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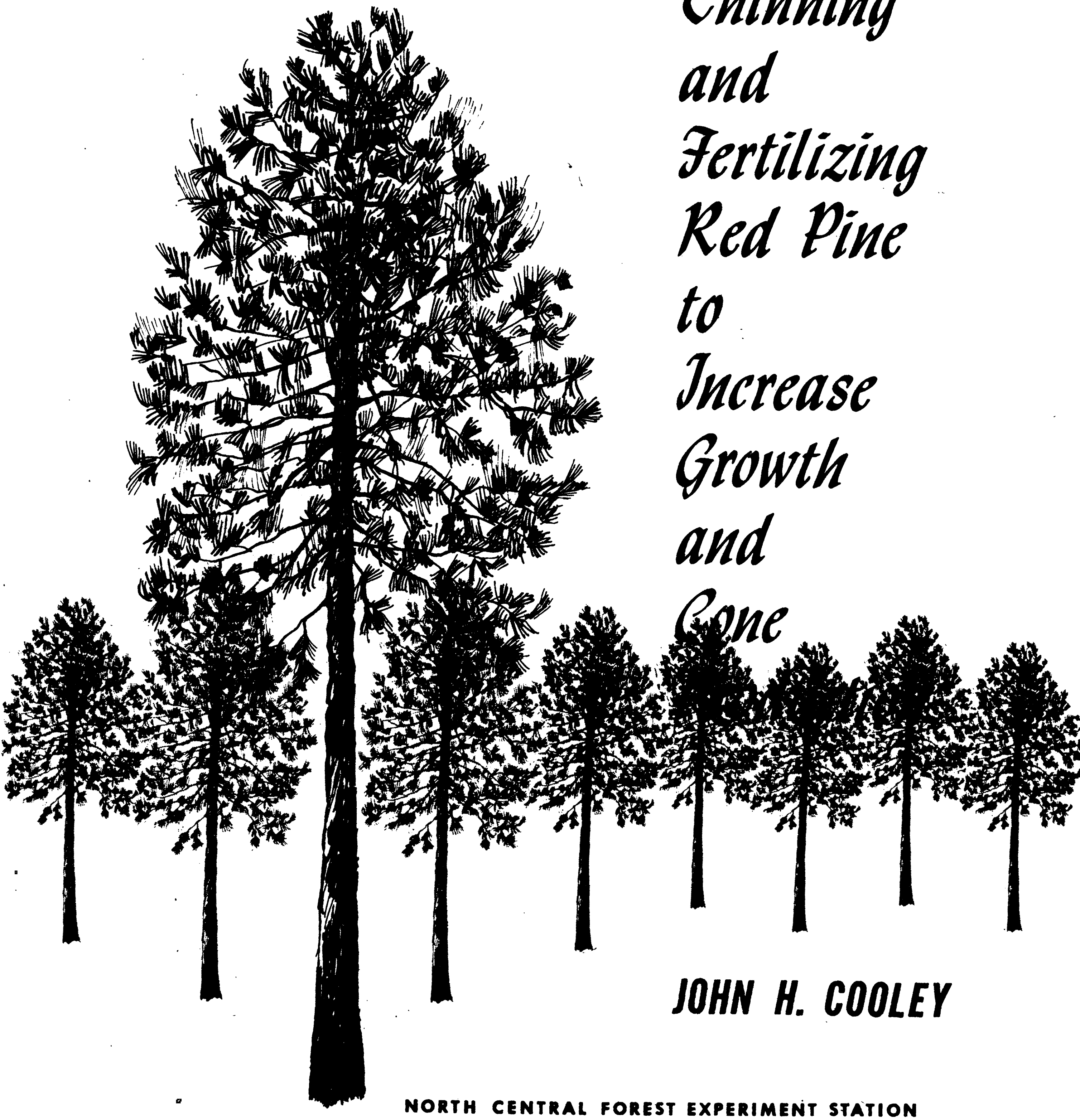

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Thinning and Fertilizing Red Pine to Increase Growth and Cone Production

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Manipulating red pine (*Pinus resinosa* Ait.) stands to increase seed production has several silvicultural implications. For example, stands that are to be regenerated naturally often require preharvest treatment to assure an adequate seed supply, and the large quantities of seed needed for artificial regeneration necessitates management of some stands for maximum seed production. It has been shown that heavy thinning is one effective way of increasing the number of mature cones (Godman 1962), and there is some suggestion that fertilization might also be effective (Cayford and Jarvis 1967). Both treatments can also increase tree growth rate.

