THE RESPONSE OF LOBLOLLY AND SLASH PINES TO PHOSPHATE MANURES.

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SUMMARY.

An experiment which involved the application of varying levels of superphosphate to a pine stand is described and discussed. The amount of fertilizer producing the optimum response was not the greatest amount applied.

Girth, wood volume and the amount of phosphate found in the needles of the trees all showed the same trends with the same treatments.

Figures obtained from ash analyses of needles of slash and loblolly pines growing on the treated plots are listed and discussed.

The financial returns obtained as a result of fertilizing with phosphates are presented and shown to be considerable.

Rock phosphate is as efficacious as superphosphate in eliminating phosphate deficiency and in producing increased yields, and is a more economical material to use.

The amount of phosphate found in the needles of loblolly and slash pines is correlated with soil phosphate values and growth increment, and the use of a needle phosphate factor in determining the requirement of the trees for phosphate dressings is described and discussed.

INTRODUCTION.

Following the success achieved in eliminating "fused needle" disease of loblolly pine (*Pinus taeda* Linn.) by phosphate treatments (Young, 1940) and the marked improvement in growth and health of this species and of slash pine (*Pinus caribaea* Morelet) after routine plantation fertilizing with phosphate fertilizers, an experiment was designed to test the response of loblolly pine to various levels of soil phosphate. Other trial plots were established with the object of measuring the response of the two species to applications of various amounts of superphosphate and ground rock phosphate. More detailed information concerning the optimum amount of phosphates to apply was required and the experiments were planned to supply these data.

As a measure of soil phosphate content, the total phosphate value of a composite sample obtained from the top 4 inches of soil was used. Previous investigations on the same soil type (Young, 1940) had shown that applied phosphate is held in this part of the soil profile and that for the untreated soil types in the area concerned there is little variation in total phosphate content throughout the profile.

In routine practice enough phosphate is added to the soil to raise the total phosphate value of the top 4 inches to 135 p.p.m. for loblolly pine and 110 p.p.m. for slash pine. These levels were determined from the results of previous investigations of soil phosphates found under standing trees of various stages of vigour (Young, 1940).

It was considered that the amount of phosphate contained in trees on various sites might provide an index of the phosphate requirements of the sites and advantage was taken of the layout of this experiment to test this possibility. It was thought further that needle analysis might be correlated with growth increment figures and with fertilizer treatments. The opportunity was also taken to obtain ash analysis data for the two species of *Pinus* concerned, as no such information could be found in the literature.

In the area selected for the experiment slash pine trees were growing to the extent of two trees per net plot. These trees were originally planted as refills for dead loblolly plants one year after the initial planting. In the case of these trees, needle sampling for phosphate content and complete ash analyses were carried out.

Over the whole experimental area during the period of investigation routine plantation treatment in regard to the brushing of eucalypt and other coppice, the selection of the best pine stems for pruning and final crop purposes, and the pruning operation itself was carried out.

SOIL TYPE, CLIMATE AND VEGETATION.

The soil type on which the experiment was located is a podsolized, light yellow-brown sand merging into a B horizon of sandy clay at 30 inches. The topography is relatively flat, well-drained, and approximately 100 feet above datum. The rainfall is chiefly of summer incidence, with a mean value of 53 inches per annum.

The natural vegetation of the area consists of *Eucalyptus pilularis* as the principal species, with *E. acmenioides*, *E. eugenioides*, *E. micrantha*, *E. corymbosa* and *Syncarpia laurifolia* as secondary species.

SOIL PHOSPHATE LEVEL TRIAL.

For the purpose of the trial an area at Beerwah in south-eastern Queensland was selected in 1939 and a 5 x 5 Latin square layout designed and located in a compartment of loblolly pine. The trees had been planted in 1931 at an 8 ft. x 8 ft. spacing and were somewhat backward in growth, though stocking was good except for the presence of the few slash pine trees mentioned above. Some fused needle disease, indicative of phosphate deficiency, existed in the area.

Each net plot of the experiment contained 0·056 acre and the total experiment 12·4 acres. An isolation strip 16 feet wide surrounded each net plot. This strip was given the same treatment as the net plot which it surrounded. Girth breast high (g.b.h.) in inches, and height (in feet) measurements were made of all the trees on each net plot and in all plots the top 4 inches of soil (12 samples per plot) was analysed for total soil phosphate.

Initial Plot Analysis.

Analysis of the initial data obtained in July, 1939, showed that the plots were comparable in height and soil phosphate values. Results of the analyses of variance of the data are as follows:—

Mean Height in feet.

s.e. mean of 5 plots = 1·104 = 6·30% of G.M.
Necessary difference for significance = 5·0.

Treatment Means	A	B	C	D	E
	17·4	16·3	18·1	17·9	17·9

There are no significant differences between these means.

Total Soil Phosphate Content (p.p.m.) of top 4 inches of soil.

The mean square for treatment is slightly less than the mean square for error.

s.e. mean of 5 plots = 5·593 = 10·24% of G.M.
Necessary difference for significance = 17·2.

Treatment Means	A	B	C	D	E
	55·4	45·8	57·0	59·4	55·4

There are no significant differences between these means.

The analysis of covariance was made to test the relation between soil phosphate content and the height of the trees.

Test of Error of Regression.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	1	27·4558	27·4558
Deviation	11	45·6874	4·1534
Error Total	12	73·1432	

F for regression = 6·61, which is significant.

There is evidence of a significant relation between total phosphate content and height, the regression coefficient (− ·1209) indicating the average decrease in height corresponding to unit increase in phosphate content.

Analysis of Residual Variance.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Treatments	4	27·3133	6·8283
Error	11	45·6874	4·1534

F. for treatment = 1·64, which is not significant.
s.e. of mean of 5 plots = ·9114 = 5·2% of G.M.

Summary—Adjusted Mean.

Treatment	A	B	C	D	E
Height	17·5	15·3	18·4	18·5	18·0

The differences C—B and D—B just attain the critical values necessary for significance, but, in view of the non-significant value of F, significance could not be claimed for them. Such differences could easily arise in the sampling of a homogeneous population.

The observed values of the total phosphate content vary about a mean value of 54·5 p.p.m., and the regression coefficient is applicable only in the range covered by the observation. If this mean value is considerably lower than the minimum requirements of the trees, as it is in this case, it is possible that the form of response curve would alter greatly when sufficient fertilizer is applied. When the supply of an essential nutrient is much below the necessary minimum, the response curve is likely to be unstable, as the influence of extraneous factors then becomes more important. These considerations suggest the possibility that the observed regression coefficient is really due to chance.

Soil Treatments.

The five treatments applied, with the resulting phosphate addition to the top 4 inches of the soil, were as follows:—

A 190 lb. superphosphate per acre = 36 p.p.m. P_2O_5

B 383 lb. superphosphate per acre = 68 p.p.m. P_2O_5

C 818 lb. superphosphate per acre = 146 p.p.m. P_2O_5

D 1,580 lb. superphosphate per acre = 281 p.p.m. P_2O_5

E Nil

The treatments were made by hand by broadcasting measured amounts of fertilizer on each plot and its isolation strip as evenly as possible.

Progress Observations.

Measurements for g.b.h. and height were made annually in the winter during dormancy and soil analyses for total phosphate content were carried out in 1939, 1943 and 1946. Similar sampling and analytical techniques were used on each occasion.

As in previous experiments (Young, 1940) there was no measurably significant response to the application of phosphate in the first year, though the foliage of trees on treated plots became longer and a deeper green in colour. In the second year, however, significant results were obtained in that for g.b.h. and height increment data all fertilized plots were significantly superior to the controls. In the following year there were similar differences, but treatment D (1,580 lb. per ac.) was also significantly superior in g.b.h. and height increments to treatment A (190 lb. per ac.).

