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A Loblolly Pine Management Guide

When and Where to Apply Fertilizer

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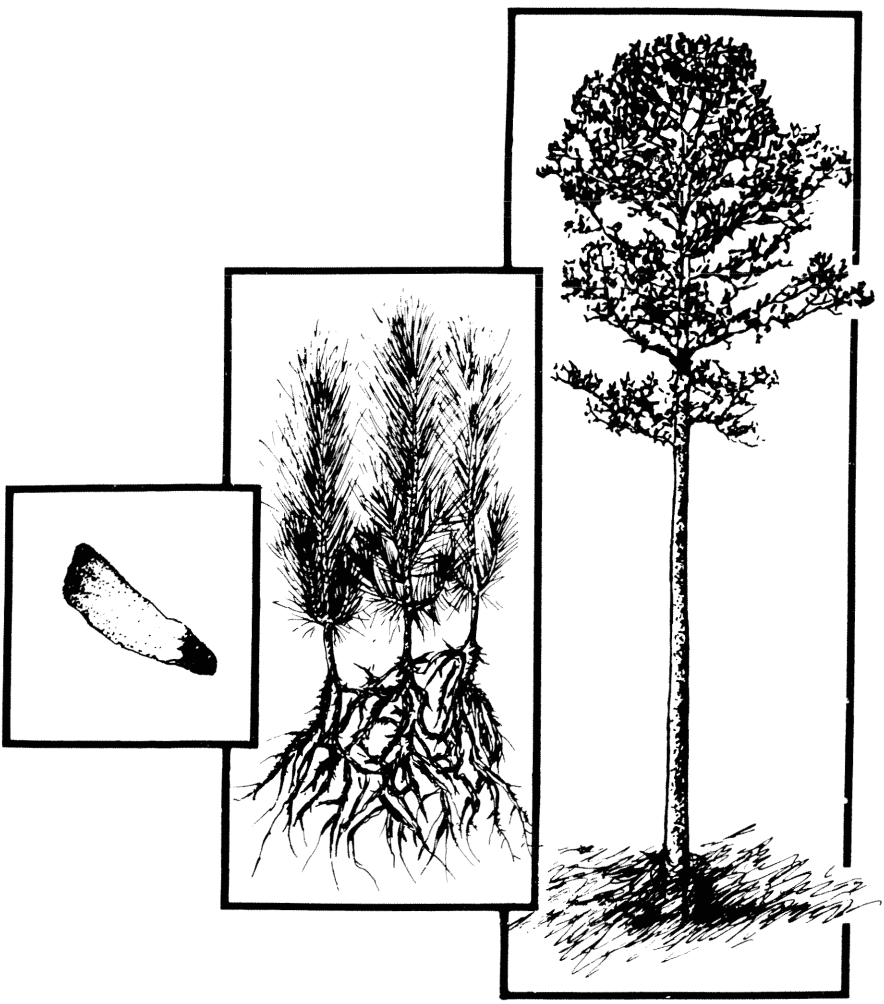

When and Where to Apply Fertilizer

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KEY POINTS

- If you are growing loblolly pine in plantations and you are looking for attractive investments in increased wood production, consider forest fertilization.

- Planning for fertilization requires months of lead time to obtain soils information, to take foliage samples, and to have them analyzed.

- Results of foliar analysis are key indicators of needs for soil nutrients, and special procedure for collecting foliage samples must be followed. If a regeneration cut is planned, foliage samples can be taken from the stand before harvest to determine the need for phosphorus application before a new stand is planted.

- Applying 50 pounds of phosphorus per acre increases loblolly pine site index (age 25) by 10 to 15 feet on typical very poorly, poorly, and somewhat poorly drained soils on the Lower Coastal Plain.

- A needle phosphorus content of less than 0.10 percent indicates a need for soil phosphorus. The growth response to phosphorus fertilization increases as the needle phosphorus content without fertilization decreases from 0.10 to 0.06 percent.

- In well-stocked (but not overstocked) stands, 5-year volume increment can be increased by 200 to 300 cubic feet per acre by applying 150 pounds of nitrogen per acre, plus 25 pounds of phosphorus per acre if both are needed.

