Station Paper No. 148

August 1962

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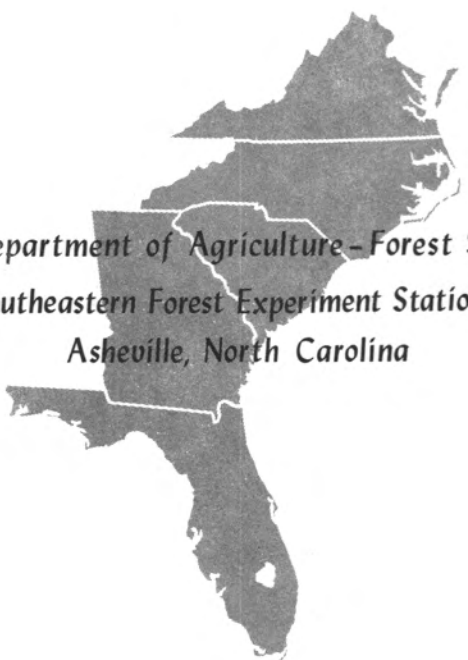

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Ralph H. Hughes and James E. Jackson[1/]

Observations in the southern pinelands have shown that serious damage to plantations by cattle browsing and trampling is limited to trees less than 6 to 8 feet tall, except where cattle are concentrated (Cassady, Hopkins, and Whitaker, 1955). The possibility that application of fertilizer with clean cultivation would increase growth rate, producing a 6- to 8-foot tree in 3 or 4 years, plus the need to know more about growth response of slash pine (Pinus elliottii Engelm. var. elliottii), prompted this study to test the effect of several kinds, rates, and combinations of inorganic fertilizers.[2/]

METHODS

A longleaf-slash pine stand, with an understory of "wiregrass" and gallberry, located near Alapaha, Georgia, was selected for the study. The soil was Lynchburg loamy sand, imperfectly drained and of low fertility. The site was cleared, stumped, and thoroughly worked with a tandem disk-harrow. Grade 1 slash pine seedlings were planted at a spacing of 10 x 10 feet over the entire area. Soil analyses showed 28 pounds available P_2O_5, as determined by the modified Truog method using colorimetry, 30 pounds available K_2O, and 400 pounds available CaO per acre.

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2/ Cooperative investigations of the Forest Service and Agricultural Research Service of the U. S. Department of Agriculture, and the University of Georgia College of Agriculture Experiment Stations, Coastal Plain Experiment Station, Tifton, Georgia. Published with the approval of the Director as Journal Series Paper No. 95.

The study consisted of a factorial test and three accessory phases totaling 42 treatments, replicated three times, each employing nitrogen, phosphorus, and potassium, as follows:

1. A 3 x 3 x 3 factorial experiment (27 treatments) with three rates of nitrogen of 0, 100, and 200 pounds per acre, and phosphorus and potassium at rates equivalent to 0, 50, and 100 pounds of P_2O_5 and K_2O per acre applied to the surface of the soil.

2. Three surface treatments involving minor elements, with two treatments using 200 pounds of nitrogen per acre and one of 400 pounds, each mixed with phosphorus and potassium to equal a 2-1-1 ($N-P_2O_5-K_2O$) ratio. One of the 200-pound nitrogen mixtures was combined with the equivalent of 2,000 pounds per acre of dolomitic limestone, the other two treatments (200 and 400 pounds) were combined with 70 pounds of MgO per acre. All three treatments were supplemented with the equivalent of 25 pounds per acre of a minor element mixture containing manganese, zinc, molybdenum, boron, and iron.

3. Ten treatments (eight new treatments, plus two from the 3 x 3 x 3 factorial, the 100-50-50 and 200-100-100 $N-P_2O_5-K_2O$ rates) involving split surface application of fertilizer of 50, 100, 200, 400, and 600 pounds of nitrogen per acre in a 2-1-1 ratio with one-half applied in February or March and one-half in June.

4. Two treatments of a single subsurface application of 100 and 200 pounds of nitrogen per acre in a 2-1-1 ratio placed 4 to 6 inches below the soil surface.

