NORTH CAROLINA FOREST SERVICE NC

Technical Resource Bulletin

August 2015 TRB-001

Fertilization on Established Loblolly Forest Stands

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Forest trees require 16 basic elements to grow and maintain health. Three of these elements, oxygen, carbon and hydrogen are derived from water and air. The rest are supplied by the soil. The "Big Three" macronutrients, nitrogen (N), phosphorus (P), and potassium (K), comprise over 67% of the nutrients found in plant tissue and are used in large quantities by forest trees (Landis 2003). Calcium, magnesium, and sulfur are used in smaller quantities but are just as important to plant health and vigor. The seven micro-nutrients, boron, chlorine, copper, iron, manganese, molybdenum, and zinc, while used in very small amounts are essential to plant metabolism.

Many forest soils across North Carolina are deficient in one or more macronutrients and can benefit from fertilization. By addressing these deficiences forest fertilization temporarily increases growth rates and thus increases wood volume. Thus, landowners can use fertilization to increase financial return.

The growth response of loblolly pine to fertilization at establishment (particularly on phosphorus deficient soils in eastern North Carolina) is well known and widely practiced. Several research studies also demonstrate a strong and consistent growth response to fertilizer applied to mid-rotation (8-20 years) and late-rotation (20 -35 years) loblolly stands (Allen 1987, Sterns-Smith 1992, Williams 2000). This is because, as tree size increases available N and P become limited leading to a reduction in leaf area and subsequent growth. Fertilization with N, N + P, or NPK + boron shortly after crown closure or after the thinning increases leaf area. Increased leaf area increases wood production. Tree response to mid-rotation fertilization typically last 6-8 years (Allen 1985, Stearns-Smith, et. al. 1992).

Identify Responsive Sites

Mid rotation fertilization is best recommended for forest stands that 1) are responsive to the nutrient amendments, 2) are large enough to justify the cost (> 40 acres), and most importantly 3) are nutrient deficient (Dickens 2003). Stand leaf area, soil characteristics, and in some cases, soil and foliar analysis provide landowners and foresters simple diagnostic information to determine fertilizer needs.

Using Soil Characteristics

Most soils respond to fertilization to some degree. For some soils growth is limited by other factors. Soil characteristics are useful to predict the potential growth response. For instance, high soil strength (resists root penetration), poor soil aeration, and low soil water supply reduce root growth and thus tree growth. By knowing the general soil group, one can identify sites that have characteristics that negatively impact growth or are commonly deficient in certain nutrients.

Sometimes knowing the general soil type is all that is needed to make recommendation. For instance, we know that N, P, K and boron are often limited on well-drained sandy soils and applying fertilizer on these sites will increase growth. However, the growth response is likely not enough to offset the costs of fertilization since other factors such as water deficits, low organic matter, and low cation exchange restrict growth. The growth response on very poorly drained clay soils varies and is hard to predict. These soils must be evaluated carefully to determine if fertilization is worthwhile. On the other hand, significant growth response is common on wet savannas, piney flatwoods, and upland clay sites that are P-deficient. Generally as drainage and sand or clay content increase response will decrease. Potential response to fertilization based on soil system and soil characteristics of the Coastal Plain are summarized in table 1.

In the Piedmont region the bedrock from which soils are derived strongly influences their quality. Granite is most common bedrock in North Carolina. Soils derived from granite or diorite have high silica content and are generally considered poor soils (phosphate deficient). Granite derived soils contain feldspar - a mineral with a high potassium (K) level. For that reason most Piedmont soils do not need additional potassium. Shale and sandstone are also high in potassium, but low in phosphorous. Basalt derived soils are some of the richest soils found in the Piedmont. A dusky red color is a good indicator of a better, rich soil. Shallow soils that restrict rooting depth due to heavy clay or rocky subsoil may not respond well to fertilization. Potential response to fertilization based on soil system and soil characteristics for the Piedmont are summarized in

Table 1. Potential response to fertilization for common Coastal Plain soils.