To further test the effects of thinning and fertilizing on red pine seed production and growth, two natural stands and one plantation were studied in Lower Michigan. Results showed that the age and site of red pine stands strongly affect their response to treatment. For instance, in a 20-year-old plantation on a good site, thinning increased the number of mature cones per tree in only 2 years out of 6, and fertilizer had no effect. However, in 53- and 55-year old natural stands on medium sites, thinning increased cone crops every year, and fertilizer increased them 2 years out of 6. Tree growth response also varied by stand age and site. Thinning increased diameter growth during the first 5 years in the 20-year-old plantation, while fertilizing decreased it initially and increased it later on. In the older natural stands, fertilizing had no effect on diameter growth, and thinning had no effect until the second growing season, after which differences among thinning levels became more pronounced each year.

METHODS

The 20-year-old plantation is located near the west side of Lower Michigan. It is planted on Kalkaska sand and has a site index of over 70. The basal area before thinning was 109 square feet per acre; there were 969 trees per acre with an average d.b.h. of 4.6 inches.

The 53- and 55-year-old natural stands, located near the east side of the Lower Peninsula, are separated by about half a mile. One is growing on Croswell sand, has a site index of 55, and was 53 years old when the study began. The original stand had 159 square feet of basal area and 581 trees per acre, with an average d.b.h. of 7.1 inches. The other is growing on Grayling sand, has a site index of 52, and was 55 years old when the study began. Originally it had 111 square feet of basal area and 454 trees per acre, with an average d.b.h. of 6.7 inches.

It seems possible that the site indices do not adequately reflect the difference in productivity of the sites on which these two older stands are growing. The stand located on Croswell sand had more and bigger trees than the one on Grayling sand, and according to Van Eck and Whiteside (1963), Croswell sand averages about 15 site index units higher than Grayling sand. Neverthless, the response in these two stands was similar and differed markedly from the response in the younger stand.

All combinations of three thinning and fertilizer levels were applied to 1/10-acre plots arranged in randomized blocks. In the younger stand there were three contiguous blocks; in the older stand growing on Grayling sand there was one block; in the stand growing on Croswell sand there were two. The 3 thinning levels were: 4 uniformly spaced trees per plot, 16 uniformly spaced trees per plot, and no thinning. The 3 fertilizer levels were:

Treatment	*Pounds per acre*
No treatment	0
Treatment 1:	
Nitrogen:	
Urea	169
Ureaform	131
Potassium	60
Phosphorus	195
Treatment 2:	
Nitrogen:	
Urea	338
Ureaform	262
Potassium	120
Phosphorus	390

Urea (45 percent N) and ureaform (35 percent N) were used in equal quantities for supplying nitrogen, potassium sulfate (40 percent K) for potassium, and superphosphate (13 percent P) for phosphorus. Thinning was done in the winter of 1960-1961 and fertilizer was broadcast during the first half of May 1961.

During late July or August of the next 6 years mature cones were counted on four sample trees in each plot. Other measurements were made with less regularity on the same trees. D.b.h. was measured the next 5 years, and height was measured the first, third, fourth, and fifth years. Needles from some plots in all stands were sampled after the first growing season, from the younger stand after the second, and from all stands again after the third. Samples were collected from midcrown position in late fall as recommended by White (1954). Needles collected in the younger stand were analyzed for mineral nutrients, both major and minor, after the first growing season and needles from all stands were analyzed after the third season. Dimensions were measured on cones collected from some of the sample trees in the older stands after the third season.

RESULTS

Cone Production Increased More By Thinning Than Fertilizing

In the younger stand, the number of cones per tree maturing 3 and 6 years after treatment was much greater on thinned plots than on unthinned plots (table 1). In these years, the proportion of sample trees producing cones was greater than at other times (table 2). In neither year was the difference between the two thinning levels statistically significant. In the third year, trees that bore cones on thinned plots had 17 times as many mature cones as comparable trees on unthinned plots. The sixth year thinned trees had about 30 times as many cones.

