



Thinned slash pine response to single midrotation vegetation control, fertilization, and/or liming in the flatwoods region of southeastern Georgia: 12-year growth parameter results

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12-YEAR STUDIES OVERVIEW

A study was installed from 2000 to 2002 in two recently thinned slash pine stands in the flatwoods region of southeastern Georgia to investigate growth response to various single midrotation vegetation control via herbicide and/or NPK fertilization and/or lime. Stand growth along with soil and foliage nutrients were assessed annually or periodically for twelve years after midrotation treatments were applied. The purpose of this paper is to report on long-term slash pine growth response as well as soil and foliar nutrient dynamics following these midrotation treatments.

WAYNE COUNTY STUDY AREA (AGE 18- THROUGH 30- YEARS) RESULTS SUMMARY

- (1) The Herbicide+NPK treatment produced the largest slash pine 12-year incremental volume growth response compared to the Herbicide only, NPK, Mow only or Mow+NPK treatments and the control. The Herbicide+NPK treatment increased 12-year growth increments: dbh (stem diameter at 4.5 feet above groundline) by 0.6" (23%), basal area/acre by 13 ft² (32%), volume/tree by 3.1 ft³ (31%), and wood yields by 14.9 tons/acre (28%) or 1.23 tons/ac/yr compared to the control.
- (2) Mowing only (2 times in the 12-year study) did not improve any of the growth parameters compared to the control, demonstrating that mechanical treatments do not provide long-term woody competition control that would improve planted pine growth.

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- (3) Twelve-year (age 18 to 30-years) slash pine total stemwood+bark green weight periodic annual increment; PAI (tons/ac/yr) were as follows: control; 4.5, NPK; 5.0, Herb; 5.4, Herb+NPK; 5.8, Mow; 4.5, Mow+NPK; 5.4.

| Treatment | periodic annual increment (tons/ac/yr) |
|-----------------|--|
| Control | 4.5 |
| NPK | 5.0 |
| Herbicide | 5.4 |
| Herbicide + NPK | 5.8 |

- (4) The herbicide only treatment’s total stemwood+bark green weight MAI was 0.9 tons/ac/yr greater than the control and 0.4 tons/ac/yr PAI greater than the NPK only treatment. The herb only treatment can be financially attractive by improving slash pine growth by 10.8 tons/ac over no treatment based on this study and could set up the stand for fertilization later in the rotation after a possible second thinning.

WARE COUNTY STUDY AREA (AGE 25- THROUGH 37-YEARS) RESULTS SUMMARY

- (1) The lime plus NPK treatment (NPK applied one year after the lime application to minimize nitrogen volatilization losses) improved thinned slash pine 12-year growth increments for dbh by 0.5” (36%), total height by 2.7’ (23%), basal area/acre by 9.8 ft²/ac (41%), volume/tree by 2.2 ft³ (34%), and wood yields by 14.7 tons/acre (42%) or 1.23 tons/ac/yr compared to the control (no NPK, Herbicide, Herbicide+NPK, or Lime).
- (2) The Herbicide only treatment improved slash pine growth by the second largest margin compared to the control and other treatments (NPK, Herbicide+NPK, and Lime only) over the 12-year study period: dbh by 0.3”, total height by 2.5’, volume/tree by 1.6 ft³ (25%), and wood yields by 8.6 tons/acre (25%) or 0.72 tons/ac/yr. Due to cost differences between the herbicide (\$90 to \$120/ac) only versus the 2 tons dolomitic lime/ac + NPK (\$90+\$210/ac= \$300/ac), the herbicide only treatment was financially more attractive of the two best treatments (Dickens and others 2025).
- (3) Twelve-year (age 25- to 37-years) slash pine mean annual increments (MAIs in tons/ac/yr) were as follows: control; 2.9, NPK; 3.3, Lime; 3.4, Lime+NPK; 4.1, Herbicide; 3.6, and Herbicide+NPK; 3.0.
- (4) The Herbicide+NPK treatment had the highest mortality (20 trees/acre or 10% of total tree/acre) of all the treatments over the 12-year study period. The Herbicide treatment had no mortality, making mortality between the Herbicide+NPK and the other treatments difference a plausible explanation why the Herbicide+NPK treatment growth response was not large compared to the control or other treatments.

| Treatment | 12-yr periodic annual increment (tons/ac/yr) |
|-----------------|--|
| Control | 2.9 |
| NPK | 3.3 |
| Herbicide | 3.6 |
| Herbicide + NPK | 3.0 |
| Lime | 3.4 |
| Lime+NPK | 4.1 |

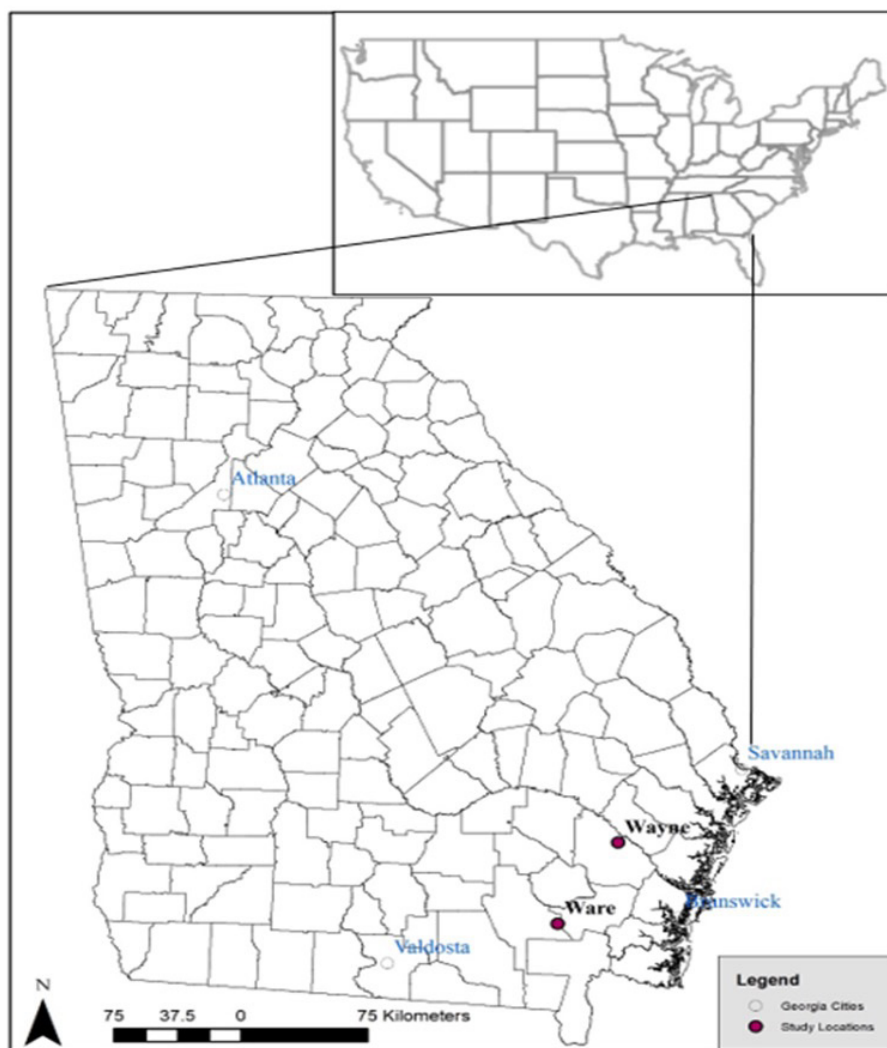


Figure 1: Wayne and Ware County cutover, thinned slash pine study area locations.

BACKGROUND

The effects of mid-rotation competition control using herbicides, fertilization, dolomite liming, mowing, and combinations of these treatments in thinned slash pine stands on common flatwoods somewhat poorly to poorly drained soils were quantified over a twelve-year period. Two randomized complete block design study areas were installed in thinned slash pine stands (4th or 5th row + select); one each in Wayne and Ware Counties, Georgia (Figure 1). There were three replications per treatment at each site. Soil series were delineated by a NRCS soil mapper (Charles Laguate 2001) on both sites prior to study establishment. At the Wayne County study area the following soil series were found: Mascotte (>50%), Sapelo, Olustee, and Rigdon soils (grouped by the University of Florida's Cooperative Research in Forest Fertilization (CRIFF) C soils; spodosols with and underlying argillic) and Albany, Lee field and Ocilla (CRIFF B soils, somewhat poorly drained with argillic @ greater than 20"). The Ware County study area was mostly Mascotte with some Sapelo (somewhat poorly to very poorly drained spodosols with an underlying argillic; CRIFF C soils).

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Slash pine mean dbh (diameter at 4.5 feet above groundline), total height, live crown ratio, volume/tree, volume/ac, total stemwood+bark green weight (tons/ac), and product class distributions were determined for each treatment at each site over time in two-year intervals. Each tree in each plot were tagged, numbered, measured for dbh, total height (Haglof Vertex III and Transponder), height to base of live crown, and merchandised into a product class (based on dbh. and assessed stem form).

STUDY AREAS SETUP

Both study areas had a mechanical site preparation treatment consisting of two pass disking with a heavy duty offset disk, then bedding. The Ware County study area was planted with 1-0 genetically improved bareroot slash pine seedlings on the beds in January 1978. The Wayne County study area was planted in January 1984 with genetically improved 1-0 bareroot slash pine seedlings. Both sites were planted at a 6x12 feet spacing.

The first site was established in Wayne County, Georgia. Eighteen 1/6-acre internal, permanent measurement plots with 1/3-acre gross treated plots and 40 feet of untreated buffer between each plot were established. There are three replications of the following treatments at the Wayne County site: control, NPK fertilizer (Table 1), Mow twice, Herbicide (Table 1), Mow+NPK, and Herb+NPK (Table 1).

In the second site, twenty-one 1/6-acre internal permanent measurement plots with 1/3-acre gross treated plots and 40 feet of untreated buffer between each plot were established at the Ware County site (Dixon Memorial Forest). There are three replications of the following treatments (Table 1) at the Ware County site: control, NPK fertilizer, lime (2 tons dolomite lime/ac to add Ca and Mg and to increase surface soil pH), Herbicide, Herb+NPK, and Lime+NPK (with the NPK treatment applied almost 13 months after the lime treatment, to minimize N volatilization losses).

All living trees in each plot were aluminum tree tagged (@ 4.5 feet for consistent diameter at breast height (dbh) measurement), numbered, and measured for dbh. (diameter tape to nearest 1/10th inch), total height, height to base of live crown (all vertical measurements with a Haglof Vertex III and Transponder), and merchandised into product classes prior to treatments. Plot treatments were randomly assigned with blocks by topography (soil moisture), TPA, and basal area. The experimental design was a randomized complete block with three replications per treatment at both sites. Baseline surface (0-6") soil samples, foliage samples (three dominant trees/plot, first flush of the previous year's growth, south side), and leaf area index estimates (digital photos and ocular) were collected. Treatments were then applied during October 2001 (herbicide treatments) and March 2002 (fertilizer treatment) at the Wayne county site (Table 1) and February 2002 (dolomite lime treatment), November 2002 (herbicide treatments), and February 2003 (fertilization treatments) at the Ware County site (Table 1)

MEASUREMENTS

At the Wayne County site all living tagged trees in each plot (dbh, total height, and height to base of live crown for live crown ratio,) were measured during the winter months seven times from 2001 to 2014 (Table 2). Foliage and surface (0-6") soil samples were collected during either January or February seven times from 2001 to 2010 (Table 2).

At the Ware County site all living tagged trees in each plot (dbh., total height, and height to base of live crown for live crown ratio) were measured eight times from 2001 to 2015. Most forest inventories were completed during the winter months. Pine foliage and surface (0-6") soil samples were collected six times during January or February from 2002 to 2011 (Table 2).

Table 1. Treatment descriptions and application timings for the two cutover, thinned slash pine competition control (herbicides), fertilization, lime, and mow trials. An application and application date at a site with ‘NA’ indicates that a treatment or treatment combination was not included at that site.

| Treatment | Wayne County | | Ware County | |
|---------------------------|---|-----------------------|---|-----------------------|
| | Applications | Application Date | Applications | Application Date |
| Herbicide | 24 oz/ac Chopper (2 lb acid equivalent (ae) imazapyr) + 32 oz/ac Garlon 4 (4 lb ae ester triclopyr) | 10/19/01 | 32 oz/ac Chopper + 16 oz/ac Garlon 4 | 11/19/02 |
| Fertilization | 250 lb ac ⁻¹ DAP + 465 lb ac ⁻¹ NH ₄ NO ₃ + 100 lb ac ⁻¹ MOP | 2/25/03 | 250 lb ac ⁻¹ DAP + 465 lb ac ⁻¹ NH ₄ NO ₃ + 100 lb ac ⁻¹ MOP | 3/8/02 |
| Dolomitic Lime | NA | NA | 2 tons ac ⁻¹ | Feb-02 |
| Mow | mow between rows | | NA | NA |
| Herbicide + Fertilization | Same as rates above | Oct 2001 and Feb 2003 | Same as rates above | Oct 2001 and Mar 2002 |
| Lime + Fertilization | NA | NA | Same as rates above | Feb 2002 and Mar 2003 |
| Mow + NPK | Same as rates above | Feb-03 | NA | NA |

Table 2. Forest, soil and pine foliage sampling schedule by study area. Stand age in years for a particular forest inventory year is included in parentheses.

| Stand inventory | Wayne County | | Ware County | | |
|-----------------|--------------|-----------------|-----------------|--------------|-----------------|
| | Soil samples | Foliage samples | Stand inventory | Soil samples | Foliage samples |
| 2001 (age 18) | 2001 | 2001 | 2002 (age 25) | 2001 | 2001 |
| 2004 (age 20) | 2002 | 2002 | 2004 (age 27) | 2002 | 2002 |
| 2006 (age 22) | 2004 | 2004 | 2007 (age 29) | 2004 | 2004 |
| 2008 (age 24) | 2005 | 2005 | 2009 (age 31) | 2007 | 2007 |
| 2010 (age 26) | 2006 | 2006 | 2011 (age 33) | 2009 | 2009 |
| 2012 (age 28) | 2008 | 2008 | 2013 (age 35) | 2011 | 2011 |
| 2014 (age 30) | 2010 | 2010 | 2015 (age 37) | | |

RESULTS

Survival/Mortality

Slash pine average trees/acre (tpa) mortality at the Wayne County study area (post-thinning) after six years ranged from 4 tpa in the mow treatment to 16 tpa in the Herbicide treatment (Table 3). The six year mortality are as follows for the other treatments: control; 12, NPK; 12, Herb; 16, Herb+NPK; 10, Mow; 4, and Mow+NPK; 10. Total tpa mortality after 12 years ranged from 10 tpa in the Herbicide+NPK and Mow treatments to 27 tpa in the control treatment. Survival rates after 12 years ranged from 87% in the control treatment to 95% in the Herbicide+NPK and Mow treatments (Table 3).

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The Ware County study area tpa mortality six years after study installation ranged from 0 tpa in the control and Herbicide treatments to 10 tpa in the Herbicide+NPK treatment. Total tpa mortality after 12 years ranged 0 tpa with the Herbicide treatment to 20 tpa with the Herbicide+NPK treatment. Survival rates after 12 years ranged from 90% in the Herbicide+NPK treatment to 100% in the Herbicide treatment (Table 3).

