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Phosphorus Fertilization at Establishment in Loblolly and Slash Pine Stands on Atlantic and Gulf Coastal Plain Sites

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INTRODUCTION

WHY FERTILIZE?

Forest fertilization in the south has increased greatly since the 1960s. Southern pine fertilization peaked in 1999 at 1.58 million acres and as of the latest survey year, 2016 has dropped to 589,000 acres (Albaugh and others 2019). The predominant species fertilized are loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm, var. *elliottii*) pine. Fertilization can enhance loblolly and slash pine growth and financial returns. Recommendations should be specific to the:

- site (soil drainage and texture, presence/depth of argillic and/or spodic horizons, land usehistory, etc.),
- species,
- age,
- stocking,
- target rotation age and products, and
- landowner objectives.

Landowner financial constraints often limit fertilization on private non-industrial forestland. Fertilization rates of return can average 5 to 8 percent and can be as high as 20 percent. Financial rate of return from fertilization depends on:

- the cost of fertilization (fertilizers+application),
- the magnitude and duration of the response,
- the stumpage price of resultant products grown,
- whether the stand is clearcut (realizing 100% of the growth gain) or thinned (realizing approximately 50% of the gain) and timing (years) or harvest after fertilization, and
- other forest product growth increases/yields that generate revenue (i.e., pine straw).

WHEN AND WHERE TO FERTILIZE

Fertilization of loblolly and slash pine plantations to maintain, enhance, or optimize growth can be economically beneficial if the stand/site in question has a deficiency in one or more nutrients, is responsive to the nutrient(s) being added, and is large enough for it to be operationally feasibleto fertilize. Generally, there are four fertilizer recommendation "windows" or cycles:

- at planting,
- early post-planning to rectify a nutrient deficiency,
- at mid-rotation after canopy closure or after the first thinning
- to enhance pine straw production (5-year cycle)

OBJECTIVES

The focus of this paper is to address the benefits of phosphorus (P) fertilization at planting on P-deficient Atlantic and Gulf Coastal Plain sites. We will discuss:

- the diagnostic tools used to determine P deficient sites,
- estimated growth response to P fertilization prior to or soon after planting, and
- P fertilizer types and application levels.

OVERVIEW - SITES AND SOILS THAT ARE P DEFICIENT

PHOSPHORUS FERTILIZING AT PLANTING

Phosphorus fertilizing at planting typically occurs on somewhat poorly (SPD) to very poorly drained (VPD) soils of the Atlantic and Gulf Coastal Plain that are P-deficient. Approximately 265,000 acres were P or N+P fertilized early after planting in the Southeast in 1998 (NCSUFNC 1999), 244,000 acres of loblolly and slash pine plantations were fertilized at establishment in the southeastern United States in 2001 (NCSUFNC 2002), and 115,000 acres were P fertilized at planting in 2016 (Albaugh and others 2019). Studies over the last 30+ years have shown that when fertilized at a broadcast rate of 50 to 80 lbs elemental-P per acre (115 to 185 lbs P_2O_5 per acre), loblolly and slash pine growth response to P fertilization at planting can be large ranging from 0.50 tons/ac/yr up to or exceeding 2.7 tons/ac/yr increase in growth lasting 15 to 20 years (Fisher and Garbett 1980, Pritchett and Comerford 1982, Gent and others 1986; Table 1, Figures 7 and 8) on soils where response tends to be largest. Due to fertilizer prices since 2004-2005, more common application rates at planting of 125 lbs/ac diammonium phosphate (DAP:18-46-0) or 125 lbs/ac triple super phosphate (TSP: 0-46-0) are used.

THE COASTAL PLAIN PHYSIOGRAPHIC REGION

The southeastern Coastal Plain covers an area from Virginia to Texas that is about 150 miles wide along the Atlantic and up to 400 miles wide along the Gulf Coast (Pritchett and Gooding 1975). Elevation ranges from sea level to a few hundred feet and is relatively flat to undulating. Sixty-three percent (101 million acres) are in the rolling to hilly topography of the upper Coastal Plain and 37 percent (60 million acres) occupies the lower Coastal Plain, coastal lowlands, often referred to as the Flatwoods (Pritchett and Comerford 1983).

The Flatwoods region, found along the U.S. Gulf and Atlantic coast, extends 50 to 75 miles inland. Elevation ranges from sea level to 100 feet. Maps of major land resource areas for Alabama, Florida, Georgia, and South Carolina showing the location of the Flatwoods region are found in Figures 1 through 4.

Flatwoods soils commonly have a relatively high and fluctuating water table, low nutrient reserves (especially N and P), and generally a sandy surface texture. Soil moisture and drainage often have the largest effect on site productivity in the Flatwoods. Small changes in elevation and depth to a fine-textured (argillic) layer or water table have a large effect on soil moisture conditions. Drainage classification and depth to subsoil horizon influence (1) effective rooting tree depth and (2) the capacity to retain fertilizers.

WET SAVANNAH COASTAL LOWLANDS - CRIFF SOIL GROUP A AND B

The soils of this region are somewhat poorly to very poorly drained, nearly level depressions, stream terraces, and broad wet flats (Jokela and Long 1999). Common vegetation is wiregrass (*Aristida stricta*), pitcher plants (*Sarracenia* spp.), St. John's wort (*Hypericum aspalanthoides*), and slash pine (Pritchett and Smith 1973). <u>Many of these soils are flooded from 5 to 30 days for one or more times/year</u> (Jokela and Long 1999) <u>with the water table ranging from 6 to 20 inches</u> <u>below the surface during drier times</u>. These soils commonly contain high levels of organic matter(4 to 8 percent) and are very acid (pH of 3.5 to 4.5). These soils generally belong to the Ochraquult or Umbraquult great soil group and include soil series such as Bladen, Leaf, Plummer, Rains, Rutledge, and Weston (Smith and others 1967). These wet savannah soils comprise the University of Florida's Cooperative Research in Forest Fertilization (CRIFF) group A and B (Figure 4 and Figure 5).

CRIFF A soils have a depth to argillic (Bt) < <u>20 inches</u>
CRIFF B soils have a depth to argillic (Bt) ><u> 20 inches or not present</u>

FLATWOODS SPODOSOLS - CRIFF SOIL GROUP C AND D

The Flatwoods spodosols occupy a large portion of the lower Coastal Plain. These soils are often very infertile, acidic, coarse textured, and moderately well to somewhat poorly drained. Common vegetation is saw palmetto (*Serenoa repens*), gallberry (*Ilex coriacea*), and runner oak (*Quercus pumula*). <u>Flatwoods soils' water table can be 5 to 20 inches below the surface for 1 to 4 days one</u> <u>or more times/year</u> (Jokela and Long 1999). The surface horizon color ranges from salt and pepper to black (on very poorly drained soils) and these soils have an underlying elluvial (E) horizon that is white to gray in color. <u>Below the E horizon is the spodic horizon (Bh)</u>, ranging in color from chocolate brown (most common), to reddish brown, to black (Figure 6). This horizon is a zone of accumulation of iron, aluminum, and organic matter and can become cemented when dry impeding root penetration. These flatwood spodosol soils make up CRIFF group C (Figure 5) and D.

CRIFF C soils have a spodic horizon (Bh) and <u>have</u> an underlying argillic (Bt) horizon
CRIFF D soils have a spodic horizon (Bh) but <u>do not have</u> an underlying argillic (Bt) horizon

Table 1 groups soils of the southeastern Coastal Plain and rates each forest soil group's probability of response to P-fertilization at planting. The soil groups were organized by the University of Florida's Cooperative Research in Forest Fertilization (CRIFF) in the 1980s (Figure 5). CRIFF soil groups A, B, and C in Tables 2, 3, and 4 are typically deficient in plant available phosphorus (P), especially as the percentage of clay increases and as soil drainage decreases. These soils in CRIFF group A, B,and C are the most responsive to P fertilization at planting.