The area was divided into three blocks of 40 plots, each plot containing 16 trees. The 40 treatments were assigned at random within blocks. (Note that 2 of these treatments were common to the factorial test and one accessory phase.)

In all treatments nitrogen was supplied by ammonium nitrate, phosphorus by 20 percent superphosphate, and potassium by 60 percent muriate of potash. Fertilizer materials were broadcast by hand in a 2-foot radius around trees in February 1957, and in a 4-foot radius in March 1958. Trees were not fertilized in 1959 or 1960. The entire area was cultivated as needed with a tandem disk-harrow to control weeds, with occasional hand weeding close to the seedlings.

Measurements were confined to the center square or four trees in each plot, leaving the outer row on each side for isolation from adjacent plots. Heights of trees were measured at the close of the growing seasons in 1957, 1958, 1959, and 1960. Diameters, 6 inches above the ground line, were measured in October 1960. Survival of nearly 100 percent was obtained by planting three seedlings in a hill initially and thinning to one per hill follow-

ing the first flush of growth. Of the 480 plot trees, 17 were cut off in cultivation the first year. These were replaced the first winter by adjoining border trees of approximately the same size.

In 1958, a small adjoining plantation was established to test further some of the most promising treatments of the main study. Treatments were $N-P_2O_5-K_2O$ at rates of 100-50-50, 0-50-0, and 0-0-0 pounds per acre, with care taken to duplicate methods of the main experiment.

RESULTS

Analyses of variance in the factorial experiment of total height of trees at the end of the growing season and of annual increase in tree height revealed consistent similarity between the two measures when related to the main variables and their interactions (table 1). Hence, the two measures apparently provided an equally objective test of fertilizer effects.

Rates and Ratios of Nutrients

First- and second-year results of the factorial were highlighted by two important trends:

1. A highly significant positive response to phosphorus.

2. A significant NxK interaction in which nitrogen without potassium and potassium without nitrogen retarded growth.

Table 1.--Analyses of variance for total height and annual height growth of slash pine in the N-P-K factorial experiment during the first, second, and third years after planting

Observation	Source of variation	D. F.	Mean squares		
			First year	Second year	Third year
Total height	Replication	2	--	--	--
	Nitrogen (N)	2	76.01	376.20	961.72**
	Phosphate (P)	2	534.45**	2,757.25**	4,707.49**
	Potash (K)	2	19.10	118.91	202.28
	N x P	4	5.03	29.37	135.26
	N x K	4	49.26*	190.51*	149.16
	P x K	4	4.97	31.72	89.46
	N x P x K	8	3.37	17.72	85.11
	Error	52	14.10	57.31	115.15
Annual height growth	Replication	2	--	--	--
	Nitrogen (N)	2	47.24	158.97	152.10*
	Phosphate (P)	2	520.36**	905.43**	252.76**
	Potash (K)	2	14.46	54.05	20.55
	N x P	4	3.94	10.18	64.77
	N x K	4	40.70*	59.24*	39.29
	P x K	4	3.83	18.66	40.54
	N x P x K	8	1.60	12.24	35.07
	Error	52	11.36	22.98	40.60

* Significant at 5 percent level.
** Significant at 1 percent level.

Although trees were not fertilized after the second year, the positive response to phosphorus persisted to the end of the fourth growing season, when final measurements were taken. The main effect of nitrogen, obscured by the NxK interaction during the first two years, emerged as an important factor during the third year.

Phosphorus was the most consistently significant and had more effect than other components included in the study. Trees in the N-P-K factorial given phosphorus at the rate of 50 pounds of P_2O_5 per acre in mixed fertilizers attained a height of 27.2 inches in 1 year, 68.6 inches in 2 years, and 115.5 inches in 3 years (fig. 1). Phosphate alone at the 50-pound rate produced trees 1, 2, and 3 years from planting that measured 28.7, 72.7, and 120.6 inches in height (fig. 2). Comparable heights for check trees not fertilized were 22.5, 60.8, and 108.2 (fig. 3). The 100-pound rate of phosphate applied singly or in combination with nitrogen and potash did not stimulate additional growth beyond that resulting from the 50-pound phosphate application. Hence, phosphate alone at the 50-pound rate was the most effective fertilizer tested.