- Responses to nitrogen fertilization are best on soils where nutrient supplies are limiting growth but moisture conditions are favorable. Highly responsive stands have basal areas of 70 to 120 square feet per acre, foliar nitrogen contents less than 1.2 percent, and site indexes (age 25) between 50 and 75 feet.

- In selected stands, investments in forest fertilization can be expected to yield returns of 10 to 28 percent if increases in product value are taken into account.

The notion of improving plant growth by increasing the supplies of soil nutrients is very old, but its application in the forests of the Southern United States is rather new. In principle, fertilizer application improves growth if the nutrients that are applied were sufficiently scarce to limit plant growth. In practice, fertilizer application is profitable if the improvement in growth more than pays the costs of treatment. Research results in recent years show that fertilizing loblolly pine stands can often be profitable, and available records show that fertilizer had been applied to some 875,000 acres of loblolly pine by 1982. The trick for a forest manager is to determine when and where opportunities to profitably fertilize exist. This guide is meant to assist in that process.

Promising Research Results

The first formal studies of forest fertilization in the Southeastern United States were with phosphorus (P) on slash pine in 1945, and with nitrogen (N) and phosphorus on loblolly pine in the 1950's. Large increases in growth were observed when phosphorus was applied to wet, phosphorus-deficient soils of the Lower Coastal Plain. Benefits from N application were also observed, but the results were not as spectacular as those from P. These early results led to the formation of cooperatives at the University of Florida and at North Carolina State University to work with forest industry in the development of forest fertilization technology.

The North Carolina State Forest Fertilization Cooperative has primarily investigated loblolly pine, the species discussed in this publication. Recommendations presented here are based largely on the results of a large number of fertilizer trials conducted by that cooperative and the Southeastern Forest Experiment Station.

On many wet soils on the Lower Coastal Plain, application of P dramatically improves loblolly pine growth. On three such soils, application of P at 50 pounds per acre at planting time improved loblolly pine growth sufficiently to increase the estimated site index (age 25) by 15 to 17 feet (table 1).

Table 1.--Height, projected site index, and projected yield for loblolly pine on three soils fertilized with 50 pounds of phosphorus per acre and not fertilized

Soil and treatment	Age when measured	Height	Site index (age 25)	Projected volume at--	
				Age 25	Age 40
	Years	- - Feet	- -	Cubic feet per acre	
Leon					
None	9	16	<35	1,500	2,200
50	9	22	50	2,350	3,150
Woodington					
None	13	24	42	1,600	2,600
50	13	34	59	3,600	4,700
Leaf					
None	15	43	67	4,022	4,884
50	15	54	84	6,200	8,000

Among the three soils, the percentage gain in site index was largest on the poorest one, the Leon. The projected volume increases at ages 25 and 40, however, were greater for the Woodington and the Leaf soils, which were of higher quality before treatment. The manager must be concerned primarily with the prospective increase in yield.

Consider the example of the Woodington soil. The estimated increase in volume per acre attributable to P application was 2,000 cubic feet at age 25 and 2,100 cubic feet at age 40. The 1983 cost of 50 pounds of P in triple superphosphate (TSP) was about $23, and the cost of application was about $10 per acre. On most soils, 50 pounds per acre are sufficient for a 40-year rotation. Thus, an investment of $33 per acre can yield 22 cords per acre of additional wood at age 25, or 23 cords of additional wood at age 40. Recall too that much of that additional wood harvested at age 40 will be sawtimber.

The poorly drained Leon and Woodington soils were bedded but not ditch-drained. These and other examples have convinced us that many wet sites which are borderline for commercial production of loblolly pine can be elevated to reasonably good sites by applying P without ditching. The poorly drained Leaf soil was ditched as well as bedded. It was productive without fertilization, but application of P further increased productivity.

Application of N alone and in combination with P has increased growth in established loblolly pine stands throughout the South. Tables 2 and 3 provide some examples of the sorts of responses that have been observed.