Table 1. Twenty-five year loblolly and slash pine response to phosphorus fertilization at planting in Southeastern Coastal Plain. Listed by CRIFF soil groups.

Soil group	Drainage class	Taxonomic subgroups	Soil series examples	Probability / magnitude of response	Stemwood+bark gain (tons/ac/yr)
A	somewhat poorly to very poorly drained	Typic, Albic, Plinthic, Aquults	Bladen, Leaf	high / large	1.2 – 3.2
B	somewhat poorly to very poorly drained	Arenic, Grossarenic Aquults, Aquents, Aquepts	Rutledge, Plummer	moderate to high / moderate to large	0.62 – 2.4
C	somewhat poorly to very poorly drained	Ultic Aquods and Humods	Mascotte, Sapelo	moderate / moderate	0.5 – 1.2
D	Poorly to moderately well drained	Typic, Aeric, and Arenic Aquods and Humods	Leon, Ridgeland	variable	0.0 - 0.8
E	moderately well to well drained	Typic and Plinthic Udults	Goldsboro, Norfolk	variable / variable	0.0 – 1.5
F	moderately well to well drained	Arenic and Grossarenic Udults, Umbrepts, Ochrepts	Blanton, Orsino	variable / low	0.0 – 1.5
G	somewhat excessively to excessively well drained	Psamments	Lakeland, Kershaw, Alpin	low / negligible	Negligible

Table 2. CRIFF Soil Group A, somewhat poorly drained (SPD), poorly drained (PD), and very poorly drained (VPD) Flatwoods soils with an argillic horizon within 20 inches of the surface (no spodic horizon present).

Soil Series	Subgroup Modifier	Great Group	CRIFF Grouping	State	Drainage
Ardilla	Fragiaquic	Paleudults	A	AL, FL, GA, SC	SPD
Basin	Fragiaquic	Paleudults	A	AL	SPD
Bayboro	Umbric	Paleaquults	A	AL, FL, GA, SC	VPD**
Bertie	Aeric	Endoaquults	A	SC	SPD
Bethera	Typic	Paleaquults	A	AL, FL, GA, SC	PD
Bladen	Typic	Albaquults	A	AL, FL, GA, SC	PD
Byars	Umbric	Paleaquults	A	AL, FL, GA, SC	VPD**
Cantey	Typic	Albaquults	A	SC	PD
Cape Fear	Typic	Umbraquults	A	GA, SC	VPD**
Coxville	Typic	Paleaquults	A	AL, FL, GA, SC	PD
Daleville	Typic	Paleaquults	A	SC	PD
Deloss	Typic	Umbraquults	A	SC	VPD**
Escambia	Plinthaquic	Paleudults	A	AL, FL	SPD
Florala	Plinthaquic	Paleudults	A	AL, FL	SPD
Gourdin	Typic	Epiaquults	A	SC	PD
Grady	Typic	Paleaquults	A	AL, FL, GA, SC	PD
Grantham	Typic	Paleaquults	A	SC	PD
Hazlehurst	Aeric	Paleaquults	A	AL, GA, SC	SPD
Hobcaw	Typic	Umbraquults	A	SC	VPD**
Hyde	Typic	Umbraquults	A	GA, SC	VPD**
Jedburg	Aeric	Paleaquults	A	AL, GA, SC	SPD
Leaf	Typic	Albaquults	A	AL, FL, GA, SC	PD
Lenoir	Aeric	Paleaquults	A	AL, GA, SC	SPD
Lumbee	Typic	Endoaquults	A	FL, GA, SC	PD
Lynchburg	Aeric	Paleaquults	A	AL, FL, GA, SC	SPD
McColl	Typic	Fragiaquults	A	SC	PD
Myatt	Typic	Endoaquults	A	AL,FL, GA, SC	PD
Nahunta	Aeric	Paleaquults	A	SC	SPD
Ogeechee	Typic	Endoaquults	A	AL, FL, GA, SC	PD
Pantego	Umbric	Paleaquults	A	AL, FL, GA, SC	VPD**
Paxville	Typic	Umbraquults	A	SC	VPD**
Pooler	Typic	Endoaquults	A	FL, GA	PD
Portsmouth	Typic	Umbraquults	A	AL, FL, GA, SC	VPD**
Quitman	Aquic	Paleudults	A	AL	SPD
Rains	Typic	Paleaquults	A	AL, FL, GA, SC	PD
Rembert	Typic	Endoaquults	A	AL, FL, GA, SC	PD

Table 2. (continued) CRIFF Soil Group A, somewhat poorly drained (SPD), poorly drained (PD), and very poorly drained (VPD) Flatwoods soils with an argillic horizon within 20 inches of the surface (no spodic horizon present).

Soil Series	Subgroup Modifier	Great Group	CRIFF Grouping	State	Drainage
Robertsdale	Plinthaquic	Paleudults	A	AL, FL, GA	SPD
Saucier	Plinthaquic	Paleudults	A/E	AL	MWD
Smithboro	Aeric	Paleaquults	A	SC	SPD
Smithton	Typic	Paleaquults	A	AL	PD
Stallings	Aeric	Paleaquuts	A	AL, FL, GA, SC	SPD
Tomotley	Typic	Endoaquults	A	SC	PD
Torhunta	Typic	Humaquepts	A	FL, GA, SC	VPD**
Wahee	Aeric	Endoaquults	A	AL, FL, GA, SC	SPD
Weston	Typic	Endoaquults	A	AL	PD
Woodington	Typic	Paleaquults	A	FL, GA, SC	PD
Yemassee	Aeric	Endoaquults	A	SC	SPD
Zephyr	Typic	Albaquults	A	FL	VPD**

**VPD soils may not be suitable for intensive pine management

Table 3. CRIFF soil group B, somewhat poorly drained (SPD), poorly drained (PD), and very poorly drained (VPD) Flatwoods soils with an argillic horizon greater than 20 inches below the soil surface (no argillic horizon present).

Soil Series	Subgroup Modifier	Great Group	CRIFF Grouping	State	Drainage Class
Adamsville	Aquic	Quartzipsamments	B*/G	FL	SPD
Alapaha	Arenic Plinthic	Paleaquults	B	AL, FL, GA, SC	PD
Albany	Grossarenic	Paleudults	B/F	AL, FL, GA, SC	SPD
Arapahoe	Typic	Humaquepts	B	SC	VPD**
Atmore	Plinthic	Paleaquults	B	AL, FL	PD
Bakersville	Cumulic	Humaquepts	B*	FL	VPD**
Ballahack	Cumulic	Humaquepts	B*	SC	VPD**
Basinger	Spodic	Psammaquents	B*/D	FL	PD
Bayou	Typic	Paleaquults	B	AL	PD
Blichton	Arenic Plinthic	Paleaquults	B	FL	PD
Bonsai	Aeric	Fluvaquents	B*	FL	VPD**
Braden	Aquic Arenic	Hapludults	B	FL	SPD
Brewton	Fragiaquic	Paleudults	B	AL, FL	SPD
Brickyard	Typic	Endoaquepts	B	FL	VPD**
Broward	Aquic	Quartzipsamments	B*	FL	SPD
Canaveral	Aquic	Quartzipsamments	B*/G	FL	MWD, SPD
Chewacla	Fluvaquentic	Dystrudepts	B	AL, FL, GA, SC	SPD
Chipley	Aquic	Quartzipsamments	B*/G	AL, FL, GA, SC	SPD
Clara	Spodic	Psammaquents	B*/D	FL	PD, VPD**
Dawhoo	Typic	Humaquepts	B*	FL, GA, SC	VPD**
Ellabelle	Arenic Umbric	Paleaquults	B	AL, FL, GA, SC	VPD**
Ft. Drum	Aeric	Endoaquepts	B*	FL	PD
Garcon	Aquic Arenic	Hapludults	B/F	AL, FL, GA	SPD
Herod	Typic	Fluvaquents	B	AL, GA, SC	PD
Hosford	Cumulic	Humaquepts	B*	FL	VPD**
Johnston	Cumulic	Humaquepts	B*	AL, FL, GA, SC	VPD**
Jumper	Plinthaquic	Paleudults	B/F	FL	SPD
Kanapaha	Grossarenic	Paleaquults	B	FL	PD
Leefield	Plinthaquic	Paleudults	B/F	AL, FL, GA, SC	SPD
Lochlossa	Aquic Arenic	Paleudults	B/F	FL	SPD
Mantachie	Aeric	Endoaquepts	B	AL, FL, SC	SPD
Margate	Mollic	Psammaquents	B*	FL	PD
Mashulaville	Typic	Fragiaquults	B	AL	PD
Masontown	Cumulic	Humaquepts	B*	AL, GA	VPD**
Muckalee	Typic	Fluvaquents	B*	AL, Fl, GA, SC	PD
Mulat	Arenic	Endoaquults	B	FL	PD

