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ABSTRACT

Plots in seven eastern white pine sawlog stands were treated with nitrogen at rates of 0, 56, 112, and 224 kg/ha. After four years the largest increase in basal area growth, 0.31 dm^2/tree, and volume growth, 13.0 m^3/ha, occurred in plots that received 112 kg/ha. It appears that an application rate of 112 kg/ha may provide a real return of 15 percent or more in some stands.

INTRODUCTION

Eastern white pine (*Pinus strobus* L.) is the most valuable conifer in the Northeast. However, the most recent forest survey of Maine (13) revealed that the area in white pine sapling and seedling stands decreased from 150,000 ha in 1971 to 25,000 ha in 1982. Thus, it may be desirable to increase growth in some sawlog stands while efforts to increase white pine regeneration and to reduce hardwood competition in younger stands are intensified. Fertilization may offer potential as a way to increase growth of managed white pine sawlog stands on nutrient deficient sites.

Little is known about the response of eastern white pine to fertilization. Stratton *et al.* (17) reported that 112 kg of potassium/ha increased basal area growth of a white pine plantation on a loamy sand in southwestern Maine by 50 percent. Nitrogen at rates of 22, 67, and 112 kg/ha did not stimulate growth, however, possibly because application rates were too low. A second plantation on a sandy loam did not respond to applications of either potassium or nitrogen. A natural white pine stand on a sandy loam in central New Hampshire responded to a combination of nitrogen (224 kg/ha) and phosphorus (28 kg/ha) but not to either nutrient alone (8). Schomaker (15) found many white pine stands in southern Maine to be deficient in nitrogen and concluded that these stands should respond to nitrogen fertilization.

In 1979 a study was initiated to test the effect of fertilization on the growth of white pine in Maine and to determine if fertilization may be an economically attractive management tool in white pine stands. Emphasis was placed on nitrogen, because it is the nutrient most frequently limiting to growth of conifer stands in the Northeast (5). This report presents growth information from the first seven sawlog stands to have completed four growing seasons since treatment with different rates of nitrogen. Also presented are estimates of the financial return that might have been earned by fertilizing these stands, given different costs and stumpage prices.

METHODS

Field Procedures

Four sawlog stands were selected for study in western Maine in 1979, and three were selected in central Maine in 1980. Three of the western Maine stands are on somewhat-excessively and excessively drained loamy sands (Adams and Colton series—sandy, mixed, frigid Typic Haplorthod and sandy-skeletal, mixed, frigid Typic Haplorthod) and one is on a moderately well-drained, fine sandy loam (Skerry series—coarse-loamy, mixed frigid Aquic Fragiorthod). The central Maine stands are on a well-drained fine sandy loam (Peru series—coarse-loamy, mixed, frigid Aquic Fragiorthod). The site index for white pine on Adams and Colton soils is about 18 m and on the Skerry and Peru soils about 21 m at age 50 (1, 3).

Plots were established in September of the respective years. Plot size varied among stands, ranging from 0.04 to 0.10 ha; all plots in any given stand were the same size. All trees were numbered and marked at breast height, and dbh was measured.

Average dbh of sawlog trees in the western Maine stands was 32.3 cm, and in the central Maine stands average dbh was 31.5 cm. Sawlog trees comprised at least 80 percent of the stems in all stands. Basal area averaged 26.4 m^2/ha in the western Maine stands and 37.2 m^2/ha in the central Maine stands.

Treatments were applied to plots in the western Maine stands in May, 1980, and to plots in the central Maine stands in May, 1981. Four rates of nitrogen (N)–0 (0N), 56 (56N), 112 (112N), and 224 (224N) kg/ha–were used. The fertilizer was applied to the entire measurement plot and outward to a distance of 1.5 m beyond the plot perimeter. Urea was the source of N. In addition, phosphorus, potassium and combination treatments were also applied to plots in each stand but produced no consistent response and are not discussed in this report. Each treatment was applied to one plot per stand. Dbh of all trees was remeasured two and four growing seasons after treatment.

