Effects of Fertilizing Moribund Pines on a Granitic Soil in Northern Ireland

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Summary

DATA are presented on the responses of slowly growing 25 year old Scots and Lodgepole pines to fertiliser application. The growth of both species increased quickly and markedly after the application of fertiliser phosphate. The rate of growth increase in Scots pine was slower but longer lasting than in lodgepole pine and growth increased almost linearly up to the highest rate applied (67.5 kg P/ha as triple-superphosphate). In lodgepole pine there was no further increase in growth at rates above 46 kg P per ha applied as superphosphate. Neither N applied as sulphate of ammonia nor K applied as muriate of potash affected the growth of Scots pine but in lodgepole applied N tended to increase and applied K to decrease growth.

There was no growth response in either species to any of six trace-elements applied in addition to a compound N P K ertiliser.

The foliar concentration of all elements determined except P were above the accepted deficiency levels. In the untreated trees foliar P concentrations were low throughout the course of the experiment; applied phosphate significantly increased foliar P concentration but at the lowest rate of application (22.5 kg P/ha as superphosphate) the concentration again approached deficiency level after seven years.

It is concluded that treatment of such crops with phosphate is economically justified. Triple-superphosphate is an effective fertiliser but rock phosphate may be preferable on cost grounds.

1. Introduction

Rostrevor forest lies in the foothills of the Mourne Mountains in the extreme south of Co. Down in Northern Ireland. On the lower slopes growth of a large variety of tree species, including hardwoods and even eucalypts, has been good. On the shallower soils of the upper slopes, however, growth has been disappointing. An inventory in 1963 showed that growth was unsatisfactory on at least 500 ha and it was decided to see if application of either major or minor nutrient

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elements would improve growth. Two separate experiments were laid down in April 1963. One was a N×P×K factorial experiment, the other a randomised block experiment involving the application of a range of minor nutrient elements. The test crop was an intimate mixture of Scots pine (*Pinus sylvestris,* Linn.) and lodgepole pine (*P. contorta,* Dougl.) which had been planted in 1938. By 1963 the trees, then 25 years old were only about 1.5 m high.

Little work has been reported on the mineral nutrition of trees growing on granitic soils in the British Isles.

2. Site and Crop Description

The experiments are at an altitude of 250 m O.D. and the site is relatively exposed. Rainfall is about 1,250 mm per annum with an average of 110 'rain-days'. The area has an easterly aspect and the slope is steep (38 %). The soils are derived from glacially deposited Mourne granitic till. They range from a humus-iron podsol to a peaty iron-pan soil depending on the local development of the iron-pan. The B horizon is strongly indurated. An upper peaty horizon varies in depth from 15–46 cm being deeper in depressions between boulders. Tree roots occur down to but do not penetrate the indurated layer. Samples of the peaty horizon and of the mineral A horizon were collected from 12 randomly chosen sites in the experimental area. The organic samples were analysed for total phosphorus and potassium concentration: the 'available' (that fraction soluble in N ammonium acetate adjusted to pH 4.4) concentration of the same elements in the A horizon was also determined. The pH was measured on a 1:2.5 soil: water suspension. Mean values are shown in Table 1.

TABLE 1
Mean concentrations of phosphorus and potassium and pH of organic and upper mineral soil horizons

Factor	Organic Horizon	Mineral 'A' Horizon
pH	3.84	4.17
	mg (total)/100 g D.M.	mg ('available')/100g D.M.
Phosphorus	45	0.17
Potassium	45	6.12

These data indicate that the potassium status of the soil is moderately high by agricultural standards but that both available and total phosphorus concentrations are very low. Soil pH is also low.

The area was planted in 1938, with a 1:2 mixture of Scots pine and lodgepole pine. The Scots pine were from seed collected at Altyre in Scotland. The provenance of the lodgepole is listed simply as 'Canadian' but the trees have all the characteristics of an 'inland' provenance (O'Driscoll, 1968).