Table 3. (continued) CRIFF soil group B, somewhat poorly drained (SPD), poorly drained (PD), and very poorly drained (VPD) Flatwoods soils with an argillic horizon greater than 20 inches below the soil surface (no spodic horizon present).

Soil Series	Subgroup Modifier	Great Group	CRIFF Grouping	State	Drainage Class
Nobleton	Aquic Arenic	Paleudults	B	FL	SPD
Ocilla	Aquic Arenic	Paleudults	B	AL, FL, GA, SC	SPD
Osier	Typic	Psammaquents	B*	AL, FL, GA, SC	PD
Ousley	Aquic	Quartzipsamments	B*/G	AL, FL, GA, SC	SPD
Pactolus	Aquic	Quartzipsamments	B*/G	AL, FL, GA, SC	MWD, SPD
Palmetto	Grossarenic	Paleaquults	B	FL	PD
Pansey	Plinthic	Paleaquults	B	AL, FL	PD, VPD
Pelham	Arenic	Paleaquults	B	AL, FL, GA, SC	PD
Pheba	Glossaquic	Fragiudults	B	AL	SPD
Pickney	Cumulic	Humaquepts	B*	FL, GA, SC	VPD**
Pineda	Arenic	Glossaqualfs	B	FL	PD, VPD**
Placid	Typic	Humaquepts	B*	FL	VPD**
Plantation	Histic	Humaquepts	B*/H	FL	VPD**
Plummer	Grossarenic	Paleaquults	B	AL, FL, GA, SC	PD
Pompano	Typic	Psammaquents	B*/G	FL	VPD**
Riceboro	Arenic	Paleaquults	B	GA	PD
Ridgewood	Aquic	Quartzipsamments	B*/G	FL	SPD
Rutledge	Typic	Humaquepts	B*	FL, GA, SC	VPD**
Sanibel	Histic	Humaquepts	B*/H	FL	VPD**
Satellite	Aquic	Quartzipsamments	B*/G	FL	SPD
Scoggin	Arenic	Endoaquults	B	FL	VPD**
Scranton	Humaqueptic	Psammaquents	B*/G	AL, FL, GA, SC	PD
Seffner	Aquic Humic	Dystrudepts	B*	FL	SPD
Sellers	Cumulic	Humaquepts	B*	FL	VPD**
Solite	Typic	Psammaquents	B*	FL	PD
Sparr	Aquic Arenic	Paleudults	B	FL	SPD
Starke	Grossarenic	Paleaquults	B	FL	VPD**
Stough	Fragiaquic	Paleudults	B	AL, FL	SPD
Surrency	Arenic Umbric	Paleaquults	B	AL, FL, GA, SC	VPD**
Valkaria	Spodic	Psammaquents	B*/D	FL	PD, VPD**
Wacahoota	Arenic	Paleaquults	B	FL	PD
Williman	Arenic	Endoaquults	B	SC	PD

* Indicates soils in which the argillic horizon is greater than 80 inches from the soil surface
** VPD soils may not be suitable for intensive pine management

Table 4. CRIFF soil group C, somewhat poorly drained (SPD), poorly drained (PD), and very poorly drained (VPD) Flatwoods soils with a spodic horizon and an underlying argillic horizon.

Soil Series	Subgroup Modifier	Great Group	CRIFF Grouping	State	Drainage Class
Ankona	Arenic Ultic	Alaquods	C	FL	PD, VPD**
Bimini	Oxyaquic	Alorthods	C	FL	SPD
Chaires	Alfic	Alaquods	C	FL	PD, VPD**
Delks	Ultic	Alaquods	C	FL	PD
Eaugallie	Alfic	Alaquods	C	FL	PD, VPD**
Electra	Oxyaquic	Alorthods	C	FL	SPD
Elred	Ultic	Alaquods	C	FL	PD
Farmton	Arenic Ultic	Alaquods	C	FL	PD
Lynne	Ultic	Alaquods	C	FL	PD
Mascotte	Ultic	Alaquods	C	FL, GA, SC	VPD**
Melvina	Oxyaquic	Alorthods	C	FL	SPD
Monteocha	Ultic	Alaqouds	C	FL	VPD
Nettles	Alfic Arenic	Alaquods	C	FL	PD, VPD**
Newnan	Oxyaquic	Alorthods	C	FL	SPD
Oldsmar	Alfic Arenic	Alaquods	C	FL	PD, VPD**
Olustee	Ultic	Alaquods	C	FL, GA, SC	PD
Pepper	Alfic	Alaquods	C	FL	PD
Pomona	Ultic	Alaquods	C	FL	PD, VPD**
Rigdon	Oxyaquic	Alorthods	C	GA	SPD
Sapelo	Ultic	Alaquods	C	FL, GA, SC	SPD, PD
Steinhatchee	Alfic	Alaquods	C	FL	PD
Susanna	Ultic	Alaquods	C	FL	PD
Tantile	Ultic	Alaquods	C	FL	PD
Tocoi	Ultic	Alaquods	C	FL	PD
Vero	Alfic	Alaquods	C	FL	PD, VPD**
Wabasso	Alfic	Alaquods	C	FL	PD, VPD**
Wauchula	Ultic	Alaquods	C	FL	PD

**VPD soils may not be suitable for intensive pine management.

PHOSPHORUS FERTILIZATION RECOMMENDATIONS

P FERTILIZATION AMOUNT AND TIMING

Phosphorus fertilization at establishment with 25 to 50 lbs elemental P per acre (58 to 115 lbs P_2O_5/ac @ 125 to 250 lbs triple super phosphate (TSP; 0-46-0/acre), when available, or 125 to 250 lbs per acre of diammonium phosphate (DAP; 18-46-0), or 110 to 220 lbs per acre of monoammonium phosphate (MAP; 11-52-0) can greatly increase loblolly and slash pine growth on CRIFF soil groups A (Table 2), B (Table 3) and C (Table 4). With current (2022) fertilizer prices DAP, MAP and TSP application levels at planting are more commonly 110 (MAP) to 125 lbs/ac (DAP and TSP).

Phosphorus fertilizer application can be:

1. banded in the rows (4 to 6 feet band),
2. broadcast applied (considered to be best single application for long-term benefit due to pine root systems extending well beyond a 4-6 ft band),
3. pre-application and incorporated in beds,
4. post-bedding but pre-plant, or
5. early post-plant.

Many researchers believe that the best results on P-deficient sites are achieved when P is applied pre- plant or soon after planting to rectify the problem as early as possible in the life of the stand. Phosphorus fertilization on these responsive, poorly to very poorly drained sites can be done either by ground or aerially. The 2005 cost for P fertilization is $30 to $55 per acre (using TSP) and a December 2009 cost using DAP of $35 @ 125 lbs per acre to $75 @ 250 lbs per acre using DAP (December 2009 prices courtesy of G & C Fertilizer Company, Pembroke, GA), $65/ac using DAP @ 125 lbs/ac (fertilizer + $0.13/lb to apply) as of October 2021 (Roche Farm and Garden, Dublin, GA) and $85-$90/ac as of May 2022..