Table 3. Trees per acre mortality six and 12 years after study establishment (post-thinning) are presented by treatment for the Wayne and Ware County slash pine studies. Survival rates by treatment are presented 12 years after treatments were applied. Cells with an 'NA' indicate that a treatment was not applied at that site.

| Treatment | Wayne County | | | Ware County | | |
|---------------|--------------------------|---------------|-------------------|--------------------------|---------------|-------------------|
| | Trees per acre mortality | | Survival rate (%) | Trees per acre mortality | | Survival rate (%) |
| | Post 6-years | Post 12-years | Post 12-years | Post 6-years | Post 12-years | Post 12-years |
| Control | 12 | 27 | 87 | 0 | 5 | 97 |
| NPK | 12 | 14 | 92 | 6 | 9 | 95 |
| Herbicide | 16 | 20 | 91 | 0 | 0 | 100 |
| Herbicide+NPK | 10 | 10 | 95 | 10 | 20 | 90 |
| Lime | NA | NA | NA | 6 | 7 | 97 |
| Lime+NPK | NA | NA | NA | 2 | 13 | 94 |
| Mow | 4 | 10 | 95 | NA | NA | NA |
| Mow+NPK | 10 | 19 | 90 | NA | NA | NA |

Twelve-year diameter at breast height (4.5 ft above groundline; dbh) growth (Figures 2 and 3)

Slash pine dbh growth over the 12-year study period at the Wayne County study area was as follows. The control mean dbh growth from age 18-24-years was 1.5" (6.9 to 8.4") and from age 24-30-years was 1.1" (8.4 to 9.5") for a total of 2.6". The NPK treatment mean dbh growth from age 18-24-years was 1.9" (7.0 to 8.9") and from 24-30-years was 1.3" (8.9 to 10.2") for a total of 3.2". The Herb treatment mean dbh growth from age 18-24-years was 1.9" (6.8 to 8.7") and from age 24-30-years 1.1" (8.7 to 9.8") for a total of 3.0" in the 12-year study period.. The Herbicide+NPK treatment mean dbh growth from age 18-24-years was 2.2" (7.0 to 9.2") and from 24-30-years was 1.2" (9.2 to 10.4") with the total mean dbh growth of 3.4", 0.8" greater than the control. The Mow treatment mean dbh growth from age 18-24-years was 1.5" (7.2 to 8.7"), the same as the control and from age 24-30-years was 1.2" (8.7 to 9.9") with a total mean dbh growth of 2.7". The Mow+NPK treatment mean dbh growth from age 18-24-years was 1.9" (7.1 to 9.0") and from age 24-30-years was 1.2" (9.0 to 10.2") for a total of 3.1" of dbh growth over the 12-year study period. (Figure 2). All treatments improved diameter growth over the control, but differences varied. The mow treatment only improved diameter growth 0.1" while the Herbicide+NPK treatment improved growth the most by 0.8" over the 12-year study period.

Slash pine dbh growth over the 12-year study period at the Ware County study area was as follows. The control dbh growth from age 25-31-years was 0.8" (8.0 to 8.8") and from age 31-37-years was 0.6" (8.8 to 9.4") for a total of 1.4". The NPK treatment dbh growth from age 25-31-years was 1.0" (8.1 to 9.1") and from 31-37-years was 0.7" (9.1 to 9.8") for a total of 1.7". The Lime treatment dbh growth from age 25-31-years was 0.8" (7.8 to 8.6") and from age 31-37-years was 0.8" (8.6 to 9.4") for a total of 1.6". The Lime+NPK treatment dbh growth from age 25-31-years was 1.0" (7.9 to 8.9") and from 31-37-years was 0.9" (8.9 to 9.8") with the total dbh growth of 1.9".. The Herb treatment dbh growth from age 25-31-years was 0.9" (8.0 to 8.9") and from age 31-37-years was 0.8" (8.9 to 9.7") for a total dbh growth of 1.7". The Herb+NPK treatment dbh growth from age 25-31-years was 0.9" (7.8 to 8.7") and from age 31-37-years was 0.8" (8.7 to 9.5") for a total of 1.7" (Figure 3). All treatments improved diameter growth compared to the control. Improvement was least with the Lime treatment, which improved growth by only 0.2" over the control. The Lime+NPK treatment improved growth by 0.5" compared to the control.

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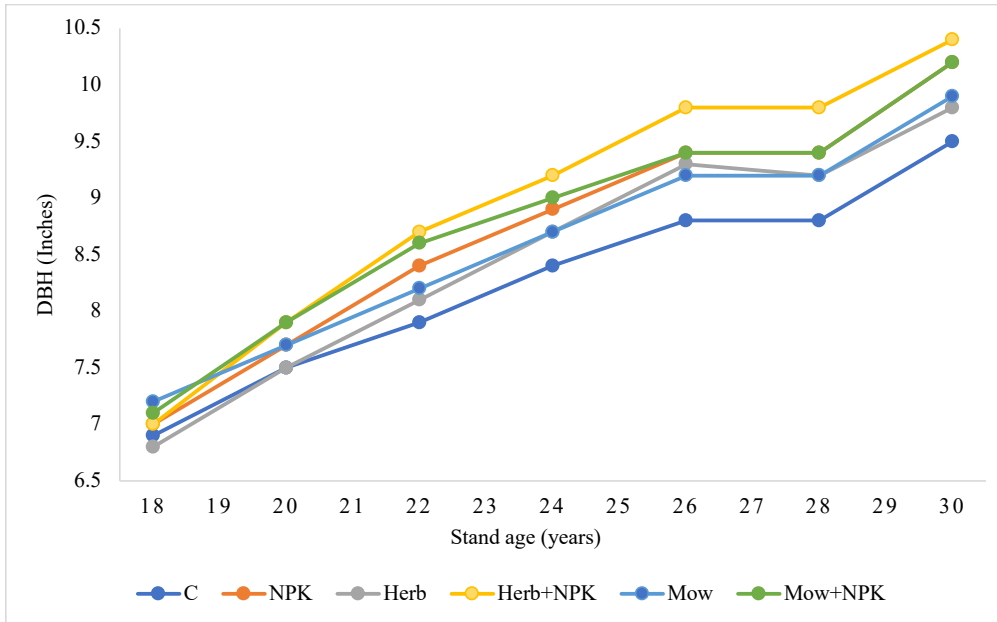


Figure 2: Wayne County, GA cutover, thinned slash pine dbh growth over the 12-year study period by treatment.

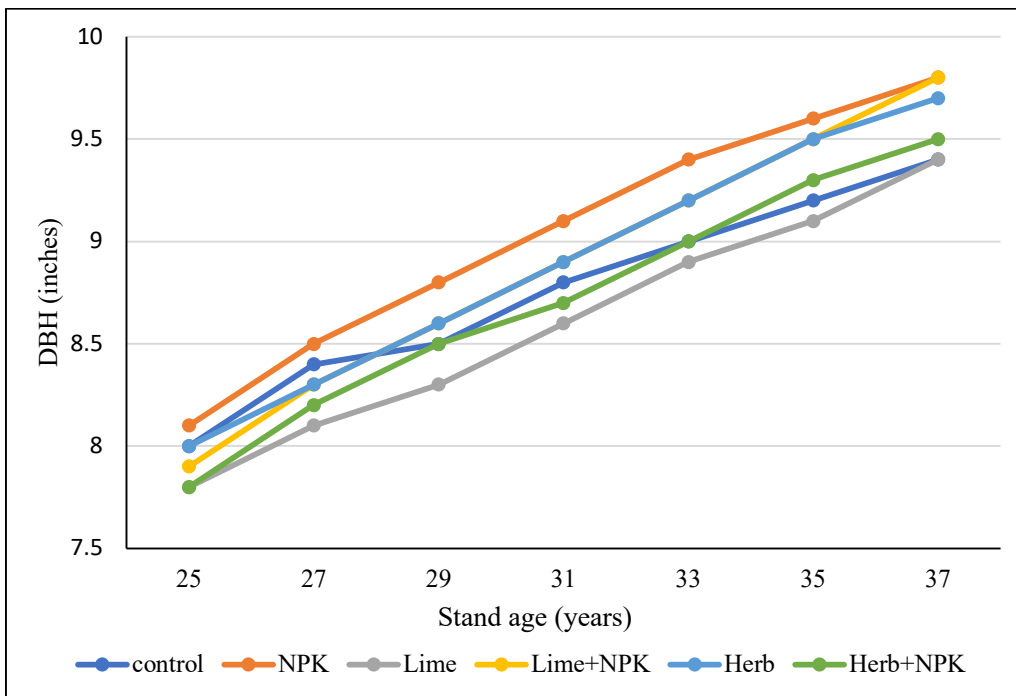


Figure 3: Ware County, GA cutover, thinned slash pine dbh growth over the 12-year study period by treatment. Age 25-, 31-, and 37-years mean dbh by treatment; control: 8.0-8.8-9.4", NPK: 8.1-9.1-9.8", Lime: 7.8-8.6-9.4", Lime+NPK: 7.9-8.9-9.8", Herb: 8.0-8.9-9.7", Herb+NPK: 7.8-8.7-9.5"

Twelve-year height growth (Figures 4 and 5)

Slash pine 12-year total height growth at the Wayne County study area (Figure 4) was as follows. The controls plot trees grew 9.3 ft (54.4 to 63.7') from age 18- to 24-years and 9.4 ft (63.7 to 73.1') from age 24- to 30-years for a total height growth of 18.7 ft. The NPK treatment trees grew 12.5 ft (54.3 to 66.8') from age 18- to 24-years and 8.8 ft (66.8 to 75.6') from age 24- to 30-years for a height growth total of 21.3 ft. The Herbicide treatment trees grew 11.3 ft (53.4 to 64.7') from age 18- to 24-years and 9.4 ft (64.7 to 74.1') from age 24- to age 30-years, for total height growth of 20.7 ft. The Herbicide+NPK treatment trees grew 11.4 ft (56.3 to 67.7') from age 18- to 24-years and 9.2 ft (67.7 to 76.9') from age 24- to 30-years for a total height growth of 20.6 ft. The Herbicide+NPK treatment trees grew 1.9 ft more than the control with all the gain coming in the 18- to 24-year period. The Mow treatment trees grew 9.3 ft (56.2 to 65.5') from age 18- to 24-years and 10.2 ft (65.5 to 75.7') from age 24- to 30-years for total height growth of 19.5 feet. The Mow+NPK treatment trees grew 11.3 ft (54.5 to 65.8') from age 18- to 24-years and 8.2 ft (65.8 to 74.0') from age 24- to 30-years and a total height growth of 19.5 ft. Height growth improvement over the control was greatest with the NPK treatment (2.6 ft), and least with the two mow treatments (0.8 ft greater than the control each). Most height growth improvement for all treatments occurred from stand ages 18 to 24 years, which was the first six years after midrotation treatments.

The Ware County slash pine study area 12-year total height growth (Figure 5) was as follows: The control treatment grew 5.8 feet (63.3 to 69.1') from age 25- to 31-years and 6.1 ft (69.1 to 75.2') from age 31- to 37-years for a total height growth of 11.9 ft. The NPK plots trees grew 7.6 ft (63.1 to 70.7') from age 25- to 31-years and 5.1 ft (70.7 to 75.8') from age 31- to age 37-years with a total height growth of 12.7 ft. The NPK plots trees height gain over the control was 1.8 ft (5.8 vs 7.6') in the 25- to 31-years period but a height growth loss of 1.0 ft in the 31- to 37-year period. The Lime treatment height growth from age 25- to 31-years was 5.4 ft (62.2 to 67.6'), the least of all the treatments including the control. From age 31- to age 37-years the Lime treatment trees grew 7.5 ft (67.6 to 73.0'), the most of all the treatments. The Lime treatment height growth over the study period (age 25- to age 27-years) was 12.9 ft. The Lime+NPK treatment grew 9.7 ft (63.6 to 71.5') from age 25- to 31- years, the most height growth of all the treatments during this period. From age 31- to 37-years the Lime+NPK trees height growth averaged 6.7 ft (71.5 to 78.2'). The Herbicide treatment trees grew 7.5 ft (63.9 to 71.4') from age 25- to 31- years and 6.9 ft (71.4 to 78.3') from age 31- to age 37-years. The total Herbicide treatment height growth, 14.4 ft, was the second most of all the treatments. The Herbicide+NPK trees height growth was 7.7 ft (62.7 to 70.4') from age 25-31-years and 6.3 ft (70.4 to 76.7') from age 31-37-years for a total of 14.0 ft height growth. All midrotation treatments had greater height growth than the control treatment over the 12-year study period. The NPK treatment had the smallest gain (0.8 ft), while the Lime+NPK treatment had the greatest height growth improvement (2.7 ft).

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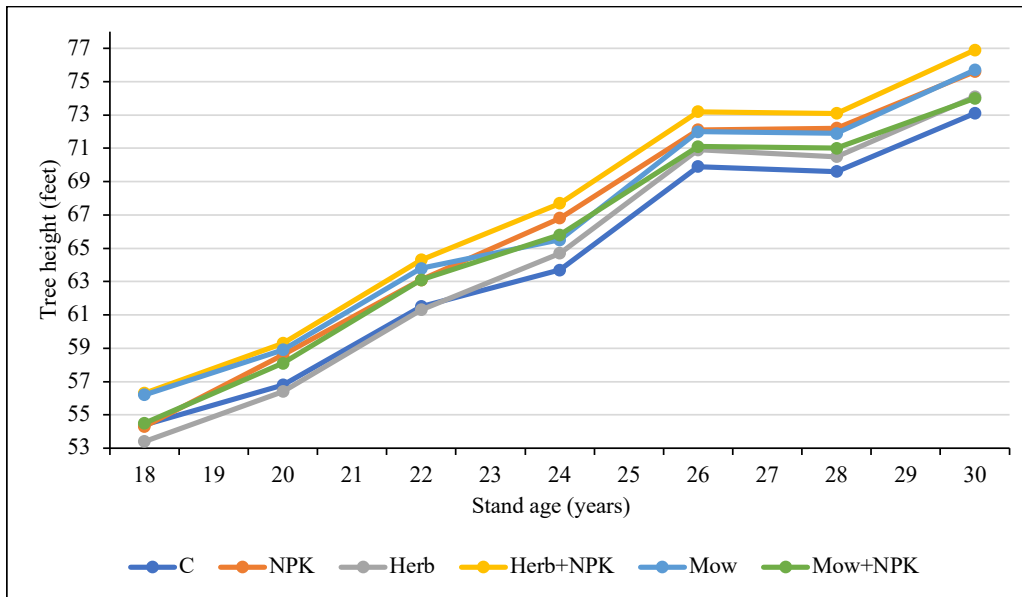


Figure 4: Wayne County cutover, thinned slash pine height growth from age 18- through 30-years by treatment

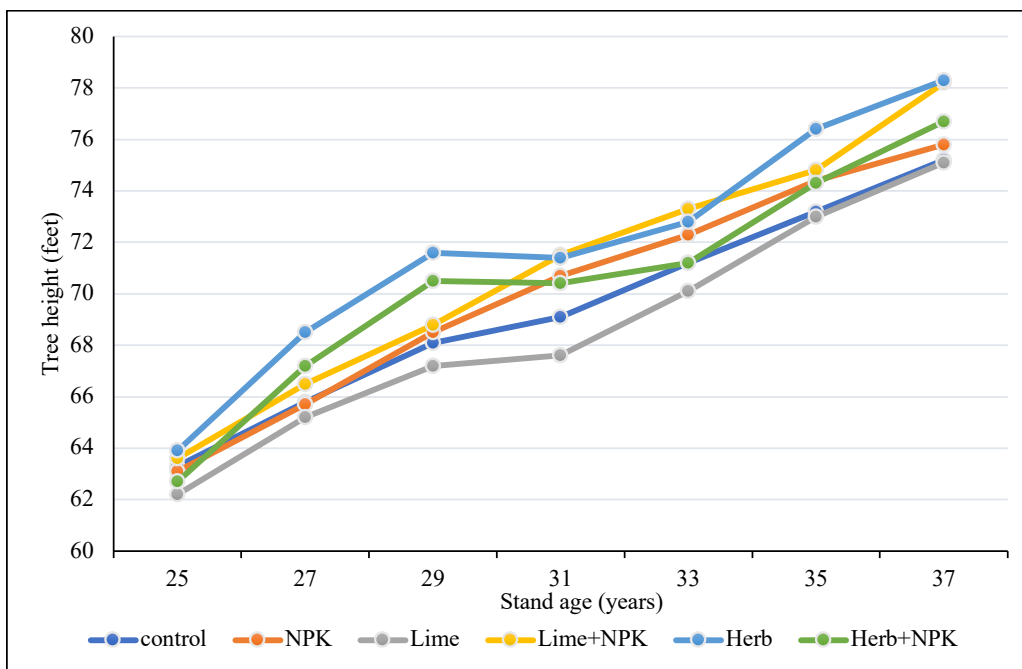


Figure 5: Ware County cutover, thinned slash pine height growth from age 25- through 37-years by treatment



