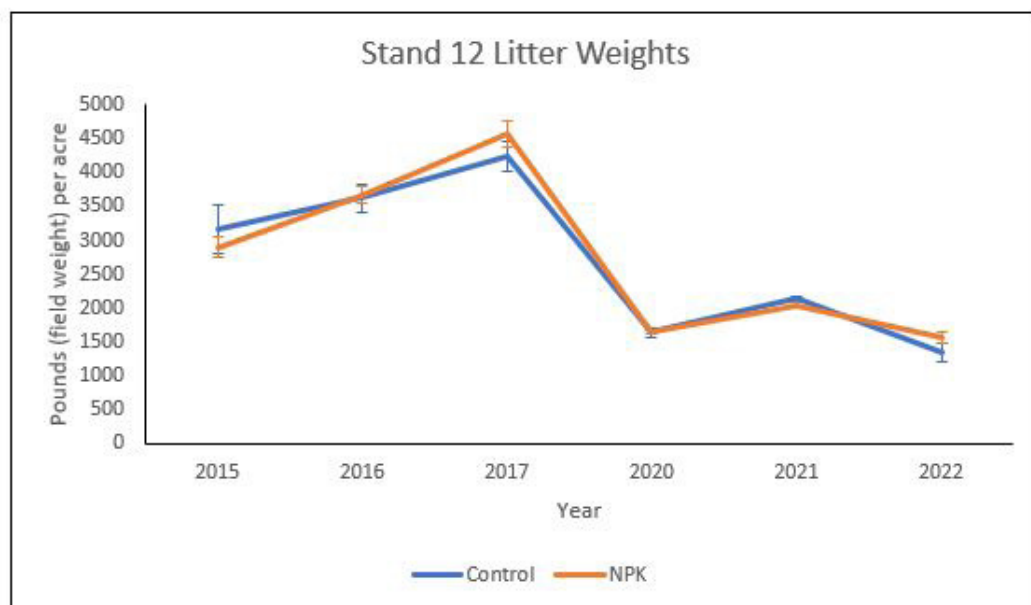


Figure 8: Longleaf pine stand 12 straw litter mean weight (field weight) and standard error on the Blanton soil series. Stand was planted January 1994, 5th row + select thinned March 2018; age 24-yrs in Colleton County, South Carolina. Fertilizer applications consisted of a 75 N, 25 elemental-P, 50 elemental-K lb/ac application during March 2015, and 75 N lb/ac applied during April 2018.

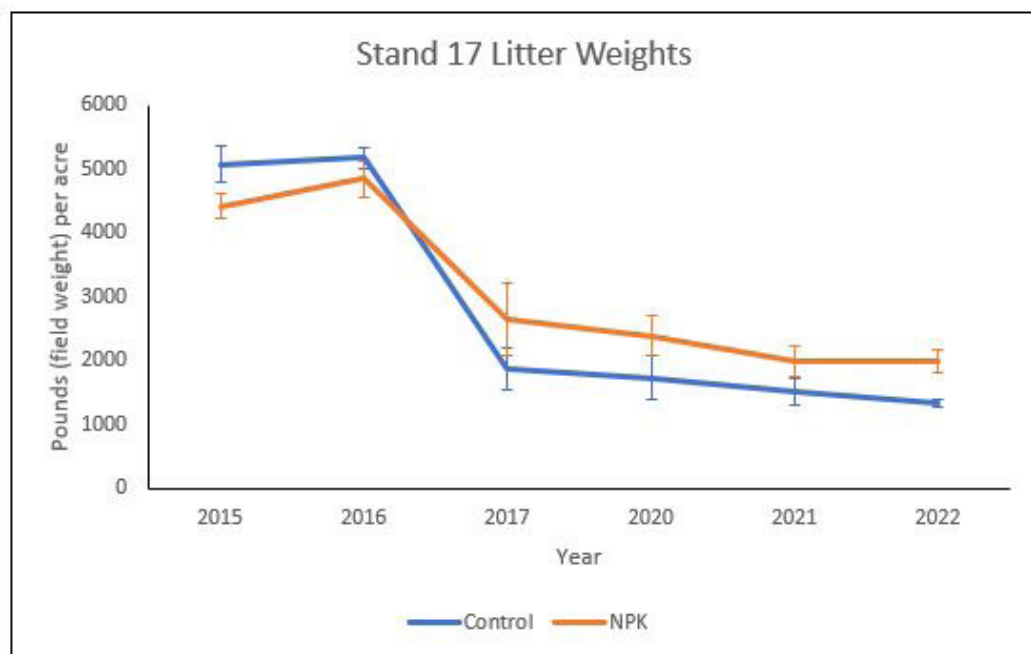


Figure 9: Longleaf pine stand 17 straw litter mean weight (field weight) and standard error on the Bonneau soil series. Stand was planted January 1994, 5th row + select thinned February 2016; age 22-yrs old in Colleton County, South Carolina. Fertilizer applications consisted of 75 N, 25 elemental-P, 50 elemental-K lb/ac application during March 2015, and 75 N lb/ac applied during April 2016.