The trees were planted directly into the soil. The vegetation was screefed but very little drainage was done at planting and none has been done since. A handful of basic slag was applied per tree at planting.

The vegetation of the unplanted area adjacent to the experiment has been much affected by burning and sheep grazing. *Calluna, Erica cinerea, E. tetralix Trichophorum caespitosum* and depauperate *Molinia caerulea* are the most common species but about 20 per cent of the ground is bare of vegetation. With the exclusion of grazing and burning within the forest, *Molinia* has increased in abundance and vigour; *Calluna* has increased but has not become dominant. *Ulex gallii* is also common in the fenced area of the experiment, but is infrequent outside.

3. Designs and Treatments

*3.1 Major Elements (Rostrevor CRD*1/63)

The experiment is in the form of a complete N×P×K factorial with two replicates. Square 0.04 ha plots were laid out in 1963. The treatments are listed in Table 2. All fertilisers were broadcast manually in April 1963. One 'reference' plot per block was left untreated, the trees were measured but the data have not been included in any statistical analyses.

TABLE 2
Fertiliser Treatments

Treatment	Fertiliser	Rate of application	
		Kg fertiliser/ha	Kg element/ha.
P_1	Superphosphate	250	22.5 P
P_2	Superphosphate	500	46 P
P_3	Triple superphosphate	325	67.5 P
N_0	Nil	—	—
N_1	Sulphate of ammonia	156	33 N
K_0	Nil	—	—
K_1	Muriate of potash	125	63 K

The 20 trees of both species nearest the middle of each treated plot were measured at 3-yearly intervals with annual height growth being determined for the intervening years. Samples of foliage were collected for chemical analysis each year from 1965–1973. Standard methods of collection and analyses were used. (See Dickson 1965.)

3.2 Minor Elements (Rostrevor CRD 2/63)

This experiment is in the form of a randomised block with two replicates. The plots were 0.04 ha in area. The treatments applied are shown in Table 3. Since it was thought likely that growth was primarily being limited by one or more of the major nutrient elements a basal treatment of 375 kg per ha of a compound fertiliser (supplying 30 kg/ha N, 40 kg/ha P and 44 kg/ha K) was broadcast over each plot at the same time as the other treatments.

TABLE 3
Treatments

Element	Symbol	Form Applied	Rate of Application (kg/ha)
Zinc	Zn	Zinc chloride	22
Copper	Cu	Copper sulphate	22
Cobalt	Co	Cobalt sulphate	22
Boron	B	Sodium borate (Borax)	11
Magnesium	Mg	Magnesium carbonate (Magnesia)	56
Molybdenum	No	Ammonium molybdate	1.5

All elements, except Mg which was broadcast dry, were applied to the ground in solution via a sprayer.

The trees were measured and foliar samples collected as in previous experiment.

4.1 Effects of Major Elements on Growth and Foliar Nutrient Concentrations

4.1.1 Phosphorus

(a) Annual Height Growth

The effect of applied phosphate on annual growth of both species over the period 1963–1973 is shown in Figure 1. Prior to treatment annual height growth was only about 5 cm and in the untreated trees it has remained so throughout the experiment. Even the lowest rate of applied phosphate more than doubled height growth by the second season after application.

Growth increase was initially more rapid in lodgepole pine. In this species the maximum height growth occurred in the seventh year after fertilizing but thereafter growth in all phosphate treatments decreased. Annual height growth was significantly better in the P_2 treatment than in the P_1 treatment but it was almost the same at the two higher rates of phosphate application. Maximum annual height growth was 44 cm.

The rate of height increase was slower in Scots pine than in lodgepole pine, but it continued to increase for ten years after treatment.