Basal area (square feet/acre) 12-year growth (Figures 6 and 7)

Slash pine basal area growth at the Wayne County study area was as follows. The control treatment basal area increased by 23 ft²/ac (55 to 78 ft²/ac) from age 18- to 24-years. From age 24- to age 30-years the control treatment grew 18 ft²/ac (78 to 96 ft²/ac) for a total of 41 ft²/ac growth over the study period. The NPK treatment trees basal area/acre increased by 26 ft²/ac (51 to 77) from age 18- to 24-years and from age 24- to 30-years grew 19 ft²/ac (77 to 96) for a total basal area increase of 45 ft²/ac. The Herbicide treatment basal area grew 28 ft²/ac (55 to 83) from age 18- to 24-years and increased another 21 ft²/ac (83 to 104 ft²/ac) from age 24- to 30-years for a total basal area growth of 49 ft²/ac. The Herbicide+NPK treatment trees basal area increased by 32 ft²/ac (50 to 82 ft²/ac) from age 18 to 24-years and grew another 22 ft²/ac from age 24- to 30-years. The Herbicide+NPK treatment basal area grew the most of all the treatments, a total of 54 ft²/ac over the study period. The Mow treatment basal area growth was the same as the control (41 ft²/ac) over the 12-year study period, illustrating that mowing alone does not significantly improve slash pine basal area growth. The Mow+NPK treatment trees grew 28 ft²/ac (56 to 84 ft²/ac) from age 18- to 24-years and 22 ft²/ac (84 to 106 ft²/ac) from age 24- to age 30-years for a total of 50 ft²/ac growth. Over the 12-year study period, the mow treatment basal area growth was the same as the control treatment (41 ft²/ac), while the NPK treatment grew only 4 ft²/ac more basal area per acre than the control. The Herbicide+NPK treatment resulted in the greatest basal area growth over the study period, which was 13 ft²/ac greater than the control.

The Ware County slash pine basal area growth was as follows. The control treatment basal area increased by 12.1 ft²/ac (65.7 to 77.8 ft²/ac) from age 25- to 31 years and 12.2 ft²/ac from age 31- to 37-years (77.8 to 90.0 ft²/ac) for a total basal area growth of 24.3 ft²/ac. The NPK treatment basal area growth was 13.8 ft²/ac (66.7 to 80.5) from age 25- to 31-years and 15.5 ft²/ac (80.5 to 96.0 ft²/ac) from age 31- to 37-years. The NPK basal area total growth was 29.3 ft²/ac over the study period. The Lime treatment basal area growth was 9.8 ft²/ac (70.7 to 80.5 ft²/ac) from age 25- to 31-years and 18.5 ft²/ac (80.5 to 99.0 ft²/ac) from age 31- to 37-years. The Lime treatment trees grew a total of 28.3 ft²/ac over the study period, 4.0 ft²/ac more than the control. All the Lime basal area gain was in the 7th through 12th year, indicating that the lime treatment's benefit was delayed, possibly with the slow change with increasing soil pH and a delayed response to the addition of calcium and magnesium to the site. The Lime+NPK treatment basal area growth was the greatest of all the treatments with an 18.8 ft²/ac (74.9 to 93.7 ft²/ac) increase from age 25- to 31-years and an increase of 15.3 ft²/ac (93.7 to 109 ft²/ac) from age 31- to 37-years for a total of 34.1 ft²/ac increase over the study period. The Herbicide treatment basal area growth was 13.6 ft²/ac (68.5 to 82.1 ft²/ac) from age 25- to 31-years and 16.9 ft²/ac (82.1 to 99.0 ft²/ac) from age 31- to 37-years for a total of 30.5 ft²/ac basal area growth over the study period. The Herb treatment slash (and loblolly) response tends to start out slowly as it did in this study with a 1.5 ft²/ac gain versus the control in years 1-6, but a much larger gain of 4.7 ft²/ac gain versus the control in years 7-12 for a total gain over the control of 6.2 ft²/ac, second only to the Lime+NPK treatment trees basal area growth. Interestingly, the Herbicide+NPK treatment basal area growth was slightly lower (24.3 ft²/ac versus 24.1 ft²/ac or 0.2 ft²/ac) than control over the study period. This is most likely due, in part, or possibly mostly due to a much higher slash pine mortality rate (20 TPA or 10%) in the Herbicide+NPK plots versus the control mortality rate (5 TPA or 3%) over the 12-year study period. Basal area growth was 0.2 ft²/ac less in the Herbicide+NPK treatment over the 12-year study period and basal area growth compared to the control was greatest with the Lime+NPK treatment (9.8 ft²/ac).

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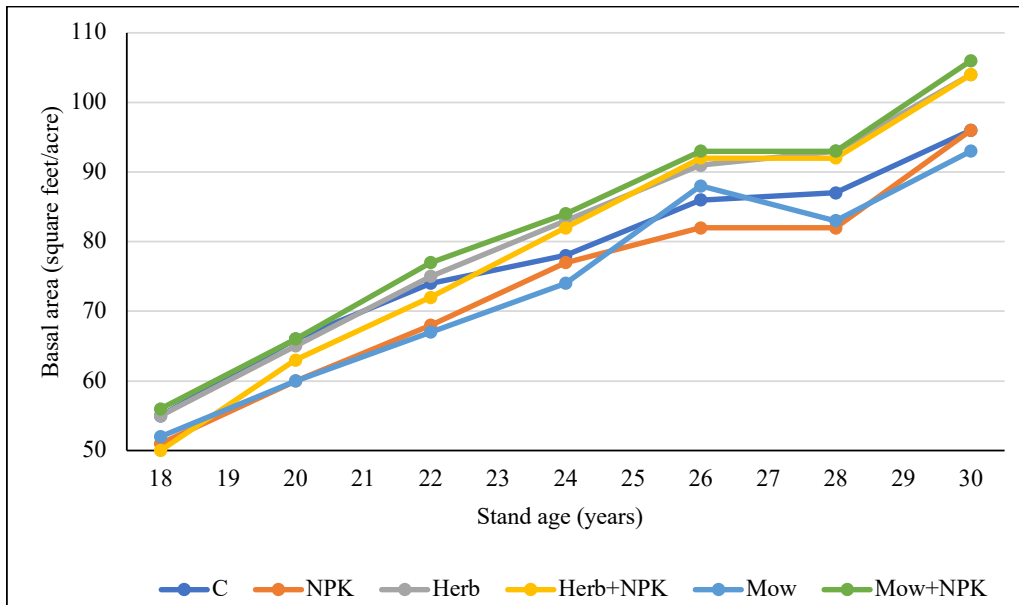


Figure 6: The Wayne County cutover, thinned slash pine stand basal area growth during the 12-year study period by treatment.

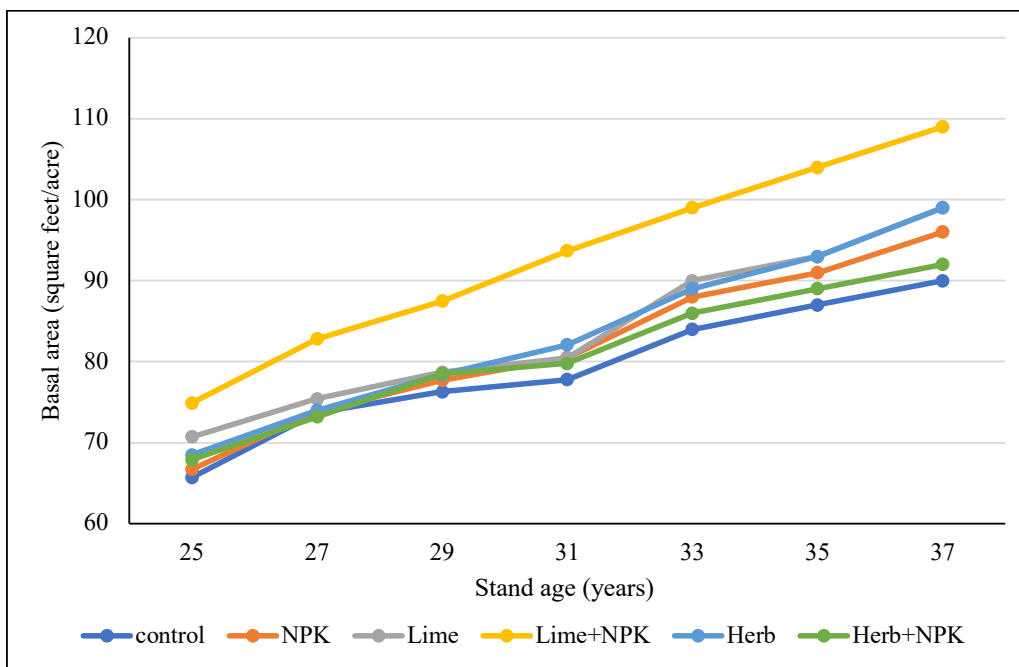


Figure 7: The Ware County cutover, thinned slash pine stand basal area growth over the 12-year study period by treatment.



Volume/tree (ft³) 12-year growth (Figures 8 and 9)

Slash pine volume per tree (volume equation from Bailey and others 1982) growth at the Wayne County study area over the study period was as follows. The control plots trees volume/tree grew 4.8 ft³ (6.8 to 11.6 ft³) from age 18- to age 24-years and 5.1 ft³ (11.6 to 16.7 ft³) from age 24- to age 30-years for a total of 9.9 ft³ over the study period. The NPK treatment trees grew 6.6 ft³ (7.2 to 13.8 ft³) from age 18- to 24-years and 6.3 ft³ (13.8 to 20.1 ft³) from age 24- to 30-years for a total of 12.9 ft³. The Herbicide treatment trees grew 6.0 ft³ (6.6 to 12.6) from age 18- to 24-years and 5.6 ft³(12.6 to 18.2) from age 24- to 30-years. The Herbicide treatment trees grew a total of 11.6 ft³. The Herbicide+NPK treatment volume/tree growth was 7.1 ft³ (7.2 to 14.3 ft³, almost twice the volume increase in the 18-24-yr period) from age 18- to 24-years and 5.9 ft³ (14.3 to 20.2 ft³) from age 24- to 30-years. The total volume/tree growth for the Herbicide+NPK treatment was 13.0 ft³. The Mow treatment volume/tree growth was 5.1 ft³ (7.4 to 12.5 ft³) from age 18- to 24-years and 5.6 ft³ (12.5 to 18.1 ft³) from age 24- to 30-years. The Mow+NPK treatment volume/tree growth was 6.6 ft³ (7.2 to 13.8 ft³) from age 18- to 24-years and 6.0 ft³ (13.8 to 19.8 ft³) from age 24- to 30-years. All midrotation treatments improved average individual tree volume growth over the control. The Mow treatment only proved volume by 0.8 ft³, while the NPK and Herbicide+NPK treatments improved individual volume growth by 3.0 and 3.1 ft³, respectively over the 12-year study period.

The Ware County slash pine volume/tree growth for the control treatment was 2.6 ft³ (10.2 to 12.8 ft³) from age 25- to 31-years and 3.8 ft³ (12.8 to 16.6 ft³) from age 31- to 37-years for a total of 6.4 ft³ over the study period. The NPK treatment volume/tree growth was 3.8 ft³ (10.5 to 14.3 ft³) from age 25- to 31-years and 3.9 ft³ (14.3 to 18.2 ft³) from age 31- to 37-years with a total of 7.7 ft³ of growth. The Lime treatment volume/tree growth was 2.4 ft³ (9.6 to 12.0 ft³) from age 25- to 31-years and 4.3 ft³ (12.0 to 16.3 ft³) from age 31- to 37-years for a total of 6.7 ft³. The Lime+NPK treatment volume/tree growth was 3.7 ft³ (9.8 to 13.5 ft³) from age 25- to 31-years and 4.9 ft³ (13.5 to 18.4 ft³) from age 31- to 37-years. The total Lime+NPK treatment volume/tree growth was 8.6 ft³ which was highest volume/tree growth of all treatments. The Herbicide treatment volume/tree growth was 3.3 ft³ (10.1 to 13.4 ft³) from age 25- to 31-years and 4.7 ft³ (13.4 to 18.1 ft³) from age 31- to age 37-years. The total Herbicide treatment volume/tree growth was 8.0 ft³. The Herbicide+NPK treatment volume/tree growth was 3.3 ft³ (9.5 to 12.8) from age 25- to 31-years and 4.1 ft³ (12.8 to 16.9) from age 31- to 37-years. The total Herbicide+NPK treatment volume/tree growth was 7.4 ft³. All midrotation treatments improved individual tree volume growth over the control. The Lime and Herbicide+NPK treatments had the smallest average per tree improvements at 0.3 and 1.0 ft³, while the Lime+NPK treatment had the greatest improvement (2.2 ft³, 34%) compared to the control over the 12-year study period.

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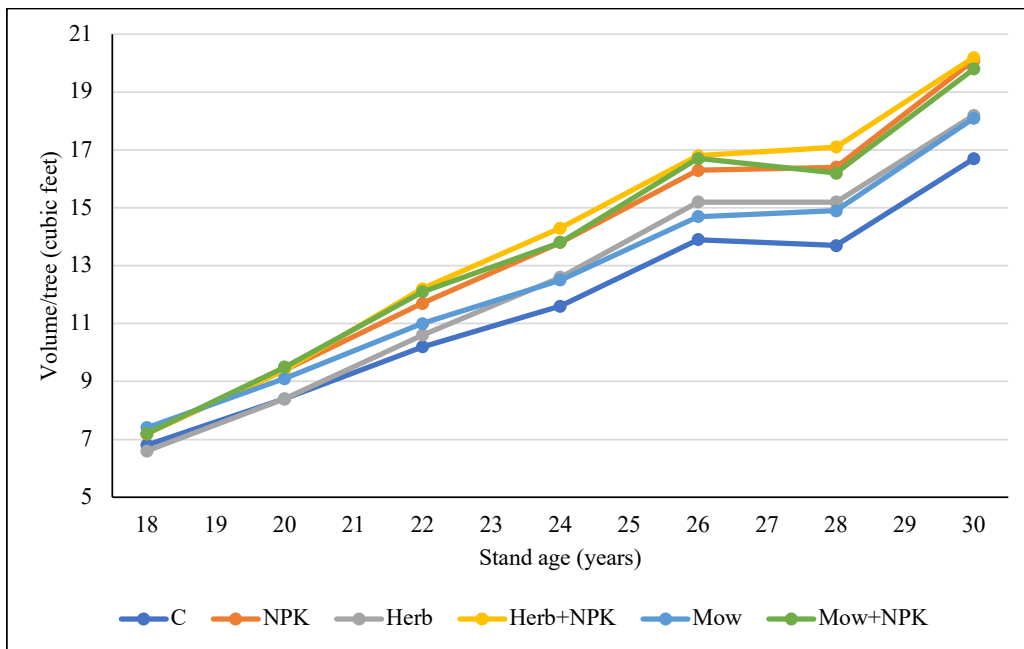


Figure 8: Wayne county cutover, thinned slash pine stand 12-year volume/tree growth by treatment. The slash pine cubic foot volume equation used is from Bailey and others 1982.