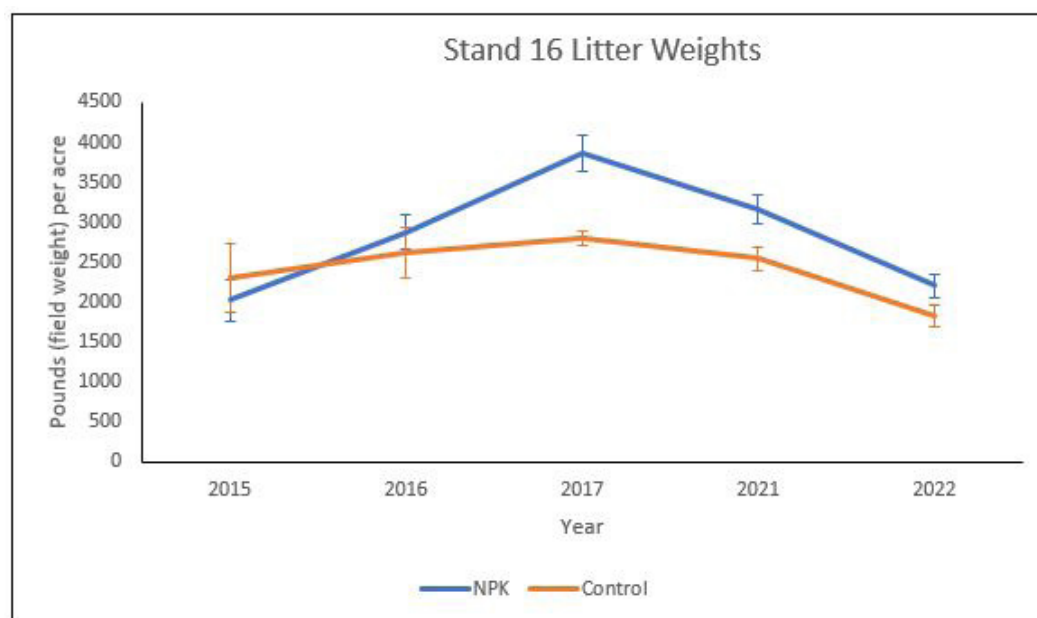


Figure 10: Longleaf pine stand 16 straw mean weight (field weight) and standard error on the Alpin soil series in Colleton County, South Carolina. Stand was planted during January 1997 and not thinned during the study period. Fertilizer applications consisted of 75 N, 25 elemental-P, and 50 elemental-K lb/ac, plus 120 lb/ac potassium magnesium sulfate, or K-Mag during March 2015. During April 2018, 55 N lb/ac was applied to stand 16.

DISCUSSION AND CONCLUSIONS

The initial NPK or NPKMg fertilizer application followed by a N application one year (stand 17) or three years (stands 12 and 16) after the initial application did not improve longleaf pine wood growth in stands 12 and 17 on the low productivity soils nor in stand 16 with moderate soil fertility as indicated by surface soil available P in this trial. When the trial began, two of the three stands (12 and 17) were good candidates for fertilization. Average stand basal area was below the maximum threshold recommended for fertilization and the threshold used for thinning decisions (120 ft²/ac). Also, disease prevalence (e.g., fusiform rust) was low, which improves potential response to fertilization (Dickens and others 2017). Results from this study did differ from two similar studies conducted on cutover sites with similar soils (CRIFF G). Chastain and Rollins (2007) did report significantly improved longleaf pine height and dbh growth three years following midrotation fertilization in an unthinned 22-year-old stand in South Carolina using both poultry litter and inorganic fertilizer. Dickens and others (2020a) found that two applications of NPK (150 N + 65 P + 125 K/ac at ages 32- and 36-years old) in a twice thinned 32-year-old longleaf stand did significantly improve six and 10-year-old longleaf pine total volume growth increments and 10-year chip-n-saw volume over the control plot trees (no fertilization) on the Sand Hills State Forest in South Carolina on a CRIFF soil group G soil (Alpin; Lamellic Quartzipsamments). Most other longleaf pine midrotation studies have reported no improvements in wood growth (Ludovici and others 2018, Clabo and others 2020). This trial and results from most other similar studies, indicate that longleaf pine's low nutrient demanding characteristic makes fertilization a questionable investment to increase wood yields. Land use history (old-field, former pasture, hay cutting field or cutover site), foliar N, P, K, Ca and Mg, leaf area index, surface soil available P, soils knowledge, tree species, age, woody competition, and basal area/acre are fertilization diagnostic tools that will aid in a fertilization prescription decision.