Table 2.--Five-year gross volume mean response to fertilizer on 15- to 25-year-old loblolly pine stands in the Lower Coastal Plain, Upper Coastal Plain, and Piedmont

Fertilization treatment (lb/acre)	Lower Coastal Plain (24 studies)	Upper Coastal Plain (28 studies)	Piedmont (49 studies)
	- - - - -	Cubic feet per acre	- - - - -
100 N	147	192	250
50 P	130	33	64
100:50 NP	276	226	239
100:50:50 NPK	247	263	296

In 15- to 25-year-old stands on the Piedmont, N alone produced about the same yield increases as N, P, and K (potassium) together. In 4- to 10-year-old stands in the same region, there was some advantage to adding P along with N (table 3). In the Lower Coastal Plain and to a lesser extent in the Upper Coastal Plain, P mixed with N was beneficial for trees in both age groups.

Table 3.--Eight-year gross volume mean response to nitrogen plus phosphorus in 4- to 10-year-old loblolly pine stands moderately deficient in phosphorus

Fertilization treatment (lb/acre)	Lower Coastal Plain	Upper Coastal Plain	Piedmont
	- - - - - -	Cubic feet per acre	- - - - - -
100 N	22 (9)	54 (13)	189 (16)
100:50 NP	276 (7)	223 (10)	307 (5)

Number of studies indicated in parentheses.

Growth rates in areas fertilized with N generally return to prefertilized levels in 5 to 8 years. In the interim, effects amount to an acceleration of stand development. Results of many studies show that N fertilization advances stand development by changing diameter distributions, mortality, and dominant heights. The average advance in stand development from 100 to 150 pounds per acre of N is equivalent to almost 1 year in the 5 years after application. More responsive stands gain considerably more than the average. Consideration of stand development is important because volume added to large trees is more valuable than that added to smaller ones, and fertilization increases growth of large trees more than smaller ones in a stand.

Reliable data on growth responses of stands over age 25 come from only seven studies--two in the Lower Coastal Plain, one in the Upper Coastal Plain, and four in the Piedmont. The 5-year volume increases from 100 pounds of N and 50 pounds of P per acre averaged 166 cubic feet per acre for four stands age 26 to 30, and 206 cubic feet per acre for three stands 31 to 36 years old. No increase in diameter growth was detectable 3 years after 200 pounds per acre of N was applied to a stand over 50 years old on a high-quality site on the Piedmont Plateau.

These results indicate a smaller increase in volume after treatment for stands over 25 than for 15- to 25-year-old stands. The greater wood value in trees 25 to 40 years old, however, should make treatment of the older stands cost effective.

Loblolly pine will respond to N applications from the time of planting if competition is controlled, and some very good growth responses have been obtained in 5- to 10-year-old stands. From an economic point of view, however, returns from treatments in young stands are less attractive than those in older stands because investments in young stands must be carried for longer periods.

The only fertilizer elements currently known to produce economically attractive growth increases in loblolly pine are N and P. K, and possibly other elements, limits growth on some sites, but further research will be needed before their application can be recommended.

Determining Fertilizer Needs

The kinds of growth responses we have described, and the attractive investment opportunities they imply, are not available everywhere. The prudent manager must learn to identify the sites where growth responses will be satisfactory.

Money spent on this identification process will be saved many times over by avoiding waste of fertilizer. We recommend foliar analysis for identifying sites to fertilize. Even where such technology is used, the prediction of responses will be less than perfect, but this technology will improve the probability of success.

Phosphorus

The selection of sites for P application should be based on soil type, soil drainage, current tree performance, and foliar tests. Stands on very poorly to somewhat poorly drained clays and sands (Aquults, Aquents, and Aquepts) on the Lower Coastal Plain generally respond well to additions of P. If the stand that is being harvested from such a wet soil has a site index (age 25) below 60 feet or if the existing stand is not vigorous, P fertilization should be considered.

Site identification can be further refined by analyzing sample needles from 1-year-old or older stands. Methods for collecting samples are described later in this publication. The total P concentration in ovendried needles is the best indicator of the need to fertilize. Guidelines for P fertilization based on foliar P concentrations for loblolly pine are:

Percent concentration	Interpretation
<0.10	Deficient, high probability of response
0.10-0.12	Critical range, generally responsive in combination with nitrogen
>0.12	Generally not responsive

Nitrogen (With and Without Phosphorus)

Selection of stands for N application depends on stand stocking and tree size as well as site factors. Stocking must be considered because it determines how fully the stand will utilize the added resource. Tree size is important in determining the economic value of a stand's growth response.