Trees in the older stands did not produce nearly as many cones, but there was some increase due to thinning each year. After the first year, when there was an apparent interaction between thinning and fertilization, the effect of thinning was independent of fertilizer (table 1). In the second year, the lighter thinning had no effect, but the heavier thinning did. In the fifth year there was no difference between the two thinning levels. In the other 3 years the heavy thinning increased cone yield more than the light thinning although the light one increased production to some extent. Trees on the plots thinned to 160 per acre had from 2.4 to 3.8 times as many cones as those on unthinned plots, and trees on plots thinned to 40 per acre had from 2.5 to 8.0 times as many.

Table 1.—*Number of cones per tree by thinning treatment*

Years since treatment	Thinning treatment: No thinning	160 trees per acre	40 trees per acre
20-YEAR-OLD STAND			
1	5	9	16
2	4	5	4
3	9	1/ 163*	171*
4	0	5	9
5	0	0	0
6	5	133*	202*
53- AND 55-YEAR-OLD STANDS 2/			
2	3	3	7*
3	16	39*	82**
4	4	15*	32**
5	1	4*	4*
6	8	25*	48**

1/ For each year, treatment means that differed significantly at the 5-percent probability level have different numbers of asterisks.

2/ First-year means are not shown for thinning treatments because there was an interaction between thinning and fertilization (fig. 1).

Table 2.—*Percent of trees with cones by thinning treatment*

Years since treatment	Thinning treatment: No thinning	160 trees per acre	40 trees per acre
20-YEAR-OLD STAND			
1	19	39	33
2	19	39	36
3	52	97	81
4	0	19	47
5	0	0	0
6	22	100	97
53- AND 55-YEAR-OLD STANDS 1/			
2	33	9	67
3	64	9	100
4	75	86	100
5	11	17	58
6	61	86	100

1/ First-year means are not shown for thinning treatments because there was an interaction between thinning and fertilization (fig. 1)

Fertilizer had no detectable influence on the number of mature cones in the younger stand. In the older stands there was an interaction between thinning and fertilization the first year after treatment (fig. 1). This immediate response is somewhat unexpected because the only processes that could have been influenced were fertilization of the female gamete and maturation. The former should have taken place soon after treatment. Possibly, the activity of insects that might have interfered with cone maturation was affected. In a Canadian study it was noted that "a smaller percentage of cones were damaged in fertilized than control trees" (Armson 1967). On the other hand, White (1968) did not note any increase in the number of mature cones in an Upper Michigan red pine stand until the third year. This response in the third year is more logical because all processes of cone development occurred after treatment. In the present study, the lower level of fertilization approximately doubled the number of mature cones in the third year, and the higher level more than tripled it (table 3). Fertilizing also increased the size of third year cones, but thinning had no effect on size.

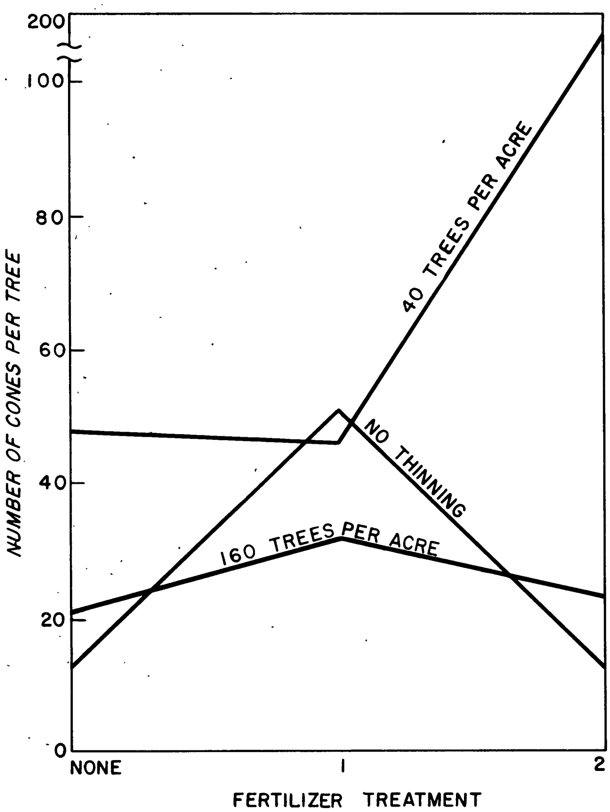

Figure 1. Effect of fertilization on cone production at different densities in the older stand 1 year after treatment.