Alterations to the fertilizer prescriptions for this study could have produced a greater response by longleaf pine to midrotation fertilization. Initial P (125 DAP) and K (100 MOP) rates were at the bottom of the recommended application rate range for DAP (125 to 250 lbs/ac) and MOP (100 to 160 lbs/ac) in longleaf pine stands with an average dbh less than 6 in (Dickens et al. 2003, Dickens et al. 2017). In addition, the follow-up fertilization (2016 or 2018) in stands 12 and 17 had no P or K. Any future work should potentially investigate altering fertilizer application rates.

Though statistically significant differences were not detected in two of the three stands, pine straw yields in the fertilization treatments typically equaled or exceeded control treatment yields within two years after the initial application as additional foliage production requires two years to be realized on the ground. Significantly improved yields were detected for stand 16. Reasons for this improvement likely originate from a combination of more stressed trees due to lack of thinning and the Alpin series soil (CRIFF G). In addition, woody competition control in this stand a couple of years prior to the first fertilization treatment likely increased the likelihood of a fertilizer response for enhanced foliage production.

The potential for midrotation fertilization to significantly improve wood and straw yields has been demonstrated by some trials and studies, but minimal evidence other than straw yield improvements with the NPK treatment in stand 16 were evident in this trial. One other possible benefit of fertilization not investigated by this trial is the potential of fertilization to reduce stand stress by maintaining growth rates on well-drained, sandy soil series especially if thinning is postponed, raking is conducted for several years in a row, or if long-term droughts occur during active raking operations. Diagnostic tools such as soil and foliage samples (Dickens and Moorhead 2018), knowing the soil series in a stand, site history, leaf area index estimates, and regular forest inventory data can assist a landowner or manager with fertilization decisions. Landowners should work with a professional forester to evaluate fertilization needs in longleaf pine stands and to help determine the economics of fertilization based on current fertilizer material and application costs, straw prices, and projected timber prices when thinning or a final harvest might occur.

ACKNOWLEDGEMENTS

We thank the landowners who allowed us to follow their three planted longleaf stands and Bob Franklin, retired Clemson University Area Forestry & Wildlife Agent and Longleaf Alliance Stewardship Forester, Derrick Phinney, Clemson University Forestry & Natural Resources Program Coordinator and Area Forestry and Wildlife Agent, Janet Steele, Clemson University Area Forestry & Wildlife Agent, and Parker Johnson - former Clemson University Area Forestry & Wildlife Agent for their assistance with the longleaf study areas measurements.