Similar and more marked differences appeared in succeeding years until 1946, when the experiment was concluded.

Data for g.b.h., height and wood volume increments and other relevant figures for the period 1939-1946 are given in Table 1.

Table 1.

GROWTH INCREMENT AND SOIL PHOSPHATE DATA FOR PHOSPHATE LEVEL TRIAL.

Superphosphate Treatment.	Plot No.	1939 Soil P_2O_5 p.p.m.	1946 Soil P_2O_5 p.p.m.	G.b.h. 1939, in.	G.b.h. 1946, in.	G.b.h. Increment 1939–46, in.	Height, 1939, feet.	Height, 1946, feet.	Height Increment, 1939–46, feet.	Sale Volume per acre 18 in. + 1946, sup. feet.	Wood Volume Under Bark per acre, 1939, cubic feet.	Wood Volume Under Bark per acre, 1946, cubic feet.	Wood Volume Under Bark per acre, 1939–46, cubic feet.
A	1	41	68	7·7	17·17	9·47	13·6	36·2	22·6	965·6	158·22	1,130·98	972·76
190 lb.	3	41	73	8·68	17·26	8·58	16·7	39·8	23·1	2,018	192·44	1,228·22	1,035·78
per acre	15	69	77	10·56	19·27	8·71	18·2	39·4	21·2	2,389	258·5	1,504·47	1,245·97
= 36 p.p.m.	17	73	68	9·9	18·13	8·23	18·5	41·2	22·7	2,759	304·5	1,522·5	1,218·00
P_2O_5	24	53	71	10·81	18·46	7·65	20·0	41·1	21·1	3,518	359·15	1,671·68	1,312·53
Mean	..	55	71	9·49	18·06	8·57	17·4	39·5	22·1	2,275	254·56	1,411·56	1,157·00
B	2	47	86	8·41	18·22	9·81	13·8	38·1	24·3	2,565	269·7	2,044·5	1,774·80
per acre	6	23	93	6·14	16·58	10·44	9·7	34·5	24·8	1,766	62·3	1,177·47	1,115·17
383 lb.	13	41	70	11·72	20·31	8·59	21·0	43·4	22·4	5,773	299·64	1,507·28	1,207·64
= 68 p.p.m.	19	41	95	11·24	19·90	8·66	21·7	42·3	20·6	4,896	346·92	1,852·20	1,505·28
P_2O_5	25	77	104	9·80	17·71	7·91	17·8	38·8	21·0	3,306	236·8	1,367·52	1,130.72
Mean	..	46	90	9·46	18·54	9·08	16·8	30·4 39·4	22·6	3,659	243·07	1,589·77	1,346·7
C	3	53	102	8·87	20·62	11·65	16·1	42·1	26·0	5,290	250·8	2,112·99	1,862·19
818 lb.	9	61	121	8·79	18·22	10·43	15·0	40·8	25·8	1,910	188·43	1,650·19	1,461·76
per acre	11	53	198	10·75	21·47	10·72	18·1	44·6	26·5	6,352	348·88	2,454·62	2,105·74
= 146 p.p.m.	20	77	182	11·25	20·94	6·69	19·9	45·4	25·5	4,928	305·03	1,912·90	1,607·87
P_2O_5	22	41	127	11·60	20·48	8·88	21·3	44·1	22·8	5,968	428·13	2,223·22	1,795·59
Mean	..	57	146	10·27	20·55	10·27	18·1	43·4	25·3	4,890	304·25	2,070·85	1,766·6
D	4	73	414	8·83	21·32	12·49	13·5	39·5	26·0	4,599	213·18	2,363·79	2,150·61
1,580 lb.	10	65	188	8·71	20·74	12·03	14·6	39·8	25·2	2,138	129·36	1,793·66	1,604·30
per acre	12	45	161	10·62	20·15	9·53	19·6	44·3	24·7	6,779	341·28	2,104·56	1,763·28
= 281 p.p.m.	16	53	361	10·77	21·79	11·02	19·3	47·8	28·5	8,013	359·31	2,582·16	2,222·85
P_2O_5	23	61	229	12·18	20·35	8·17	22·5	45·6	23·1	8,005	449·92	2,079·36	1,629·44
Mean	..	58	271	10·22	20·87	10·65	17·9	43·3	25·5	5,978	310·61	2,184·71	1,874·1
	5	49	72	9·92	17·24	7·32	17·2	33·5	16·3	1,866	279·4	1,046·48	767·08
E	7	49	59	10·02	16·24	6·22	18·3	35·3	17·0	1,338	308·21	1,132·2	823·99
	14	69	60	8·21	14·52	6·31	13·3	28·7	15·4	Nil	183·68	759·68	574·00
Nil	18	65	65	11·60	16·78	5·18	21·6	38·0	16·4	1,950	388·57	1,235·78	847·21
	21	45	55	11·32	17·20	5·88	19·3	40·1	20·8	1,486	301·5	1,169·82	868·32
Mean	..	55	62	10·29	16·39	6·10	17·9	35·1	17·2	1,380	292·27	1,068·37	776·1

G.b.h. Increment.

In g.b.h. over the period of the experiment there was a significant response to treatment, and analysis of the data obtained provided the following results of mean g.b.h. increase in inches, 1939-46 :—

F value = 48·390, which is highly significant.

s.e. per plot = ±·568 = 6·35% G.M.

s.e. mean of 5 = ±·254 = 2·84% G.M.

Necessary difference for significance = ·78 (5% level), 1·10 (1% level).

Plate 1.

Loblolly Pine.—Plot initiated in 1935 with no fertilizer. Photo. 1946.

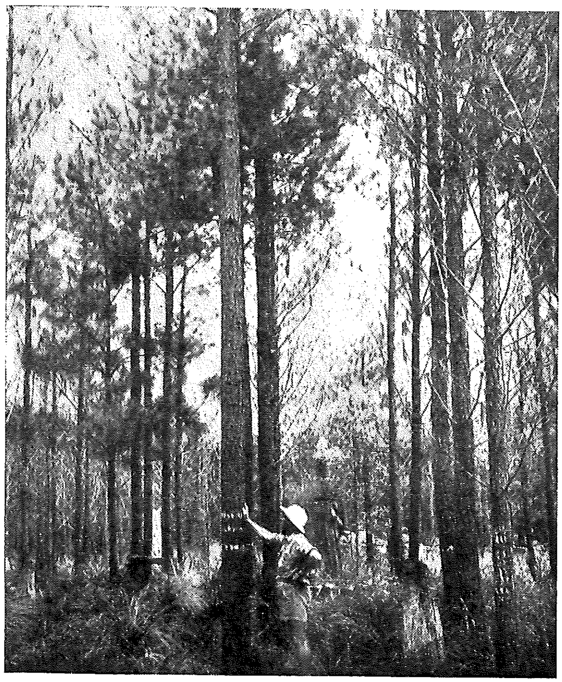

Plate 2.

Loblolly Pine.—Plot treated with superphosphate in 1935. Photo. 1946.

The means for the various fertilizer treatments were:—

	Treatment.	Mean.	Significantly exceeds at 1% level.
D	1,580 lb. superphosphate per acre ..	10·65	B, A, E
C	818 lb. superphosphate per acre ..	10·27	B, A, E
B	383 lb. superphosphate per acre ..	9·08	E
A	180 lb. superphosphate per acre ..	8·53	E
E	Nil	6·18	

This shows that, as regards g.b.h., all treatments were significantly superior to the untreated plots and that response to the fertilizer varied with the quantity applied, except in the case of the heaviest application (D) which gave a response not significantly greater than that of the next heaviest (C). This demonstrated that the optimum phosphate application for girth increment is in the neighbourhood of that given to treatment C, *i.e.*, 818 lb. per acre.