In the fourth year there were cone production differences between the two older stands that might be associated with soil differences. Trees growing on Croswell sand averaged 23 cones each and those on Grayling only 6. There were also differences between the older and younger stands that could be at least partly attributed to soils. The average site index reported for Kalkaska sand, on which the younger trees are growing, is much higher than for either Croswell or Grayling (Van Eck and Whiteside 1963), and the site indices observed on the study plots bear this out. In 5 out of 6 years trees on unthinned plots in the older stands had more mature cones than comparable trees in the younger stand, but in the 2 years that the younger trees bore heavily, those on thinned plots had from 2.0 to 5.5 times as many cones as comparable trees in the older stands.

Table 3.—*Cone production and cone size in the older stand in the third year after treatment*

Fertilizer treatment	Trees bearing cones	Cones per tree	Cone length	Cone diameter
	Percent	Number	Inches	Inches
None	66.7	24	1.6	1.0
1	91.7	50	1.7	1.1
2	94.4	82	1.8	1.1

D.b.h. Growth Increased More in Younger Stand

In the first year after thinning, trees on thinned plots in the younger stand grew more than those on unthinned plots, and the difference became progressively greater during the next 2 years (table 4). The heavy thinning increased growth no more than the lighter thinning until the fourth year.

In the older stands the effect of thinning was delayed about 1 year. There was no detectable response the first year, and no significant difference between thinning levels until the fifth year. Otherwise, the pattern of response was much the same as in the younger stand, but the magnitude was much smaller. For the entire 5 years, thinning to 160 trees per acre increased d.b.h. growth by 172 percent in the younger stand, but only by 49 percent in the older ones. Thinning to 40 trees per acre increased growth by 208 percent and 77 percent, respectively.

In the older stands there were no differences in d.b.h. growth that could be attributed to fertilizer treatments. However, in the younger stand fertilization decreased d.b.h. growth significantly at all thinning levels in the second year after application, and increased it in the fifth year. The shift from adverse to beneficial response came about gradually (fig. 2), probably as a result of the tree's adjustment to higher nutrient levels and reduction of salt concentration in the rooting zone. This fertilizer response was independent of the thinning treatment.

Discounting the adverse initial effect, which lasted 2 years for the lower level of fertilization and 3 years for the higher, it would appear that fertilization increased d.b.h. growth by about 15 and 25 percent for the lower and higher levels, respectively. It is too soon to be positive about the duration of fertilizer effects, but the data imply that the lower level had its maximum effect 4 years after application, while the effect of the higher level was still increasing 5 years after application. Heiberg *et al.* (1964) reported that height growth on a fertilized potassium-deficient soil reached a maximum 5 or 6 years after application and continued to be greater than on unfertilized areas for 17 years. However, this was observed on a degraded agricultural soil where the sustained response was attributed to reestablishment of a stable level of potassium. Such a long-term response is not likely where nitrogen is the principal limiting element, because nitrogen tends to be more subject to attrition.

Several investigators have reported increased height growth in red pine after fertilization

Table 4.—*Annual d.b.h. growth after thinning*
(In inches)

Years since treatment	Thinning treatment: No thinning	Thinning treatment: 160 trees per acre	Thinning treatment: 40 trees per acre
20-YEAR-OLD STAND			
1	1/ 0.18*	0.27**	0.28**
2	.16*	.34**	.31**
3	.17*	.57**	.66**
4	.19*	.49**	.56***
5	.10*	.50**	.65***
53- AND 55-YEAR-OLD STANDS			
1	.18*	.19*	.19*
2	.17*	.23**	.26**
3	.16*	.29**	.35**
4	.21*	.29**	.35**
5	.17*	.32**	.42***

1/ For each year, treatment means that differed significantly at the 5-percent level have different numbers of asterisks.