Analytical Procedures

Statistical Analysis

Analysis of covariance was used to predict basal area growth for the first and second two-year growth periods. Pretreatment individual tree basal area was used as a covariate, and individual tree basal area growth for the first two years was added as a covariate to predict growth for the second two years. (Basal area/ha was also tested as a covariate, but proved nonsignificant). Interactions among the stands, treatments, and the covariate were tested. A spline variable was included in the analysis to provide a smooth join point for the intersection between the end of the first growth period and the beginning of the second.

Two predictive equations were used to estimate individual tree basal area growth for the four-year study period. The first equation predicted tree growth for the first two years, based on stand and individual tree parameters. The second equation predicted growth for the second two years using the same stand and individual tree parameters plus the estimated growth for the first two years of the study. For example, at an application rate of 112N (N), the equations for basal area growth/tree in any given stand (Stand) for the first (Stand (1)) and second (Stand (2)) two-year periods are:

1. BA Growth = N + Pretreatment BA + Stand (1) + Stand (1) x Pretreatment BA + Stand (1) x N + Pretreatment BA x N.
2. BA Growth = N + First two-year BA growth + Stand (2) + Stand (2) x First two-Year BA growth + Stand (2) x N + First two-year BA growth x N.

The value of N is the same in all stands and for both two-year periods.

The values for Stand are specific to a given stand and are not the same in both two-year periods.

Basal Area Comparisons

Basal area growth comparisons among treatments and between western and central Maine were made using a 33-cm-dbh tree. Across all stands the average dbh of sawlog trees was approximately 33 cm. The tree of average dbh for each stand was not used in the comparisons, because this might have made the effect of fertilization appear greater in stands of larger average dbh.

Volume Comparisons

Volume comparisons among stands and treatments were also made using a 33-cm-dbh tree. Assuming all trees were 33 cm in dbh, the number of 33- cm-dbh trees/ha in each stand was estimated by dividing basal area/ha by the basal area of a 33-cm-dbh tree. Volume (Maine Rule) was estimated from the basal area increase, which was converted to a dbh increase, and the average height of a 33-cm-dbh tree, approximately 24 m. Young's (19) volume tables were used. Fertilization has little effect on height growth of mature trees, and it was assumed that height growth of treated and untreated trees during the post treatment period was essentially the same.

Rate of Return Estimation

Real rates of return were estimated for volume gains produced by 112 kg of N/ha. Stumpage prices of $21/m^3$, $19/m^3$, and $17/m^3$ were assumed. The former price is representative of a high value stand and the latter is almost identical to the most common stumpage price for white pine in Maine during 1986

(4). Returns were calculated assuming 0, 1, and 2 percent/year real increases in stumpage price for the four-year post treatment period.

Returns were estimated using fertilization costs of $124 and $100/ha. From 1978 through 1985 the price of N purchased locally as urea remained fairly constant at about $0.70/kg of N. The cost (fertilizer + all costs associated with application) of treating loblolly pine plantations with 168 kg of N/ha by helicopter was reported by the North Carolina State Forest Fertilization Cooperative to be approximately $0.84/kg of N (2). A higher cost of $1.10 per kg of N was used here. This allows $0.40/kg for costs associated with application. This higher cost was used to allow for the greater expense that would likely occur for treatment of natural white pine stands in Maine. The price of N had dropped to about $0.50/kg by June, 1986. Because of this decline in the price of urea, a second fertilization cost, $0.90/kg of N, was also used.

Estimated volume increases were reduced by 20 percent before returns were calculated to allow for possible "growth response falldown" (16). "Growth response falldown" is the phenomenon in which gains in growth realized from operational fertilization programs are frequently less than estimates of growth increases based on results from experimental plots. "Growth response falldown" occurs primarily for two reasons. First, experimental plots are treated by hand, whereas operational fertilization is normally done by helicopter. When fertilizer is applied from the air the distribution is usually much less uniform than when it is applied by hand from the ground. Second, variability in stocking levels from one part of a stand to another is frequently greater than the variability that exists among experimental plots. Both of these factors lead to a smaller response on a stand-wide basis than would be expected based on results from experimental plots. Variability in fertilizer distribution is usually more important than stocking variability. A reduction of 20 percent is considered reasonable for most stands (16).

