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Fertilizer response expectations, application levels, and material needs for loblolly, longleaf and slash pine at mid-rotation

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INTRODUCTION AND BACKGROUND

Forest fertilization in the southeastern United States has been practiced since the 1960's. Fertilization in the SE US peaked in 1999 at 1.58 million acres (Albaugh and others 2019) when sawtimber stumpage prices (in Georgia the state-wide yearly average was $46/ton; TM-S 1999) and demand were high. Forest fertilization declined to 589,000 acres in 2016 (Albaugh and others 2019) due to a number of factors including lower pine sawtimber stumpage prices (in Georgia the state-wide average was $26/ton in 2016; TM-S 2016), lower demand for sawtimber as housing starts declined dramatically since the 2008 recession, and higher fertilizer prices. In 2016, nitrogen+phosphorus (NP) were applied to 474,000 acres, while phosphorus (P) alone was applied to 115,000 acres (Albaugh and others 2019). Midrotation fertilization applications are mostly NP with some nitrogen+phosphorus+potassium (NPK) treatments where K is found to be deficient. Phosphorus only (with some NP) applications tend to be at planting on very poorly, poorly, and somewhat poorly drained lower Coastal Plain soils that are typically bedded, P deficient, and have high organic matter content (that provides nitrogen).

Loblolly (Pinus taeda L.) is the primary pine species fertilized due to its large growth response to fertilization, high commercial value, and large native range followed by slash (Pinus elliottii Engelm.) then longleaf (Pinus palustris Mill.) pine. Numerous southern pine fertilization studies have been performed in the SE US since the late 1960's. Loblolly pine fertilization studies have been the most numerous and extensive, followed by slash pine fertilization studies and lastly longleaf pine fertilization studies. Table 1 summarizes the fertilizer NP or NPK response from these studies for the three commercially important species at mid-rotation (at canopy closure or after thinning).

Table 1: *A summary of fertilizer response to a single NP or NPK fertilizer application at mid-rotation*

PINE SPECIES	AVERAGE GROWTH RESPONSE	LOW END OF RESPONSE[1]	UPPER END OF RESPONSE[1]
	Tons per acre per year		
Loblolly	1.60	0.96	2.2
Longleaf	0.90		
Slash	1.20		

[1]An estimated 40% ± the mean growth response covers approximately 80% of cited NP fertilization sites based on work at North Carolina State University (NCSU) and Virginia Tech (VT) for loblolly pine over an eight year period. Longleaf and slash pine mean NP or NPK growth response estimates over a four, six or eight year period are presented from studies by the University of Florida (UFL), NCSU, VT, and University of Georgia (UGA).

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FERTILIZATION DIAGNOSTIC TOOLS AND LANDOWNER/FORESTER CONSIDERATIONS FOR MIDROTATION FERTILIZATION

A loblolly, slash, or longleaf pine stand can be deemed responsive to fertilization using the following diagnostic tools: soil available-P analysis, foliar nutrient analysis (Fisher 1980, Pritchett 1968, Wells and others 1973), and leaf area index, plus soil series or soil group information for the southeastern Coastal Plain (Fisher 1980) and land use history knowledge. If considering pine plantation fertilization the landowner should factor (1) the cost of the fertilizer materials plus application, (2) the estimated growth response over a 4- to 10-year period to the single fertilizer application, and (3) the anticipated stumpage price for the extra wood grown at the end of the period. If a thinning occurs after the NP or NPK application, then approximately 40-60% of the extra wood gained is captured. One-hundred percent of the extra wood gain is realized when fertilizing with NP or NPK after thinning followed by a clearcut. Refer to "Rate of return estimates for an 8-year period with a single fertilizer application" publication by Dickens and others (2016) for various financial scenarios which assumes 100% of the extra wood growth is captured.

Figure 1 illustrates the general NP mid-rotation loblolly pine response to a single NP fertilizer application. Note the growth benefit peaks four years after application and lasts over eight years. Figure 2 shows the differences in loblolly pine response based on varying levels of N (0, 100, 200, and 300 lbs/ac) and varying levels of P (0, 25 or 50 lbs P/ac).