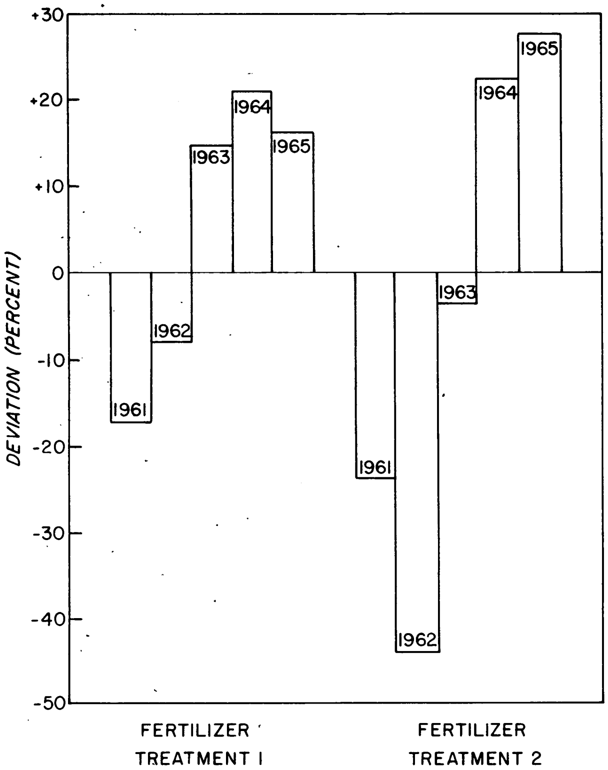

Figure 2. D.b.h. growth in the younger stand during the 5 years following fertilization, as percent deviation from growth on unfertilized plots.

(Heiberg *et al.* 1964; Gagnon 1965; Leech 1965) but no such effect could be detected in this study, partly because height was not measured accurately and partly because the deformed stems of heavily fertilized trees in the younger stand reduced height growth.

Treatments Increased Needle Size and Nutrient Content More in Younger Stand

Needles collected after the first growing season from fertilized trees in the younger stand were 24 percent longer and 39 percent heavier than those from unfertilized trees. Differences between the two levels of fertilization were less than 1 percent. Fertilization increased foliar nitrogen concentration and decreased aluminum concentration (table 5). These were the only elements that differed significantly among treatments. Potassium concentrations ranged from 0.5 to 0.9 percent, well above the deficiency level reported by Heiberg and White (1951).

Some discoloration or wilting of needles was observed on 17 trees in the younger stand that had received the higher level of fertilization, on seven that had received the lower level, and on three that were unfertilized. Malformation of apical leaders was also observed on some of the fertilized trees (fig. 3), due to inability of the succulent new growth to support the additional weight of foliage that resulted from fertilization. In some trees it caused a permanent deformation of the main stem.

Table 5.—*Nitrogen and aluminum concentration in foliage collected from the younger stand*

Fertilizer treatment	Nitrogen		Aluminum	
	First year	Third year	First year	Third year
	Percent	Percent	Ppm	Ppm
None	1.43	1.21	606	587
1	2.20	1.48	285	447
2	2.83	1.70	214	292