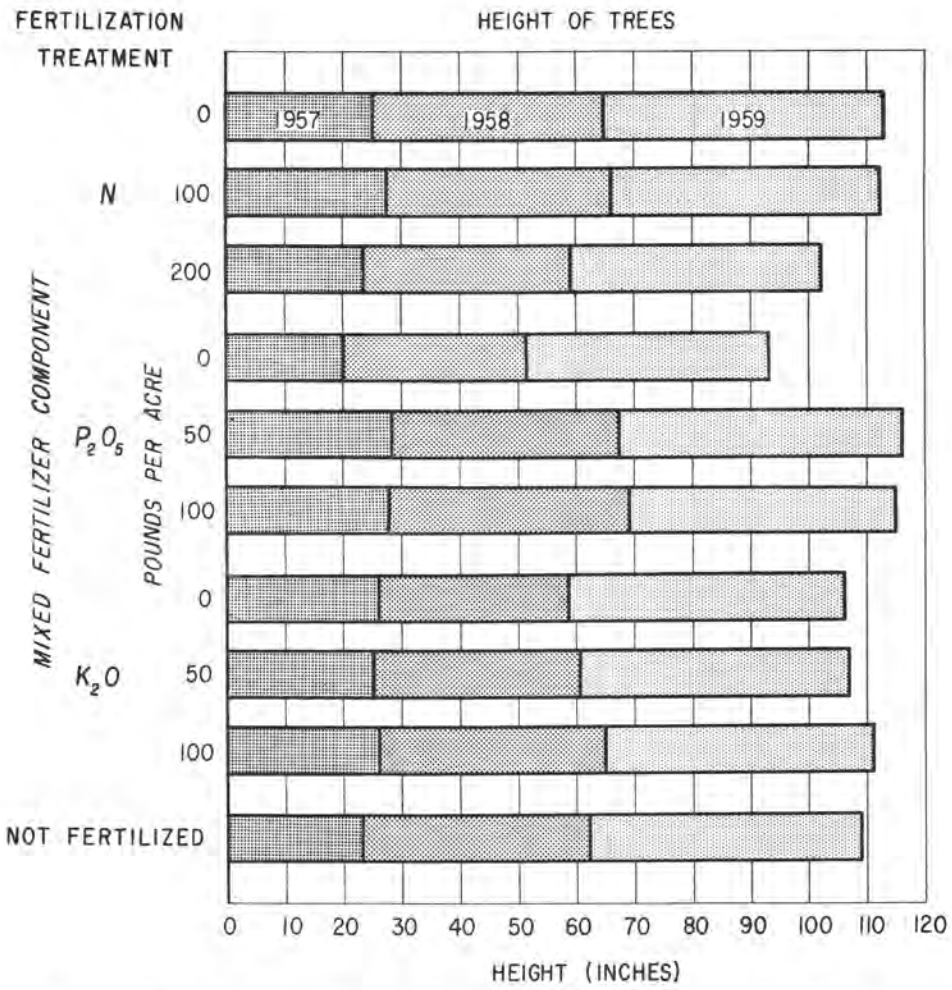

Figure 1.--Average effect of N, P_2O_5 and K_2O mixed fertilizers broadcast around trees February 1957 and March 1958 on height of slash pine planted January 1957. Trees were not fertilized in 1959.

Figure 2.--Seedlings (1-0 stock) annually fertilized with phosphate alone at the rate of 50 pounds per acre reached a height of 72.7 inches in two years.

Figure 3.--Seedlings in plots that were cultivated but not fertilized attained a height of 60.8 inches in two years.

Mixtures lacking phosphorus did not stimulate growth. These trees had average heights of only 19.4 inches the first year, 51.0 inches the second year, and 92.3 inches the third year. In Florida, Barnes and Ralston (1953) observed a similar increase in height growth of young slash pine following heavy application of colloidal phosphate at planting time.

By the end of the fourth growing season, trees given mixed fertilizer containing 50 pounds of phosphate measured 4.50 inches in diameter at stump height (table 2). Trees in plots that received no phosphate averaged only 3.83 inches.