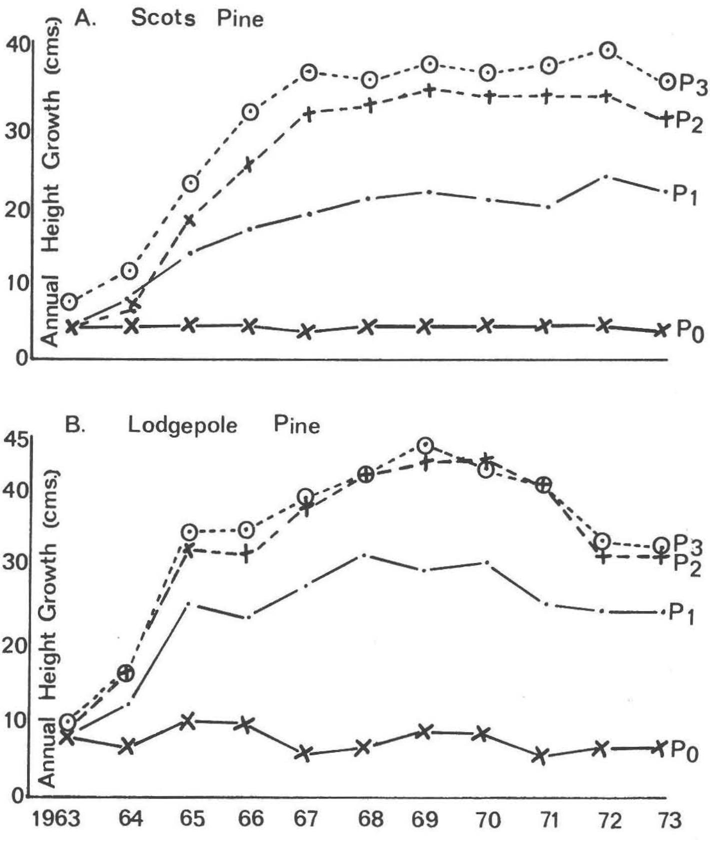

Figure 1: Effect of applied phosphate on annual height growth 1963–73. (Rostrevor C.D.R. 1/63).

After the second season annual leader growth in Scots pine increased progressively with increase in rate of applied phosphate. The maximum annual height growth of 39 cm occurred in the P_3 treatment in the tenth season after treatment.

(b) Mean Height, Top Height and Height Increment

Total height of each tree in the measurement plots was measured at the end of the eleventh growing season after treatment. The effects of applied phosphate on mean height (the arithmetic mean of all measured trees), the mean of the three tallest trees in the measurement plot (corresponding approximately to 'top height' (Hamilton and Christie 1971) and height increment 1963–1973 (the difference between mean height at December 1962 and mean height December 1973) are shown in Table 4.

TABLE 4
Effects of applied phosphate on Mean Height, 'Top Height' and Height Increment

Species	P_0[1]	Phosphate Treatment P_1	P_2	P_3	S.E.m.
		Mean Height Dec. 1973 (m)			
S.P.	2.12	3.74	4.66	5.63	0.26**
L.P.	2.81	5.00	6.02	6.29	0.36 n.s.
		'Top Height' Dec. 1973 (m)			
S.P.	3.22	5.50	6.26	7.02	0.23**
L.P.	4.68	6.30	7.55	7.73	0.35*
		Height Increment 1963–1973 (m)			
S.P.	0.44	1.98	2.94	3.53	0.17***
L.P.	0.72	2.65	3.59	3.55	0.20*

1. 'P_0' data not included in statistical analyses.

Table 4 illustrates that Scots pine is more responsive to rate of applied phosphate than lodgepole pine: the response curve for Scots pine was in all cases almost linear whereas with lodgepole pine a quadratic component was very evident. At the highest rate of applied phosphate height increment in Scots pine was only 2 cm less than in lodgepole pine but at the two lower rates height increment in lodgepole pine was greater than in Scots pine.

In the most effective treatments both species have grown almost 3 m taller than the untreated trees in the eleven years since fertilizing.

(c) Basal Area Growth

The effect of applied phosphate on basal area at the end of the eleventh growing season is shown in Table 5.