Height Increment.

Analysis of data obtained for height increment (in feet) over the same period is as follows:—

F value = 11·656, which is highly significant.
s.e. per plot = ±2·712 = 11·08% G.M.
s.e. mean of 5 = ±1·213 = 4·95% G.M.
Necessary difference for significance = 3·74 (5% level), 5·24 (1% level).

The means for treatments were:—

	Treatment.	Mean.	Significantly exceeds 1% level.
D	1,580 lb. superphosphate per acre	27·36	E
C	818 lb. superphosphate per acre	27·20	E
B	383 lb. superphosphate per acre	25·70	E
A	190 lb. superphosphate per acre	24·82	E
E	Nil	17·32	

This shows in the case of height increment that all the phosphate treatments gave results significantly superior to the control and that there was no significant difference between the results obtained from the various superphosphate applications.

Merchantable Volume.

Thinnings from plantations are normally sold to sawmillers for case manufacture. Stems taken for this purpose must at present have a minimum diameter of 3 inches at the small end. Results of analysis of figures in superficial feet per acre showing the difference between treatments (excluding the "nil" treatment) in producing merchantable thinnings in 1946 are given below:—

F value = 43·677, which is highly significant.
s.e. per plot = 523·28 = 12·47% G.M.
s.e. mean of 5 = 234·02 = 5·58% G.M.
Necessary difference for significance = 763 (5% level), 1,110 (1% level).

Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D 1,580 lb. superphosphate per acre ..	5,907	B, A	C
C 818 lb. superphosphate per acre ..	4,890	B, A	
B 383 lb. superphosphate per acre ..	3,661	A	
A 190 lb. superphosphate per acre ..	2,330		

In this respect treatments D and C again proved their superiority over the other treatments, and in addition treatment B was significantly superior to treatment A. At the 5% level treatment D was superior to treatment C.

The cost of fertilizer application, including labour and materials, and the value of thinnings resulting from each treatment were per acre as follows:—

Treatment.	Cost of Treatment Per Acre.	Value of Thinnings.	Profit.
	£ s. d.	£ s. d.	£ s. d.
D	5 0 0	8 17 0	3 17 0
C	2 15 0	7 7 0	4 12 0
B	1 11 0	5 10 0	3 19 0
A	1 1 0	3 10 0	2 9 0
E	..	2 0 0	2 0 0

Commercial values of similar timber obtained later in the district are considerably above those used in this calculation. These figures do not allow for compound interest on capital outlay but illustrate the relative proceeds and show that in value of thinnings alone over a 7-year period each of the fertilizer additions applied was profitable and that the most profitable treatment was C. Treatment B was more profitable than treatment D in spite of the insignificant but slightly greater timber volume received from the latter (Table 1).

Thinning is considered commercially practicable when 3,000 sup. ft. per acre are available. In the case of this experiment treatments D, C, and B had reached this stage whereas treatments A and E were not sufficiently developed (Table 1). The length of time necessary for treatment E (no fertilizer) to reach the 3,000 sup. ft. limit is not known but would be so long that during that period the growth of the selected final crop trees would be restricted owing to competition, so the extra capital cost for maintenance of the plantation over the longer rotation would have to be added to production costs.

For the sake of thinnings alone, fertilizing, in this instance at least, is shown to be highly desirable and profitable.

Total Wood Volume Increase.

The total cubic volume of wood per acre produced by each treatment during the 1939–46 period was calculated from the measurements obtained and from volume curves supplied by the Queensland Forestry Sub-department.

These curves were constructed from data obtained from the species concerned which were growing on the area under consideration. The results of the calculations for under-bark volume increase per acre in cubic feet are as follows:—

F value = 19·640, which is highly significant.
s.e. per plot = ±226·92 = 16·39% G.M.
s.e. mean of 5 = ±101·48 = 7·33% G.M.
Necessary difference for significance = 312·7 (5% level), 438·4 (1% level).

	Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D	1,580 lb. superphosphate per acre	1,874·1	B, A, E	
C	818 lb. superphosphate per acre	1,766·6	A, E	B
B	383 lb. superphosphate per acre	1,346·7	E	
A	190 lb. superphosphate per acre	1,157·0		E
E	Nil	776·1		

There were no significant differences between treatment means for U.B. Vol. per acre, 1939. The correlation coefficient for U.B. Vol. per acre, 1939 and U.B. Vol. increase per acre, 1939–46 is equal to ·554, and this is significant at the 5 per cent. level. Accordingly the table of corrected means, with significance of differences, is as follows:—

	Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D	1,180 lb. superphosphate per acre	1,813·7	A, B, E	
C	818 lb. superphosphate per acre	1,719·2	A, E	B
B	383 lb. superphosphate per acre	1,423·9	E	
A	190 lb. superphosphate per acre	1,210·8	E	
E	Nil	753·1		

On conversion of cubic feet into superficial feet of wood per acre (factor of 9·4), the figures for each treatment, at a contemporary case-timber sale value of 3s. per 100 sup. ft. of timber, for the area in question are as follows:—

——	Cost of Treatment.	Total Wood Volume Super. Feet.	Value.	Volume Increment, 1939–46.	Value.	Net Profit.
	£ s. d.		£ s. d.		£ s. d.	£ s. d.
D. ..	5 0 0	20,536·27	30 6 0	17,048·78	25 11 0	20 0 0
C. ..	2 15 0	19,565·99	29 7 0	16,160·48	24 5 0	21 10 0
B. ..	1 11 0	14,943·838	22 8 0	13,384·66	20 1 0	18 10 0
A. ..	1 1 0	13,268·844	19 18 0	11,381·52	17 1 0	16 0 0
E. ..	nil	10,042·678	15 1 0	7,079·14	10 12 0	10 12 0

In this case, as with the merchantable thinnings, it is seen that, if clear felled in 1946 and sold as case timber, it was profitable to apply any of the fertilizer treatments and that in addition the return received from the application heavier than the C treatment (D) gave a lower profit than the C treatment.

Plate 3.
Loblolly Pine.—Plot initiated in 1940 with no fertilizer. Photo. 1940.

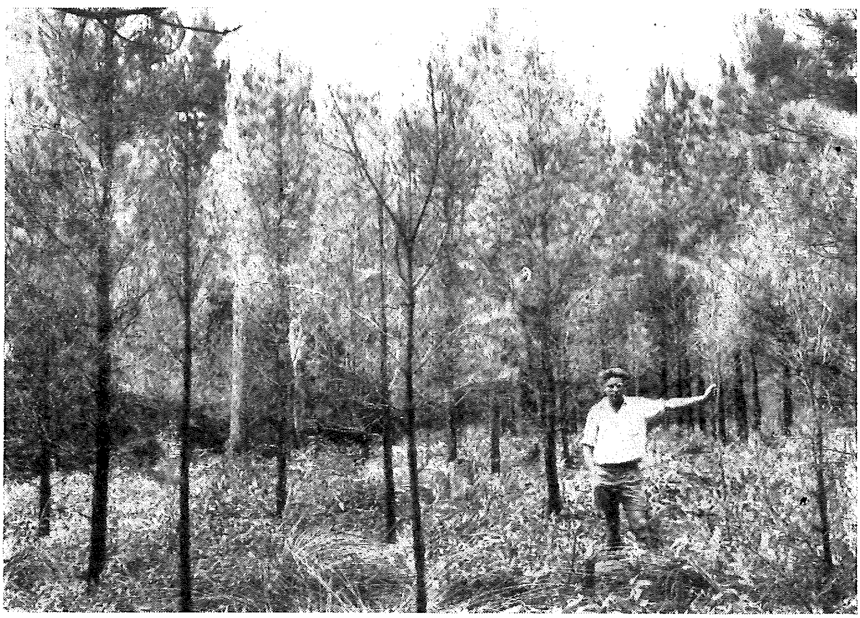

Plate 4.
Loblolly Pine.—Same plot as Plate 3 (no fertilizer). Photo. 1946.