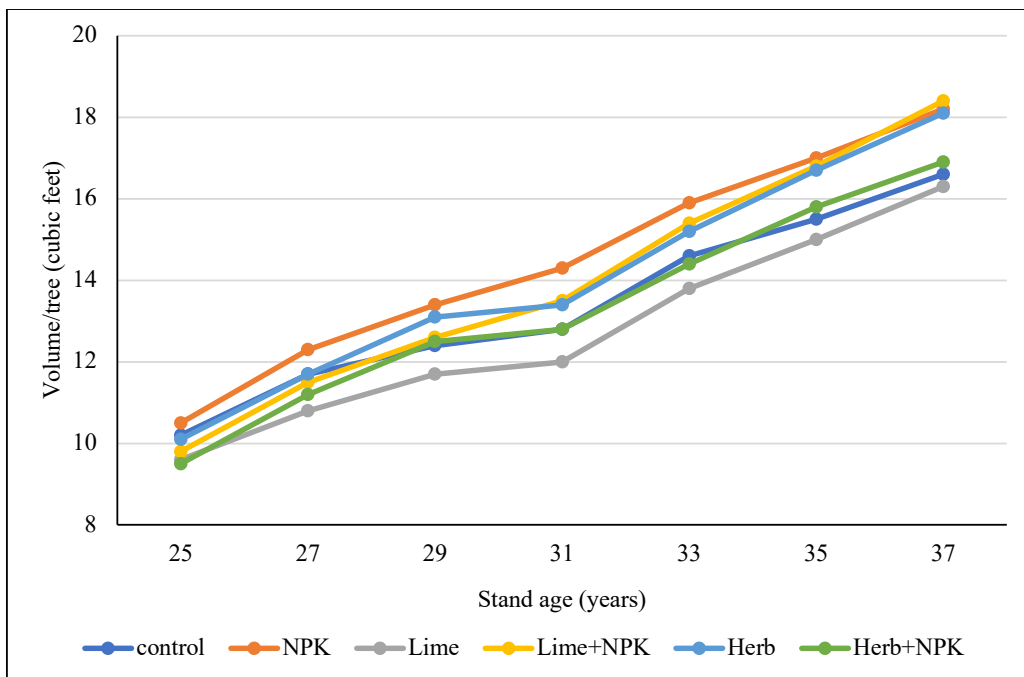


Figure 9: Ware county cutover, thinned slash pine stand 12-year volume/tree growth by treatment. The slash pine cubic foot volume equation used is from Bailey and others 1982.



Tons/acre (total stemwood+bark green weight) 12-year growth (Figures 10 and 11).

The Wayne County slash pine study area tons/ac (green weight stemwood+bark equation from Bailey and others 1982) productivity over the study period are as follows. The control treatment grew 25.9 tons/ac (43.9 to 69.8 tons/ac) from age 18- to 24-years and 28.3 tons/ac (69.8 to 98.1 tons/ac) from age 24- to 30-years. The control treatment grew a total of 54.2 tons/ac over the study period for a 4.5 tons/ac/yr periodic annual increment (PAI). The NPK treatment trees grew 31.9 tons/ac (41.2 to 73.1 tons/ac) from age 18- to 24-years and 27.9 tons/ac (73.1 to 101.0 tons/ac) from age 24- to 30-years. The total NPK treatment tons/ac grown over the study period was 59.8 tons. The Herbicide treatment grew 33.2 tons/ac (43.3 to 76.5 tons/ac) from age 18- to 24-years and 31.2 tons/ac (76.5 to 109.7 tons/ac) from age 24- to 30-years. The total Herbicide treatment tons/ac grown was 64.4. The Herbicide+NPK treatment grew 36.9 tons/ac (40.6 to 77.5) from age 18- to 24-years and 32.2 tons/ac (77.5 to 109.7) from age 24- to 30-years. The total Herbicide+NPK treatment tons/ac production was 69.1 tons/ac. The Mow treatment grew 27.1 tons/ac (42.0 to 69.1) from age 18- to 24-years and 27.0 tons/ac (69.1 to 96.1) from age 24- to 30-years. The total Mow green weight volume production was 54.1 tons/ac. The Mow+NPK treatment grew 36.2 tons/ac (44.6 to 80.8 tons/ac) from age 18- to 24-years and 28.9 tons/ac (80.8 to 109.7 tons/ac) from age 24- to 30-years. The total green weight volume production for the Mow+NPK treatment was 69.1 tons/ac, 10.9 tons/ac more than the control with a PAI of 5.4 tons/ac/yr. The Mow+NPK and Herbicide treatments produced essentially the same amount of wood over the 12-year study period, which make the Herbicide only treatment financially more attractive (lower cost) than the Mow+NPK and NPK treatments. Other than mowing, all midrotation treatments produced more wood over the 12-year study period. The mow treatment was essentially the same as the control treatment, which makes mowing only not growth or financially beneficial from a post-thin slash pine wood production standpoint. The herbicide+NPK treatment produced the greatest gain in tons/ac compared to the control (+14.9 tons/ac). The herbicide treatment also resulted in a strong response with an additional 10.3 tons/ac wood produced.

The Ware County slash pine study area tons/ac productivity over the study period are as follows: The control trees grew 15.2 tons/ac (58.8 to 74.0 tons/ac) from age 25- to 31-years and 19.7 tons/ac from age 31- to 37-years for a total of 35.0 tons/ac/yr and a PAI of 2.9 tons/ac/yr over the study period. The NPK treatment trees grew 18.2 tons/ac (59.7 to 77.9 tons/ac) from age 25- to 31-years and 21.7 tons/ac (77.9 to 99.6 tons/ac) from age 31- to 37-years. The NPK treatment grew a total of 39.9 tons/ac with a 3.3 tons/ac/yr PAI over the study period. The Lime treatment trees grew 12.5 tons/ac (62.3 to 74.8 tons/ac) from age 25- to 31-years and 27.9 tons/ac (74.8 to 102.7 tons/ac) from age 31- to 37-years. This second six-year period from age 31- to 37-years for the Lime treatment growing 27.9 tons/ac was greater than all other treatments. This late benefit may indicate that the lime value to enhance site productivity is slow to take effect, but with an increase in pH and the additional Ca and Mg there is value to this treatment, especially in conjunction with a NPK treatment one year later. The Lime treatment total tons/ac production was 40.4 tons, with a PAI of 3.4 tons/ac/yr over the study period. The Lime+NPK treatment produced the highest tons/ac production of all the treatments with 24.0 tons/ac (67.1 to 91.1 tons/ac) from age 25- to 31-years and 25.7 tons/ac (91.1 to 116.8 tons/ac) from age 31- to 37-years. The total Lime+NPK treatment tons/ac production was 49.7 tons/ac, with a PAI of 4.1 tons/ac/yr.

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The Herbicide treatment trees grew 18.1 tons/ac (61.6 to 79.7 tons/ac) from age 25- to 31-years and 25.5 tons/ac (79.7 to 105.2 tons/ac) from age 31- to 37-years. The Herbicide treatment total tons/ac production was 43.6 tons/ac, with a PAI of 3.6 tons/ac/yr. It is interesting to note that the Herbicide treatment's 7th through 12th year response was 7.4 tons/ac greater than the year 1 through 6 of the study. Other literature (Oppenheimer and others 1989, Pienaar and others 1983) shows the same trend for the herbicide treatment response being slow to start, especially compared to a NP or NPK fertilizer treatment which starts out fast but tends to decline after 4-6 years (Hynynen and others 1995) but gets a larger growth response into the 6-12 years post-application period. The Herbicide+NPK treatment trees grew 16.3 tons/ac (60.3 to 76.6 tons/ac) from age 25- to 31-years and 19.5 tons/ac (76.6 to 96.1 tons/ac) for a total of 35.9 tons/ac growth during the study period. The Herbicide+NPK treatment trees grew just 0.9 more tons/ac than the control with a PAI of 3.0 tons/ac/yr. The low PAI for the Herbicide+NPK treatment, again, most likely due having the highest mortality rate of all the treatments (10% compared to 3% for the control and no mortality in the Herbicide treatment) over the 12-year study period. The Lime+NPK treatment was by far the best performing treatment compared to the control producing 14.9 tons/ac more wood over the 12-year study periods. Other treatments besides Herbicide+NPK ranged from 4.9 to 8.6 tons/ac more than the control.

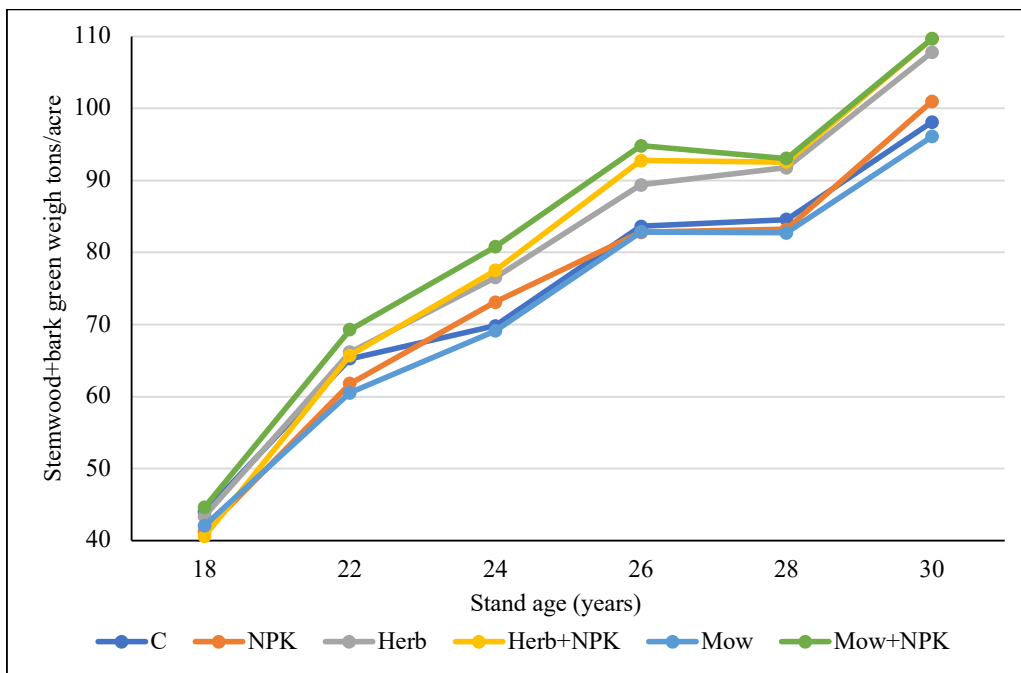


Figure 10: Wayne County cutover, thinned slash pine stand total stemwood+bark green weight tons/ac production by treatment over the 12-year study period.

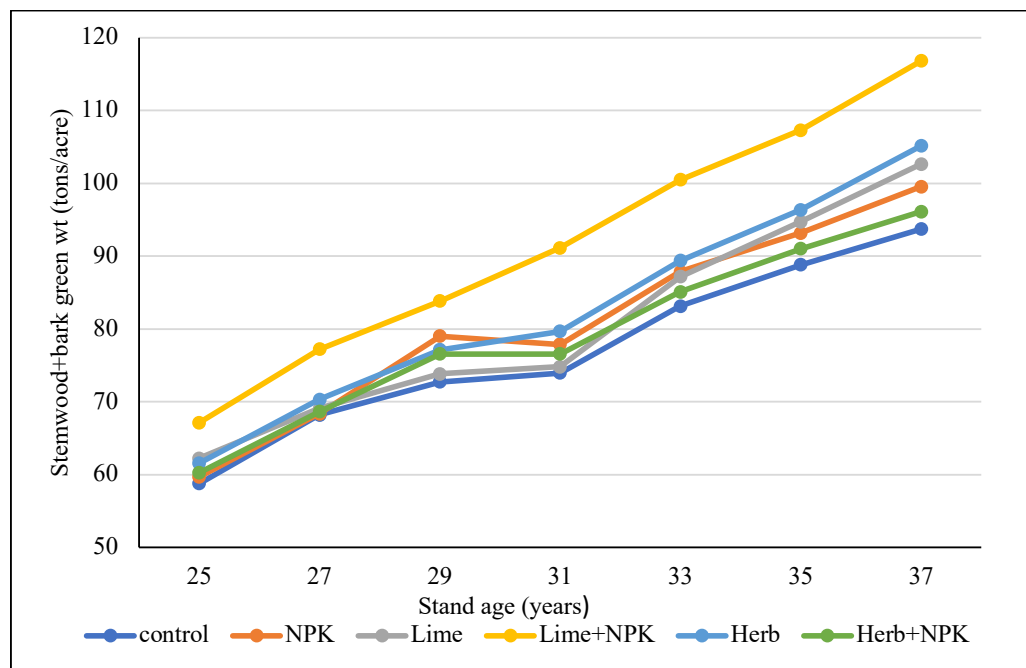


Figure 11: Ware County cutover, thinned slash pine stand total stemwood+bark green weight tons/ac production by treatment over the 12 year study period.

Surface (0-6”) soil pH and nutrient levels (Figures 12-16)

Surface soil results at the Wayne County study area are as follows for the control, NPK, Herb, and Herbicide+NPK treatments. The Mow and Mow+NPK treatments are not included as they were not growth, time or financially attractive.

The pre-treatment (age 17-years) surface soil pH ranged from 4.3 (control and Herbicide) to 4.6 (Herbicide+NPK). Soil pHs declined to their lowest levels at 4.0 (control), 3.9 (NPK and Herbicide), and 4.2 (Herbicide+NPK) at age 22-years. At age 24-years, six years into the study from treatments time (age 18-years), soil pHs values were 3.9 (Herbicide), 4.2 (control), 4.6 (NPK), and 4.8 (Herbicide+NPK). Surface soil Mehlich 1 P levels pre-treatment (age 17-years) ranged from 1.67 mg/kg (control) to 2.83 mg/kg (Herbicide+NPK). Mehlich 1 P is considered a soil P extraction method (an estimate of phosphorus that is available to plants) that is well correlated to slash and loblolly pine growth or deficiency on Coastal Plain somewhat poorly, poorly and very poorly drained spodosols with an underlying argillic (Bt) horizon and for soils that have a Bt within 80” or no Bt. The minimum sufficiency Mehlich 1 P level is considered 5 mg/kg (Ballard and Pritchett 1975). Only the Herbicide+NPK treatment plots surface soils had Mehlich 1 P levels above 5 mg/kg at ages 19-, (6.33) 20- (10.4) and 24-years (9.75). Even the NPK treatment’s plots surface soils Mehlich 1 P levels did not get to or above 5 mg/kg from age 17- to age 24-years. Age 24-years Mehlich 1 P levels were 1.44 (control), 3.35 (NPK), 2.81 (Herbicide) and 9.75 mg/kg (Herbicide+NPK). Surface soil potassium (K) pre-treatment (age 17-years) ranged from 11.5 (control) to 13.0 (NPK and Herbicide+NPK) to 13.5 mg/kg (Herbicide). There was a soil K concentration increase in the 20th year with levels rising to 21.3 (Herbicide), 21.9 (control), 22.7 (NPK) and 23.4

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mg/kg (Herbicide+NPK). By age 24-years, soil K levels declined to 13.1 (Herbicide+NPK), 14.2 (Herbicide), 17.0 (NPK), and 18.8 mg/kg (control). Surface soil calcium (Ca) pre-treatment levels ranged from 57.8 (control), 60.8 (Herbicide+NPK), 68.2 (NPK), and 78.5 mg/kg (Herbicide). Peak Ca levels by treatment occurred at year 20 for the control (107), 123 for NPK at age 19-years, 124 for Herbicide at age 19-years, and 111 mg/kg for Herbicide+NPK at age 20-years. By age 24-years Ca soil levels declined to 51.2 (control), 31 (NPK), 59.4 (Herbicide) and 87 (Herbicide+NPK). Pre-treatment (age 17-years) surface soil magnesium (Mg) ranged from 7.94 (NPK), 12.3 (control), 12.7 (Herbicide+NPK) to 15.5 mg/kg (Herbicide). The highest soil Mg levels were noted at age 20-years for the control (18.7), 17.2 for NPK at age 19-years, 19.3 for Herbicide at age 19-years and 17.3 mg/kg for Herbicide+NPK at age 19-years. By age 24-years, the control plot soil Mg concentration was 14.1 for the control, 8.87 for NPK, 14.8 for Herbicide and 17.1 mg/kg for Herbicide+NPK.