Recognition of stands with N deficiencies from their soil and site characteristics is, at best, inexact. The objective, of course, is to find stands where a lack of N alone or in combination with P is limiting tree growth. There is no point, for example, in adding N to a site where there is not enough soil moisture to permit a large increase in tree growth. Site index can be an indicator of nutrient deficiency, but it integrates other factors as well, including soil moisture and other environmental resources. As with P, we have found that N deficiencies are most reliably determined through foliar analysis.

We have also developed general guidelines for identifying promising sites for N application. With these guidelines, many sites can be categorized as likely to be very responsive, moderately responsive, or weakly responsive:

Very responsive. This category includes sites where insufficient nutrient supplies are limiting growth but moisture availability and other site factors are favorable. Examples include most clayey upland Piedmont soils (e.g., Cecil and Davidson), poorly to moderately drained sandy Coastal Plain soils (e.g., Chipley, Ocilla, and Pactolus), and moderately well-drained soils with relatively deep spodic horizons (e.g., Centenary and Echaw).

Moderately responsive. This group includes a broad range of soil and site conditions typified by moderately well to well-drained upland loamy soils (e.g., Orangeburg, Norfolk, and Ruston). On these sites, insufficient moisture may restrict fertilizer response during some portion of the year.

Weakly responsive. On many sites in this group, nutrient limitations are overshadowed by gross deficiencies in other environmental factors, like moisture availability and soil rooting volume. Many well-drained upland soils must be placed in this category because insufficient moisture will limit response to fertilizer application during most years. Certainly, this condition exists in soils with a sandy surface horizon more than 40 inches deep (e.g., Troup and Lakeland). Rooting volume restrictions occur in soils with thick spodic horizons occurring near the soil surface (e.g., Murville and Lynn Haven) and in soils with shallow bedrock or a fragipan (e.g., Lax and Talladega). Also included in the group of nonresponsive soils must be those that already have sufficient nutrients present. Such sites will normally be the very best--those with site indexes at age 25 of more than 70 feet. Typical members of this group are mineral soils with a thick organic matter accumulation at the surface which have been artificially drained and fertilized with P (e.g., Bayboro and Pantego).

After promising sites have been identified in the way just described, the following guidelines should be used in selecting stands to treat:

1. Stand stocking should be moderate (70-120 square feet per acre of pine basal area).

2. The N concentration of ovendried sample needles should be less than 1.2 percent. If the P concentration is less than 0.12 percent, P should be applied along with N.

3. Treat 5 to 8 years before the planned harvest.

4. The site index for age 25 should be between 50 and 75 feet.

On the sites identified in this manner, N at 150 pounds per acre should be applied. Where P also is needed, apply 25 pounds per acre. At least 75 percent of the stands identified in the manner described should respond to treatment in an economically attractive way if there is a market for mixed wood products.

The potential for overstocked, stagnated natural stands to respond to fertilization is questionable. If foliar tests in such stands indicate a need, P application may be effective, but N application should probably be delayed until the stand is thinned.

Nitrogen fertilization can be economically attractive in 3- to 10-year-old stands in the Lower Coastal Plain if the stand also has severe P deficiency. Where P must be applied, the cost of applying N as well is little more than cost of the additional fertilizer.

Fertilizers and Methods for Applying Them

Inorganic Fertilizers

Phosphorus may be applied as triple superphosphate (TSP) (20 percent P), diammonium phosphate (DAP) (18 percent N, 20 percent P), or fine-ground rock phosphate (GRP) (9 to 13 percent P). The first two are highly soluble, whereas the last is only slowly soluble. Although long-term comparisons on loblolly pine have not been made, TSP and GRP appear to be equally effective. When a source of GRP is nearby, its cost is usually lower per pound of P than is TSP. The cost of applying GRP may be higher, however, because it is harder to spread than TSP and because more of it must be applied to add a given amount of P. DAP is an option where both N and P are needed.