MAJOR FERTILIZER FORMS OF NITROGEN, PHOSPHORUS, AND POTASSIUM USED IN FORESTRY

The primary form of N applied as fertilizer in southern pine plantations is urea (46-0-0, Albaugh and others 2019). Diammonium phosphate (18% N, 46% P_2O_5 or 20% elemental-P and no K; 18-46-0) and monoammonium phosphate (11% N, 52% P_2O_5 or 22.6% elemental-P and no K: 11-52-0) are the most commonly used fertilizer materials to deliver the full dose of P and a partial dose of N. The nitrogen in DAP or MAP is not subject to volatilization. The most common form of fertilizer for K applications is muriate of potash which is potassium chloride (60% K_2O or 50% elemental K; 0-0-60).

N VOLATILIZATION LOSSES FROM UREA AND OTHER N FERTILIZER SOURCE OPTIONS

Urea is now most commonly treated with a urease inhibitor called N-(n-Butyl) thiophosphoric triamide or NBPT (such as Agrotain, N-edge, etc.) to prevent volatilization losses, especially when applied in warmer temperatures and without rainfall in the immediate future. Raymond and others (2016) studied N losses after surface application of urea (46-0-0) and three enhanced efficiency fertilizers; urea treated with NBPT, CUF (39-9-0), and polymer coated urea at a rate of 200 lbs/acre elemental N in mature loblolly pine stands in Virginia, South Carolina, North Carolina, Arkansas, and Alabama. Urea losses as ammonia 15 days after spring and summer applications averaged 40% N, while all three enhanced efficiency fertilizers reduced losses to ~10% of applied N. Nitrogen losses in the form of ammonia-N (NH_3-N) have been shown to be higher for urea when applied in the summer (51% N loss) versus when applied in the winter (18% N loss) after 29 days (Elliot and Fox 2014). Kissel and others (2000) studied ammonia volatilization losses when using urea at 180 lbs N/ac (390 lbs urea/acre) as a function of time of year. They found 23%, 15% and 1% N losses when applied in June, October, or January, respectively over the 20 day study period. In general, N losses are highest from urea when air temperature and relative humidity are high, wind speeds are high, soils are moist, and the mineral soil is exposed or bare (little to no forest floor present) (Zerpa and Fox 2011). To minimize N losses, urea can be applied during late winter months when air temperatures are cooler, though losses can still reach 50% from untreated urea even in winter in the Southeast (Raymond and others 2020). We recommend treating urea with a urease inhibitor even in winter months if temperatures are warm.

FACTORS AFFECTING MIDROTATION FERTILIZATION RESPONSE

The response to a mid-rotation NP or NPK application can vary depending on a number of factors in a loblolly, longleaf or slash pine stand including level of hardwood competition, stand basal area, tree mortality within the stand, soils, land use history, fertilizer timing, rainfall after fertilization, fertilizer N losses, and other factors. Hardwood competition should be at a minimum for the greatest pine response and if basal area is too high (>90-100 ft^2/ac), the landowner should consider a thinning and fertilize after the thinning. This high basal area stand factor is especially true for slash pine and the need to thin before NP fertilization. Figure 3 is a histogram of a Forest Productivity Coop Regionwide study from 24 study areas on loblolly pine mid-rotation 8-year response to a NP treatment compared to a control (no fertilizer).

NP OR NPK APPLICATION LEVELS BY PINE SPECIES AND STAGE OF STAND DEVELOPMENT

Use the application levels shown in Table 2 for nitrogen (N), phosphorus (P), and potassium (K) by pine species, stand development stage and/or stem diameter at 4.5 feet (diameter at breast height: dbh). Table 3 shows the amount of N, P and K applied in pounds when urea, diammonium phosphate (DAP), and muriate of potash (MOP or KCl) are used.

Note photo 1: due to reports of many young longleaf pine trees with excessive lean from the 150 N lbs/ac (plus P and K) and after conferring with the Forest Productivity Cooperative, we recommend 75 lbs/ac N (plus needed P and K based on P and K foliar analysis and soil available-P level) when longleaf stand diameters at 4.5 feet (dbh: diameter at breast height) are less than 6" and 125-135 lbs/ac N (plus needed P and K) when longleaf dbhs are equal to or greater than 6".