Plate 5.

LOBLOLLY PINE.—Plot of same age and adjacent to plot in Plates 3 and 4, but fertilized in 1940 with superphosphate. Photo. 1946.

Furthermore, the quality value of the timber on the treated plots is increasing rapidly in the case of the select pruned trees, which all produce ply and first-quality clean wood and command the greatly enhanced price for this type of wood when harvested. Plates 3-5 indicate the degree of response to superphosphate.

The unfertilized areas may of course eventually reach this stage also, but in at least double the time as calculated from present increment. This being so, two rotations for fertilized trees would be produced during the time to maturity of one crop of unfertilized trees.

Soil Phosphate Increase.

The total amount of phosphate in the top four inches of soil for each plot in 1939 before treatment and in 1946 at the conclusion of the trial is shown in Table 1. It will be noted that the soil phosphate content increased with treatment but that the figures did not account for the whole amount applied.

Analysis of the soil made on samples taken down the profile below the 4-inch level showed that, except in the case of the heaviest treatment (D), there had been no leaching downwards of the phosphate—that is, it was completely fixed within the 4-inch sampling depth. This is consistent with the analytical data, which showed that the soil type in question had a phosphate-fixing capacity of on the average 250 p.p.m. In the case of treatment D the total phosphate value of the 4-8-inch depth had increased, indicating that with this treatment some leaching occurred. With a fixing capacity of 250 p.p.m. in the top four inches this would be expected when 281 p.p.m. were added, as the top section would be over-saturated and the surplus leached down and fixed below. No increase in soil phosphate was found below 8 inches.

In no case, however, at the end of the 7-year period from fertilizing does the phosphate content of the soil reach the total of the applied and original phosphate values. This difference can only be accounted for by the amount taken up by the trees and either held there or deposited on the soil surface in the dead needles. This amount is large, as Table 2, showing the amount of phosphate in green and dead needles, illustrates.

In the case of treatment E (no fertilizer) the soil phosphate value has risen on the average 7 p.p.m. in the top four inches of the profile. The accuracy of the analytical method used is $\pm$ 8 p.p.m. and perhaps accounts for this increase when combined with sampling error. In addition it would be expected that the trees are taking up some phosphate from lower depths in the soil and that some of this is being returned to the soil surface in the dead needles (Table 2). With the rotting of these needles this plant phosphate would be absorbed in the surface soil and so increase its total phosphate content.

Whether this action would in time raise the soil phosphate concentration to a figure adequate for tree nutrition requires further investigation, but observations carried out on a dune sand on Fraser's Island off the Queensland coast support this idea, as trees of the same species planted on this sand with a total soil phosphate value of 24 p.p.m. grew very slowly and exhibited all the symptoms of fused-needle disease for a period of 20 years, after which they began to thrive. By this time a thick humus layer, formed from pine needles and other leaves and plant detritus, had accumulated and had apparently built up a sufficiently concentrated plant-nutrient supply to fulfil the conditions necessary for normal growth of *Pinus*.

Phosphate Content of Pine Needles.

For the purpose of estimating the phosphate content of the needles of the trees on each plot a composite sample consisting of needles from each of four co-dominant trees on each net plot was obtained. The needles were gathered on the same day from the same relative positions on each tree. This position was standardized and was the end three inches of needle-covered lateral branch on the whorl originating nearest to a trunk diameter of two inches. This whorl was found to be the highest to which it was convenient to climb.

The results of the analyses are shown in Table 2.

Table 2.

PHOSPHATE CONTENT OF GREEN AND DEAD NEEDLES.

Superphosphate Treatment.	Plot No.	Loblolly Pine. P_2O_5 in Green Needles, Dry Basis.	Loblolly Pine. P_2O_5 in Dead Needles, Dry Basis.	Slash Pine. P_2O_5 in Green Needles, Dry Basis.
		p.p.m.	p.p.m.	p.p.m.
	1	1,892	378	1,286
A	8	2,075	477	1,680
	15	2,195	329	1,094
190 lb. per acre	17	1,642	407	1,614
	24	2,177	360	1,564
Mean	..	1,996	390	1,448
	2	2,300	449	1,580
B	6	2,327	528	1,995
	13	2,274	448	2,073
383 lb. per acre	19	2,113	475	1,988
	25	2,454	476	2,127
Mean	..	2,294	475	1,953
	3	3,179	618	2,013
C	9	3,084	759	2,172
	11	2,538	739	2,556
818 lb. per acre	20	3,192	630	2,028
	22	2,748	657	2,478
Mean	..	2,948	681	2,249
	4	3,105	1,065	2,566
D	10	3,453	1,189	2,808
	12	3,165	1,148	1,751
1,580 lb. per acre	16	3,023	1,138	2,856
	23	3,195	1,294	2,439
Mean	..	3,188	1,167	2,484
	5	1,330	349	1,314
E	7	1,398	363	1,254
	14	1,446	420	1,091
Nil	18	1,409	460	1,071
	21	1,657	340	1,272
Mean	..	1,448	386	1,200

The needles were fully developed when gathered in June, 1946, at the end of the autumn growing period. The slash- and loblolly-pine needles were gathered at the same time but in the case of the former species were obtained from only two trees per plot as explained above. Three pounds of green needles were obtained per plot for each species.

For the dead needles, fresh autumn-fallen needles were gathered from the forest floor over the area of each net plot, care being taken to avoid the needles shed by the few slash-pine trees. All samples were bagged according to their origin, and chemical analyses were made on an oven-dry basis.

Statistical analysis of the chemical data obtained for phosphate content of green needles of loblolly pine led to the following results:—

F value = 73·575, which is highly significant.
s.e. per plot = ±184·301 = 7·76% G.M.
s.e. mean of 5 = ±82·422 = 3·47% G.M.
Necessary difference for significance = 254·0 (5% level), 350·0 (1% level).

	Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D	1,580 lb. superphosphate per acre	3,188·2	B, A, E	
C	818 lb. superphosphate per acre	2,938·2	B, A, E	
B	383 lb. superphosphate per acre	2,293·6	E	A
A	190 lb. superphosphate per acre	1,996·2	E	
E	Nil	1,448·0		

This demonstrated that the trend is in the same direction as that for g.b.h. and wood volume, that there is no significant difference between the results given by treatments D and C, and that both of these were significantly better than treatments B, A, and E. Treatment B figures exceeded those of E (1% level) and A (5% level) and those of treatment A exceed those of treatment E.

It would thus appear that from the phosphate uptake standpoint there is again no advantage to be obtained by applying phosphate in quantities in excess of that found in treatment C.

The figures obtained from the analysis of the dead needles of loblolly pine yielded the following results:—

F value = 166·648, which is highly significant.
s.e. per plot = ±56·859 = 9·1% G.M.
s.e. mean of 5 = ±25·428 = 4·10% G.M.
Necessary difference for significance = 78·3 (5%level), 109·8 (1% level).

	Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D	1,580 lb. superphosphate per acre	1,166·8	C. B, A, E	
C	818 lb. superphosphate per acre	680·6	B, A, E	
B	383 lb. superphosphate per acre	475·2		A, E
A	190 lb. superphosphate per acre	390·2		
E	Nil	386·4		

The same trend as occurred with the green needles was again displayed, with the notable exception that treatment D exceeded treatment C very significantly. There was no difference between treatment A and E. The reason for these variations is unknown but it is surmised that, with excess phosphate available to the tree as in treatment D, the conditions of phosphate transfer are such before needle abscission that the flow of this nutrient back to the tree from the old needles does not take place to such an extent as when there is a phosphate deficiency or balance.