LITERATURE CITED

- Albaugh, T.J., H.L. Allen, B.R. Zutter, and H.E. Quicke. 2003. Vegetation control and fertilization in midrotation *Pinus taeda* stands in the southeastern United States. *Annals of Forest Science* 60: 619-624.
- America's Longleaf Restoration Initiative. 2021. Strategic priorities and actions 2022-2024. https://americaslongleaf.org/media/4tocjgyt/aff_americaslongleaf_strategiesprioritiesactions2021_final.pdf. Date accessed: April 14, 2023.
- Blevins, D., H.L. Allen, S. Colbert, and W. Gardner. 1996. Woodland Owner Notes – Nutrient management for longleaf pine straw. North Carolina Cooperative Extension Service, College of Agriculture and Environmental Science, Department of Forestry, North Carolina State University. WON-30.
- Brendemuehl, R.H. 1981. Options for management of sandhill forest land. *Southern Journal of Applied Forestry* 5(4): 216–222.
- Campbell, J.H., and Morris, L.A. 2018. Land use and soil legacy in the Lower Coastal Plain: A case study of Wormsloe State Historic Site, Georgia. *Journal of Soil and Water Conservation* 73(4): 386-399.
- Chastain, J.D., and P.A. Rollins. 2007. Using poultry litter to fertilize longleaf pine plantations for enhanced straw production. In 2007 American Society of Agricultural and Biological Engineers Annual Meeting, Minneapolis, MN. American Society of Agricultural and Biological Engineers Paper number 074062. 17 p.
- Clabo, D.C., E.D. Dickens, and D.J. Moorhead. 2020. Old-field longleaf pine (*Pinus palustris* Mill.) long-term growth and yield response to midrotation fertilization. *Forest Science* 66(6): 726-736.
- Dickens, E.D., D.J. Moorhead, and B. McElvany. 2003. Pine plantation fertilization. *Better Crops* 87: 12–15.
- Dickens, E.D., D.J. Moorhead, and P. Minogue. 2017. Longleaf pine stand fertilization. University of Georgia Warnell School of Forestry and Natural Resources—Center for Invasive Species and Ecosystem Health. BW-2017-07. 6 p.
- Dickens, E.D. and D.J. Moorhead. 2018. Sampling loblolly, longleaf, and slash pine foliage for nutrient analyses. University of Georgia, Warnell School of Forestry & Natural Resources, Athens, GA. 4 p. Available at: <https://bugwoodcloud.org/resource/files/14825.pdf>.
- Dickens, E.D., R. Cook, D. Clabo, D.J. Moorhead, and L.A. Morris. 2020a. Fertilizer response expectations, application, levels, and material needs for loblolly, longleaf and slash pine at mid-rotation. University of Georgia, Warnell School of Forestry & Natural Resources, Athens, GA. WSFNR-20-51A. 7 p.
- Dickens, E.D., D. Clabo, and D.J. Moorhead. 2020b. Effect of lime stabilized biosolids and inorganic fertilizer applications on soil and foliar nutrient status, growth, pine straw production, and economics in a thinned longleaf pine stand – ten-year results. University of Georgia, Warnell School of Forestry and Natural Resources, Athens, GA. WSFNR-20-33A. 21 p.
- Fox, T.R. 2004. Species deployment strategies for the southern pines: Site specific management practices for the flatwoods of Georgia and Florida. In Dickens E.D., J.P. Barnett, W.G. Hubbard, and E.J. Jokela (eds.). *Slash pine: still growing and growing! proceedings of the slash pine symposium*. General Technical Report SRS-76. Asheville, NC, U.S. Department of Agriculture, Forest Service, Southern Research Station. pp 50–55.

Longleaf Pine Midrotation Fertilization Response for Stands Growing on Cutover Sites in the Lower Coastal Plain



UNIVERSITY OF
GEORGIA
Warnell School of Forestry
& Natural Resources

- Harris, T., S. Raut, B. Bullock, C. Montes, J. Dahlen, and D. Dickens. 2022. Cutover and old-field planted longleaf pine total and merchantable stemwood with bark green weight equations for unthinned stands. University of Georgia Warnell School of Forestry, Athens, GA. WSNR-22-10A. 4p.
- Haywood, J.D. 2009. Influence of pine straw harvesting, prescribed fire, and fertilization on a Louisiana longleaf pine site. *Southern Journal of Applied Forestry* 33(3):115–120.
- Jose, S., E.J. Jokela, and D.L. Miller. 2006. The longleaf pine ecosystem: An overview. pp. 3-9. In: Jose, S., E.J. Jokela, and D.L. Miller (eds.) The longleaf pine ecosystem: Ecology, silviculture, and restoration. Springer, New York.
- Ludovici, K., R. Eaton, and S. Zarnoch. 2018. *Longleaf pine site response to repeated fertilization and forest floor removal by raking and prescribed burning*. USDA Forest Service, Southern Research Station, e-Res. Pap. RP-SRS-60, Asheville, NC. 9 p.
- Ostertag, T.E., and K.M. Robertson. 2007. A comparison of native versus old-field vegetation in upland pinelands managed with frequent fire, South Georgia, In: Masters, R.E. and K.E.M. Galley (eds.). *Proceedings of the 23rd Tall Timbers Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems*. Tall Timbers Research Station, Tallahassee, FL. pp. 109-120.
- Wells, C.G., D.M. Crutchfield, N.M. Berenyi, and C.B. Davey. 1973. Soil and foliar guidelines for phosphorous fertilization of loblolly pine. USDA Forest Service, Southeastern Research Station, Forest Service Research Paper SE-110, Asheville, NC. 15 p.

The University of Georgia Warnell School of Forestry and Natural Resources offers educational programs, assistance, and materials to all people without regard to race, color, national origin, age, gender, or disability.

The University of Georgia is committed to principles of equal opportunity and affirmative action.