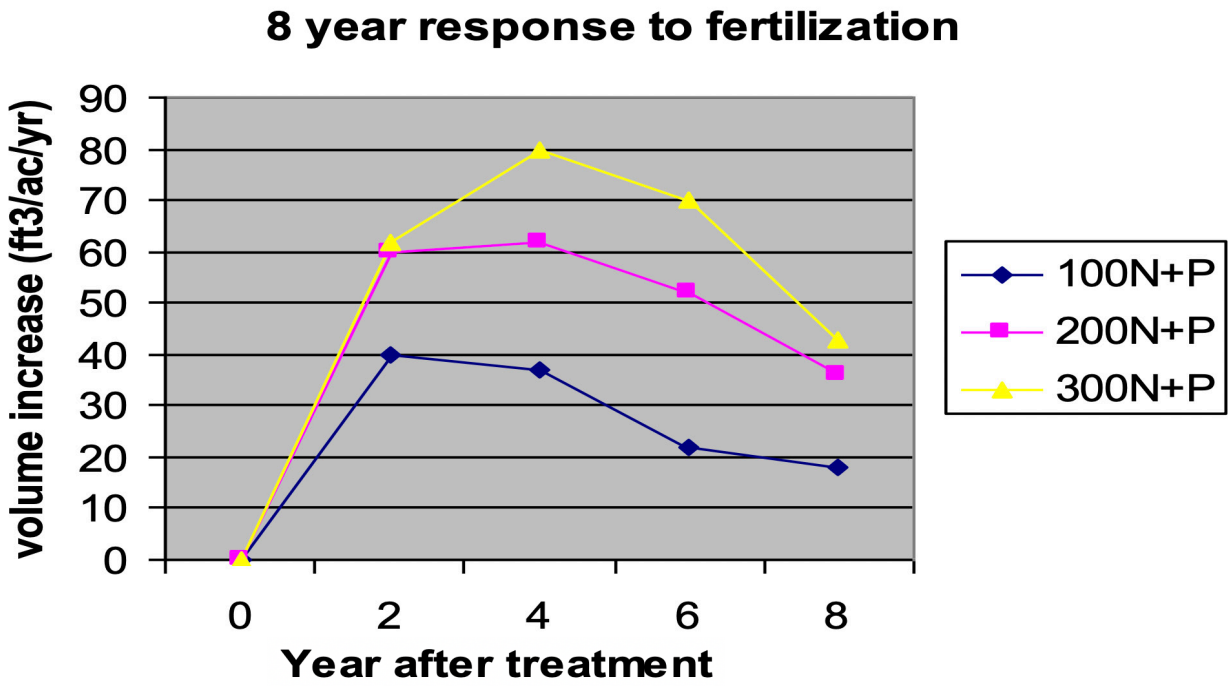

Figure 1: *Mid-rotation loblolly pine volume growth response (compared to no fertilization control plot trees) to NP (N with 25 or 50 lbs/ac P) fertilization (graph adapted from Hynynen, and others 1995). One ton of loblolly pine wood+bark is approximately 32 cubic feet.*