Table 2.--Average diameter[1/] of slash pine in relation to mixed fertilizer component, October 27, 1960 (end of fourth year)

Component	Rate[2/]			Least significant difference (5 percent)
	0	1	2	
	- - Diameter in inches - -			
N	4.35	4.45	4.12	0.15
P_2O_5	3.83	4.50	4.60	0.15
K_2O	4.22	4.30	4.40	0.15

1/ Measured 6 inches above ground line with diameter tape.

2/ A 3x3x3 factorial with N at 0, 100, and 200 pounds per acre, and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

Nitrogen alone at the 200-pound rate resulted in a highly significant depression in growth. Stunting was more severe the second year than the first, and persisted through the fourth growing season. When surveyed October 27, 1960 (end of fourth year), these trees measured only 3.17 inches in diameter and 119.2 inches in height in contrast to 4.07 inches in diameter and 158.2 inches high for trees not fertilized. By the third year, nitrogen at the 200-pound rate in mixed fertilizer had emerged as a depressing factor on height, when compared with nitrogen at the 100-pound rate.

Potash in mixtures with nitrogen at the 100-pound rate (averaged for all levels of phosphorus) produced significantly taller trees than most other combinations by November of the first year (table 3). Height with average P_2O_5 and N and K_2O at 100 pounds was 28.6 inches by the end of the first growing season. On the other hand, addition of potash without nitrogen and application of nitrogen without potash reduced tree height, thus accounting for a significant NxK interaction. A sharp reduction in height accompanied increasing amounts of nitrogen without potash, and the same with respect to potash without nitrogen. This effect was not so pronounced the second growing season and, as noted previously, by the end of the third year had lost its significance. Average response to potash was not significant.

Minor Elements

Minor elements, with lime or magnesium added to heavy application of N-P-K mixed fertilizers, did not significantly increase tree growth.

Table 3.--Height of trees in relation to potash and nitrogen (averaged with $P_0 + P_1 + P_2$) broadcast around seedlings in February 1957 and March 1958 [1/]

Item	N_0	N_1	N_2	Average
		Inches		
HEIGHT OF TREES NOVEMBER 18, 1957 [2/]				
K_0	26.4	24.8	20.6	23.9
K_1	24.0	25.4	23.1	24.1
K_2	22.6	28.6	25.1	25.5
Average	24.3	26.3	22.9	24.5
HEIGHT OF TREES NOVEMBER 7, 1958 [3/]				
K_0	67.3	63.7	51.3	60.7
K_1	63.3	63.9	59.9	62.4
K_2	62.5	68.2	64.0	64.9
Average	64.4	65.3	58.4	62.7
HEIGHT OF TREES NOVEMBER 23, 1959 [4/]				
K_0	113.9	108.8	94.1	105.6
K_1	107.1	109.4	102.7	106.4
K_2	112.5	113.3	105.2	110.7
Average	111.2	110.5	100.7	107.6

1/ A 3x3x3 factorial with N at 0, 100, and 200 pounds per acre; and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

2/ Least significant difference (5 percent) for average N = 2.1; for K = 2.1; and for interaction (NxK) = 3.6 inches.

3/ Least significant difference (5 percent) for average N = 4.1; for K = 4.1; and for interaction (NxK) = 7.2 inches.

4/ Least significant difference (5 percent) for average N = 5.9; for K = 5.9; and for interaction (NxK) = 10.1 inches.

Although these trees grew rapidly and displayed high vigor, supplements to N-P-K mixtures did not appear essential (table 4). Depression of height growth, as evidenced by heavy applications in the N-P-K factorial test, seemed to be caused by an excess of nitrogen or potassium in the absence of phosphorus and not to deficiencies of minor elements, lime, or magnesium.

Split Application

Split application of fertilizer was no better than single application, although five widely varying rates were tested (table 5). Trees given a split application, one-half broadcast around trees in February or March and one-half in June, averaged about the same size as those given a single application. By the end of the fourth growing season, however, trees given split applications at the minimum rate (50-25-25 pounds of $N\text{-}P_2O_5\text{-}K_2O$) measured 4.70 inches in diameter at stump height and trees in the unfertilized check plots measured only 4.07 inches. Trees given the minimum rate in a single application measured 4.33 inches. These results suggest a need for testing split and single applications of fertilizer materials at lower rates than those tried in this experiment.