Where a P deficiency has been identified, apply sufficient fertilizer to add 40 to 50 pounds of P per acre. Apply at the time of planting or as soon after as practical. The season of application has no important effect on the pine response. On stands age 3 or older, DAP can be applied to add N as well as P if an N deficiency is suspected. The additional cost of DAP over TSP is relatively small and permits an economical aplication of a small amount of N.

Ammonium nitrate (33 percent N) and urea (46 percent N) are the most common fertilizers used to add N to forest soils. Some of the nitrate N in ammonium nitrate can be lost in leaching if heavy rains follow application. Some ammonium N can be lost from urea as NH_3 gas passed to the atmosphere. Since neither source has proved superior for application to southern pine, the choice should be based on the comparative local costs per unit of N applied.

In general, an application rate of 100 to 150 pounds of N per acre is likely to be most attractive economically. Additional growth stimulation can be achieved by applying 200 to 250 pounds of N per acre, but that additional growth is seldom sufficient to justify the cost of applying the additional 100 pounds of N.

Several application methods have been successful in the South. P has been broadcast before disking or bedding, banded prior to bedding and incorporated into the soil during bedding, and broadcast from the air or ground or sidedressed after planting. Since no consistent difference in growth has been associated with the method of application, the cheapest method with the equipment at hand should be favored.

Nitrogen has been applied from helicopters and fixed-wing aircraft with good success. Where ground equipment can be used, however, ground application is probably cheaper.

Sewage Sludge

Sewage sludge is often an effective source of N, P, and other elements for trees. In 8- and 27-year-old loblolly pine stands, 400 pounds per acre of highly available N in sewage sludge has been as effective as commercial fertilizer. A sludge in which the N was in a less available form produced a smaller immediate growth increase when the equivalent of 600 pounds per acre of N was applied. The benefits of this treatment, however, may be expressed for a longer period. That study is still in progress.

There are several important factors to consider when application of sewage sludge is contemplated. First, the cost of the material is likely to be low, but the cost of application may be quite high. Second, sludges vary widely in their contents. The candidate material must be carefully analyzed, and pilot tests of its effects are advisable before large-scale applications are begun. Finally, the approval of health authorities is required in most States before sewage sludge can be applied.

Nitrogen-Fixing Plants

The culture of nitrogen-fixing plants in forests may be considered an indirect form of N fertilization. Leguminous plants established in loblolly pine plantations at planting or 1 to 2 years after planting add several hundred pounds of N per acre to the soil before they are shaded out by the pine. Growth increases of loblolly pine have been observed 3 or 4 years after the planting of lespedeza species in young stands. The duration of the increases is not yet known, and the technology for use of nitrogen-fixing plants in forestry is still being developed. Use of such plants is promising, but only pilot testing is recommended before attempting a large project.

Fire and Fertilization

Burning should be avoided in loblolly pine stands immediately before and for a few years after N applications. Although little research has been done on effects of fire on fertilization results, some general effects are known. If urea is applied over the alkaline ash that is present for a few months after a fire, some of the fertilizer N will be lost to the atmosphere as ammonia. Furthermore, burning within 3 to 4 years after N application is likely to volatilize N from whatever fertilizer still remains and from the nitrogen-rich litterfall that follows fetilization. To avoid such losses, avoid burning for 6 months prior to application and for 4 years after application of N fertilizer.

Environmental and Other Side Effects

Forests produce more than trees, and foresters will want to know the effects of fertilizing on the entire forest ecosystem. Perhaps the largest current concerns are with water quality. Results from the Piedmont and Coastal Plain show little or no measurable increases in N or P in streams after fertilization of pine stands. Increases do occur when fertilizer inadvertently falls on open water, but movement from the land to the water appears to be slow and small. When parts of watersheds have been fertililzed, applying material only where it is needed, no changes in water qualilty have been detected.

Fertilizing loblolly pine increases growth of understory plants, adding soil protection and improving wildlife habitat. Specific data for these benefits are lacking, but the increase in understory growth is easily observed. Fertilizing increases the nutritional content as well as the volume of understory plants, making them more valuable as wildlife food. Particularly on phosphorus-deficient soils, application of fertilizer can be expected to significantly improve deer habitat.