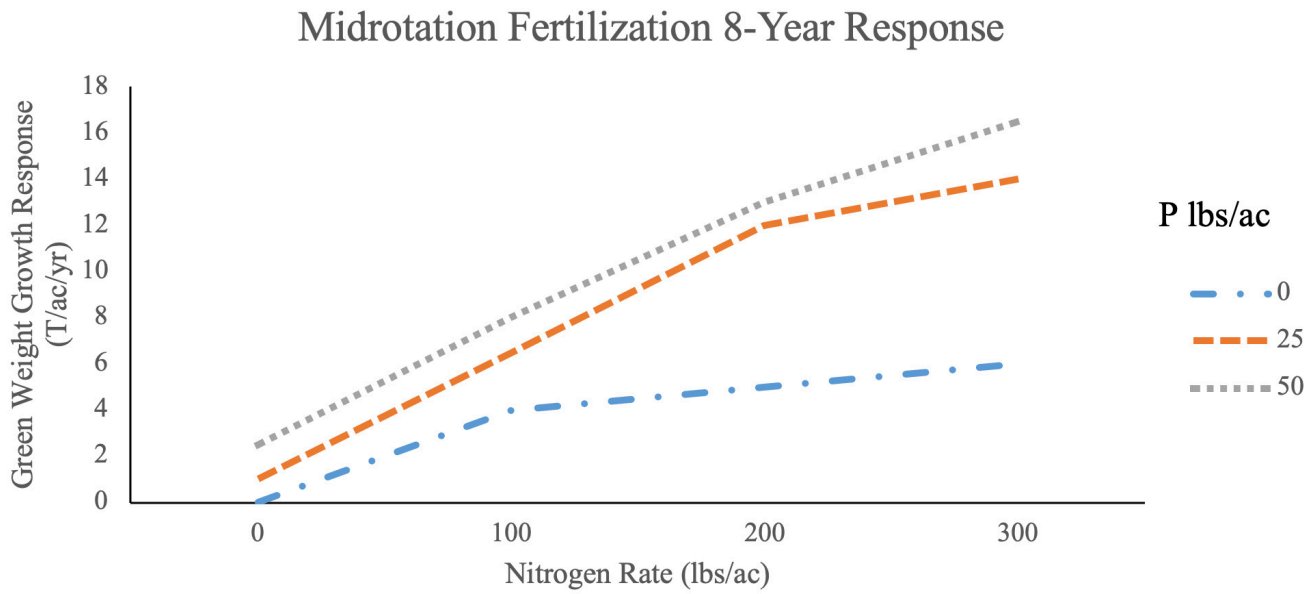

Figure 2: *Loblolly pine 8 year green weight growth response to varying levels of N (0, 100, 200, or 300 lbs/ac) and P (0, 25 or 50 lbs/ac). Typical post mid-rotation or post thin loblolly pine prescription is 200 N + 25 P per acre (graph adapted from Fox et al., 2007)).*