Subsurface Application

Spot placement of fertilizer 4 to 6 inches below the ground surface resulted in rapid growth of trees equal to surface application (table 6), and in contrast to surface application, discouraged growth of weeds. Though native pine-wiregrass vegetation had previously occupied the site, surface application of fertilizer (other than phosphate alone) encouraged rapid invasion of weeds. An ocular estimate in May 1958 of weed growth on areas around trees fertilized in March indicated an average of $2\frac{1}{2}$ times more annual herbage with broadcast application than with subsurface application of fertilizer. Prompt cultivation was required to prevent crabgrass (Digitaria spp.) and other annual grasses and weeds from forming a sod.

Table 4.--Size of trees in relation to minor elements with lime or magnesium added to heavy applications of N-P-K mixed fertilizers 1/

Treatment				Height of trees			Diameter
N	P_2O_5	K_2O	Supplement	1957	1958	1959	1960
-- Pounds --			Kind	---------- Inches ----------			
200	100	100	Check	26.8	62.7	113.8	4.60
200	100	100	Minor elements and magnesium	26.2	66.4	112.4	4.70
200	100	100	Minor elements and lime	29.6	71.2	115.8	4.73
400	200	200	Minor elements and magnesium	27.8	69.4	114.1	4.60

1/ See page 2 for list of minor elements.

Table 5.--Size of trees with split application and single application of N-P-K mixed fertilizers

Treatment			Split application				Single application			
			Height			Diameter	Height			Diameter
N	P_2O_5	K_2O	1957	1958	1959	1960	1957	1958	1959	1960
-- Pounds --			---------- Inches ----------							
50	25	25	25.7	68.4	115.3	4.70	25.1	66.8	111.2	4.33
100	50	50	29.8	75.4	121.1	4.77	29.0	71.7	120.9	4.63
200	100	100	26.1	67.2	102.7	4.53	26.8	69.4	113.8	4.60
400	200	200	25.5	63.3	104.1	4.47	24.6	61.2	105.9	4.43
600	300	300	29.3	75.1	118.6	4.70	30.2	70.6	115.3	4.80
Average			27.3	69.9	112.4	4.63	27.1	67.9	113.4	4.56

Table 6.--Size of trees with subsurface and surface applications of mixed fertilizers

Treatment			Subsurface application				Surface application			
			Height			Diameter	Height			Diameter
N	P_2O_5	K_2O	1957	1958	1959	1960	1957	1958	1959	1960
-- Pounds --			---------- Inches ----------							
100	50	50	28.9	75.2	121.5	4.57	29.0	71.7	120.9	4.63
200	100	100	25.5	71.0	118.9	4.70	26.8	69.4	113.8	4.60
Average			27.2	73.1	120.2	4.63	27.9	70.5	117.3	4.62

Year Effect

As mentioned previously, three fertilizer treatments from the factorial experiment (N-P_2O_5-K_2O at rates of 100-50-50, 0-50-0, and 0-0-0 pounds per acre broadcast around trees) were further tested with seedlings planted in 1958. As was the case for trees planted in 1957, mixed fertilizer, or phosphate alone, stimulated additional growth on trees planted in 1958 (fig. 4). Fertilized trees 2 years after planting, on the average, were about a foot taller than trees not fertilized.

Growth was considerably less, however, for trees planted in 1958, although care was taken to treat the two plantations alike with respect to planting stock, site preparation, planting procedure, clean cultivation, and in other ways. Seedlings planted in 1957 grew in height continuously from March through September, whereas the 1958 plantings increased in height very little beyond their first flush of growth. The slower growth was attributed to subnormal precipitation, only 44 percent of the mean, during the 1958 July to September period. A normal accumulation of rainfall during the July to September period accompanied the continued rapid growth of trees planted in 1957.