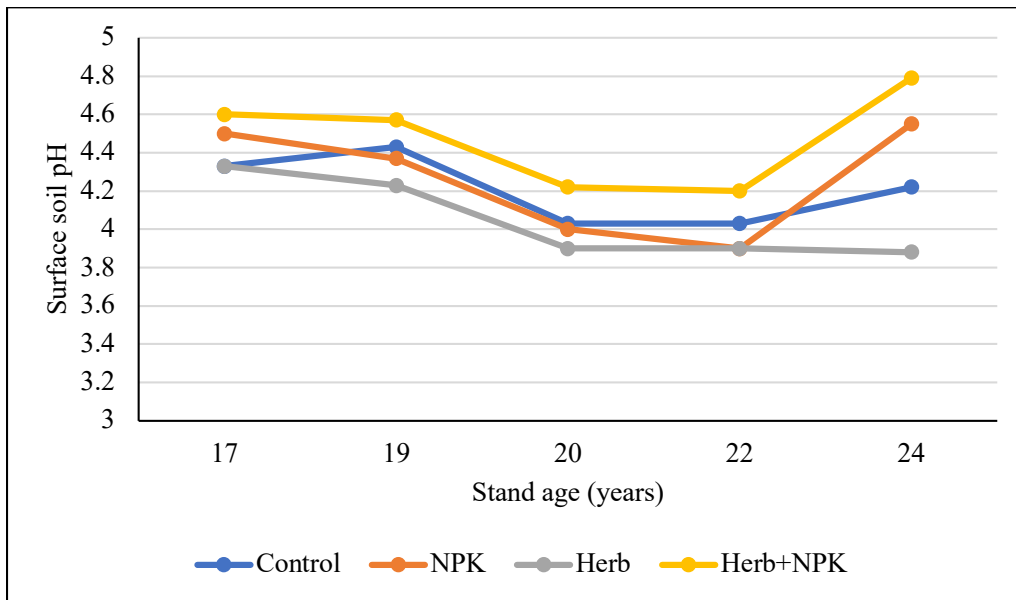


Figure 12: Wayne County cutover, thinned slash pine surface (0-6”) soil pH from pre-treatment (age 17-years) through age 24-years (6 years into the study)

Thinned slash pine response to single midrotation vegetation control, fertilization, and/or liming in the flatwoods region of southeastern Georgia: 12-year growth parameter results

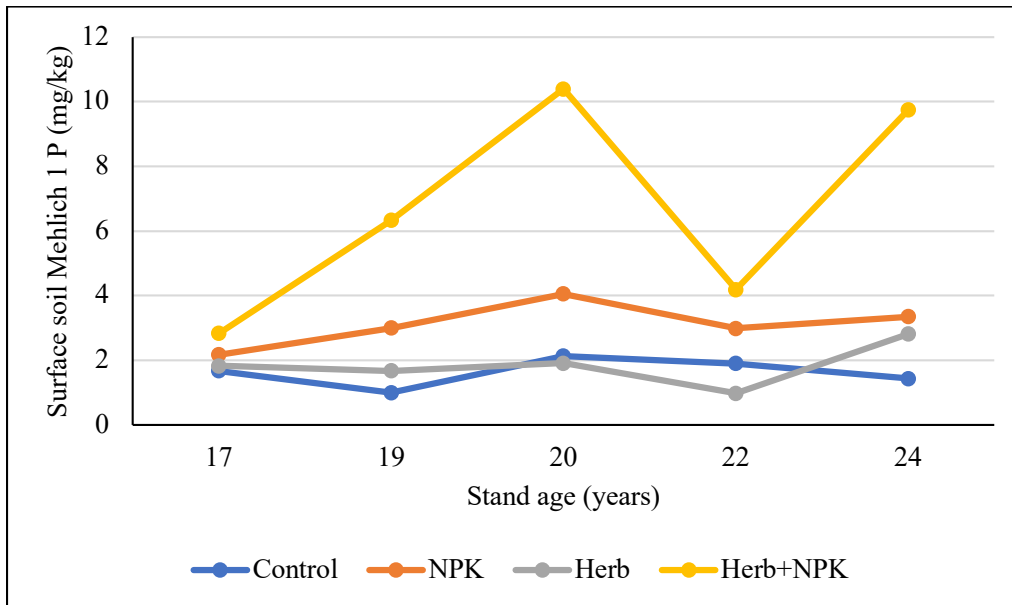


Figure 13: Wayne County cutover, thinned slash pine surface (0-6") soil Mehlich 1 phosphorus (P) concentrations (mg/kg). The 5 mg/kg line is the minimum sufficiency level for Mehlich 1 P on Coastal Plain somewhat poorly, poorly and very poorly drained soils with an argillic (Bt) horizon (CRIFF A and B soils) or an argillic and spodic (Bb) horizon (CRIFF C soils) of which the Wayne count study area had CRIFF B and C soils.

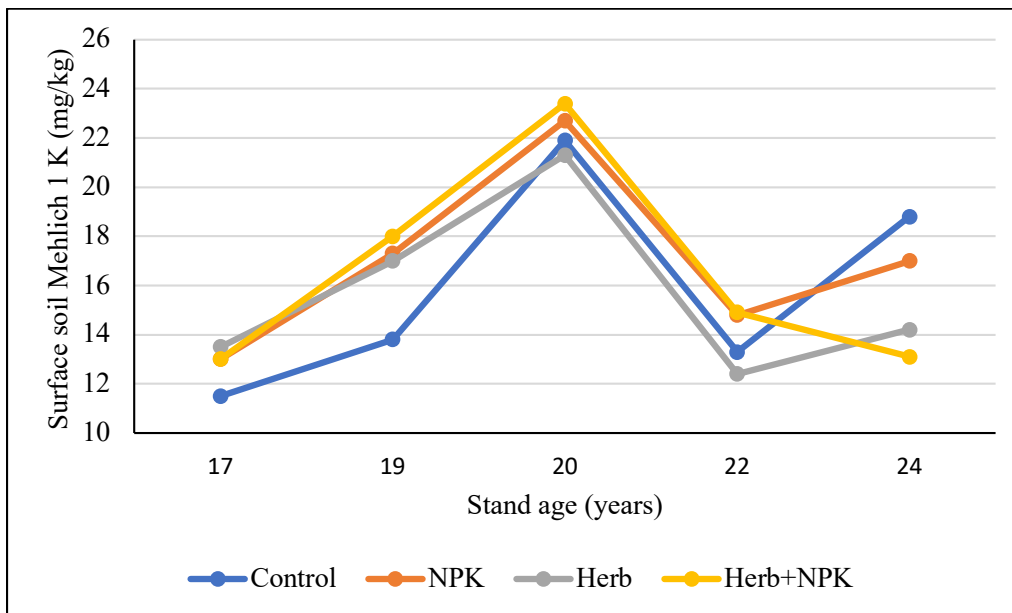


Figure 14: Wayne County cutover, thinned slash pine surface (0-6") soil Mehlich 1 potassium (K) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil K and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

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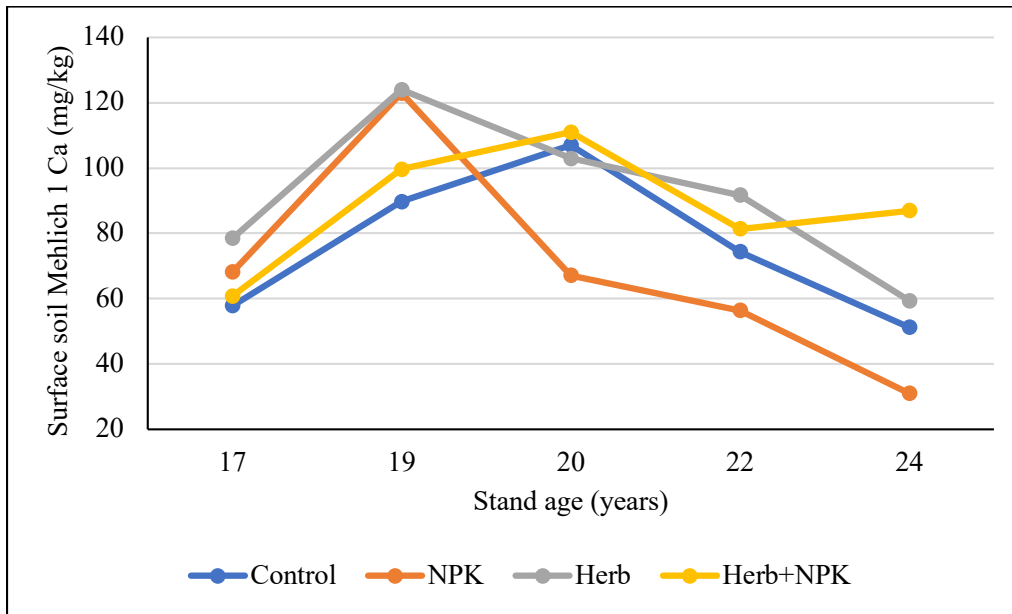


Figure 15: Wayne County cutover, thinned slash pine surface (0-6") soil Mehlich 1 calcium (Ca) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil Ca and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

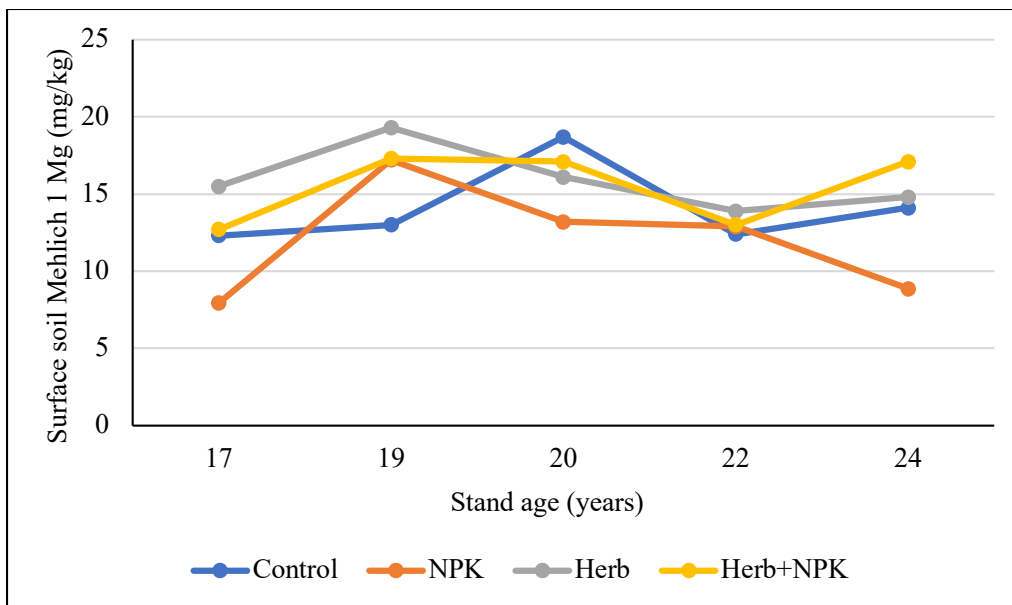


Figure 16: Wayne County cutover, thinned slash pine surface (0-6") soil Mehlich 1 magnesium (Mg) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil Ca and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

Ware county surface (0-6") soil pH and nutrient status (Figures 17 – 21)

The Ware County cutover, thinned slash pine baseline (pre-treatment; age 24-years) surface (0-6") soil pH ranged from 3.97 (NPK) to 4.13 (Lime+NPK). At age 25-years with all treatments installed, surface soil pH ranged from 4.0 (NPK) to 4.53 (Herbicide+NPK). The 2 tons/ac dolomitic lime treatment (Lime) soil pH increased from 4.07 at age 24-years to 5.2 at age 28-years, declining to 4.66 at age 29-years and 4.19 by age 31-years, finishing at 4.0 by age 37-years. The Lime+NPK treatment surface soil pH rose from 4.13 at age 24-years to 5.03 at age 28-years, but declined to 4.05 one year later, 4.0 by age 31-years and ended at 3.73 by age 37-years. The Herbicide treatment soil pH declined steadily from 4.13 at age 25-years to 3.5 by age 37-years. The Herbicide+NPK treatment soil pH also declined steadily from age 25-years at 4.53 to 3.5 by age 37-years. The control and NPK treatment soil pH also declined by approximately 0.5 (4.07 and 3.97) from age 24-years to age 37-years (3.53 and 3.43, respectively). Surface soil Mehlich 1 phosphorus (P) age 24-years pre-treatment levels ranged from 0.83 (Lime+NPK) to 2.0 mg/kg (control). The age 25-years Herbicide and Herbicide+NPK soil P, pre-treatment levels were 2.33 and 1.5 mg/kg, respectively. Using the Mehlich 1 P minimum sufficiency guideline of 5 mg/kg (Ballard and Pritchett 1975), the following were the treatments and year(s) where Mehlich 1 P (mg/kg) was at or greater than 5 mg/kg: Lime 12.4; NPK 8.58; Lime+NPK, 8.33 and Herbicide+NPK 17.3 with all at age 28 years. The highest Mehlich 1 P concentrations (mg/kg) for the two other treatments and year are as follows: control; 2.28 at age 35, Herbicide; 2.11 at age 35. By age 37-years Mehlich 1 P soil levels (mg/kg) were as follows: control 0.67; Lime 0.5; NPK 1.33; Lime+NPK 0.67; Herbicide 0.5; and Herbicide+NPK, 0.5. Surface soil potassium (K) pre-treatment (age 24-years) levels were 6.17 for the control, 4.83 for Lime, 6.33 for NPK and 6.17 for Lime+NPK. Age 25-years pre-treatment soil K for Herbicide was 8.33 and 8.17 for Herbicide+NPK. The highest soil K mg/kg levels were found at age 28-years for all treatments: control 14.2; Lime 17.5; NPK 18.2; Lime+NPK 14.0; Herbicide 14.8; and Herbicide+NPK 22.9. Soil K levels (mg/kg) at the end of the study (age 37-years) were as follows: control 6.17; Lime 4.83; NPK 6.33; Lime+NPK 6.17; Herbicide 5.5; and Herbicide+NPK 5.5. Surface soil calcium (Ca) levels (mg/kg) pre-treatment (age 24-years) for the control was 27.3, Lime 19.2; NPK 16.8; and Lime+NPK 22.3. Pre-treatment (age 25-years) Ca for Herbicide was 22.0 and for Herbicide+NPK was 21.8 mg/kg. Soil Ca had a large increase in the Lime and Lime+NPK treatment plots starting one year after the 2 tons/ac dolomitic lime was applied (age 25-years) with the Lime Ca level at 66.6 (was 19.2 in year 24) and the Lime+NPK level at 58.2 (versus 22.3 in year 24). The Lime and Lime+NPK treatments Ca continued to have elevated levels compared to the other treatments all the way through age 37-years getting as high as 264 mg/kg for the Lime treatment in year 29 and 196 mg/kg for the Lime+NPK treatment at age 31 years. The other treatments' Ca levels remained in the 14 (NPK in year 29) to 35.5 mg/kg range (control in year 35) over the study period. Surface soil magnesium (Mg) pre-treatment levels (age 24-years) for the control were 8.33, Lime 6.67, NPK; 7.5, and Lime+NPK; 9.17 mg/kg. Pre-treatment (age 25-years) Mg soil levels for the Herbicide treatment was 7.0 and 6.67 for the Herbicide+NPK. The Lime and Lime+NPK treatments' soil Mg increased one year after the lime application to 17.2 and 17.3 mg/kg, respectively and continued to increase to mg/kg levels as high as 63.7 for the Lime in year 29 and 51.7 mg/kg by age 35 years for the Lime+NPK. By the end of the study period (age 37-years) the Lime (25.5) and Lime+NPK (22.8) Mg soil levels were greater than the control, NPK, Herbicide and Herbicide+NPK treatment plots (5.0 to 7.0).