TABLE 5
Effect of applied phosphate on Basal Area at Dec. 1973

Phosphate Treatment	B.A./ha (sq. m.)		No. Trees/ha		B.A./tree (sq. m.)		(B.A./ha) (sq. m.)	Total No tree/ha
	S.P.	L.P.	S.P.	L.P.	S.P.	L.P.		
P_1	3.35	11.60	2,040	2,560	.002	.005	14.95	4,590
P_2	4.85	18.95	1,780	2,410	.003	.008	23.80	4,190
P_3	9.05	16.65	1960	2,090	.005	.008	25.70	4,050
s.e.m.	1.23*	1.20**			.0006*	.0007**		

The greater responsiveness of Scots pine to rate of applied phosphate already illustrated by height data is even more apparent for diameter growth. At the highest rate of applied phosphate the basal area per hectare of Scots pine was almost three times greater than at the lowest rate, whereas in lodgepole pine the maximum increase due to treatment was just over 50 per cent. However the basal area expressed either on a per hectare or per tree basis, was very much higher in lodgepole pine at all levels of applied phosphate. Total crop basal area ranged from 14.95 m^2 (4,590 trees/ha) in the P_1 treatment to 25.70 m^2/ha (4,050 trees/ha) in the P_3 treatment.

(d) Foliar phosphorus concentration

The effects of applied phosphate on foliar P concentrations at the end of four growing seasons are shown in Table 6.

TABLE 6

Effects of applied phosphate on foliar phosphorus concentrations % D.M.

Treatment	Species	1965	1967	1969	1973
P_0*	S.P.	.10	.10	.07	.10
	L.P.	.08	.08	.08	.09
P_1	S.P.	.14	.13	.10	.12
	L.P.	.13	.12	.10	.11
P_2	S.P.	.18	.18	.14	.13
	L.P.	.15	.16	.14	.13
P_3	S.P.	.18	.19	.15	.15
	L.P.	.15	.18	.14	.13
S.E.m. ±	S.P.	.003***	.006***	.004***	.006 n.s.
	L.P.	.004**	.003***	.004***	.005*

* P_0 data not included in statistical analyses.

Except for Scots pine in 1973, applied phosphate significantly increased foliar P concentration. There were big differences in foliar P concentration in both species between the control and the lowest rate of applied phosphate and between this and the two higher rates. In Lodgepole pine there was no difference between the two higher rates except in 1967 but in Scots pine foliar P concentrations were higher in the P_3 treatment in each year except 1965. Neither applied nitrogen nor potash significantly affected foliar P concentration throughout the course of the experiment.

In the untreated plots foliar P concentrations were at or below the deficiency level of 0.10 per cent dry matter suggested by Van Goor (1970) and at the lowest rate of phosphate application both species had reached this value by the seventh season after treatment, although values were again higher in the sleventh season.

4.1.2 Nitrogen and Potassium

(a) Height growth

Neither applied nitrogen nor applied potash significantly affected the height growth of Scots pine. In Lodgepole pine applied nitrogen tended to increase and applied potash to decrease height growth but neither effect was statistically significant for any individual year except 1968 when leader growth was 39.1 cm in the K_0 treatment and 34.4 in the K_1 treatment (S.E.m. ± 1.13).

Both nitrogen and potash significantly affected the growth of lodgepole pine over the three growing seasons 1967–1969 (incl.). This is shown in Table 7.

TABLE 7

Effect of nitrogen and potash on growth of Lodgepole pine 1967–1969 (incl.) (cm)

Treatment	N_0	N_1	P mean			
P_1	83	85	84			
P_2	113	126	119			
P_3	108	132	120			
N mean	101	114	108			
			K mean	P_1	P_2	P_3
K_0	106	121	113	89	127	125
K_1	97	107	102	79	111	116

S.E. N mean $= \pm 3.5$* S.E. K mean $= \pm 3.5$* S.E. P mean $= \pm 4.3$***
S.E. N×P mean $= \pm 6.1$ n.s.