Loblolly pine is relatively efficient at taking up nutrients that are in short supply. It survives in soils that are too deficient in nutrients for survival of many native species. Thus, applying fertilizer to such soils in sufficient quantitites to improve pine growth can be expected to benefit other plant species even more.

Increases in severity of fusiform rust have been reported in loblolly pine stands fertilized at the time of planting. The increases, however, do not appear to have been sufficient to negate the benefits of fertilizing.

Nitrogen fertilizing of pine increases foliage and branch weights. In stands that have recently been thinned to correct severe overstocking, the additional branch and foliage weights may increase the risk of ice breakage. This risk can be reduced by thinning before overstocking becomes severe, and by delaying fertilization for a year or two after thinning.

Foliage Sampling

The recommendations presented in these guidelines cannot be followed without the results of foliar analyses. In this respect, fertilizer prescriptions in forestry differ from those in agriculture, where prescriptions are usually based on soil analyses. Efforts are underway to arrange for reliable, low-cost foliar analyses for forestry.

A separate foliage sample is required for each unit that differs appreciably in soil type or stand growth. If both soil and foliage samples are being collected, they should represent the same management units or areas. Low concentrations of available phosphorus in soil tests are not reliable indicators of the need for P, but high test values show phosphatic or highly fertilized soils and rule out the need of fertilization.

Needles are easy to remove from seedlings and saplings, but special equipment is needed for larger trees. Pole pruners are useful in collecting needles from trees up to about 35 feet tall. A gun is best for sampling foliage in taller trees. A 12-gauge shotgun on full choke does the job quite well when loaded with number 4 shot.

The foliage sample for each area or unit should be a composite collected from a minimum of 15 (and preferably more) dominant and codominant trees selected at random from the area. For experimental plots (0.05 to 0.25 acres), a composite sample from 7 to 10 trees is usually adequate.

Four rules must be followed:

1. Collect samples in December through March.

2. Collect a primary lateral branch from the upper one-half of the dominant or codominant tree. At the point of collection, the crown should be essentially free of competition for light.

3. Take needles only from the first flush of growth from the previous

growing season on the primary lateral branch. The needles should be representative of the upper crown and largely free of disease or insect damage. The first flush is usually the largest, and it often follows a small flush of short needles (fig. 1).

4. Carefully label the samples to be sure you know what area they came from.

The composite sample sent to the laboratory should consist of at least 200 needle fascicles that are free of soil and other contamination.

Within 12 hours of collection, the samples must be refrigerated, stored on ice, or placed in a drier. Dried samples are preferable for transporting to the laboratory. Drying is best done in a forced-air oven at temperature of 140 to 160 °F, (60 to 70 °C) for 24 to 28 hours.

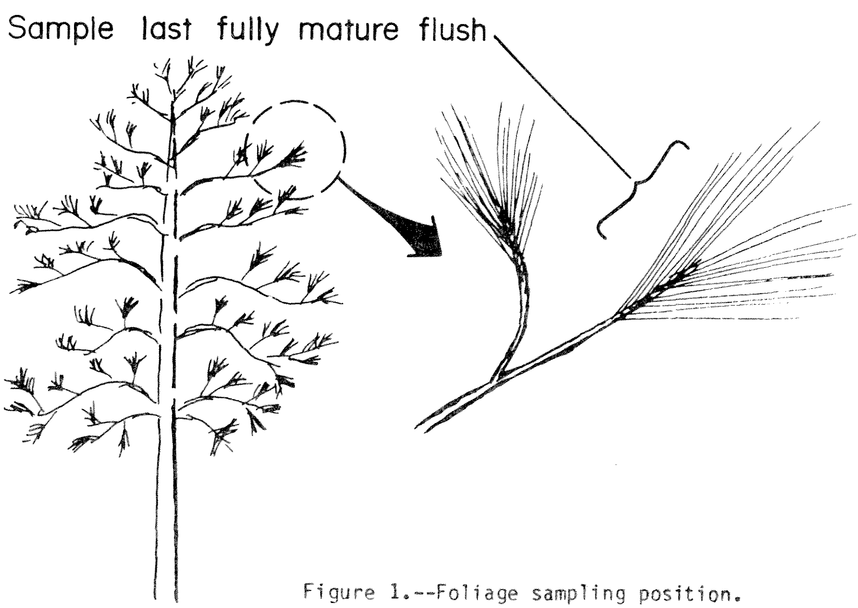

Figure 1.--Foliage sampling position.