Thinned slash pine response to single midrotation vegetation control, fertilization, and/or liming in the flatwoods region of southeastern Georgia: 12-year growth parameter results

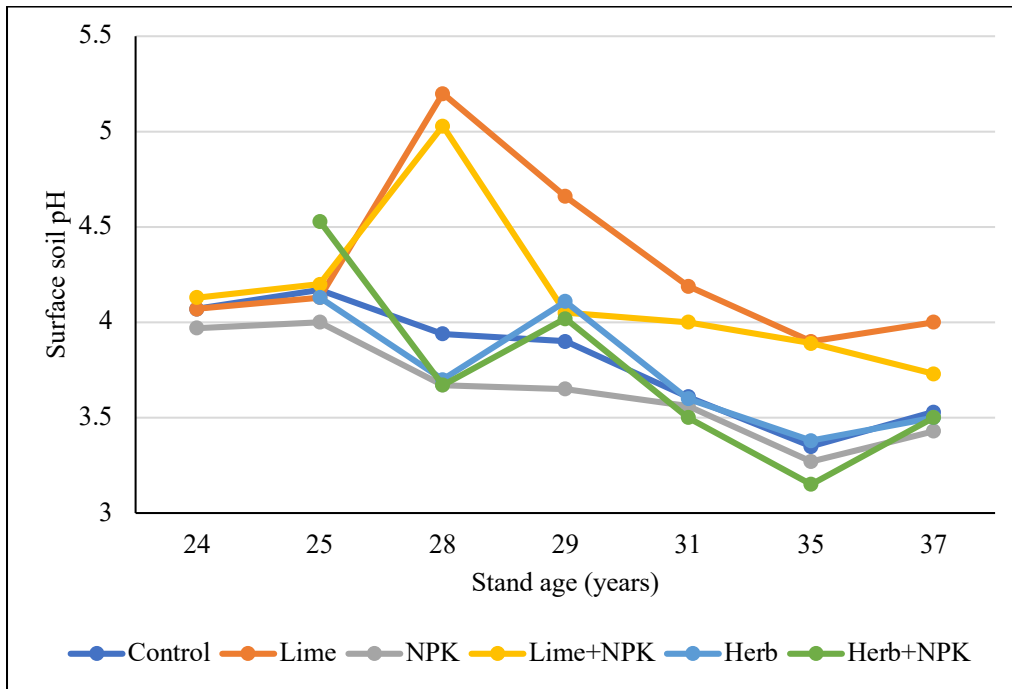


Figure 17: Ware County cutover, thinned slash pine surface (0-6") soil pH from pre-treatment (age 24-years) through age 37-years

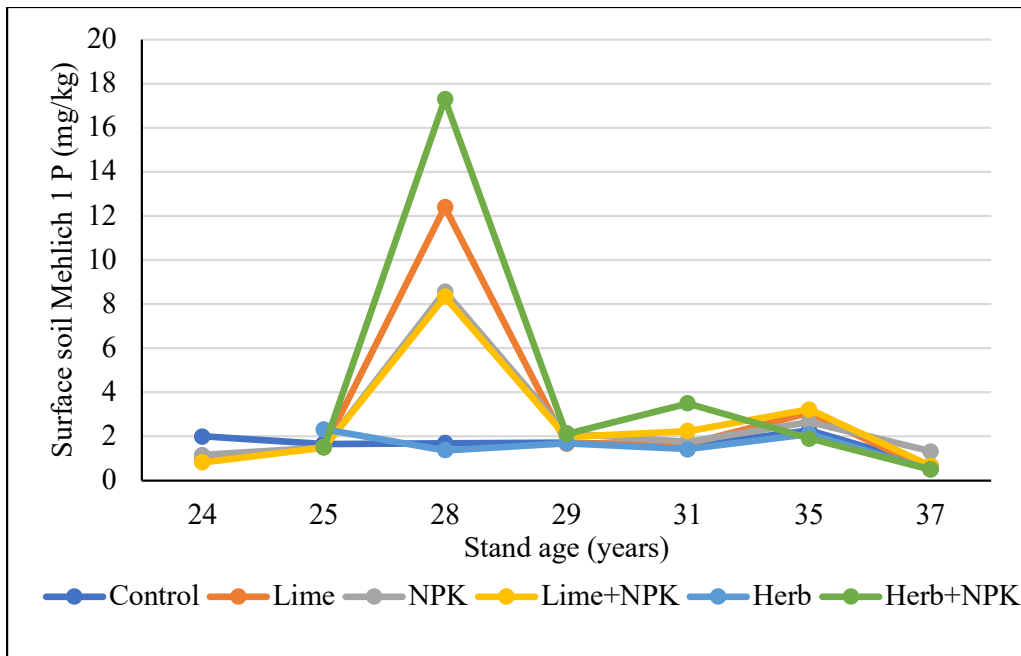


Figure 18: Ware County cutover, thinned slash pine surface (0-6") soil Mehlich 1 phosphorus (P) concentrations (mg/kg). The 5 mg/kg line is the minimum sufficiency level for Mehlich 1 P on Coastal Plain somewhat poorly, poorly and very poorly drained soils with an argillic (Bt) horizon (CRIFF A and B soils) or a spodic (Bh) with and underlying argillic horizon (CRIFF C soils) of which the Ware County study area had CRIFF C soils.

Thinned slash pine response to single midrotation vegetation control, fertilization, and/or liming in the flatwoods region of southeastern Georgia: 12-year growth parameter results

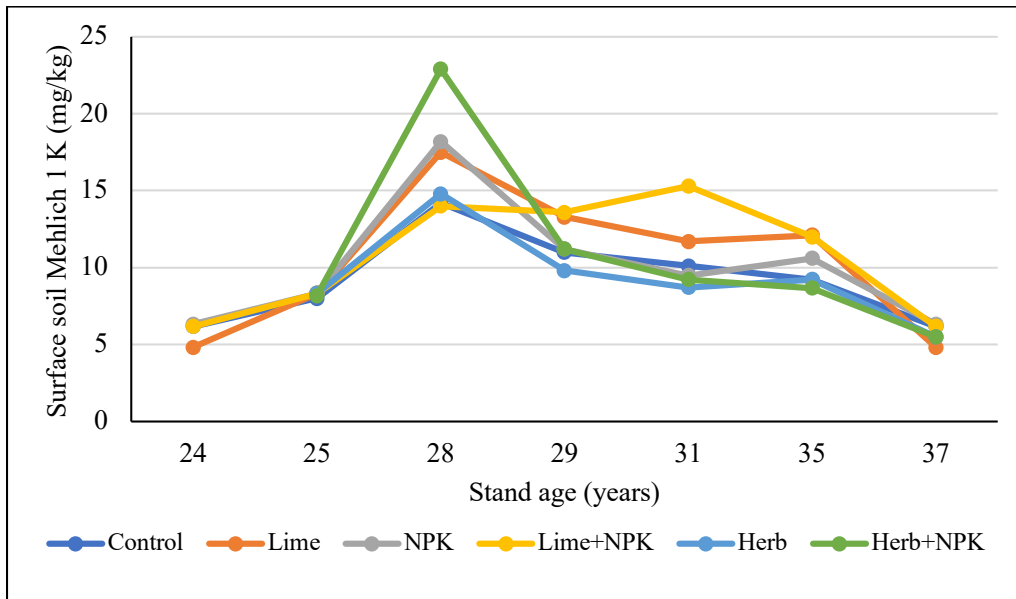


Figure 19: Ware County cutover, thinned slash pine surface (0-6") soil Mehlich 1 potassium (K) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil K and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

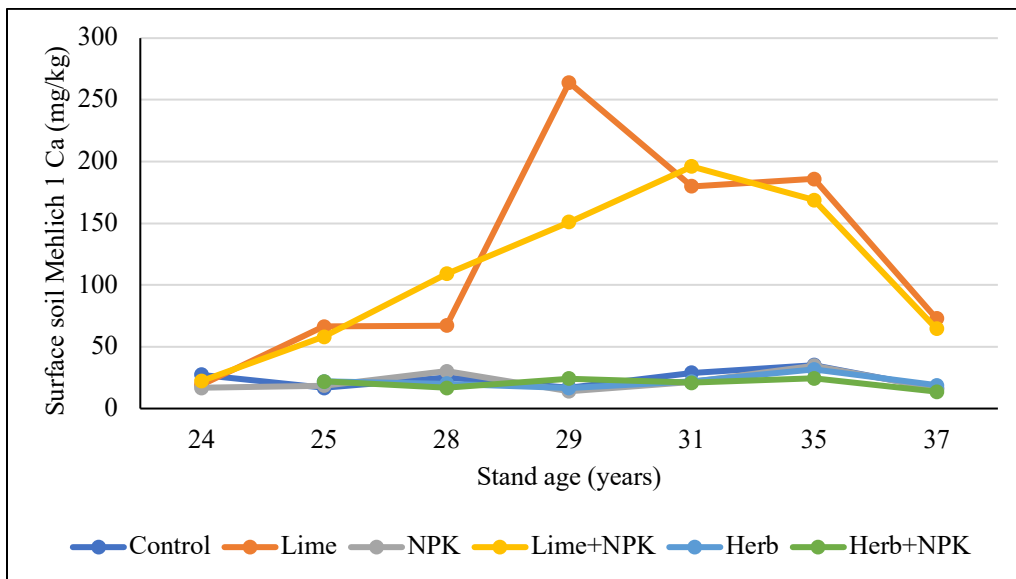


Figure 20: Ware County cutover, thinned slash pine surface (0-6") soil Mehlich 1 calcium (Ca) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil Ca and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

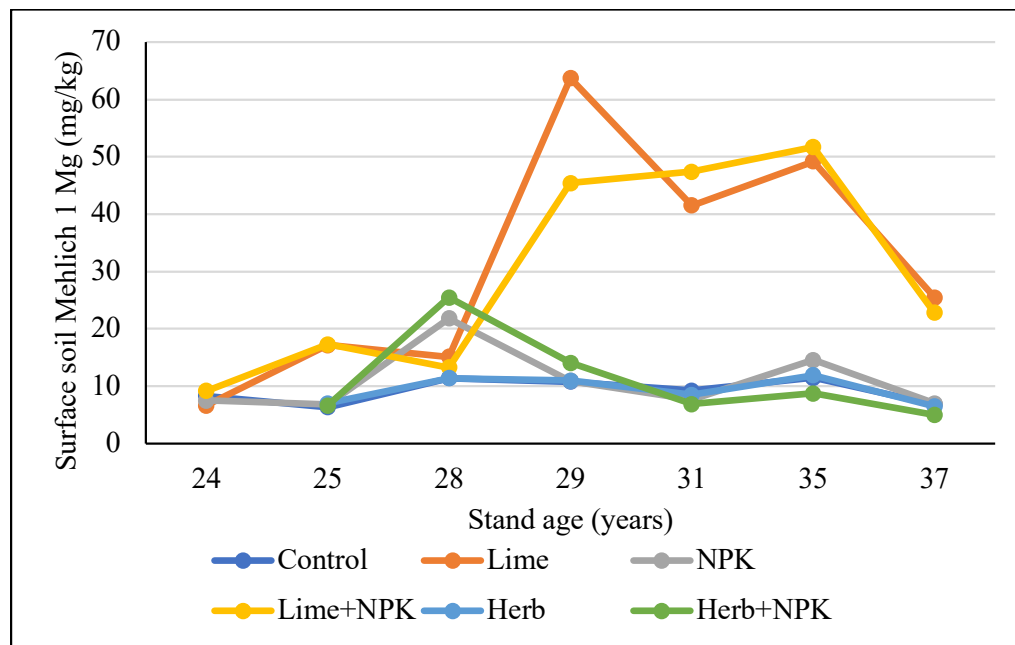


Figure 21: Ware County cutover, thinned slash pine surface (0-6”) soil Mehlich 1 magnesium (Mg) concentrations (mg/kg). There is currently (2024) no well-developed correlation between surface soil Ca and slash, loblolly or longleaf pine deficiency or sufficiency as it relates to growth.

Slash pine foliar nutrient levels over the 12-year study period (Figures 22 – 32)

The Wayne County slash pine baseline (age 18-years) foliar nitrogen (N) levels were all below sufficiency (1.0%, Jokela 2004, Dickens and Moorhead 2003) for slash pine. Baseline foliar N ranged from 0.853% (Herbicide+NPK) to 0.943% (control). Control plot slash pine foliar N levels were not above sufficiency during the collection period from age 18- to age 26-years, ending at 0.82% at age 26-years. The NPK treatment slash pine foliar N rose to 1.34% at age 19-years and was above sufficiency at ages 20-years (1.14%) and age 22-years (1.07%). Foliar N was 0.74% by the last collection time at age 26-years for the NPK treatment trees. Slash pine foliar N from the Herbicide plots rose to at sufficiency at age 19- (1.0%) and slightly above sufficiency (1.03%) at age 20-years then decline to below sufficiency by age 21-years. At age 26-years, the end of the foliage collection period, Herbicide foliar N was 0.83%. Slash pine foliar N collected from the Herbicide+NPK plots rose to above sufficiency at age 19-years (1.41%) and remained above sufficiency (1.07 and 1.01%) at ages 20- and 21-years. Slash pine foliar N collected from the Herbicide+NPK plots fell to below sufficiency at age 22-years (0.93%) and by age 26-years was 0.785%. Baseline (age 18-years) slash pine foliar phosphorus (P) was below sufficiency (0.09%, Jokela 2004, Dickens and Moorhead 2003) for the control (0.07%), NPK (0.07%), Herb (0.07%) and Herbicide+NPK (0.07%). Foliar P from the control plots remained below sufficiency through the collection period that ended at age 26-years. Foliar P levels from the NPK plots rose to sufficiency (0.09%) at age 19-years, and remained above sufficiency (0.10 and 0.10%) at ages 20- and 21-years. By age 22-years slash pine foliar P was below sufficiency (0.08%) and remained below sufficiency through the last collection period at age 26-years (0.08%). Slash pine foliar P from the Herbicide plots reached sufficiency (0.09%) at age 20-years but were below sufficien-

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cy during the rest of the collection period from age 18- to age 26-years ending with a 0.07% foliar P level. The Herbicide+NPK foliar P levels rose to above sufficiency (0.093%) at age 19-years, one year after the Herbicide+NPK treatment and remained at (0.09% at age 26-years) or above sufficiency for the collection period. Baseline (age 18-years) slash pine foliar potassium (K), using the lower sufficiency minimum of 0.25% (Jokela 2004, Dickens and Moorhead 2003), was below sufficiency in the control (0.23%), Herbicide (0.21%) and Herbicide+NPK (0.213%) and slightly above the 0.25% level in the NPK plots (0.267%). Control plot slash pine foliar K was above the minimum sufficiency level at ages 21- (0.31%) and 22-years (0.26%) but below sufficiency the last two collection times at 0.2% (age 24-years) and 0.18% (age 26-years). The NPK slash pine foliar K levels were above sufficiency at ages 19- and 20- (0.32%) 22- (0.38%), and 24-years (0.27%) but was below minimum sufficiency by age 26-years (0.20%). Foliar K in the Herbicide treatment rose to slightly above minimum sufficiency at age 19-years (0.26%), declining to 0.22% at age 20-years, then rising to 0.30 and 0.24% at ages 21- and 22-years, then declining to 0.22% (24-years) and 0.19% (age 26-years). Foliar K in the Herb+NPK treatment rose from 0.21% at age 18-years to 0.38% at age 19-years and remained above 0.30% through age 22-years then declined to below sufficiency at age 24-years (0.23%) and 26-years (0.16%). Slash pine foliar calcium (Ca) levels were above the minimum sufficiency (0.08-0.12%, Jokela 2004, Dickens and Moorhead 2003) level for all treatments at all collection ages. Baseline slash pine foliar magnesium (Mg) was at 0.06%, (Jokela 2004, Dickens and Moorhead 2003) the minimum sufficiency threshold, for the Herbicide treatment and rose to above sufficiency for the control (0.10), NPK (0.10%) and Herbicide+NPK (0.08%). Foliar Mg levels were above sufficiency levels from age 19- through the last collection time at age 26-years.