The response to P lasts 10 to 20 or more years on these sites. A soil and/or foliage test can help verify any P deficiency (see Table 5 for minimum P level guidelines). If the previous stand has been clearcut, foliage samples from adjacent well-established stands on the same soils and stand history can be used. A lower P dose (20 lbs per acre elemental-P) can be used if the stand will be N+P fertilized within the next 5-10 years.

Up until 2022, this relatively low cost of historic (2010-2021) 125 lbs/ac DAP along with a long-lived fertilizer response and dramatic volume gain make P fertilization of P-deficient wet savannah (CRIFF group A and B) and Flatwoods (CRIFF group C) soils (Figure 7 and 8) an attractive management option, especially if bedding on these poorly drained soils was not performed or was not economically feasible for the landowner (Figure 8).

Phosphorus fertilization at planting or early post-planting can significantly influence early into mid-rotation stand growth as illustrated by the pictures of 16-year-old loblolly pine on a poorly drained, heavy Bladen (CRIFFgroup A) soil in Berkeley County, South Carolina (Pictures 1, 2, and 3; McKee and Wilhite 1986).

More recently, diammonium phosphate (DAP 18-46-0) has been used on these sites (commonly@ 125 to 250 lbs per acre broadcast rate) where there is excellent weed control to provide both nitrogen (N) and P. <u>Vegetation control is imperative if landowners want to N+P fertilize at planting.</u> Post-plant vegetation control is commonly done 20 to 60 days prior to DAP applicationto minimize competing vegetation when the DAP is applied. Where P is the nutrient mostlimiting growth, the benefits of adding N can be small compared to the gain of adding P alone and without good woody and herbaceous weed control, the addition of N (i.e; DAP) to a P-deficient site can reduce planted pine survival and growth.

RECOGNIZING THE P-DEFICIENCY EARLY POST-PLANTING

Many Coastal Plain and Flatwoods sites that are somewhat poorly to very poorly drained and were site prepared and planted can be P deficient and not realized at planting. Often seedling growth is poor. The needles are sparse and yellow-green to light green, especially in mid-winter into mid-spring. Loblolly and slash pine on these sites will respond to P fertilization through at least the first two to five years after planting even when unwanted hardwoods and/or herbaceous vegetation may be present. A soil and/or foliar test will often verify the P deficiency (Table 5). Refer to Table 1 then to Tables 2, 3, and 4 for potentially P-deficient soils of the Coastal Plain.

Diagnostic Tools

Various diagnostic tools and techniques are used often in combination, to determine the magnitude, duration and economic benefit of fertilizing pine plantations that may be P deficient. These diagnostic tools include:

1. soil groups, soil surveys (mapping units), soil drainage class,
2. soil sampling and analysis,
3. foliar sampling and analysis,
4. visual symptoms, and to a lesser extent indicator plants.

Soil Groups

An important diagnostic tool for the Flatwoods on very poorly to somewhat poorly drained soils is determining what soil groups (CRIFF) your candidate stands fall under. Soil series mapping separates soils into units of common taxonomic properties. Soil series maps of your property should be available on the web (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). Soil augering during the dormant season to at least 60" and verifying depth to the top of the argillic horizon (Bt; a subtle increase in clay) and presence/depth of a spodic horizon (usually a chocolate color; the old marine sediment organic layer) and water coming into the augered hole will aid in CRIFF soil group determination. If your candidate stands' soil series fall under the CRIFF soil groups A, B, or C and a soil test for the stand shows a low level of phosphorus, then the stand will have a moderate (C soils) to strong (A and B soils) likelihood of responding to phosphorus fertilization.

Soil Sampling and Analysis

Most land-grant universities have Agricultural Service Laboratories that perform testing for soil and foliar nutrients. Call your county Extension office to see if they provide soils and foliage testing services. If so, get several soil boxes or bags from the nearest office. Some private labs can also perform these analyses. Both soil and foliage tests can indicate if a nutrient is below a "critical level," which assumes that a stand will respond to fertilization of that nutrient. These "critical levels" are empirical and come from field or greenhouse trials. Soil sampling can be done any time of year. Soil should be sampled at 0 to 6-inch depth from several locations per stand, first remove any thatch, debris or litter, then place each soil sample in a clean, plastic bucket (1 to 5 gallon) and thoroughly mix the sample. Typically, six to eight one-inch diameter soil cores will fill up a sample box or bag. Place each composite soil sample into a sample box or bag and label the sample by stand. Ideally there should be at least three composite soil sample bags per 20 to 40-acre stand. If the soil is wet, after thoroughly mixing the composite sample and placing in labeled bags, open up each bag to air dry once back in the office. Close the soil sample bags after 24 to 48 hours once the soil and bags have dried. While soil sampling, bring a stand map and make sure to "map" where each sample was taken from in each stand. Ask the lab what soil phosphorus "extraction" procedure is used and how the results are reported (either as ppm: parts per million or as lbs/acre) and compare your results with those of Table 5. If your soil sample(s) lab results are below the "critical" extractable P level (for that particular lab procedure used) then the probability of response to P fertilization is high. These P deficient sites will be mostly somewhat poorly to very poorly drained soils of the Lower Coastal Plain. Currently there are no "critical" levels of N, Ca or Mg in the soil for loblolly or slash pine.

Foliage Sampling and Analysis

Foliage samples should be taken in the dormant season (mid-December to early-February) from at least 6-10 dominant (tallest with good crowns) trees per stand. This sampling occurs where a young, semi-mature, or mature stand is present on the site in question that will be cut or in an adjacent stand on the same soils and land use history. Samples should be selected from dominant trees in the stand from the:

- south side,
- upper 1/3 of the crown, and
- first flush of growth (Refer to https://bugwoodcloud.org/resource/files/14825.pdf) from aprimary lateral branch.

Older stands may require a 12 gauge shotgun with a full or turkey choke and number 4 or 6 shot to obtain samples from the south side, dominant and co-dominant tree crowns. Combine the samples in an 8.5 x 11-inch paper envelope (> 1/2 volume), properly label and date the envelope, and transport it in a cooler with frozen jugs of water. Refrigerate (do not freeze) the samples until you are ready to get them to the lab or Extension office. Send the foliage samples to your county Extension office early in the week (Monday, Tuesday, or Wednesday) or take the samples to the lab personally, so they do not sit in a truck or warehouse over the weekend. The foliage analysis should include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), copper (Cu), and manganese (Mn).

Have the lab analyze the samples and compare the results with those listed in Table 5. Foliage analysis can also identify any nutrient imbalances. Loblolly and slash pine foliage nutrient balance should be maintained at the approximate N:P:K:Ca:Mg:S ratio of 100:10:35:12:6:10 for optimal growth.

Visual Symptoms and Indicator Plants

*Visual symptoms on CRIFF soil group A, B, and C (as well as other P deficient soils) include:

- light green to yellow needles,
- sparse and or short needles,
- few branches,
- very poor growth (short trees with small diameters) as stands develop or in adjacent stands (* Note that other nutrients may be limiting crop tree growth as well. Soil and foliage analysis will help with diagnosis).

Indicator plants for CRIFF soil group A, B and C include (may be found on other soils):

- wiregrass,
- pitcher plants,
- St. John's wort,
- saw palmetto,
- gallberry,
- blueberry, and
- runner oak (Jokela and Long 1999)

Table 5. Soil and foliar nutrient guidelines (minimum) for loblolly and slash pine stands.