RESULTS AND DISCUSSION

Basal Area Growth

The effect of fertilization on basal area growth was highly significant ($P \leq 0.01$). The largest increase in basal area growth/tree occurred at 112N, with the next largest increase at 224N (Table 1). Growth at 56N was not significantly different from the control. The increase at 112N appears to be greater in western Maine than in central Maine (0.37 dm^2/tree vs 0.25 dm^2/tree). However, growth in one of the central Maine stands was not improved by 112N, and the average increase in the remaining two stands was virtually identical to the average increase of the western Maine stands. The relative increase at 112N across all stands was 23 percent, 27 percent in western Maine and 19 percent in central Maine. Mean basal area growth at 224N was 0.13 dm^2/tree more than the control and was the same in both regions.

Table 1. Mean four-year basal area growth of a 33-cm-dbh white pine tree following fertilization with nitrogen. (dm^2 /tree)

	Nitrogen Application Rate (kg/ha)			
Location	0	56	112	224
All Stands	1.36	1.33	1.67	1.49
Western Maine[a]	1.36	1.32	1.73	1.49
Central Maine[b]	1.35	1.34	1.60	1.49

[a] Four stands.

[b] Three stands.

The largest increase in basal area/tree at 112N, 0.45 dm^2 more than the control, occurred in the densest stand. The increase in the least dense stand was 0.33 dm^2/tree. This result, combined with the non-significant effect of basal area/acre as a covariate, suggests that in many managed stands in which basal area has been periodically reduced by cutting, stand density should not be high enough to limit response of individual trees to N fertilization.

The relative increases in growth observed here compare favorably with those reported elsewhere, including those for loblolly pine in the South (6) and Douglas-fir in the Pacific Northwest (12). However, in most instances the largest response in those regions has occurred at rates greater than 112 kg of N/ha. Ballard (6) reported that maximum response of loblolly pine occurred at 224 kg/ha and Peterson (12) that maximum response of Douglas-fir occurred at approximately 448 kg/ha, although there was little difference between 224 and 448 kg/ha.

Response Pattern of Basal Area Growth

There was a large difference in pattern of response at 112N among western Maine and central Maine stands (Table 2). In western Maine 0.25 dm^2/tree of the total 0.37 dm^2/tree occurred during the first two-year period. In contrast, only 0.06 dm^2/tree of the total 0.25 dm^2/tree four-year response in central Maine occurred during the first two years. A similar trend was also evident at 224N.

It should be noted that there were also major differences in growth of the control trees between the two areas. Growth during both periods in western Maine was virtually identical (0.67 dm^2/tree vs 0.69 dm^2/tree). However, in central Maine growth during the second two-year period was 0.75 dm^2, compared to

0.60 dm^2 during the first two-year period. The difference in central Maine may have resulted from a difference in some weather factor(s) between the two periods.

Table 2. Mean basal area growth of a 33-cm-dbh white pine tree by two-year periods during the four years following fertilization with nitrogen. (dm^2/tree)

	Nitrogen Application Rate (kg/ha)							
	0		56		112		224	
Location	1st	2nd	1st	2nd	1st	2nd	1st	2nd
All Stands	0.64	0.72	0.62	0.71	0.81	0.87	0.70	0.79
Western Maine[a]	0.67	0.69	0.65	0.67	0.92	0.81	0.74	0.75
Central Maine[b]	0.60	0.75	0.59	0.75	0.66	0.94	0.65	0.84

[a] Four stands.
[b] Three stands.

Volume Growth

The largest volume increase, about 13.0 m^3/ha, occurred at 112N (Table 3). The volume increase/ha was virtually identical in both the western Maine stands and the central Maine stands. Volume increase at 224N was greater in central Maine than in western Maine. This was due to the higher basal area in the central Maine stands, because basal area response/tree to 224N was virtually the same at both locations.