The overall effect of nitrogen in increasing growth over the three-year period is significant and there is a suggestion that its effect is greater at the higher rates of applied phosphate. The N×P interaction is, however, not significant. Rate of applied phosphate did not affect the magnitude of the growth decrease due to applied potash.

The effects of applied nitrogen and potash on height increment in both species over the eleven years of the experiment is shown in Table 8.

TABLE 8

Effects of applied nitrogen and potash on height increment 1963–1973 (cm)

	Scots Pine			Lodgepole Pine		
	N_0	N_1	K mean	N_0	N_1	K mean
K_0	2.68	3.10	2.89	3.18	3.44	3.31
K_1	3.00	2.48	2.74	3.11	3.31	3.21
N mean	2.84	2.79		3.14	3.37	

S.E. N or K mean $= \pm 0.13$ n.s. S.E. N or K mean $= \pm 0.17$ n.s.
S.E. N×K mean $= \pm 0.19$* S.E. N×K mean $= \pm 0.23$ n.s.

No main effects of applied nitrogen or potash on height increment were significant but the N×K interaction on height increment in Scots pine was significant at the 5% level. Either element on its own increased growth slightly but where both were applied there was a reduction in growth. This did not happen with lodgepole pine.

(b) Foliar Nitrogen Concentration

Application of nitrogen in 1963 had no significant effect on foliar N concentration in any year. Even in the untreated trees, however, foliar N concentration was relativey high: the lowest values were 1.59 and 1.26 per cent dry matter in Scots pine and lodgepole pine respectively. Applied phosphate consistently increased foliar N concentration in lodgepole pine but not in Scots pine; the effect was significant only in 1965 when values ranged from 1.39 per cent dry matter at the lowest rate to 1.52 per cent dry matter at the highest rate. Applied potash did not affect foliar N concentration in either species.

(c) Foliar Potassium Concentration

Foliar K concentration in either species was not significantly affected by applied potash. Values in Scots pine ranged from 0.54 per cent dry matter in 1973 to 0.66 per cent dry matter in 1965. In lodgepole pine the corresponding values were lower at 0.4 and 0.46 per cent dry matter respectively.

Rate of applied phosphate did not affect oliar K concentration in Scots pine although values were higher in the phosphate treated plots than in the untreated 'control' plots, but in lodgepole pine foliar K concentration increased with increase in rate of applied phosphate although the differences were significant only in 1969 when concentrations ranged from 0.39 to 0.44 per cent dry matter in the P_1 and P_3 treatments respectively.

4.2 Effects of Minor Elements on Growth and Foliar Nutrient Concentrations

(a) Height growth

The effect of minor element treatment on height increment 1962–1973 is shown in Table 9.

TABLE 9

Effects of minor elements applied in 1963 height increment 1962–1973 (m) of Scots and Lodgepole pines

	Trace element treatment							
Species	Nil	Mo	Co	Zn	B	Mg	Cu	S.E.m. ±
S.P.	2.72	3.06	2.97	2.92	3.03	3.33	2.61	0.32 n.s.
L.P.	3.01	3.42	3.33	2.72	3.32	3.40	3.31	0.26 n.s.

None of the minor elements applied significantly affected height increment over the period of the experiment in either species. Nor was leader growth in either species for the years 1965, 1967, 1969 or 1973 significantly affected by treatment.

(b) Foliar Nutrient concentrations

The foliage of each species was analysed chemically at the end of the 1973 growing season but as with growth there was no statistically significant effects of treatment. The mean values of foliar nutrient concentration for all treatments are shown in Table 10.