Soil Group	Soil type	Drainage	Major Soil Series	Probability of Success	Mid-rotation Fertilizer Rate (lbs./ac)	Volume Gain
Lower Coastal Wet savannas	Sand to loamy sand with clay subsoil	Very poorly-somewhat poorly	Chowan, Pantego, Leaf	High P-deficiency	150 - 200 N 40-50 P	50 ft^3/ac/yr.
Lower Coastal Piney flatwoods	Sandy with a spodic layer	Very poorly - moderately poorly	Leon, Lynne Haven, Murville	Moderate (Infertile)	150 N 25 -50 P 30 K 1.5 boron	55 ft^3/ac/yr.
Middle Coastal Upland	Shallow sand to loamy sand < 20" with clay subsoil	Moderately well - well	Norfolk, Goldsboro Rains	High	200 N 25-50 P	30 -90 ft^3/ac/yr.
Upper Coastal & Piedmont Upland	Deep sand to loamy sand >20" with clay subsoil	Moderately well - well	Fuquay Wagram	Low	200 N 25-50 P	10 -40 ft^3/ac/yr.
Sandhills Sandhills	Deep sands	Excessively well drained	Candor. Lakeland, Kershaw Ailey	Low	200 N 25-50 P 30 K + 1.5 boron	10 -40 ft^3/ac/yr
Organic Bay Swamp Pocosin	Organic soils Mucks	Very poorly Drained	Pamlico, Belhaven, Pungo Ponzer	Moderate (Trafficability)	150 N 25 P	20 -60 ft^3/ac/yr.

Adapted from Vann and Jokela & Long.

Visual Indicators

A flat crown top, low leaf area, and chlorotic foliage provide simple but effective visual indicators of poor stand health and vigor; of these leaf area (an estimate of how many leaves a stand has) is the best. Loblolly pine reaches peak leaf area in the summer months. Peak leaf area index (LAI) below 1.3 is an indicator that the stand is not getting enough resources for optimal growth. NCSU Forest Nutrition Cooperative research found that annual volume growth doubles when stand leaf area index is doubled (Allen 2005). Leaf area index is determined by using a leaf area comparator or analysis of satellite imagery. A sparse crown, where you see more sky than leaves, is visual indicator of low leaf area. Unless some other factor limits growth these trees will likely respond to fertilization. Leaf area is a reliable indicator of stand vigor, and to determine stand nutrient deficiencies. N.C. State University (NCSU) Forest Nutrition Cooperative recommends maintaining a peak leaf area index of at least 3.5 to maximize growth. LAI below 3.5 imply the stand needs N+P. The lower the leaf area index the more likely and greater the growth response will be to fertilization.

Site Quality and Stand Density

Site quality and stand density influence growth response. Generally, stands with high site index show the greatest volume response to fertilization, perhaps due to an ability to use additional nutrients most efficiently (Duzan et.al.1982). Duzan also found that the magnitude of response is greater on high sites in the Coastal Plain than in the Piedmont. Poor quality stands (low site index) may have significant responses when low nutrition availability limits growth, but have no response where growth is influenced by other factors such as too much or too little moisture. Response to fertilization is positive over a range of stand density, but shows a greater response at lower basal areas where the trees have room to grow and have sufficient foliage to use the added nutrients. Growth response for loblolly pine is maximized when the stand is maintained at 90-140 square feet of basal area (Duzan, et.al.1982, Allen 1987). Fertilizing stands with basal area greater than 130 is not recommended, because of the increased risk of bark beetle infestation, unless a thinning or harvest is planned within 3 years and 5 years respectively (NCFNC 2005).

Soil and Foliar Tests

Soil nutrient tests provide an index of short-term nutrient availability. Soil tests do not measure the nutrient demand of the trees or how much the tree is able to extract from the soil. They are of limited use to foresters seeking to predict forest stand needs for the next 5-10 years. Phosphorous is the exception. P- deficient soils respond to fertilization with a long lived and dramatic volume gain that

Table 3. Critical values for foliar and soil nutrient content in loblolly

	N	P	K	Ca	Mg	S	B	Cu
Foliar	1.2	0.12	0.35	0.12	0.07	0.12	4-8 ppm	2-3 ppm
Soil (0-6 in.)		<3-5 ppm	<15 ppm					

Table 2. Potential response to fertilization for common Piedmont soils.