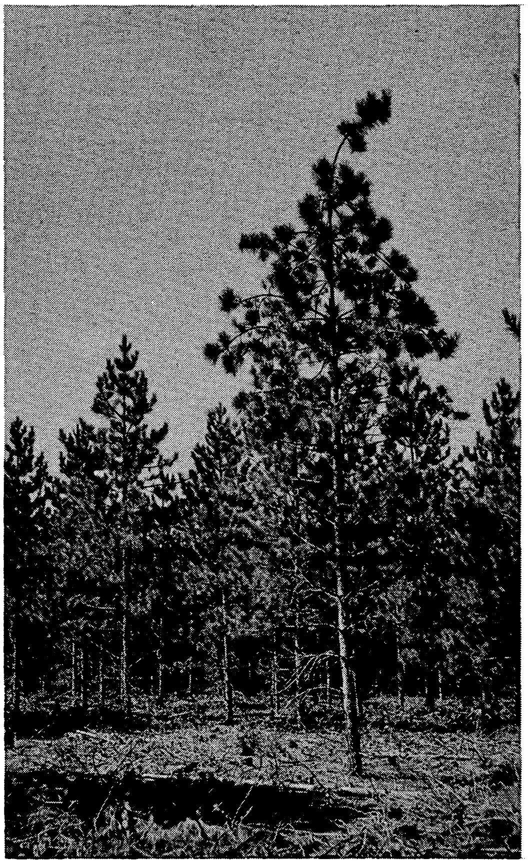

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Figure 3. Apical leader malformation was observed on some of the heavily fertilized trees in the younger stand.

It would appear that a fertilizer response persisted into the third growing season, but in all samples there was less nitrogen than after the first season. Aluminum content decreased in unfertilized trees, but increased in trees at both fertilizer levels, more for the lower than the higher. Needles from plots fertilized at the lower level were 12 percent longer, but no heavier, than those from unfertilized plots; needles from the higher level were 10 percent longer and 83 percent heavier than those from the lower.

Thinning also increased needle size in the younger stand, and there was some indication that it increased nitrogen content of the needles; however, there was no discernible interaction between thinning and fertilization.

Needles collected after the first growing season from the older stands were neither weighed nor analyzed for nutrient content. Fertilization did not have a significant effect on their length, and wilting, discoloration, or terminal deformation were not observed. Increased needle length attributable to thinning was significant at the 99 percent level.

Needles collected in the older stands after the third growing season were analyzed more thoroughly, but neither fertilization nor thinning had a significant effect on their length, weight, or nitrogen content. The average nitrogen content of all samples was 1.24 percent – lower than fertilized trees in the younger stand, but not significantly different than unfertilized trees.

Potassium and phosphorus in most samples were within the range observed in the younger stand, but there were differences among samples that were attributable to soils, thinning, fertilization, and interaction between thinning and fertilization. Potassium concentration in samples from plots on Grayling sand averaged 0.55 percent while comparable plots on Croswell sand averaged 0.49. For unthinned plots and the light thinning, percent potassium increased with fertilizer level, but for the heavy thinning the trend was just the opposite (fig. 4). Both soils and thinning influenced the effect of fertilization on phosphorus concentration (fig. 5).

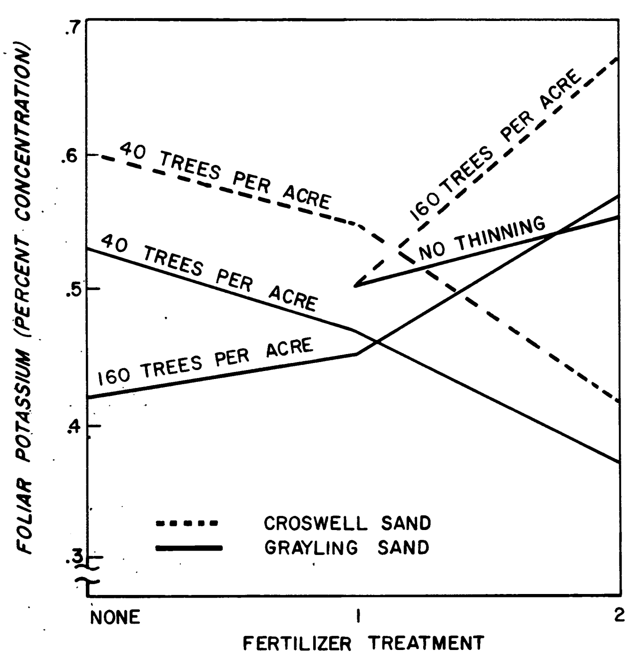

Figure 4. Percent concentration of potassium in foliage collected 3 years after treatment in the older stand.