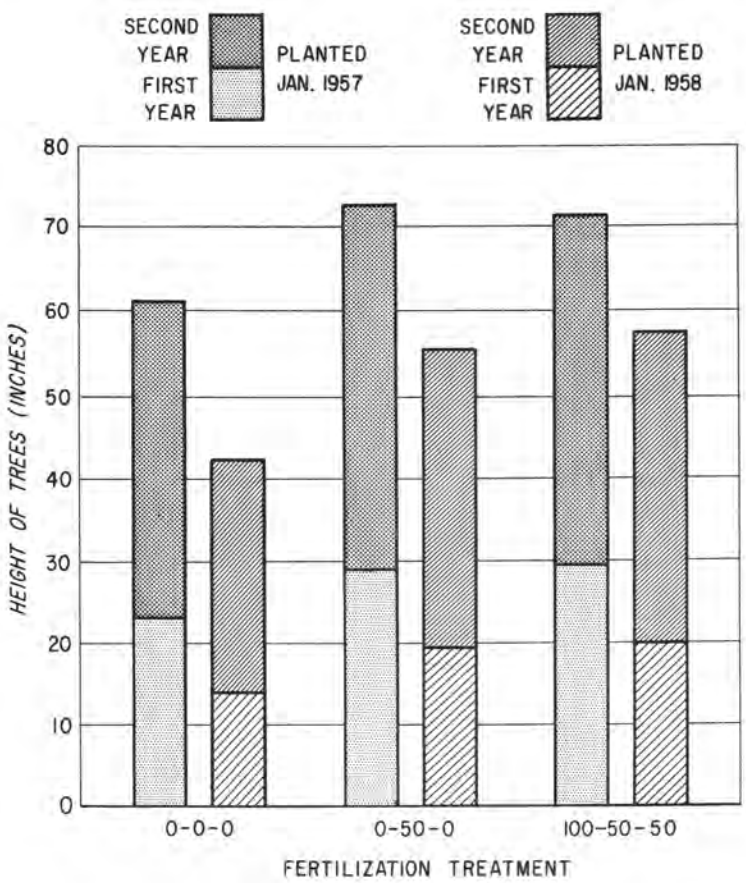

Figure 4.--Height of trees 1 and 2 years from planting related to year planted and fertilization treatment.

Year effect, as indicated by height of trees measured at the end of the first and second growing seasons for trees planted in 1957 and 1958, was greater than response to fertilizer. Fertilized trees that were planted in 1957 averaged 9.6 inches taller after 1 year and 16.1 inches taller after 2 years than trees planted in 1958 (fig. 4). On the other hand, these trees on the average were only 6.0 inches taller after 1 year and 12.9 inches taller after 2 years than trees not fertilized.

Insects and Diseases

Fertilizers broadcast around trees in 1957 and 1958, accompanied by clean cultivation, apparently increased the susceptibility of plantation trees to attack by certain insects and diseases. Attacks by tip moths, Rhyacionia spp., persisted through the first two growing seasons. In 1957, monthly sprays applied to individual trees, March through August, with a 1-percent DDT water emulsion killed most of the emerging larvae. The incidence of attack in other plantations not sprayed was 72 percent. In 1958, the initial spray was timed to coincide with moth emergence in the spring. By this procedure, sprays in March and in May again gave satisfactory control. Frequent DDT sprayings seemed to favor increase in spider mite populations. An acaracide (Kelthane) added to the spray mixture was followed by a sharp reduction in mites.

A severe attack by one of the phloem insects, Dioryctria amatella (Hulst),[3/] first observed near the end of the second growing season, caused extensive damage. Because the larvae tunnel around the stem rather than vertically, they rapidly girdle a tree. Presence of larvae was readily observed by the presence of frass and pitch from open cavities in the bark. A survey in January 1959, 2 years from planting, showed girdling in 29.5 percent of the trees. A year later the incidence of attacks had increased to 35.6 percent. By June 21, 1960, losses charged to girdling and cankering were 10.5 percent and to stem cankering alone 0.8 percent. About one-third of the dead trees with Dioryctria attacks also had stem cankers. Only a few new attacks were observed in 1960.