Soil Group	Soil type	Bedrock	Major Soil Series	Probability of Success	Mid-rotation Fertilizer Rate (lbs./ac)	Volume Gain
Felsic Crystalline Upland Piedmont and Foothills	Shallow sandy loam with a kaolinitic clay subsoil	Granite,gneiss, mica bedrock,	Cecil (>1m) Appling(>1m)	High	150 N 25 -50 P	60 -90 ft^3 /ac/yr.
			Pacolet (<1m) Wedowee (<1m)	P-deficient		
Carolina Slate - Middle Piedmont Uplands	Silt loam with a silt plus very fine sand subsurface; reddish clay subsoil .	Slate bedrock	Georgeville(>1m) Herendon(>1m)	Moderate	150 N 25 -50 P	55 ft^3 /ac/yr
			Badin(<1m) Goldston(<1m)			
Triassic Basin - Piedmont Upland	silty loam with a yellowish brown to yellow red clay subsoil.	Shale and sand-stone bedrock	Maydon (>1m) Creedmor(>1m) White Store(>1m)	Low P-deficient	Not recommend-ed	
Mixed Felsic -Malfic Piedmont Upland	Sandy loam to silty loam with a red to yellow red to dusky red clay subsoil	Felsic Granite	Cecil (>1m) Pacolet (<1m)	High P-deficient	150 - 200 N 25 -50 P	60 -90 ft^3 /ac/yr.
		Malfic Basalt	Enon (>1m) Mechlenburg (>1m) Wilkes(<1m)	High	150 - 200 N 25 -50 P	60 -90 ft^3 /ac/yr.

Adapted from Vann and Jokela & Long,.

Prescription Guidelines for Fertilization of Established Loblolly Pine Stands

Prescription	If BA is……	and peak LAI is	and the stand is…	then fetilize*
# 1	BA <130 and hrdwd < 20 BA	< 1.3	P-deficient	36 N + 40 P (200lbs DAP) and 150 N in 2-3 years
		<1.3	K and/or B deficient	150N, 45 lbs K and/or 2 lbs B
		> 1.3 but <3.5	N & P limited	150 N + 20 P to 200 N +20 P add 2 lbs B or 45 lbs K if needed
		> 3.5	unthinned	Do Not Fertilize
		> 3.5	thinned	150 N + 20 P to 200 N +20 P add 2 lbs B or 45 lbs K if needed
# 2	BA >130 and hrdwd < 20 BA		thin w/in 2 yrs	Follow prescription in #1
			OR clearcut w/in 5 yrs	Do Not Fertilize
			no harvest activity planned	Do Not Fertilize
# 3	Hrdwds > 20 BA and LAI indicates need for fertilization	Control hardwoods prior to fertilization and follow guidelines in #1		

* Values are in pounds per acre of elemental nutrient

Adapted from the Forest Nutrition Cooperative may extend into the second rotation (Vann 1884, Allen 2005). The P index value provided by a soil test is useful to determine phosphorous deficiency. Soils with phosphorous levels less than 3-5 ppm are considered deficient, and thus are good candidates for P fertilization at any age. Foliar analysis provides better information on what the tree is able to utilize from the soil. Critical values summarized in Table 3. help identify foliar nutrient deficiencies in loblolly and longleaf pine.

Expected Volume Gains

Volume gains for individual stands vary and are hard to accurately predict. However, most established forest stands respond to fertilization with significant increases in production. Over 85% of research sites installed by NCSU Forest Nutrition Cooperative responded to applications of N+P. Growth gains of 50 cubic feet/acre/year over a six-year period are typical for most stands. Volume increases of over 100 cubic feet/acre/year are possible. Results of two region wide studies reported average annual growth of 75 and 85 cubic feet over four to six year after application of 200N+50P (NCSU Forest Nutrition Cooperative 1998). Annual volume production on potassium (K) deficient sites averaged less than 40 cubic feet/acre with N+P fertilization but increased by an average of 35 cubic feet/acre/year if K is applied.

Thinning and Fertilization

The effects of thinning and fertilization are additive. Dense stands with BA greater than 130 should be thinned prior to, or within, 2 years after fertilization. The thinning harvest should leave the best co-dominant and dominant trees that are most likely to have the greatest diameter growth response to fertilization. The extra growth on the largest and best trees produces more wood in highest-value product classes (i.e. chip-n-saw, sawtimber, and poles).

Application Rates

For loblolly pine 150 to 200 pounds/acre of elemental N plus 25 pounds/acre of P is recommended for most sites. For K or Boron deficient sites add 30 pounds of K and 1.5 pounds of Boron for each 100 pounds of N. The application of N or P as separate treatments is not recommended since the growth response is better with a combined N+P application (Jokela 2000). Diammonium phosphate (DAP - 18-46-0) and Urea (46-0-0) are the more commonly recommended fertilizers applied to forest stands. The best time to apply is from November to early March. To maintain the optimum growth response fertilization should be repeated every 6-8 years. To fully realize volume gain after fertilization one must wait 6-8 years before thinning or harvesting.

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