In the case of the green-needle analyses of slash pine, examination of the data resulted as follows:—

F value = 16·621, which is highly significant.

s.e. per plot = ±294·663 = 15·78% G.M.

s.e. mean of 5 = ±131·177 = 7·06% G.M.

Necessary difference for significance = 406·0 (5% level), 569·2 (1% level).

	Treatment.	Mean.	Significantly exceeds at levels 1%	5%
D	1,580 lb. superphosphate per acre	2,484·0	A, E	B
C	818 lb. superphosphate per acre	2,249·4	A, E	
B	383 lb. superphosphate per acre	1,952·6	E	A
A	190 lb. superphosphate per acre	1,447·6		
E	Nil	1,200·4		

The same trend was shown again and there was no difference between treatments D, C, and B. It is noteworthy, however, that the phosphate concentrations in the needles of this species differ materially in level from those obtained for loblolly pine and are approximately 500 p.p.m. less. This is in accord with previous findings (Young, 1940) concerning the lower phosphate requirement of slash pine as compared with loblolly pine. In the case of the former species it would appear that the optimum phosphate application required for the site in question is approximately half that needed for loblolly pine.

Ash Analysis of Green and Dead Needles.

The opportunity was taken to obtain figures for the ash composition of green and dead needles of loblolly pine and green needles of slash pine. For this purpose the samples obtained from all plots of any one treatment were compounded and analysed as one sample.

The results of the analyses are shown in Table 3. All results are given as a percentage of dry matter as obtained after oven-drying. The mean results obtained by averaging the results of analyses of all treatments are also shown.

Table 3.

ASH ANALYSIS OF NEEDLES OF LOBLOLLY AND SLASH PINES.

Superphosphate Treatment.	Percentage of Dry Matter.										
	Ash.	SiO_2.	Sesqui-oxides.	P_2O_5.	CaO.	MgO.	Na.	K_2O.	CO_2.	SO_4.	Cl.
Loblolly Pine—*Green Needles*— lb.											
A 190 ..	3·4468	1·4062	0·2673	0·1896	0·1852	0·2052	Trace	0·5230	..	..	..
B 383 ..	3·6103	1·4073	0·2801	0·2294	0·2098	0·1886	Trace	0·5264	..	..	..
C 818 ..	4·0204	1·4983	0·4255	0·2948	0·2228	0·1816	Trace	0·5730	..	..	..
D 1,580 ..	4·0817	1·4014	0·4200	0·3188	0·2284	0·2206	Trace	0·5172	..	..	..
E Nil	3·0389	1·4763	0·2206	0·1448	0·1782	0·1415	Trace	0·5172	·1716	·0888	0·022
Mean	3·6256	1·4379	0·3227	0·2175	0·2049	0·1875	Trace	0·5326	..	..	..
Loblolly Pine—*Dead Needles*— lb.											
A 190	3·8435	1·8202	0·1183	0·0390	0·3884	0·1616	Trace	0·1192	..	..	..
B 383	4·0762	1·9609	0·1289	0·0475	0·4177	0·1954	Trace	0·1028	..	..	..
C 818	4·6252	1·7958	0·1983	0·0681	0·4216	0·1859	Trace	0·1318	..	..	..
D 1,580 ..	4·5243	1·6824	0·2293	0·1167	0·4353	0·2216	Trace	0·1009	..	..	..
E Nil	3·6382	1·7086	0·1016	0·0386	0·3404	0·1616	Trace	0·1192	0·3560	0·0798	0·019
Mean	4·1415	1·7936	0·1553	0·0620	0·4006	0·1852	Trace	0·1148	..	..	..
Slash Pine — *Green Needles*— lb.											
A 190	2·2082	0·1258	0·1781	0·1448	0·1480	0·3417	Trace	0·5374	..	..	..
B 383	2·2887	0·1722	0·2077	0·1953	0·1366	0·2911	Trace	0·4826	..	..	..
C 818	2·6975	0·1505	0·3352	0·2249	0·1721	0·3430	Trace	0·6177	..	..	..
D 1,580 ..	2·5744	0·1593	0·2896	0·2484	0·1214	0·2963	Trace	0·6050	..	..	..
E Nil	2·6832	0·1263	0·1666	0·1200	0·1342	0·3242	Trace	0·5128	0·1838	0·150	0·04
Mean	2·4904	0·1468	0·2354	0·1867	0·1425	0·3193	Trace	0·5511	..	..	..

The figures obtained from the analyses are discussed under their separate item headings below.

Total Ash.

In the case of the green needles of loblolly pine the ash content varies in much the same way as growth increment—that is, there is an increase with treatment up to treatment C, which is approximately the same as treatment D. This trend also occurs with the dry needles, which have a higher total ash content.

With slash pine this trend is not shown and there is little variation between treatments. The mean ash content for this species is approximately two-thirds of that for loblolly pine. This is possibly bound up with the higher nutrient demands of the latter species. Most of the difference, however, is made up of silica content.

Silica.

There is little variation between treatments as regards silica content within any of the three series. The amount in the dead needles of loblolly pine is, however, greater than that in the green needles by approximately 20 per cent.

A trend towards a progressive decrease of silica in loblolly-pine needles with a progressive increase of phosphate is indicated. In slash pine, however, this trend is absent.

Loblolly pine contains approximately 10 times as much silica in its green needles as does slash pine, this factor being responsible for the greater part of the difference in total ash content. The high silica content of loblolly-pine needles compared with slash-pine needles is reflected in the physical hardness of the former.

Sesquioxides.

The trend with sesquioxides is much the same in all three series and varies with the growth increment of the trees and according to the treatments applied That is, as in the case of ash content, the percentage rises with treatment with little difference between treatments C and D except in the case of slash pine, where there is a distinct drop in the case of treatment D from the peak attained by treatment C.

The dead loblolly needles have approximately one-half the sesquioxide content of the green needles of the same species. This is probably due to the abstraction of nutrients from the old needles before abscission.

The slash-pine needles have approximately one-third less sesquioxide content than the loblolly samples. This again reflects the different nutrient demands of the two species.

Phosphate.

The amount of phosphate in the green needles of loblolly pine is directly proportional to growth increment. This shows that a needle analysis made under the conditions described should approximate 0·2556 per cent. for adequate nutrition, and phosphate dressings should be applied to achieve this concentration.

The dead loblolly needles have a much higher phosphate content for the highest dressing than for the lower dressings. This probably means that there is excess phosphate available in the tree and this excess is being disposed of to at least some extent in the cast needles.

The plot which produced the highest wood volume increment in treatment C (plot II of Table 1) had a green-needle phosphate content of 0·2556% P_2O_5. This increment is of the same order as the highest increments in plot D and may be taken as an index of the optimum needle concentration of P_2O_5 required.

When one divides the difference between the mean values for green-needle phosphate content of each treatment and the control by the amount of fertilizer per acre added, a figure for increase in phosphate content per hundredweight of superphosphate is obtained for each treatment; and, since treatment C gave the best results, the mean of all the treatment increases up to the C treatment could be taken as an interim constant for fertilizer calculation.

Thus needle phosphate increment—

E to A 1 cwt. superphosphate gives 0·0304%
E to B 1 cwt. superphosphate gives 0·0249%
E to C 1 cwt. superphosphate gives 0·0205%

Average needle phosphate content per cwt. superphosphate E to C = ·0253%

If the needle phosphate content of any stand is estimated under the conditions of this experiment and is less than the optimum of 0·2556 per cent. P_2O_5, then the difference between the amount found and the optimum, divided by 0·0253, should give the number of hundredweights of superphosphate (21 per cent. P_2O_5) required as an addition for adequate phosphate nutrition with the soil-type and species in question. Much field work of course is essential to verify this but as a working hypothesis it should give satisfactory results.