Attacks by Dioryctria were closely related to fertilization treatment. Fertilizer mixtures in the factorial experiment of either N, P_2O_5, or K_2O at the 100-pound per acre rate resulted in a highly significant increase in the incidence of insect attack (table 7). Of the three components, incidence of attack was most closely associated with mixtures containing phosphorus. Even at the 50-pound rate, phosphate in mixed fertilizers increased insect attack fourfold over treatments containing no phosphate. Again, injury was most prevalent among fast growing trees. An increase in the incidence of attacks with increase in height of trees as tested by chi-square analysis was significant at the 1-percent level (fig. 5). As was the case with rust cankers and tip moth, damage was negligible among slow-growing trees of the same size in an adjoining plantation.

3/ Identified by E. P. Merkel, Entomologist, Lake City Research Center.

Table 7.--Percent of trees with Dioryctria amatella in relation to mixed fertilizer component

Component	Rate 1/			Least significant difference (5 percent)
	0	1	2	
	- - - - - - Percent - - - - -			
N	21.1	46.5	32.4	14.8
P_2O_5	9.9	40.8	49.3	14.8
K_2O	32.4	21.1	46.5	14.8

1/ A 3 x 3 x 3 factorial with N at 0, 100, and 200 pounds per acre, and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

Southern fusiform rust (Cronartium fusiforme), of no consequence during the first year, caused widespread cankering during the second growing season. By the second winter, 10.3 percent of test trees had stem cankers. An adjoining plantation established in wiregrass sod contained very few cankers. The trees, planted in 1955 for another study, grew much slower and at 4 years from planting averaged approximately the same height in 1958 as trees in the 2-year-old fertilized plantation. These observations agree with those in Alabama where Gilmore and Livingston (1958) observed a significant increase in the number of stem cankers on cultivated and fertilized trees.

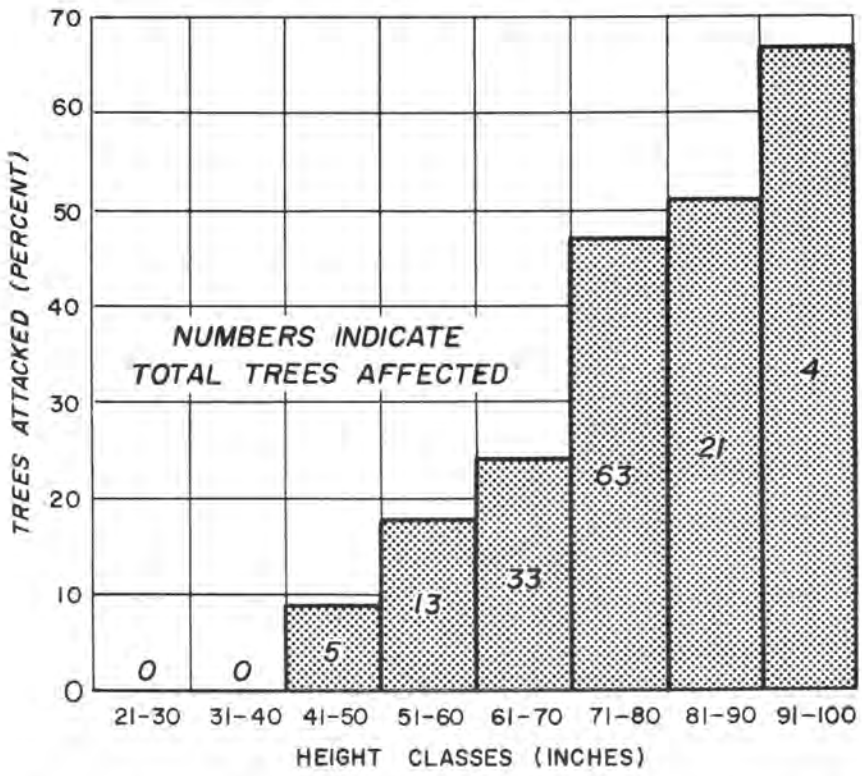

Figure 5.--Incidence of Dioryctria attacks by height classes of trees measured at end of second growing season.