Stand Parameter	Nutrient				
	N	P	K	Ca	Mg
Surface soil (lb/ac)	--	6-10[a] 10-12[b] 12-16[c] 8-14[d]	--	--	--
Foliage (%)					
Loblolly	1.2	0.12	0.25 - 0.30	0.15	0.08
Slash	1	0.09	0.25 - 0.30	0.1	0.06

Approximate soil P lbs/ac minimum range is based on the [a]Mehlich I , [b]Mehlich II, [c]Mehlich III, [d]Bray P2 procedure. Check with the lab for the soil extraction procedure used. If the soil test P results are expressed in ppm, multiply ppm by 2 to approximate lb/ac. Ballard and Pritchett 1975.
[e]Foliage sufficiency levels from Allen 1987, Jokela 2004

FERTILIZER TYPES AND APPLICATION LEVELS

There are a number of common fertilizer types used in forest fertilization in the southeastern U.S. to rectify a P deficiency at planting. Common phosphorus fertilizers include ground rock phosphate (GRP, 11-18 percent elemental-P), concentrated super phosphate (CSP, 20 percent elemental-P also called triple super phosphate TSP) and normal super phosphate (9 percent P). Many of the phosphorus only fertilizers (TSP, GRP, CSP) are currently (as of December 2009 through November 2021) not widely available in the southeastern United States. Check with your fertilizer dealer or applicators for TSP or other straight P fertilizer material availability. Diammonium phosphate (DAP) has both N (18 percent) and P (20 percent elemental-P) in the fertilizer. Monoammonium phosphate (MAP) also has both N (11 percent) and P (21 to 24 percent elemental-P). DAP and MAP often have lower application costs because a smaller amount of fertilizer is needed per acre to meet target P levels. Fertilization using the above fertilizer materials can be done any time of the year. Historically the target application levels for P at planting have been 25 to 50 lbs/ac of elemental- P. Using 40 lbs/ac elemental-P as a target rate, this would equate to 200 lbs/ac DAP, 200 lbs/ac TSP, 175 lbs/ac MAP, 270 lbs/ac GRP, or 445 lbs/ac normal super phosphate. Using 25 lbs/ac elemental-P as a target application level, this would equate to 125 ls/ac DAP, 125 lbs/ac TSP, 110 lbs/ac MAP, 170 lbs/ac GRP, and 280 lbs/ac normal super phosphate.

STEPS TO DETERMINE IF A SITE MEETS P DEFICIENCY CRITERIA

- Obtain a Natural Resource Conservation Service (NRCS) county soil survey map where your stands are located either from your County NRCS office or from the web (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). Delineate the stand(s) in question on the soils map. Using the soil series symbols on the map and key in the NRCS County soil survey; list the soil series and cross-check with those soils listed in Tables 2, 3, and 4. If greater than 50 to 60 percent of the soils mapped on your site are found in Tables 2, 3, or 4 then chances are likely that loblolly or slash pine will respond to P fertilization at planting.

- If possible, verify the soils present on the site in question with help from a NRCS soil mapper or other competent soil mapper. NRCS soil surveys are not always 100 percent correct, so verification can be valuable. Soil augering to at least 60” in several locations within each candidate stand will help verify the probability of response to P at planting.

- Take at least 3 composite soil samples per stand (20 to 40 acres). Perform as described earlier.

- Take at least 3 composite foliage samples per stand (20 to 40 acres). Perform as mentioned earlier.

P FERTILIZATION DECISION MAKING

If > 60 to 70 percent of stand’s soils are CRIFF group A, B, or C and, soil test P < 6 to 10 lbs per acre (Mehlich I procedure used at UGA) and, foliar P < 0.12 percent (loblolly) or 0.09 percent (slash) from present stand, adjacent stand (same soils and management history) or current seedlings/saplings, then fertilization may be necessary. Fertilize with 125 to 250 lbs triple super phosphate (when available) per acre (broadcast rate) either pre-plant or soon after planting. Diammonium phosphate (DAP), MAP, GRP, or other P or N+P fertilizer materials can be used targeting application rates of 25 to 50 lbs elemental P per acre (58 to 115 lbs/ac P_2O_5).

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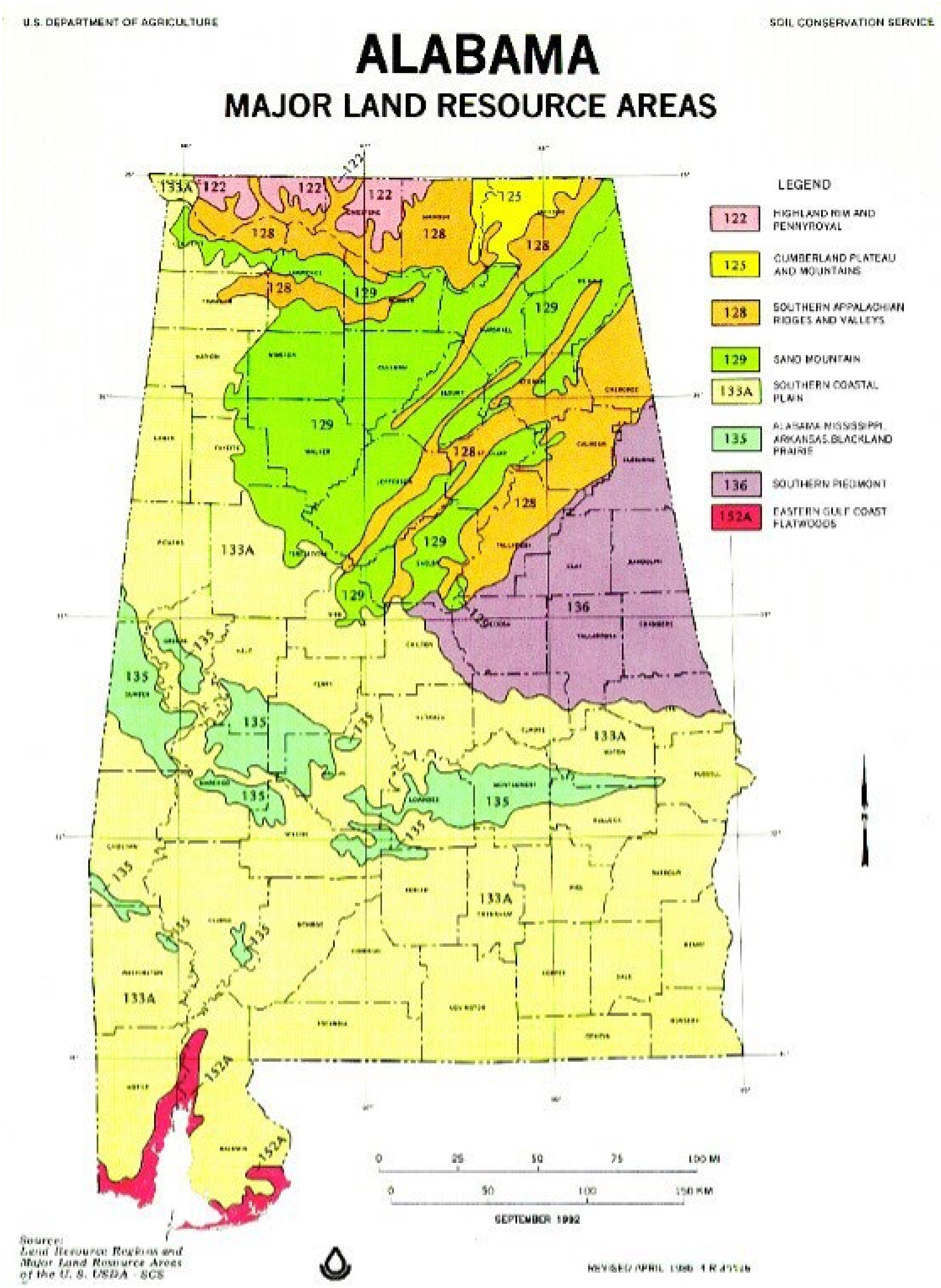

Figure 1: *USDA NRCS map of the major land resource areas (MLRAs) for Alabama. The Gulf Coast Flatwoods region is noted by number 152A.*