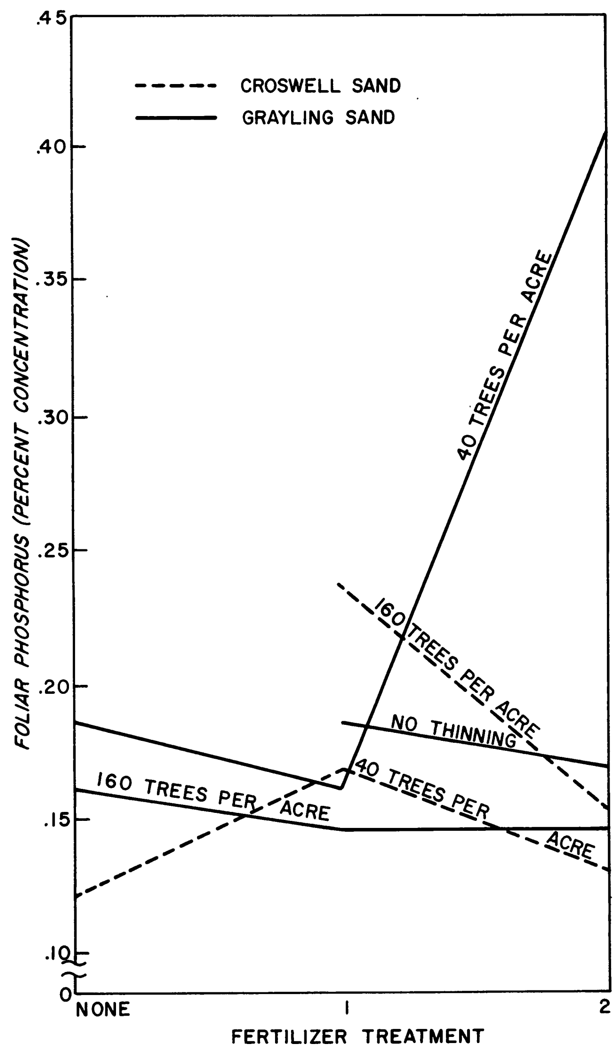

Figure 5. Percent concentration of phosphorus in foliage collected 3 years after treatment in older stand.

DISCUSSION and CONCLUSION

Even though the stands in which this study was carried out are referred to as "younger" and "older," the reader should not assume that age was the only important contrast between them. Differences between Croswell and Grayling sand suggest that soils are also important, and it is entirely possible, in fact probable, that genetic make-up and climate influenced response. It is difficult to generalize on the effects of treatment because the observed responses were undoubtedly the combined effects of all these factors and perhaps others.

The response to thinning seems consistent and easily explained. It increased growth and cone yield more in the younger stand partly because leaving the same number of trees per acre increased growing space per unit of biomass more for smaller trees than for larger ones. There may also be differences in physiological processes related to age or site quality. Apparently the effect of thinning on cone production can be entirely nullified, and the frequency with which this occurs varies from stand to stand. Again, age or site quality might be controlling factors, but it seems likely that weather is also implicated (Lester 1967).

The physiology of response to fertilization is much more complex; therefore, it is not surprising that its effect is more variable. Additions of mineral nutrients can increase growth rate and cone yields even though there are no obvious deficiency symptoms, but response to the same rate of application will vary from stand to stand. In one stand, fertilizing may result immediately in toxicity symptoms and growth reduction, while in another it may increase cone yields but have no effect on growth. It seems logical to expect that the fertilizer response would be conditioned by age and size of the trees as well as physical and chemical properties of the soil. Perhaps foliar analysis will indicate the probable response. At least in this study, increased foliar nitrogen was associated with increased growth. In any event, the growth increase that can be achieved with addition of mineral nutrients is likely to be small relative to the acceleration due to thinning. White (1968) points out that investment in fertilization to increase growth of low-value products, such as red pine pulpwood, generally are not profitable, but similar investments to increase seed production may be "quite reasonable."

Based on this study, then, there are three general recommendations that can be made:

1. Thinning for seed production should be limited to young stands on good sites, because response is much better than in older stands on poor sites.
2. Stands managed for seed production *must* be heavily thinned.
3. The effectiveness of fertilization should be determined for each prospective stand before extensive programs are begun.

In connection with the third recommendation it should be noted that the determination cannot be based on a 1-year observation. An immediate increase in foliar nitrogen is a strong indicator that fertilizer will increase growth over the long run, but the initial reaction to a heavy application may be reduced growth. The effect on cone yield cannot be assessed with any certainty until there is a good crop.

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