Economics of Forest Fertilization

There is nothing unique about forest fertilization as a business investment. Even the uncertainty of yield increase is common with other practices. Fertilization involves the outlay of cash today with the expectation of generating a return over and above cost at some point in the future. Forest fertilization must compete successfully for funds that can be invested in other ways. Computation of the return on investment (ROI) is one way to compare forest fertilization with other investment opportunities. That procedure has been followed in the examples provided here.

In the simple cash-flow patterns typical of forest fertilization, ROI can be interpreted as the earning rate for invested capital after taxes are taken into account.

We present two examples to illustrate the economic returns from fertilization. One is for P application at planting or a few years thereafter. The second is for application of N and P at stand age 20. There is no thinning, and the stands are clearcut at age 25. These examples were selected because experimental data were available to estimate the changes in yield associated with the treatments.

In taxing timber income, fertilization costs may be capitalized, expensed, or amortized upon negotiation with the Internal Revenue Service. In our examples, the cost of fertilizing at planting time was capitalized, and the cost of fertilizing 5 years before harvest was amortized over the 5-year period. These choices were arbitrary and do not represent recommendations of costing procedures.

In addition to tax treatment, four other factors--product mix, stumpage prices, treatment costs, and growth responses--are important in determining the profitability of a fertilizing operation.

In our analysis, the product mix included pulpwood (to a 4-inch top), chip'n'saw wood (to a 6-inch top), and saw logs (to a 9-inch top). Stumpage prices were $15 per cord for pulpwood, $40 per cord for chip'n'saw wood, and $150 per thousand board feet for saw logs. It was assumed that stumpage prices would increase at a real rate of 2 percent a year. On a high site (70 feet at age 25), 10 to 15 percent of the volume would be in saw logs, 55 percent in chip'n'saw wood, and the remainder in pulpwood.

Costs for the fertilizer and its application were assumed to be $30 per acre for applying 40 pounds P at planting and $60 per acre for applying 150 pounds N and 50 pounds P 5 years before harvest.

Applying Phosphorus at Planting

Responses to P application at planting time were estimated by projecting volume and value gains over a 25-year rotation where site index (25 years) was improved by 5, 10, and 15 feet. Volume gains for these improvements were estimated over a range in initial site indexes for unthinned loblolly pine plantations. A planting density of 700 trees per acre was assumed. Volume gains are presented in table 4, and after-tax ROI in table 5.

The long-term improvements in site make fertilizing of phosphorus-deficient soils economically attractive. Estimated ROI ranges from 9.0 to 15.6 percent. These estimates are probably conservative because they do not reflect the increased opportunities for midrotation thinning to increase cash flow or for N fertilization to increase final yields.

Table 4.--Volume gains over a 25-year rotation in unthinned stands where phosphorus fertilization increases 25-year site index by 5, 10, and 15 feet

Initial 25-year site index (feet)	Site index improvement		
	5 feet	10 feet	15 feet
	- - - - - Cubic feet per acre - - - - -		
45	510	1,053	1,625
50	543	1,115	1,701
55	572	1,158	1,752
60	586	1,180	1,772
65	594	1,186	1,769
70	592	1,176	1,746

Table 5.--After-tax returns on investments over a 25-year rotation in unthinned stands where phosphorus fertilization increases 25-year site index by 5, 10, and 15 feet

Initial 25-year site index (feet)	Site index improvement		
	5 feet	10 feet	15 feet
	- - - - - - - - Percent - - - - - - -		
45	9.0	12.3	14.3
50	9.5	12.7	14.7
55	9.9	13.1	15.1
60	10.2	13.4	15.3
65	10.4	13.6	15.5
70	10.6	13.7	15.6

Preharvest Fertilization

Responses to fertilizing 5 years before harvest were based on estimated changes in stand diameter distribution after the application of 100 pounds N and 50 pounds P per acre. The 5-year volume increases on moderately responsive sites were estimated for a range of initial stand densities and site indexes (fig. 2). Value and ROI estimates (table 6) were calculated assuming that the volume and value gains would be obtained at the end of the 5-year response period.