The Ware County slash pine baseline (age 24-years) foliar nitrogen (N) levels were all below the minimum sufficiency level (1.0%, Jokela 2004, Dickens and Moorhead 2003) for all treatments, ranging from 0.82% (Herbicide) to 0.92% (control). The control plot slash pine foliar N levels over the collection period never rose to the minimum sufficiency level, ending at 0.81% at age 33-years. The Lime plot slash pine foliar N levels also did not rise above minimum sufficiency levels over the collection period, ending with a N level of 0.72% at age 33-years. Slash pine foliar N level in the NPK treatment rose to above sufficiency at age 27-years to 1.08% but was below sufficiency for the rest of the collection periods, ending at age 33-years at 0.72%. The Lime+NPK slash pine foliar N levels did not get to or above the N sufficiency level, ending with 0.74% N at age 33-years. The Herbicide treatment slash pine foliar N was at sufficiency (1.0%) at age 31-years but was below sufficiency at all other collection times, ending at 0.82% at age 33-years. The Herbicide+NPK slash pine foliar N at age 31-years was at sufficiency (1.0%) at age 31-years but was below sufficiency the rest of the collection periods ending at 0.84% at age 33-years. Baseline foliar phosphorus (P) levels for all treatments were below minimum sufficiency (0.09%, Jokela 2004, Dickens and Moorhead 2003), ranging from 0.06% (NPK) to 0.08% (Herbicide+NPK). The control treatment's foliar P was above sufficiency (0.10%) only at age 33-years with the other collection times below sufficiency. The Lime treatment's slash pine foliar P level, like the control treatment, had one collection time, age 33-years where it was above sufficiency (0.10%) with the rest of the collection times below sufficiency. The NPK treatment plots slash pine foliar P level was above sufficiency (0.09%) at age 27-years, with the rest of the collection times below sufficiency, ending at 0.07% at age 33-years. The Lime+NPK slash pine foliar P levels did not reach minimum sufficiency guidelines over the collection period, with an ending 0.08% P concentration at age 33-years. The Herbicide treatment slash pine foliar P did not have any concentrations that reached the minimum 0.09% guideline over the collection period. The Herbicide+NPK slash pine foliar P levels was 0.09% at ages 29- and 33-years with the other years being below sufficiency. Foliar potassium (K) baseline levels ranged from 0.18% (Herbicide and Herbicide+NPK), below the minimum sufficiency of 0.25% (Jokela 2004, Dickens and Moorhead 2003) to minimum sufficiency at 0.25% (Lime). Slash pine foliar K levels for all treatments did not reach the minimum sufficiency guidelines for the collection times though age 31-years, with ending levels ranging from 0.12% (Lime+NPK) to 0.19% (control). Baseline slash pine foliar calcium (Ca) ranged from below

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sufficiency (0.08 to 0.12%, using 0.12% as the sufficiency threshold (Jokela 2004, Dickens and Moorhead 2003) for the NPK (0.09%) and Lime (0.10%) with the rest of the treatments being above 0.12%. Foliar Ca levels increased from 0.23 to 0.28% for the Lime and from 0.16 to 0.25% for the Lime+NPK treatments from ages 25- to age 29-years, ending with 0.16 and 0.12% at the end of the collection period. The NPK slash pine foliar Ca levels rose to above sufficiency at ages 25-, 27- and 29-years, ending at 0.08% at the end of the collection period. The Herbicide slash pine foliar Ca levels were above the 0.12% level in years 25- and 29-years ending slightly below sufficiency (0.11%) at age 33-years. The Herbicide+NPK treatment had a baseline Ca level of 0.20% and 0.21% at age 29-years, declining to 0.11% by age 33-years. Baseline slash pine foliar magnesium (Mg) was above minimum sufficiency (0.06% Jokela 2004, Dickens and Moorhead 2003) for all treatments. All the treatments had Mg foliar levels above sufficiency at all collection times except for the control at age 25-years (0.057%) and the Lime treatment at age 25-years (0.055%).

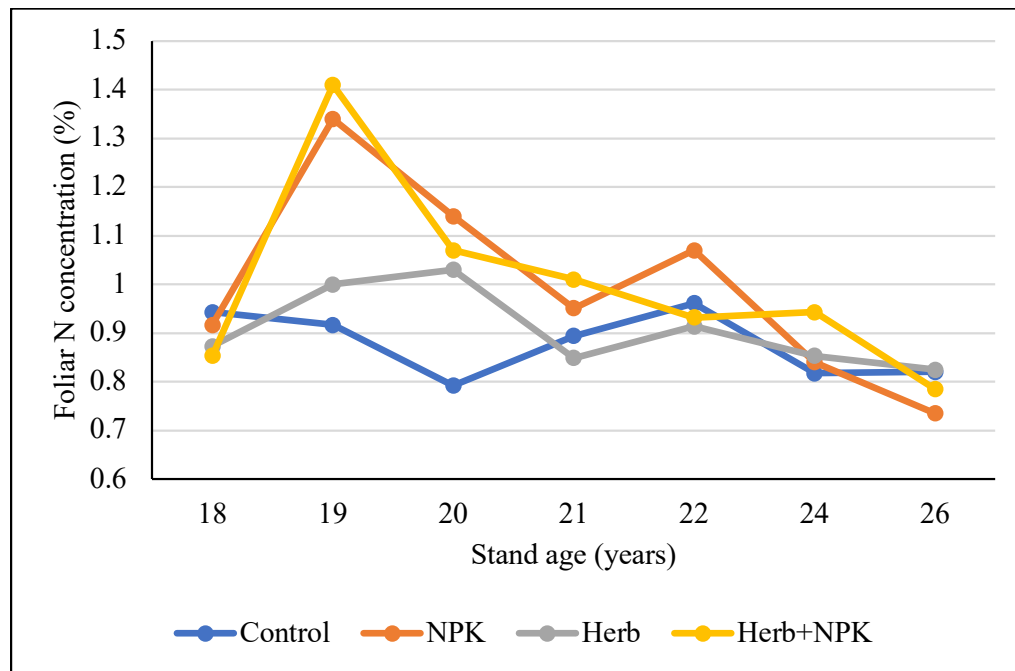


Figure 22: Wayne County cutover, thinned slash pine foliar nitrogen (N) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar N guideline for slash pine is 1.0% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure.

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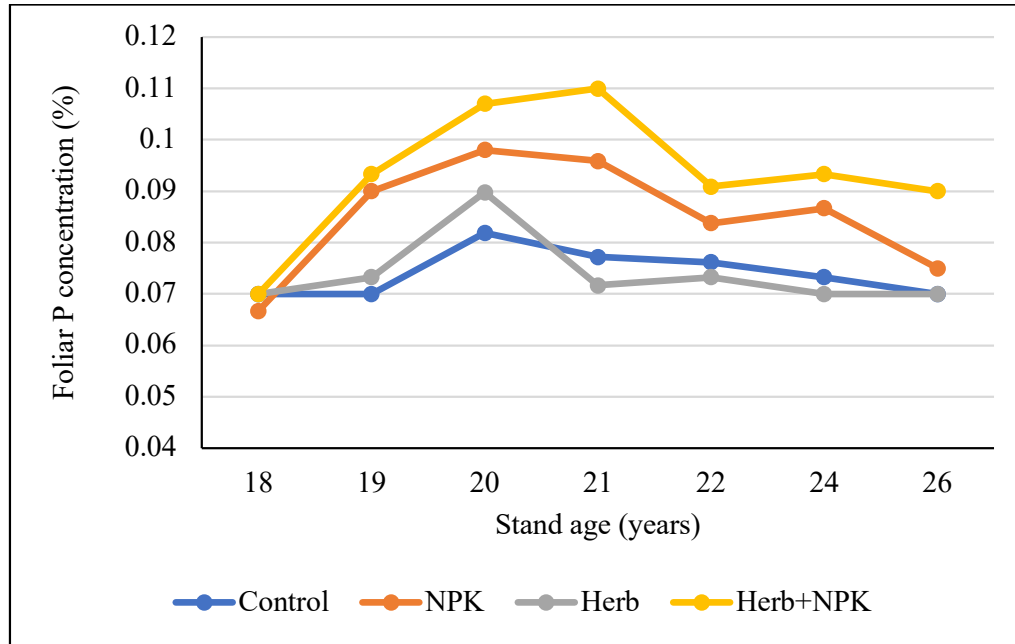


Figure 23: Wayne County cutover, thinned slash pine foliar phosphorus (P) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar P guideline for slash pine is 0.09% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure.

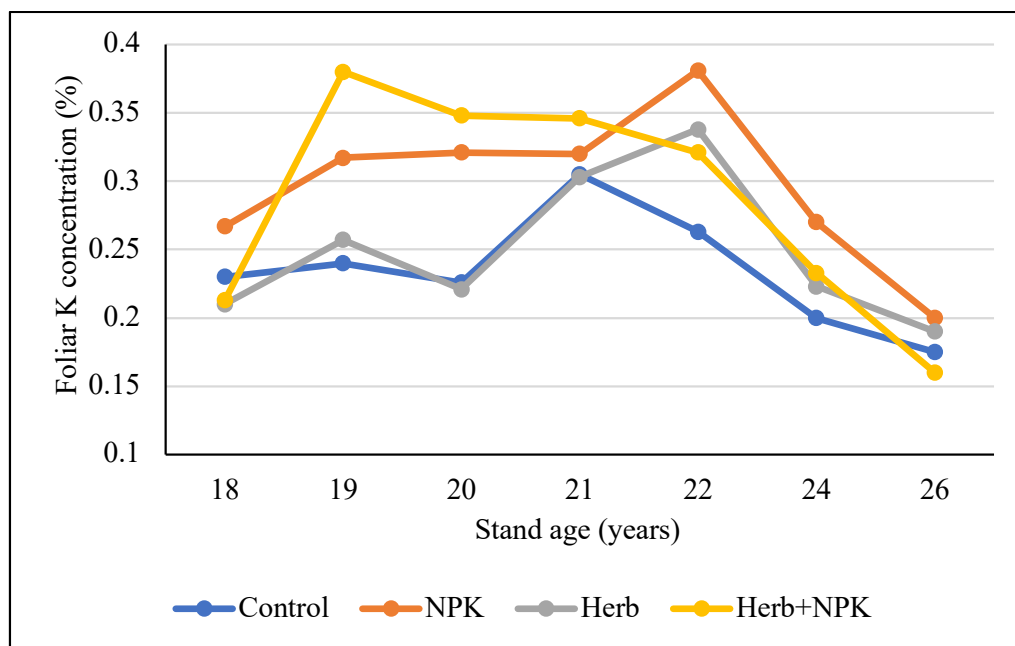


Figure 24: Wayne County cutover, thinned slash pine foliar potassium (K) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar K guideline for slash pine is 0.25-0.30% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the above figure using the 0.25% minimum.

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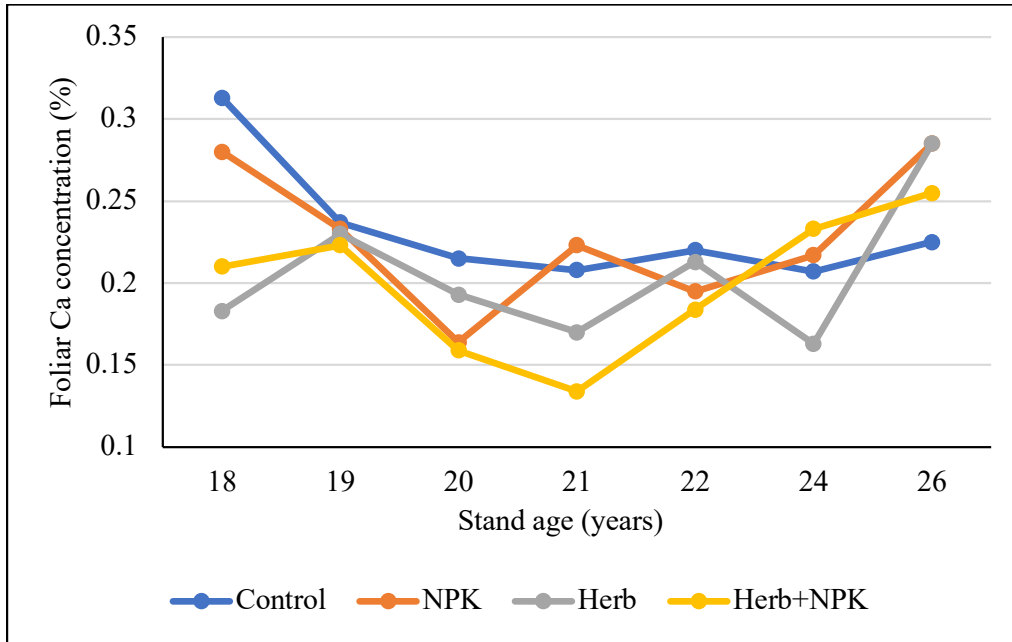


Figure 25: Wayne County cutover, thinned slash pine foliar calcium (Ca) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar Ca guideline for slash pine is 0.08-0.12% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure using the 0.12% minimum.

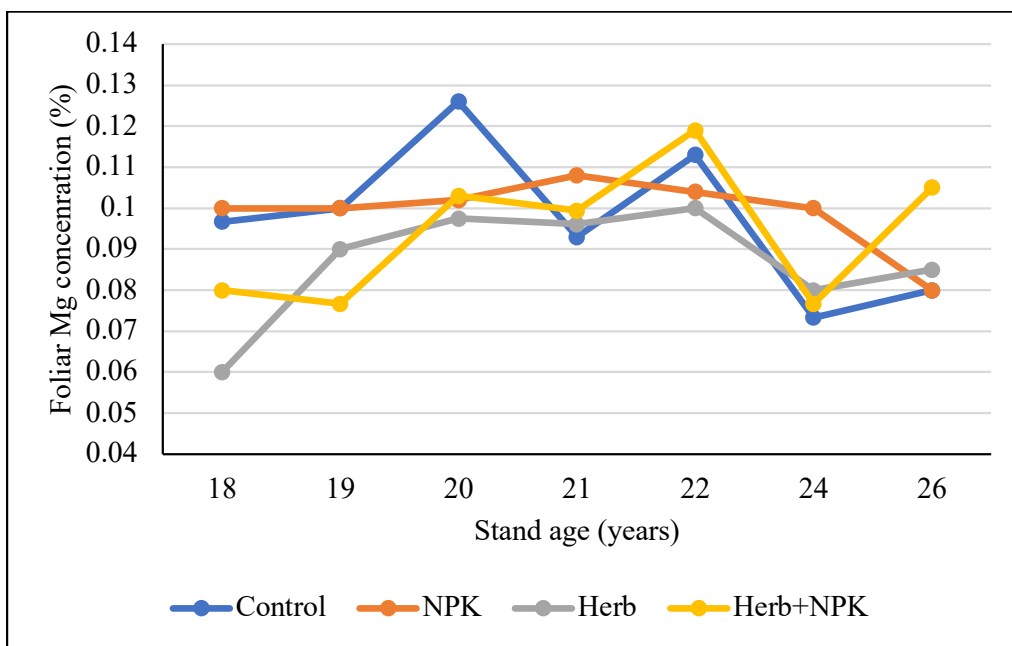


Figure 26: Wayne County cutover, thinned slash pine foliar magnesium (Mg) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar Mg guideline for slash pine is 0.06% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure.