DISCUSSION

Although response to fertilization was the primary aim of the experiment, it should be pointed out that cultivation alone stimulated rapid growth of slash pine seedlings. An adjoining plantation established apart from the present study in an undisturbed wiregrass "rough" provided a direct comparison. Cultivated seedlings attained a height of 60.8 inches in 2 years; in undisturbed wiregrass, seedlings required an additional 2 years to attain the same height. In other studies at Alapaha the authors observed that seedlings planted in competition with improved forage species did not benefit appreciably from broadcast application of fertilizer materials.

It is not uncommon for pine seedlings to respond to a complete fertilizer and not to a single element (Allen and Maki, 1955), or as shown in the present study, high concentrations of a fertilizer may depress growth. The depressing effect of nitrogen and potassium does not mean that the loamy sand soil type had abundant N and K, but rather that, on south Georgia soils, young slash pine do not respond to N or K in the absence of the other components of a fertilizer mixture.

Since phosphate furnished additional growth equal to applications of complete N-P-K mixtures, the phosphate alone, of course, gave cheapest additional growth. Two annual applications of superphosphate at the rate of 50 pounds of P_2O_5 per acre per year, which cost less than one-half cent per tree, gave a 20-percent increase in growth, equivalent to 1 foot in height over a 2-year period.

Responses may be expected to vary with soil type. Tests by Buckeye Cellulose Corporation in west Florida on Leon soils showed a response to N, P, and Ca, whereas on Lakeland soils N and K burned the slash pine seedlings and phosphate benefited growth (Walker, 1958). Further testing of the phosphate component on deep sands is needed to establish optimum rate, best ratio of N, P, and K, season and frequency of application, and placement of fertilizer materials.

Tests involving split application of nutrients suggest that widely varying rates of mixed N-P-K fertilizers may be used to promote growth of seedling pine trees, but that practical application would not exceed the N_1 P_1 K_1 rate (100 pounds N, 50 pounds P_2O_5, and 50 pounds K_2O). Further tests, taking into account weather effects from year to year, are needed to determine the most efficient rate and ratio in terms of cost per unit of tree growth. Differences in growth of trees planted in different years emphasize, as with farm crops, that response to fertilization is dependent in a large measure upon the prevailing weather pattern and other phenomena that occur through time.

SUMMARY

Forty-two fertilizer treatments were replicated three times in a cultivated slash pine plantation established in 1957 on Lynchburg loamy sand in southern Georgia. Seedlings were fertilized only twice, in 1957 and 1958. Average height of four trees in each replication was taken as the unit of observation.

Seedlings in check plots not fertilized reached a height of 60.8 inches in two growing seasons. In a 3 x 3 x 3 factorial experiment, where mixed fertilizers containing phosphorus were broadcast around trees at a rate of 50 pounds of P_2O_5 per acre, trees attained a height of 68.6 inches. Nitrogen and potash (K_2O), each at a 100 pounds per acre rate mixed with 0-, 50-, and 100-pound levels of phosphate, in most cases gave good response, but addition of potash without nitrogen or nitrogen without potash retarded growth. Phosphate alone at the 50-pound rate was the most efficient fertilizer tested; trees thus fertilized measured 28.7, 72.7, and 120.6 inches high 1, 2, and 3 years from planting. Nitrogen at the 200-pound rate, alone or in mixtures, retarded tree growth.

Additional tests involving (1) N-P-K with minor elements and lime, (2) split application of nutrients involving widely varying rates of N, P, and K, and (3) subsurface application of fertilizer did not reveal significant increases in growth when compared with single annual surface application of mixed fertilizers. Subsurface applications had the advantage of preventing excessive growth of weeds.

Rapid growth stimulated by cultivation and fertilization apparently increased the susceptibility of plantation trees to attacks by insects and diseases. Attacks by Dioryctria amatella were closely related to fertilization treatment, particularly to phosphorus. When compared with treatments containing no phosphorus, phosphate at the 50 pounds per acre rate quadrupled the incidence of Dioryctria. Attacks increased with an increase in growth rate of trees. Damage by this insect or by southern fusiform rust was negligible among slower growing trees planted nearby in native wiregrass sod.

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