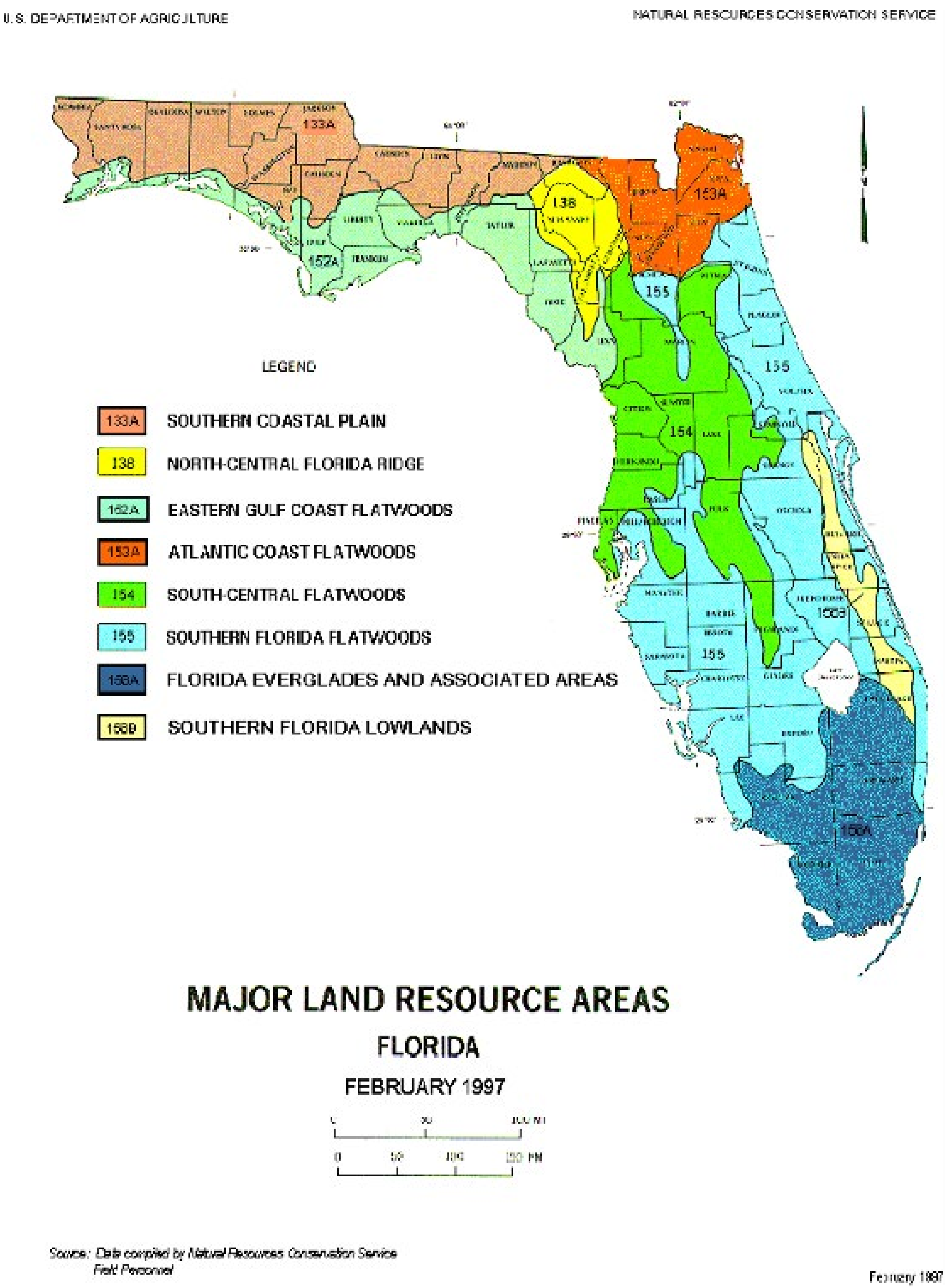

Figure 2: *USDA NRCS map of the major land resource areas (MLRAs) for Florida. The Flatwoods regions in Florida are noted by numbers 152A (Eastern Gulf Coast Flatwoods), 153A (Atlantic Coast Flatwoods), 154 (South-Central Flatwoods), and 155 (Southern Florida Flatwoods).*

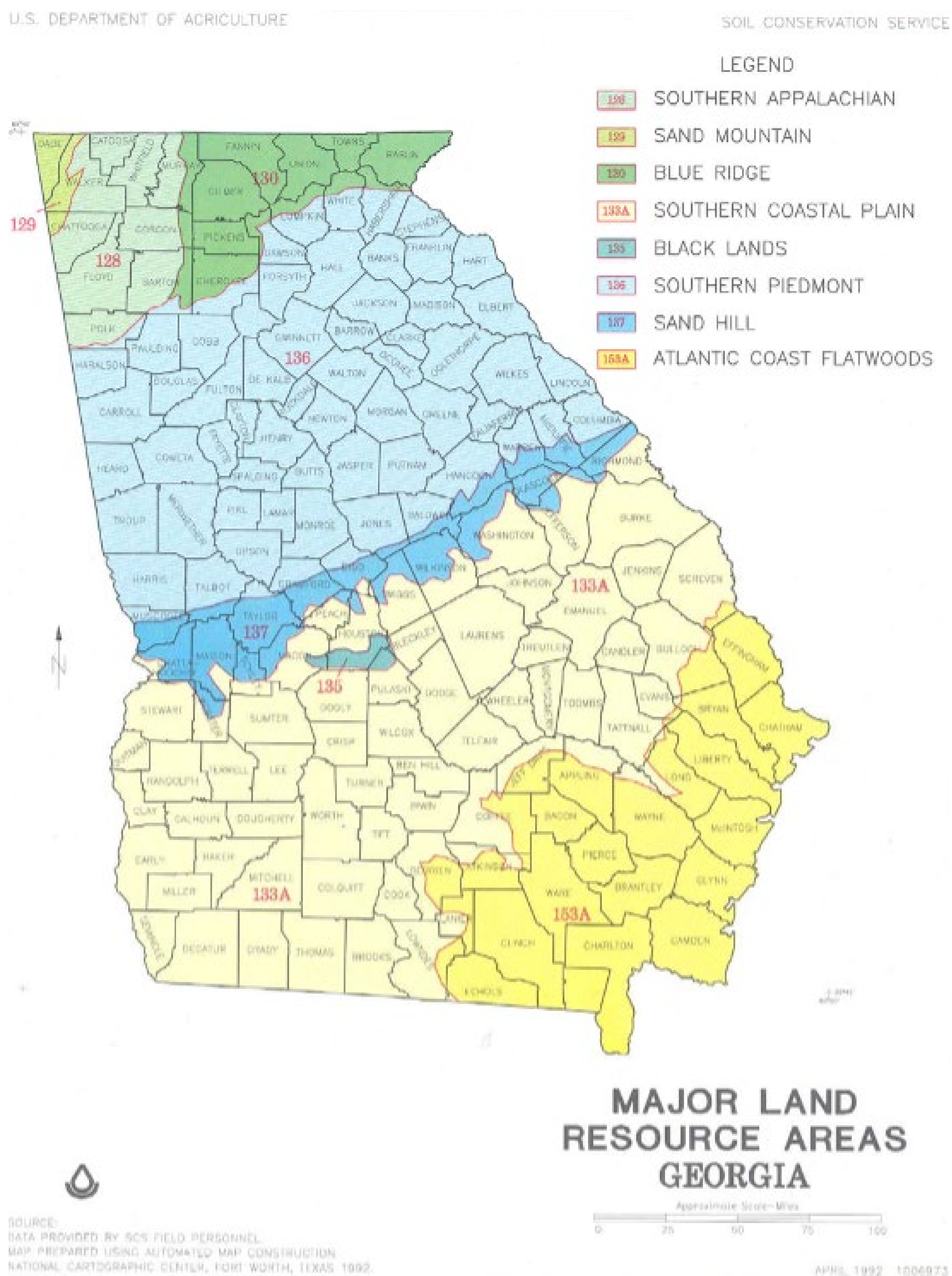

Figure 3: *USDA NRCS map of the major land resource areas (MLRAs) for Georgia. The Flatwoods region is noted by number 153A (Atlantic Coast Flatwoods).*