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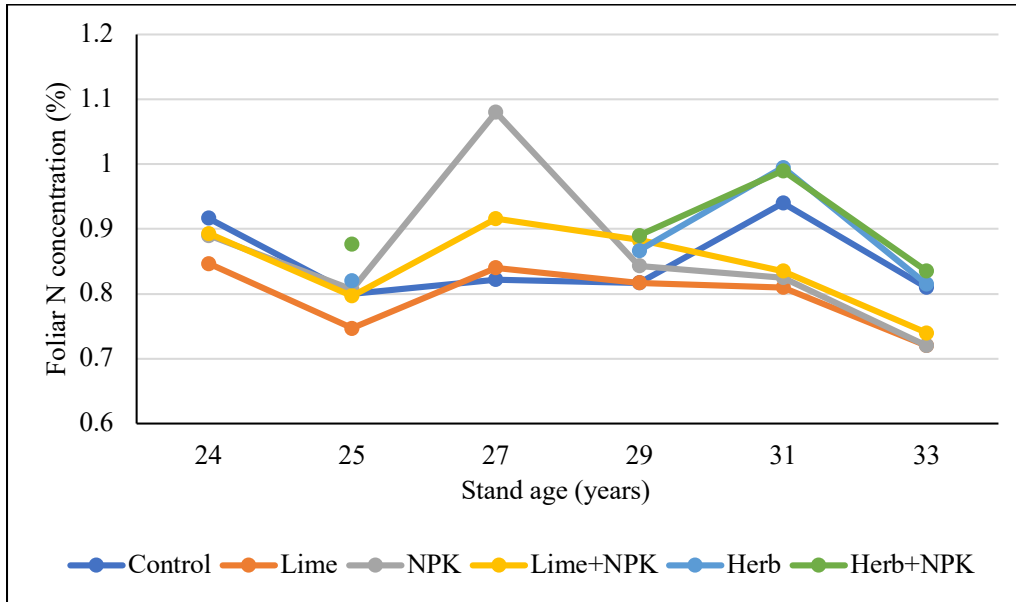


Figure 27: Ware County cutover, thinned slash pine foliar nitrogen (N) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar N guideline for slash pine is 1.0% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure.

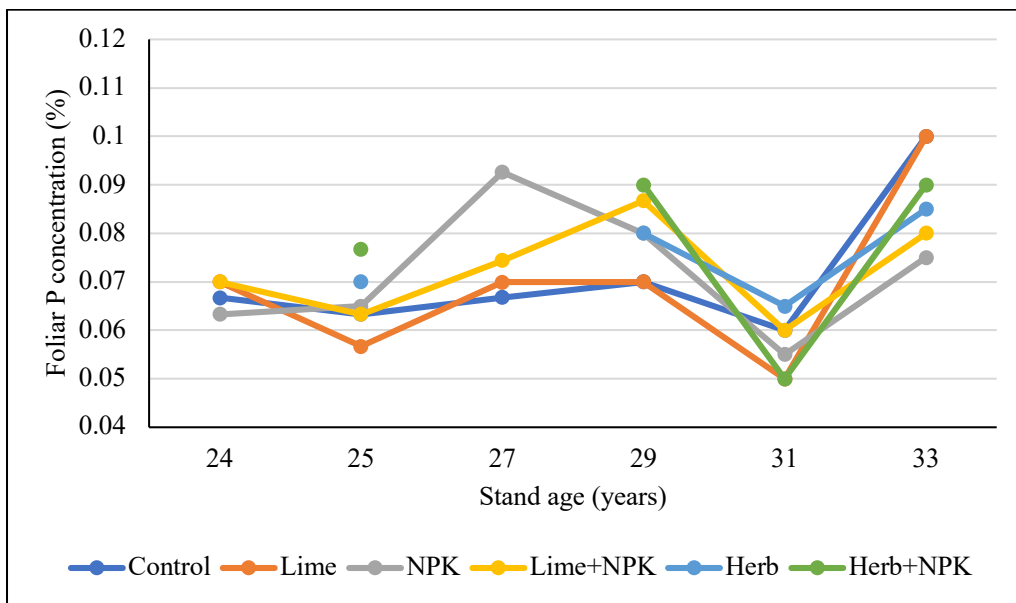


Figure 28: Ware County cutover, thinned slash pine foliar phosphorus (P) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar P guideline for slash pine is 0.09% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure.

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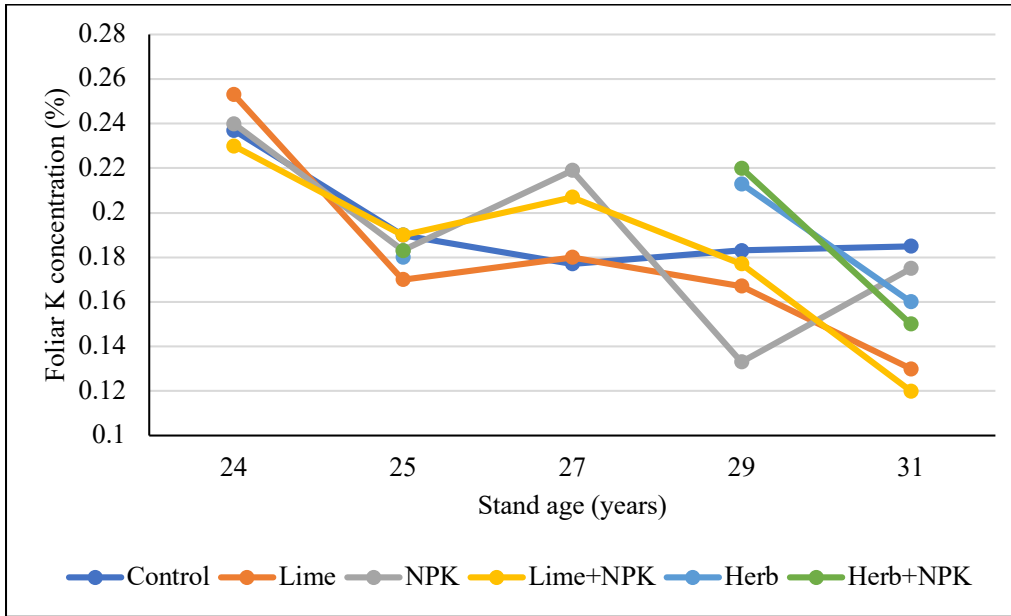


Figure 29: Ware County cutover, thinned slash pine foliar potassium (K) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar K guideline for slash pine is 0.25 – 0.30% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure using the 0.25% minimum.

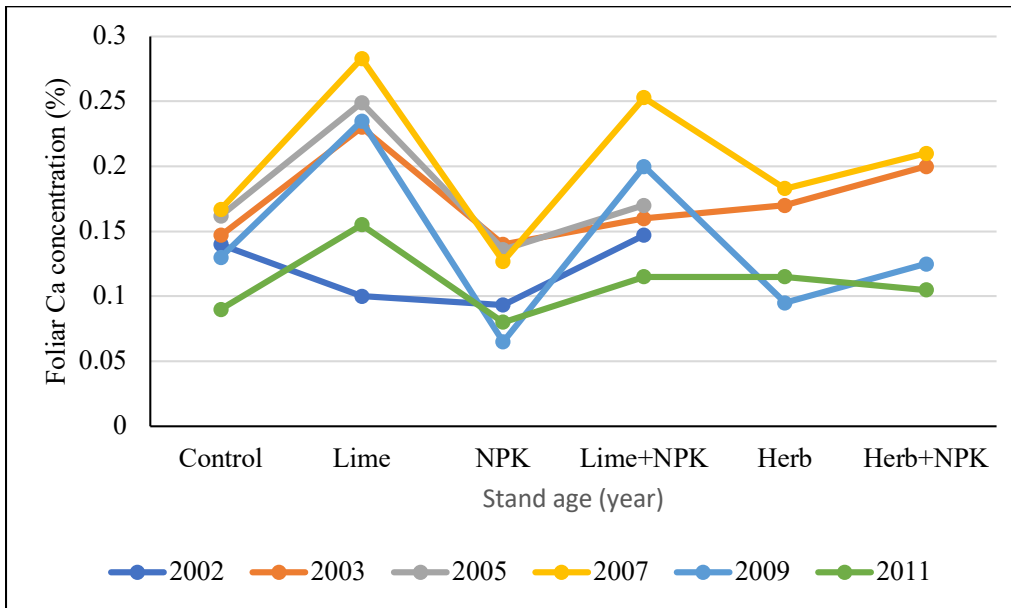


Figure 30: Ware County cutover, thinned slash pine foliar calcium (Ca) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar Ca guideline for slash pine is 0.08 – 0.12% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure using the 0.12% guideline.

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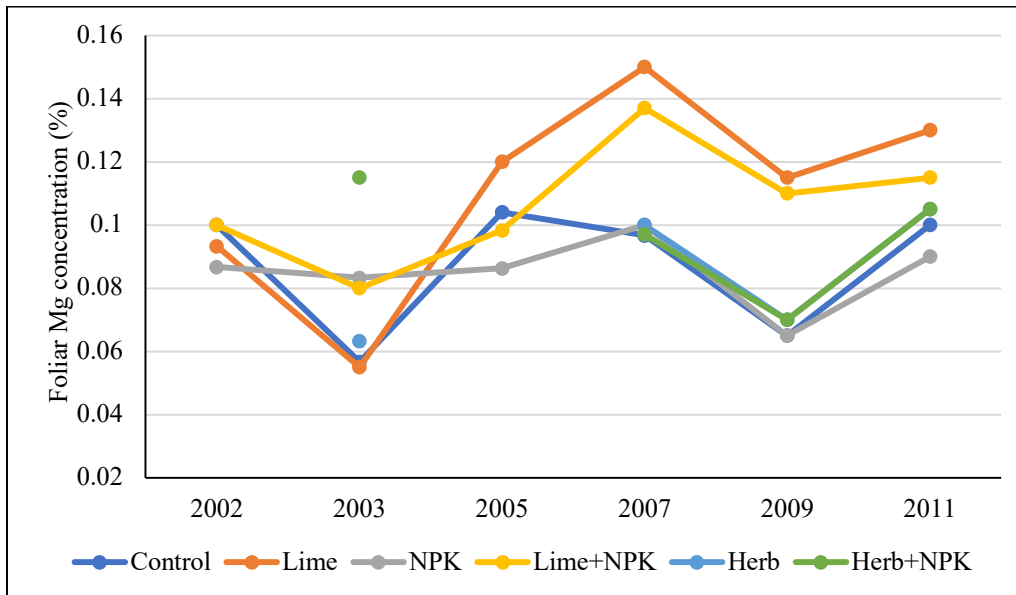


Figure 31: Ware County cutover, thinned slash pine foliar magnesium (Mg) levels collected from dominant trees within each plot. The sufficiency (minimum) foliar Mg guideline for slash pine is 0.06% (Jokela 2004, Dickens and Moorhead 2003) and is noted with a bold line in the figure using the 0.12% guideline.

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Photo 1. The 2 tons/acre dolomitic lime application at the Ware County cutover, thinned slash pine study Lime only plot.

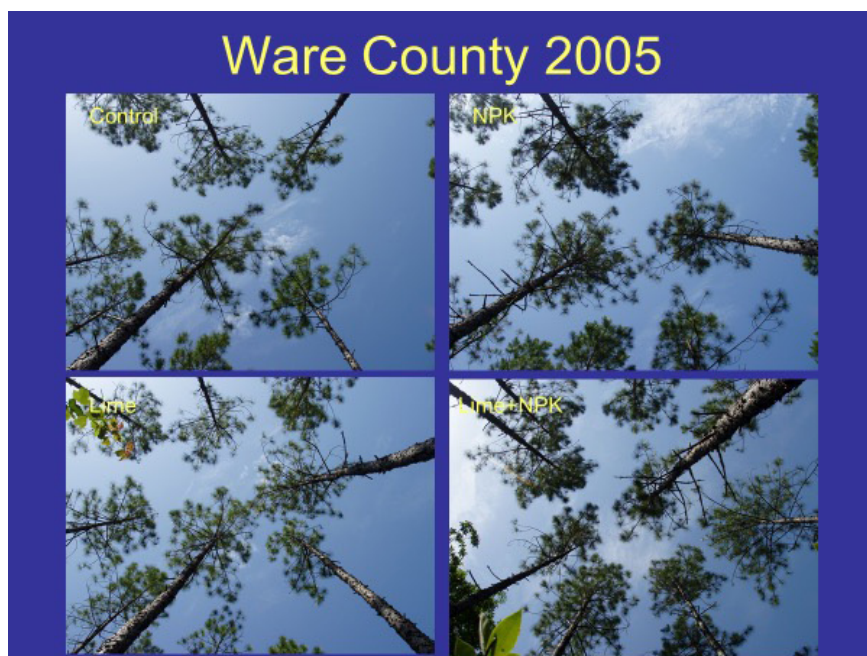


Photo 2. Ware County, 2005 leaf areas (taken July 2005) by treatment for the control, NPK, Lime, and Lime+NPK, two and a half growing seasons after the NPK treatment (Feb 2003) and three and a half growing seasons after the Lime treatment (Feb 2002).

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Photos 3 and 4. Ware County cutover, thinned slash pine control (C; left photo) and Lime treatment (L; right photo) plot at age 37-years. Photos taken March 2015.



Photo 5. Ware County cutover, thinned slash pine at age 37-years, the NPK plot, 12 years after treatment. Photo taken March 2015.

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Photo 6. Ware County cutover, thinned slash pine stand at age 37-years, the Lime+NPK treatment plot photo 12 years after the NPK application and 13 years after the 2 tons/acre dolomitic lime application. Photo taken March 2015.

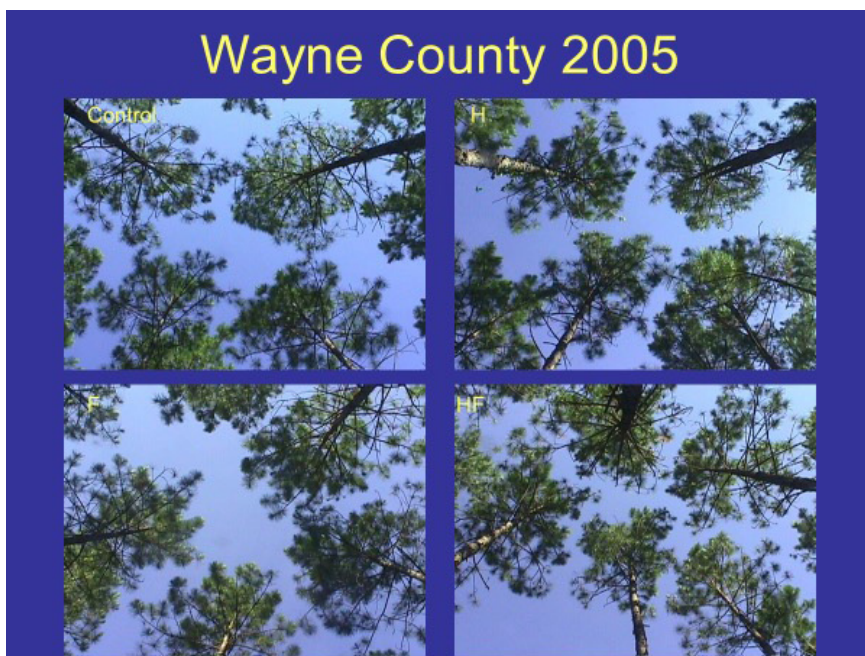


Photo 7. Wayne county, cutover, thinned slash pine leaf areas (photo taken July 2005 at age 21.5 years old) in a control plot, Herbicide (H; Oct 2001) only plot, NPK (F; Mar 2002) plot and a Herbicide+NPK (HF) plot three and a half growing seasons after treatments.



Photo 8. Wayne county cutover, thinned slash pine Herbicide+NPK treatment plot photo.

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