Volume response to fertilization as determined from measurements of dbh and height may be lower than the actual response, because fertilization tends to improve tree form. This means that a relatively large part of the total increase

Table 3. Change in volume growth from the control for eastern white pine stands during the four years following fertilization with nitrogen (not allowing for possible "growth response falldown"). (m^3/ha)

	Nitrogen Application Rate (kg/ha)		
Location	56	112	224
All Stands	-0.60	12.96	5.04
Western Maine[a]	1.06	12.92	3.73
Central Maine[b]	0.02	12.99	6.79

[a] Four stands.
[b] Three stands.

in volume may occur in the upper bole. Pegg (11) reported that the Girard form class of loblolly pine fertilized with 180 kg of N/ha improved by six points more than the control trees over a 12-year period. Broerman (7) used an arbitrary form factor, the ratio of diameter inside bark at 7.8 m to diameter inside bark at 1.7 m, to examine the effect of fertilization on stem form of slash pine. He found that after nine years the ratio for unfertilized trees had increased by 0.045, whereas the ratio of trees treated with a combination of 132 kg of N, 29 kg of P, and 55 kg of K/ha increased by 0.085. The effect of fertilization on form of the upper stem will likely be greatest in trees with long, branch-free boles (18).

A timber company could view the increased volume growth resulting from fertilization in several ways. This volume represents additional wood that the company may cut from its own lands, thus avoiding the necessity of purchasing the same volume of timber from noncompany lands. This may be especially important if the price of wood on the open market is high due to competition from other companies. Also, additional volume realized in high quality stands would result in the production of more high grade lumber. Finally, increased growth following fertilization of pole stands would allow the company to cut more volume from its sawlog stands. The private landowner would also benefit from the additional growth resulting from fertilization by being able to sell more timber than would otherwise be possible.

Rates of Return

The real return earned at 112N varied with fertilization cost and stumpage price (Table 4). The real increase in stumpage price is also an important factor. A one percent/year real increase in stumpage price increases the real rate of return by approximately one percent over four years. This means that with a two

Table 4. Average real rates of return earned in white pine sawlog stands fertilized with 112 kg of nitrogen/ha assuming two different fertilization costs (based on a volume gain of 13.0 m ^{3}/ha over the four-year period following fertilization reduced by 20 percent to compensate for "growth response falldown"). (percentage)

Stumpage Price ($/m^3)	Fertilization Cost	
	$100/ha	$124/ha
17	16	9
19	19	12
21	22	15

percent/year increase in stumpage price and an initial stumpage price of \$17/m^3, the real return over four years would be 18 percent with a cost of \$100/ha and 11 percent with a cost of \$124/ha.

Compared with returns earned elsewhere, those above are quite good. Economic analyses by Holley (9) indicated that fertilizing loblolly pine plantations with 112kg of N/ha should yield returns in excess of 20 percent on many Piedmont and Coastal Plain sites during the first four to five years after treatment. Miller and Fight (10) estimated that returns of 34 percent could be earned over eight years by fertilizing Douglas-fir sawlog stands on poor sites in the Pacific Northwest with 224 kg of N/ha.

Although estimates of costs used here are for aerial application, many sawlog stands, especially those recently thinned in conjunction with a chipping operation, should be treatable from the ground. Treatment from the ground is slower than treatment from the air, but "where ground equipment can be used it is generally less expensive per unit of land area than aerial application" (14). In addition to a lower cost, ground application would probably reduce or eliminate "growth response falldown" for three reasons: 1) application would be more uniform than from the air, 2) volatilization losses of urea retained on tree crowns following aerial application would be eliminated, and 3) stands treatable from the ground, especially those recently thinned, would likely have a relatively uniform density throughout.

Fertilizing from the ground also has the advantage in that portions of a stand which may be overstocked or understocked, which have a dense understory, or which should not be treated for other reasons, such as proximity to a stream, can be easily avoided. Avoiding such areas is more difficult with aerial application.

Results presented here speak favorably for N fertilization of white pine stands. However, more data will be required to establish if there are differences in response among major groups of soils, among different regions of the state, and between pole stands and sawlog stands. In addition, the approximate cost of fertilizing from the ground should be ascertained.

CONCLUSIONS

The following conclusions were made from a limited sample. They may change as more data become available.

1. Fertilization of white pine sawlog stands with 112 kg of N/ha may prove to be an attractive management practice, producing volume gains (before allowing for possible "growth response falldown") in excess of 13m^3/ha in some stands during the first four years following treatment.

2. Real returns on the investment in fertilization will vary with a number of factors, including the price of fertilizer, the cost of application, the stumpage price and the real increase in stumpage price during the investment period, but may be greater than 15 percent in some stands.

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