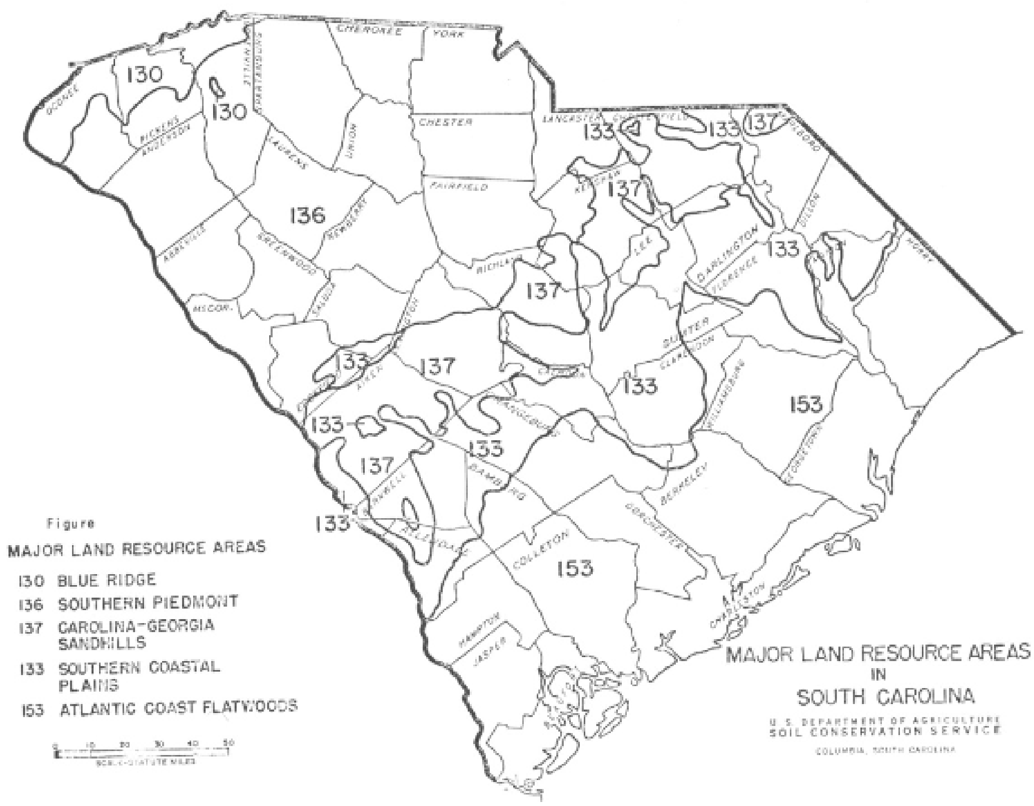

Figure 4: *USDA NRCS map of the major land resource areas (MLRAs) for South Carolina. The Flatwoods region is noted by number 153 (Atlantic Coast Flatwoods).*

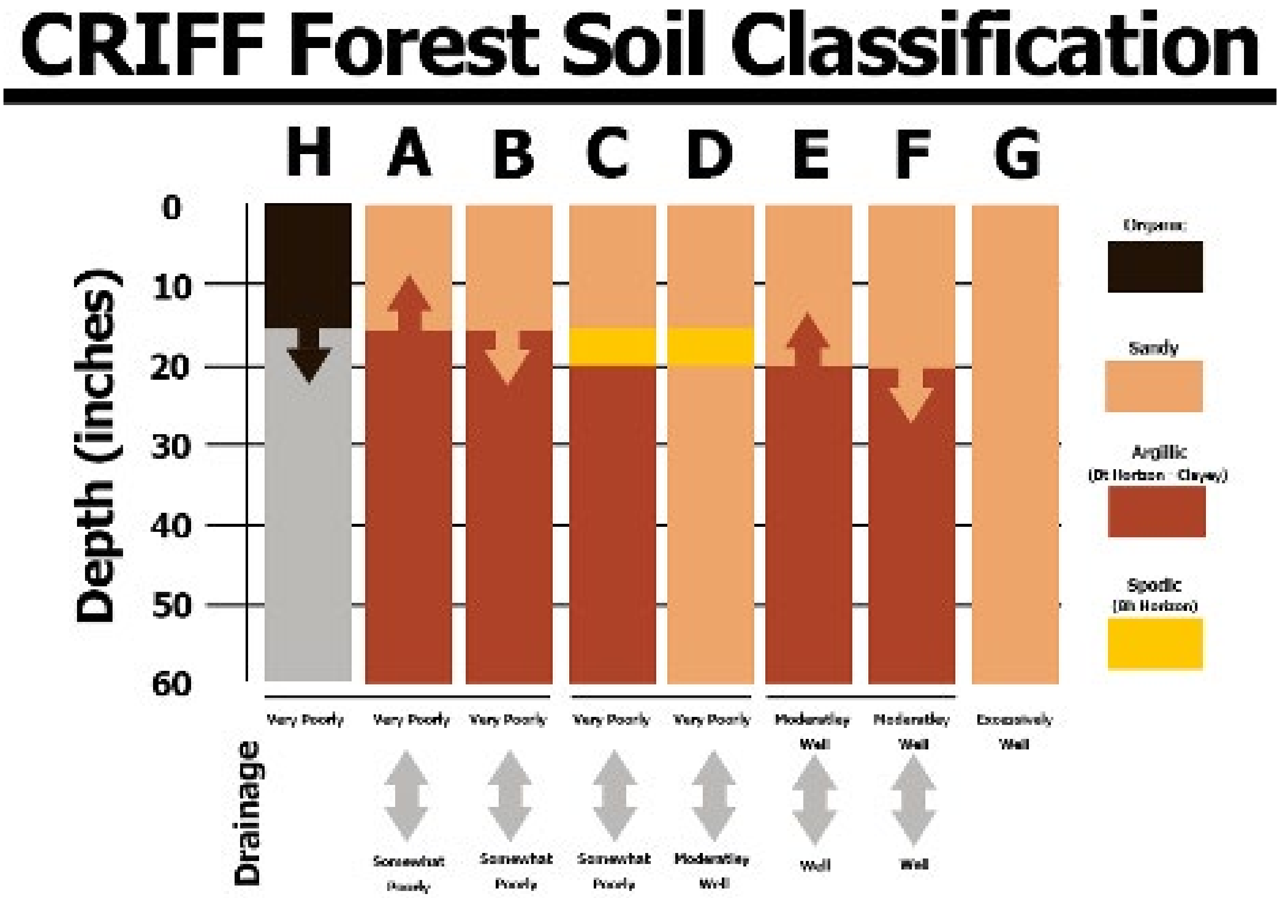

Figure 5: *A soil classification system developed by the University of Florida Cooperative Research in Forest Fertilization (CRIFF) as an aid in determining fertilization requirements in the Atlantic and Gulf Coastal Plain (Pritchett and Comerford 1983).*