Lime.

The calcium content of green and dead needles of loblolly pine shows in both cases a progressive increase with the phosphate dressing applied up to treatment C, when no further significant increase in amount is found. This is in accord with volume increment trends. In the case of slash pine, however, there does not appear to be any relationship between the figures obtained.

The calcium content of the dead needles of loblolly pine is approximately double that of the green needles and proportional to each treatment. In comparison with slash pine, loblolly pine contains a much greater quantity of calcium in its green needles.

Magnesia.

In the case of loblolly pine there is approximately the same amount of magnesia present in green and dead needles and in both cases there is a tendency, though variable, for the magnesia content to increase with the intensity of the phosphate dressing. This tendency is not evident in the case of slash pine and the magnesium content of this species is much higher than that of loblolly pine.

Soda.

Only a trace of sodium was found in any sample from both species.

Potash.

The potash content of the green needles of loblolly and slash pine varies little. There is a tendency towards an upward trend in concordance with the intensity of the phosphate application and in both cases treatment C is highest and exceeds treatment D. Treatments A, B, D, and E are very similar. The same trend is evidenced by the figures obtained for the dead needles of loblolly pine which, however, on the whole contain approximately one-fifth of the amount of potash present in the green needles.

Carbon Dioxide, Sulphate, and Chlorine.

Only one estimation for each of these was made for each of the three series. The carbon dioxide is approximately the same for both species but the dead needles of loblolly pine yield twice as much as do the green ones. Green slash-pine needles are higher in sulphate than green loblolly-pine needles, which in turn are slightly higher in sulphate than dead needles of the same species. The chlorine content of the green needles of slash pine is almost twice as great as that of green loblolly-pine needles and the latter are slightly richer in chlorine than dead needles of the same species.

Correlation of Volume Increase and Needle Phosphate Content.

The mathematical correlation between wood volume increment per acre and needle phosphate content for each treatment as shown by the analysis of covariance is as follows:—

	Sums of Squares and Products.				Correl. Coeff.	Regr. Coeff.
——	D.F.	y	xy	x^2		
Rows	4	281,473	−149,195	131,401	−·776	−1·135
Columns	4	156,010	−189,658	241,655	−·977*	−·785
Treatments	4	4,045,164	6,351,967	9,996,484	·999*	·635
Error	12	617,902	−31,384	407,604	−·062	−·077
Total	24	5,100,550	5,981,730	10,777,143	·807	·555

Green Needle P_2O_5 p.p.m. 1946, (x) and U.B. Vol. Increment 1939–46 (y).

* = significant at the 1% level (p· <·01).

The coefficients shown above are calculated from the sums in the separate lines, derived from row means, column means, &c. The total correlation coefficient is significant and positive, indicating that the volume increment increases with increasing phosphate content of the green needles over the 25 individual plot values, the rate of increase being ·555 per unit increase in P_2O_5. The highly significant value of the correlation between treatments shows that a similar trend exists for the five treatment means, reflecting the close similarity between the response curves for P_2O_5 and volume increment. The remaining individual correlations are negative, that between the column means being significant at the 1 per cent. level. The significance of this correlation between column means is of little importance when considered in conjunction with the residual variability indicated by the error term, as shown in the following analysis:—

ANALYSIS OF REDUCED VARIANCE—U.B. VOLUME INCREMENT.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Row regrn.	1	169,399	169,399
Row residual	3	112,074	37,358
Rows	4	281,473	70,368
Column regrn.	1	148,849	148,849
Column residual	3	7,161	2,387
Columns	4	156,010	39,002
Treatment regrn.	1	4,036,168	4,036,168
Treatment residual	3	8,996	2,999
Treatments	4	4,045,164	1,011,291
Error	12	617,902	51,492

Compared with the error mean square the only regression term in the above analysis which attains significance is the treatment regression. The apparently high correlations shown by the row and column means are thus not inconsistent with non-significant association when the variability to which the means are subject is taken into account.

Even though the apparent anomalies shown by row and column means are not significant on the above analysis it is to be expected that, on a simple hypothesis of increasing phosphate accompanying increasing volume increment, these coefficients would be positive. One possible reason for the lack of such an indication is that the green-needle P_2O_5 determinations are subject to high sampling errors, an estimate of which is given below. The range of phosphate values within treatments is about 400 on the average and the range of column means 274, whereas that of the treatment mean is 1,740. If the sampling error is high these ranges, except that for treatments, are well within the limits due to random sampling and correlations arising therefrom could be attributed to accidents of sampling.

An indication of the extent of these sampling errors can be obtained by considering the figures for loblolly pine and slash pine in each plot. If it is assumed that for each treatment the difference between the two varieties is constant, the residual of the analysis of variance of 25 differences provides an estimate of the sampling error.

ANALYSIS OF VARIANCE—MEAN P_2O_5 GREEN NEEDLES.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Rows	4	343,091	85,773
Columns	4	233,989	58,497
Treatment	4	15,338,361	3,834,590
Error	12	270,924	22,577
Total	24	16,186,365	
Sampling Error	20	1,462,014	73,101

This gives ± 270 p.p.m. as the sampling error to which a single determination is subject. Also, with the exception of the treatment term, all mean squares are less than the sampling error, that for error being significantly so. This indicates that variations other than between treatment means are less than would normally be expected through the operation of sampling variations alone, and in the circumstances correlation with volume increment would be purposeless for other than treatment means.

This means that there is a good positive correlation between green-needle phosphate content and the means for each treatment, but that the sampling was not adequate enough to obtain similar figures for plots. Such sampling would entail many more analyses per individual plot; under the circumstances of this experiment it was physically impossible to do this.

Correlations with Wood Volume Increase.

Similar results were obtained for correlations between soil phosphate increase and wood volume increase, and dead-needle phosphate content and wood volume increase. The degree of sampling of both soil and dead needles was insufficient for plot correlation but enough for treatment mean correlations.

Fused-needle Incidence.

The incidence of fused-needle symptoms on the various treatments in 1939 and 1946 was estimated and is shown in Table 4.

Table 4.

FUSED-NEEDLE DISEASE INCIDENCE IN PHOSPHATE LEVEL TRIAL.

Superphosphate Treatment per Acre.	Per cent. Fused-neecedle Affected Stems.	
	1939.	1946.
A 190 lb.	48	4·7
B 383 lb.	50	1·1
C 818 lb.	45	..
D 1,580 lb.	43	..
E Nil	44	47·0

It will be noted that symptoms of this disease as previously described (Young, 1940) have entirely disappeared in treatments C and O and have decreased in A and B. Treatment E (control) still shows as bad a picture as it did at the initiation of the experiment. It is assumed from this and other work that the symptoms in question are those of phosphate deficiency as described fully in a previous bulletin (Young, 1940), where mycorrhizal activity and soil phosphate relationships are discussed.

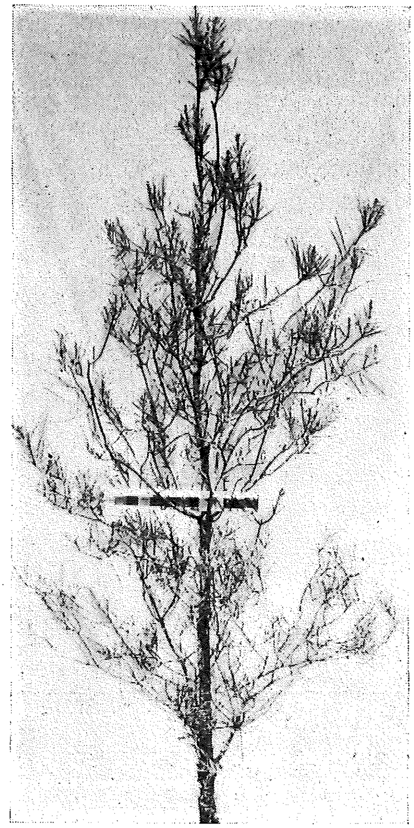

Plate 6.