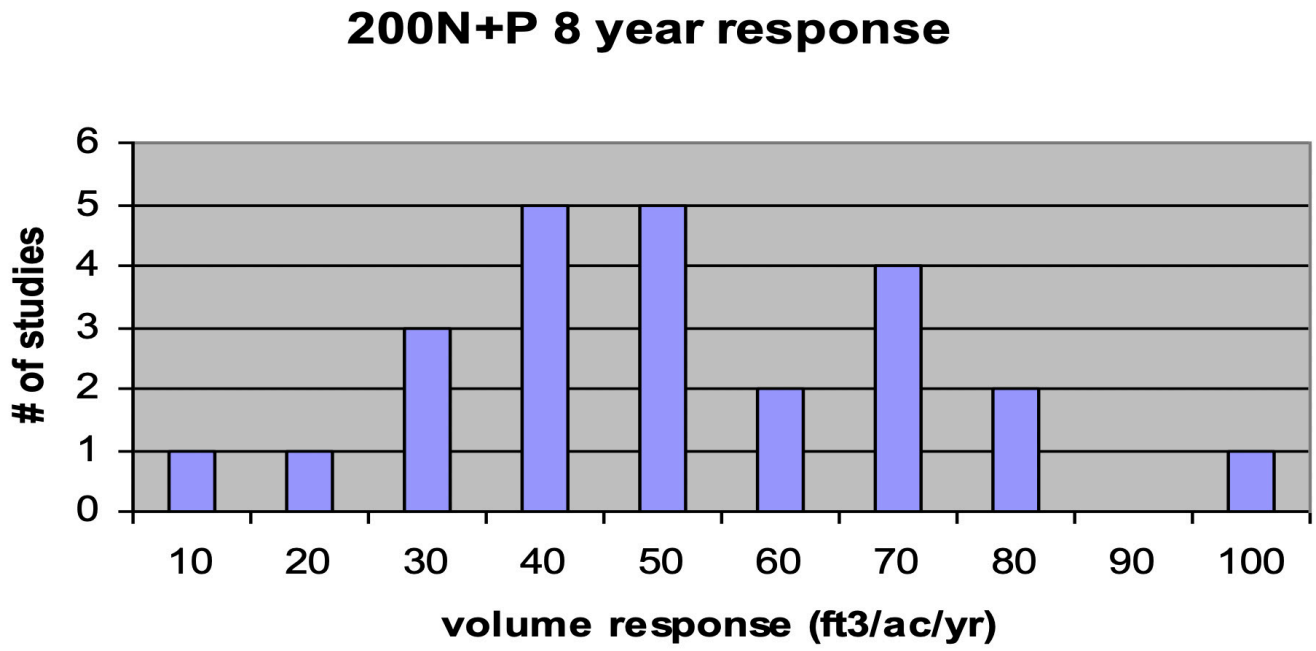

Figure 3: *Loblolly pine mid-rotation volume/ac/yr response over an eight year period histogram showing the number of study sites that had a 10-100 ft³/ac/yr response (from Forest Productivity Coop Regionwide study summary report 1998). One ton of Southern pine wood+bark is approximately 32 cubic feet.*

Table 2: *Recommended fertilizer application rates (elemental – lbs/ac) for loblolly, longleaf, and slash pine*

SPECIES	STAND PHASE/SIZE	NITROGEN (N)	PHOSPHORUS (P)	POTASSIUM (K)	CA, MG, S, B, CU, MN, FE
		lbs/ac			
Loblolly	Canopy Closure	125	25	50-80	As needed based on foliar analysis or other diagnostics
	Post-thin	175-200	25	50-80	
Slash	Canopy Closure	110	25	50-80	
	Post-thin	150-175	25	50-80	
Longleaf	dbh<6”	75	25	50-80	
	dbh≥6”	125-135	25	50-80	

[1]To convert from elemental-P to P_2O_5 multiply by 2.3. To convert from P_2O_5 to elemental-P divide by 2.3.
[2]To convert from elemental-K to K_2O multiply by 1.2. To convert from K_2O to elemental-K divide by 1.2.
[3]Approximate application levels are based on stand needs: 25 to 40 lbs Ca/ac, 25 lbs Mg/ac, 25 to 40 lbs S/ac, 0.5 to 1 lb B/ac, 3 to 5 lbs Cu/ac, 3 to 5 lbs Mn/ac, and 10 to 15 lbs Fe/ac
[4]Albaugh and others (2010)

Table 3: *Common fertilizer materials application level recommendations for loblolly, longleaf, and slash pine stands after canopy closure that have a good probability of response to fertilization.*

PINE SPECIES & STAGE OF STAND DEVELOPMENT OR DBH	UREA (46-0-0)[1]	DIAMMONIUM PHOSPHATE[2,3] (DAP; 18-46-0)[4]	MURIATE OF POTASH (0-0-60)[4]
	lbs/ac		
Loblolly: Canopy Closure	223	125	100 (up to 150)
Loblolly: Post-thin	330-385	125	100 (up to 150)
Slash: Canopy Closure	190	125	100 (up to 150)
Slash: Post-thin	275-330	125	100 (up to 150)
Longleaf <6” dbh	115	125	100 (up to 150)
Longleaf ≥6” dbh	220-245	125	100 (up to 150)

[1]Use the particular urea application level for a given loblolly or slash pine stand development stage or diameter size for longleaf when used with the 125 lbs/ac DAP (18-46-0).
[2]In place of DAP, Mono-ammonium phosphate (MAP) may be available and can be used in place of DAP @ 110 lbs/ac MAP to achieve 25 lbs elemental-P/acre (58 lbs P_2O_5/ac) but urea dosage will need to be increased to achieve N application levels in Table 2.
[3]The 125 lbs DAP/ac is most often used with urea at canopy closure and after thinning.
[4]Fertilizer grade (e.g. 18-46-0) is reported as %N-%P_2O_5-%K_2O, not elemental P and K.

Photo 1: *Ten-year-old planted longleaf pine one year after a NPK treatment @ 150 lbs/ac N. The nitrogen level was excessive for this young longleaf stand.*

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