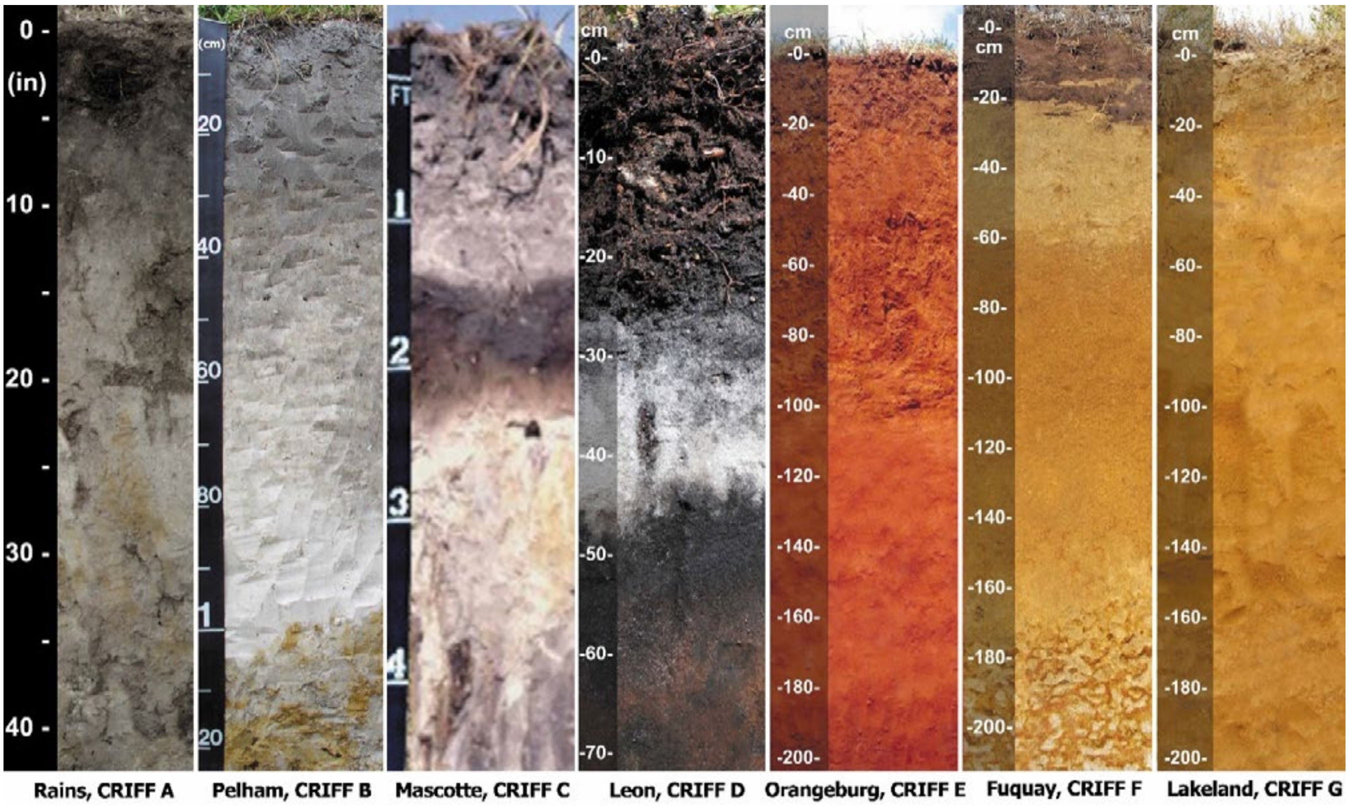

Figure 6: *Soil profiles of Coastal Plain soil series representing CRIFF groups. Rains and Pelham are poorly drained (PD) soil series; Rains has an increase in clay within 20 inches, and Pelham has an increase in clay between 20 and 40 inches. The Mascotte series is very poorly (VPD) or poorly drained and has a spodic horizon. Mascotte has an increase in clay (Bt) within the profile.*

Picture 1: *Flat planted loblolly pine @ age 16-years-old (Herbicide site prep only, no bedding, no phosphorus) on a poorly drained Bladen soil in Berkeley County, South Carolina. Trees are 2-3 inches dbh (diameter @ 4 ½ feet above groundline) and 15-20 feet in height.*

Picture 2: *Flat planted loblolly pine with 80 lbs elemental-P/ac (184 lbs P_2O_5/ac) broadcast applied pre-plant @ age 16-years-old on a poorly drained Bladen soil in Berkeley County, South Carolina. Trees are 6-8 inches dbh (diameter @ 4.5 feet above groundline) and 45-50 feet tall.*

Picture 3: *Bedded and phosphorus fertilized with 80 lbs elemental-P/ac (184 lbs P_2O_5/ac) broadcast applied pre-plant @ age 16-years-old on a poorly drained Bladen soil in Berkeley County, South Carolina. Trees are 8-11 inches dbh (diameter @ 4.5 feet above groundline or dbh) and 50-55 feet tall.*

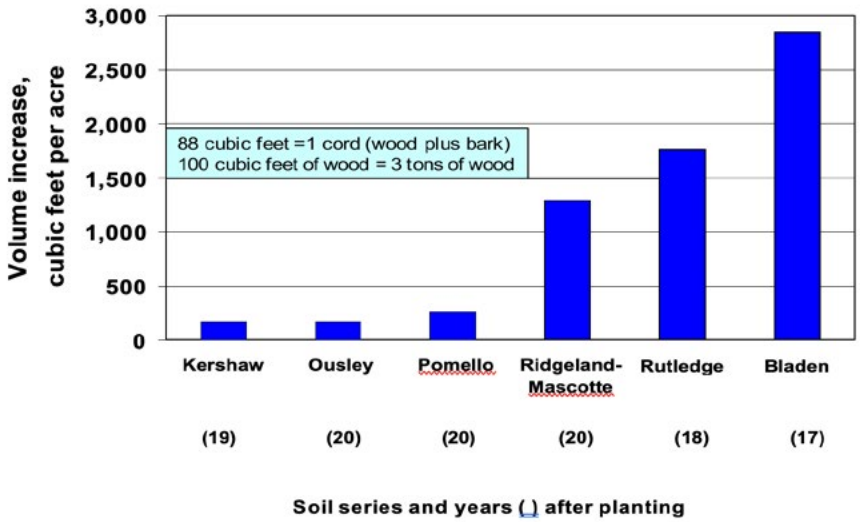

Figure 7: *Slash pine volume response increase to phosphorus (P) fertilization (@ 80 lbs P_2O_5/ac) at planting compared to no P at planting (Pritchett and Comerford 1982). Soils were low in available-P ranging from excessively well drained (Kershaw) to poorly drained (Mascotte- Ridgeland CRIFF soil group C/D, Rutledge CRIFF group B and Bladen CRIFF soil group A).*

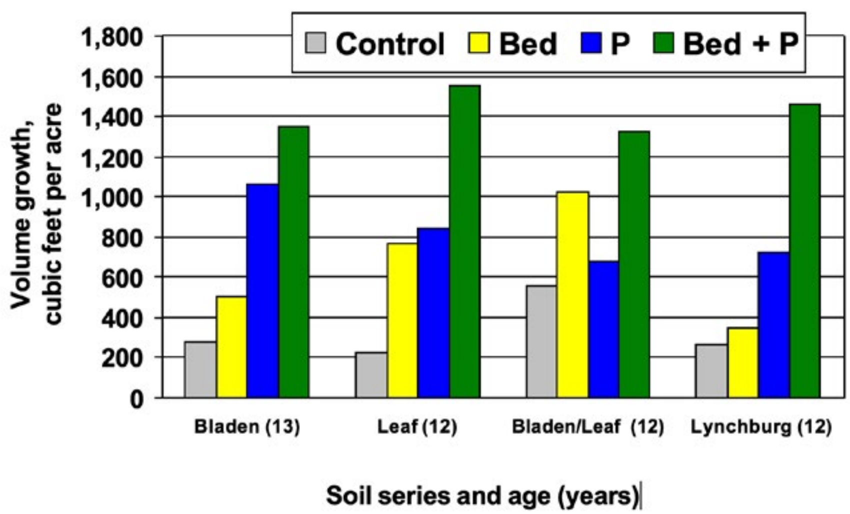

Figure 8: *Loblolly pine response to bedding, phosphorus (@ 138 lbs P_2O_5/ac) only, and bedding plus phosphorus (P) on low soil P, somewhat poorly to poorly drained Flatwoods soils (Gent and others 1986) compared to no bedding or phosphorus (control treatment).*