LOBLOLLY PINE.—Aged 12 years, with typical severe phosphate-deficiency symptoms ("fused needle"). Photo. 1946.

ROCK PHOSPHATE APPLICATIONS.

Loblolly Pine.

At the time the experiment described above was initiated observation plots were established on which rock phosphate was used instead of superphosphate. These trials were set out as a supplementary strip of plots along one side of and contiguous to the Latin square described above. The net plot size and isolation areas were of similar dimensions. Owing to the restricted area available no replications could be established and the rock phosphate plots were intended to be strictly observational.

The object of this additional trial was to gain further indications of the response of the plantation trees to rock phosphate applications as compared with superphosphate treatment. Previous work in the locality had suggested that there was no difference in the response given by the trees to the two fertilizers when applied as carriers for the same amount of P_2O_5. This is regarded as important, because whereas the prices per ton of superphosphate and rock phosphate are approximately the same the phosphate content of the latter is approximately double that of the former. In addition relative cheapness of rock phosphate P_2O_5 cartage costs would be lower, as only half the quantity of this material would have to be handled if it were used instead of superphosphate.

The fact that, when superphosphate is applied to most of these soils, the phosphate is fixed and none can be isolated as available phosphate when laboratory-treated soil samples are analysed within 15 minutes of application was established in the laboratory and lent support to the idea that the application of an already fixed form of the phosphate, such as rock phosphate, would be just as efficient as a source of this plant nutrient for pine trees as would be application of a soluble phosphate which became fixed immediately after application.

The treatments applied to the plots were:—

1. 146 lb. rock phosphate per acre = 52 p.p.m. P_2O_5 to top 4 in. soil.
2. 336 lb. rock phosphate per acre = 120 p.p.m. P_2O_5 to top 4 in. soil.
3. 986 lb. rock phosphate per acre = 352 p.p.m. P_2O_5 to top 4 in. soil.

The adjacent untreated plots of the superphosphate trial were used as checks and the superphosphate-treated plots themselves were used for relative response comparisons.

The observations for growth, soil phosphate, and needle phosphate were carried out at the same time as those for the superphosphate trial. The resulting data are summarized in Table 5.

Table 5.

GROWTH, WOOD VOLUME AND PHOSPHATE CONTENT DATA OBTAINED FROM ROCK PHOSPHATE APPLICATIONS TO LOBLOLLY PINE AND PHOSPHATE DATA FOR SLASH PINE.

Plot.	Phosphate added per top 4 in. Soil. p.p.m	Soil P_2O_5, 1939 p.p.m.	Soil P_2O_5, 1946 p.p.m.	G.b.h., 1939 (in.)	G.b.h., 1946 (in.)	G.b.h., Increase, 1939–46 (in.)	Height, 1939 (feet).	Height, 1946 (feet).	Height, Increase, 1939–1946 (feet.)	Sale volume, 18in. + G.b.h., 1946 sup. ft.	Wood volume under bark, 1939. (cu. ft.)	Wood Volume under Bark, 1946 (cu. ft.)	Wood Volume under Bark, Increase, 1939–46 (cu. ft.)	p.p.m. Needle Phosphate Content. *P. taeda*, 1946.	p.p.m. Needle Phosphate Content. *P. caribaea*, 1946.
1	52	57	157	6·63	16·12	9·49	11·07	35·5	18·3	1,041	85·65	925·02	839·37	1,914	2,444
2	120	65	169	8·14	18·32	10·18	13·2	36·5	18·2	1,777	112·14	1,270·92	1,158·78	1,898	1,532
3	352	53	196	8·07	19·30	11·23	13·8	32·7	19·4	3,779	179·48	1,833·26	1,653·78	2,816	2,552

On comparing directly adjacent plots in the superphosphate trial—that is, plot 1 with plot 1, 2 with 2, and 3 with 3 (Tables 1 and 2)—and allowing for variations in phosphate application, it will be appreciated that there is no indication that that type of phosphate has given a significant difference in response.

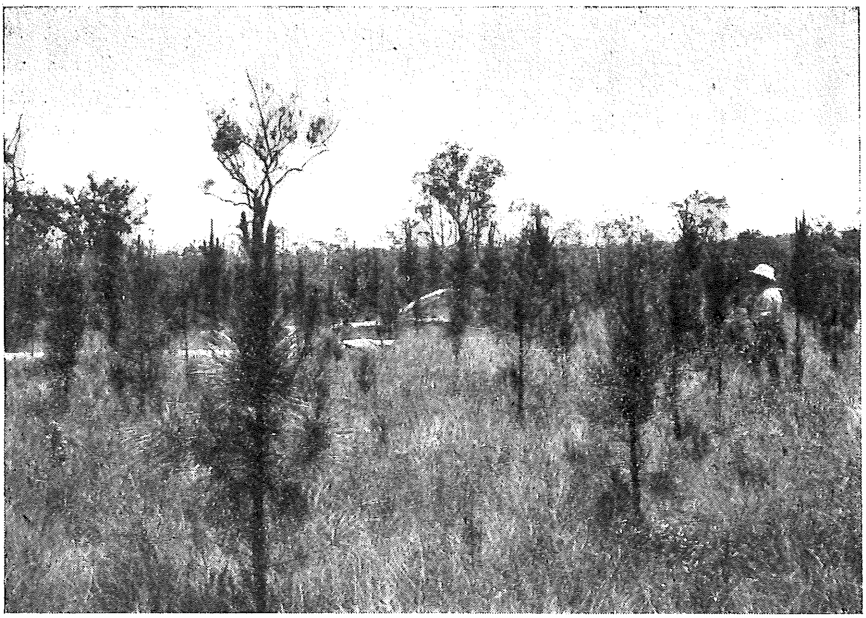

Plate 7.
SLASH PINE.—Plot treated with rock phosphate in 1939. Photo. 1939.

Plate 8.
SLASH PINE.—Same plot as Plate 7 (treated with rock phosphate). Photo. 1946.

Plate 9.
SLASH PINE.—Same plot as Plate 7, but untreated. Photo. 1939.

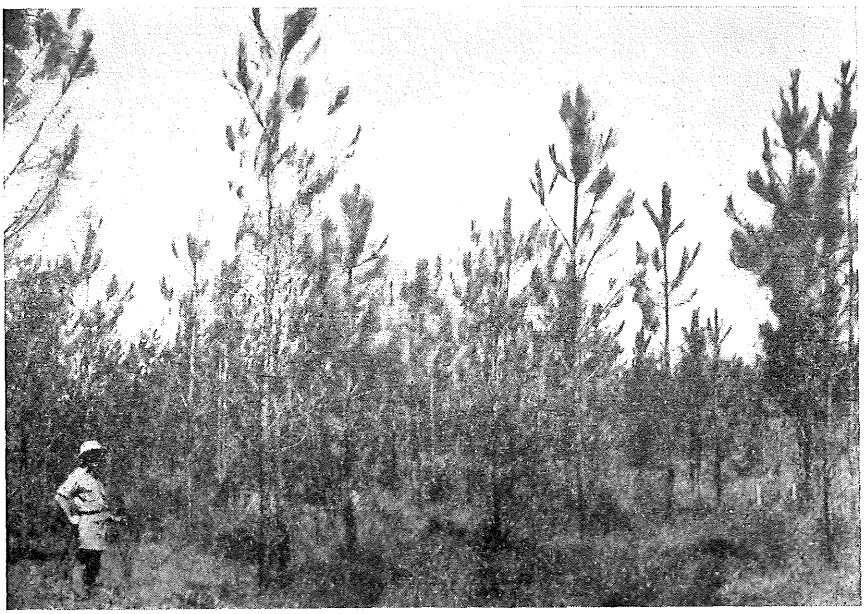

Plate 10.
SLASH PINE.—Same plot as Plate 9 (no fertilizer). Photo. 1946.