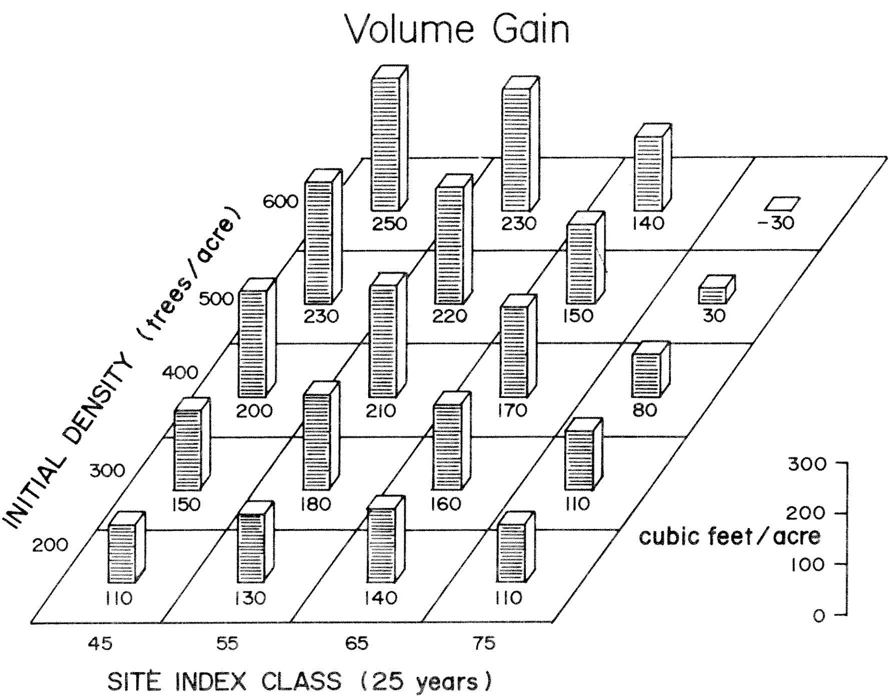

Figure 2.--Five-year volume response to application of 100 pounds nitrogen and 50 pounds phosphorus per acre in unthinned loblolly pine stands at age 20.

Table 6.--After-tax returns on investment for costs amortized over 5 years with merchandised volume gains from N + P fertilizer response (as per figure 3)

Initial density (trees/acre)	Site index class (25-year)			
	45	55	65	75
	----- Percent -----			
600	13.9	17.3	12.8	0.1
500	12.4	16.3	13.9	5.6
400	10.1	14.9	14.2	5.6
300	6.8	12.2	12.9	8.8
200	1.8	7.6	9.6	8.7

Although the volume gains are relatively modest (about 240 cubic feet per acre), they combine with shifts in diameter distribution toward larger trees to produce attractive ROI. The estimated ROI values range up to 17.3 percent, and the values shown in table 6 are quite conservative for several reasons. First, the growth increases are based on observed responses to 100 pounds N and 50 pounds P, while the treatment costs are based on application of 150 pounds N and 50 pounds P. A few studies indicate that it is advisable to apply 150 pounds N, but growth data are insufficient to reliably estimate the response to the additional N. Second, the growth responses indicated can be obtained on many sites by applying N alone. Third, expensing of the fertilizer cost would have increased the ROI values.

The conservative procedures we followed in the economic analyses leave little doubt about one primary conclusion: Fertilization provides very attractive investment opportunities for managers of loblolly pine forests. Fertilization also offers strategic opportunities to increase supplies of southern pine--a major objective of forest products manufacturers who grow much of the timber they process. As prescription technology is more finely tuned, risks associated with fertilizer application will be reduced and financial returns will become even more attractive.

Additional Readings

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KEYWORDS: *Pinus taeda*, economic returns, nitrogen, phosphorus, foliage analysis.

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