The sampling error for needle phosphate content is of course too great and the differences not large enough in the case of the single plots to permit of hard and fast conclusions being drawn.

It was noted in the case of rock phosphate applications that measureable growth response did not occur until one season later than that in which a response was received from superphosphate additions. This means that the superphosphate-treated plots have an initial season's advantage in stimulated growth over the rock-phosphate-treated plots. Thereafter, however, the responses are approximately parallel. The rock phosphate application had the same effect on fused-needle incidence as did the superphosphate.

Slash Pine.

A further rock phosphate fertilizer trial was established in the 1939-40 season in a slash-pine plantation on the same forest reserve. The soil-type in this instance was poorer than that previously described but possessed the same general profile with a reduced A horizon. It was underlain by a sandy clay at 18 inches. The mean total phosphate content of the top four inches of soil of the area was 27 p.p.m.

The slash pine on the site was planted in 1934 and was extremely backward in growth. All trees exhibited some form of phosphate deficiency symptoms. The plot was laid out as a simple block with two replications of each of three treatments. Each gross plot contained 0·134 acre and an isolation strip treated similarly to the net plot and 16 feet wide surrounded each net plot. The treatments applied were:—

1. 772 lb. superphosphate per acre = 120 p.p.m. total P_2O_5 per top 4 inches soil.
2. 336 lb. rock phosphate per acre = 120 p.p.m. total P_2O_5 per top 4 inches soil.
3. Control (no application).

The rock phosphate used (40 per cent. P_2O_5) contained approximately double the amount of phosphate per unit weight that was in the superphosphate (21 per cent. P_2O_5).

The trees were planted at an 8 feet x 8 feet spacing and routine plantation treatment was carried out on the plot, as was described for the superphosphate application trial. Measurements of growth responses were made annually and a summary of the data obtained during the currency of the experiment is shown in Table 6.

The rock phosphate response was again delayed for one season, and when this is taken into account it is apparent that the response given to the same amounts of phosphate applied as rock phosphate and as superphosphate was equal. This is important when considering the cost of the two materials (*vide* previous discussion).

Table 6.

SUMMARY OF OBSERVATIONS MADE ON TRIAL OF ROCK PHOSPHATE AND SUPERPHOSPHATE APPLICATIONS TO SLASH PINE.

Plot.	Treatment.	P_2O_5 added to top 4 in.	Original Soil P_2O_5.	Soil P_2O_5 1946.	G.b.h., 1940.	G.b.h., 1947.	G.b.h., Increment, 1940–47.
	Per acre.	p.p.m.	p.p.m.	p.p.m.	(in.)	(in.)	(in.)
A ..	Superphosphate 772 lb.	120	27	58	4·45	14·37	9·92
B ..	Rock Phosphate 336 lb.	120	27	59	4·1	13·17	9·07
C ..	Untreated ..	Nil	27	28	4·45	9·23	4·78

All symptoms of fused-needle (phosphate deficiency) disease disappeared in the treated plots, and growth increment in 1946 was equivalent to that on a first-quality site. (See Plates 7-10.)

Another trial was set out in similar country in another compartment on the same reserve, and superphosphate was used as the only dressing. The trees were slash pine which were planted in 1934. The soil-type was similar to the last described but with a deeper A horizon and better drained. The trial was commenced contemporaneously with the previous one. The experiment consisted of two replications of a superphosphate treatment at the rate of 560 lb. per acre and two untreated control plots. Each gross plot had an area of 0·135 acre, and a treated 16-feet-wide isolation strip surrounded each net plot. The mean initial total phosphate content of the top 4 inches of soil was of a higher order than that found in the other area just discussed. A summary of the relevant data obtained annually during the course of the trial is shown in Table 7.

Table 7.

RESULTS OF SUPERPHOSPHATE APPLICATION TO SLASH PINE.

Treatment.	Initial Soil P_2O_5 0–4 in. 1940.	Soil P_2O_5 0–4 in. 1946.	G.b.h., 1940.	G.b.h., 1947.	G.b.h., 1940–47.	Underbark Volume Increment per acre 1940–46.
	p.p.m.	p.p.m.	In.	In.	In.	Cu. ft.
560 lb. Superphosphate—100 p.p.m. P_2O_5 per top 4 in. soil	45	55	6·07	17·10	11·03	48
Control (untreated) ..	32	34	6·15	14·74	8·59	23·7

The girth increment of the phosphate-treated plots exceeded that of the untreated ones and was also superior to that of the previous treatment. This latter effect may have been due to the higher initial phosphate value of the treated plots and the better soil conditions of the site. The addition, however, was economically worth while as the value of the additional wood put on by the fertilized plots and calculated at the low case-timber price of 3s. per 100 sup. feet per acre in the period 1940–46 was £1 19s. for the extra 1,344·2 sup. feet produced. The cost of fertilizing was £1 15s. per acre.

In the case of a number of other fertilizer plots previously described elsewhere (Young, 1940) all areas subjected to the application of phosphate fertilizers either alone or in combination with other nutrients have given similar growth responses in accordance with the original soil phosphate value and the amount of P_2O_5 added. It is noteworthy, however, that when ammonium sulphate was used in a combination the response to phosphate was reduced below that received when the same amount of the phosphate fertilizer was used alone. Treatment with ammonium sulphate alone seriously

Plate 11.
LOBLOLLY PINE.—Plot treated with ammonium sulphate 1936. Photo. 1946.

affected growth of plantation slash- and loblolly- pines (Plate 11). Plots treated once with this material in 1938 are still adversely affected in appearance and have exhibited almost complete cessation of growth ever since. They are now far inferior to the untreated control plots in vigour and wood volume present and a number have actually died. This effect is possibly due to the leaching of phosphate from an already deficient soil by the action of the ammonium sulphate. The repressive effect on phosphate response when ammonium sulphate is used in combination with a phosphate fertilizer can be attributed to the same action.

GENERAL.

The conclusion reached as a result of the experiment described above is that in the soil types dealt with deficiency of phosphate is a major factor in causing poor pine growth. This deficiency is readily and economically overcome by the application of phosphate in suitable quantities to raise the phosphate status of the soil to a level sufficient for adequate pine nutrition. Such treatment is financially profitable and produces a much-needed commodity in a shorter growing period. In the case of loblolly pine on the soil type under discussion the optimum total P_2O_5 value of the top 4 inches of soil was shown in the experiments described to approximate 200 p.p.m. (treatment C).

The use of total phosphate as an indicator of phosphate level in these soils is the only possible soil factor which can be employed as there is no "available" phosphate present. The use of needle phosphate values in the case of existing pine stands holds promise, particularly as such a factor could be applied to all soil types whereas total phosphate value of the top 4 inches of the soil would probably be an unsatisfactory figure to use when soil phosphate content varied down the profile and also, perhaps, when the phosphate is combined in different ways in the soil complex. There is no alternative, however, to the use of a total soil phosphate determination in these soils, if healthy development of a stand is to be secured from time of planting.

Further field and laboratory work is necessary to standardize the "needle phosphate" technique and place it upon an easily practicable basis for use as an index for phosphate requirements of existing stands.

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