TABLE 10
Mean Foliar nutrient concentration of Scots and Lodgepole pines at end of eleventh growing season

	Foliar Nutrient Concentration					
Species	N	P	K	Mg	Zn	Cu
		per cent matter			p.p.m. dry matter	
S.P.	1.68	.10	.58	.10	47	6.2
L.P.	1.42	.09	.47	.08	48	8.1

The concentration of the major nutrients, N, P and K, are similar to those in the previously described experiment with levels being higher in Scots pine than in lodgepole pine, concentrations of N and K appear adequate but foliar P concentration is in the deficiency range eleven years after the application of 40 kg P per ha.

5. Discussion

The results of the experiment clearly demonstrate that P deficiency is the major nutritional factor limiting the growth of Scots and lodgepole pines on the site described and that this limitation can be overcome by phosphate application. However, there are distinct differences in response between the species. The most obvious visual difference was in the habit of the untreated trees and their development following fertilizing. There was a marked lack of apical dominance in Scots pine which did not occur in lodgepole pine although there was little difference between the two in colour and general vigour. Following treatment single straight stems developed on all Scots pine and by the end of the experiment there was no difference in form between the two species.

Other differences between the species were that the growth of Scots pine continued to increase longer than in lodgepole pine and it also increased progressively with increase in rate of phosphate applied whereas in lodgepole pine there was no difference in growth between the two higher rates.

Although foliar P concentrations tend to be higher in Scots pine, especially in the earlier years of the experiment, this cannot account for the difference in length of time over which the two species respond. In the P_2 treatment for instance foliar P concentrations were the same in 1969 (at 0.14% D.M.) and in 1973 (at 0.13% D.M.) but growth pattern over this period was quite different in that annual height growth in Scots pine was increasing while in lodgepole pine it was decreasing. This suggests that the P deficiency level is lower in Scots pine than in lodgepole pine.

Lodgepole pine responded more quickly to fertiliser treatment than did Scots pine, probably because it responded to nitrogen as well as phosphate application. Although the response to nitrogen was statistically significant only for height increment between 1967 and 1969 (inclusive) growth in lodgepole pine was consistently better in the presence of applied nitrogen throughout the experiment. The length of response period suggests that some recycling of applied nitrogen had occurred. Applied nitrogen had no effect on the growth of Scots pine at any stage but the levels of foliar N concentration were considerably above those in lodgepole pine. The fact that foliar N concentration did not fall below 1.59 per cent dry matter even in the untreated plot suggests that Scots pine obtained adequate N from the soil.

Although applied potash did not affect the growth of Scots pine it consistently decreased height growth in lodgepole pine. In spite of this height and presumably dry matter reduction foliar K concentration was not significantly higher in the potash treated plots. Since potash application did not affect N or P uptake it is difficult to account for its effect in decreasing growth.

Although there are many reports of minor element deficiency restricting tree growth (see e.g. Stone 1968, Baule and Fricker,)1970) neither species responded to any of the lements applied. This and the fact that the foliar concentrations of the elements determined (i.e. Mg, Zn and Cu) lie within the intermediate ranges quoted by Leaf (1968) and Stone (1968) suggests that growth in this site is not being limited by minor element deficiency.

The fact that phosphate increased growth for up to ten years after application indicates that neither fication within the soil nor loss by leaching were serious. This is supported by the fact that there was no downslope movement of P. Although the slope was steep (38%) and the P applied in water soluble forms the boundaries between the treated plots and the untreated surrounds remained distinct for eleven years.

6. Conclusions

Phosphorus was applied in two forms, superphosphate and triple-superphosphate. With Scots pine both forms were apparently equally effective, there being positive linear response to increase in rate of elemental P applied. Growth response in lodgepole pine, however, was quadratic with no extra increase at the highest rate of applied P, this being in the form of triple-superphosphate. This could mean that triple-superphosphate is an ineffective source of P for lodgepole pine but this is unlikely and it is more probable that the highest rate (67.5 kg P/ha) exceeds the P requirement of lodgepole pine on this site. It must, however, be remembered that the lodgepole pine in this experiment is an inland type and the P requirement of a more vigorous provenance may be higher.

Although both forms of P applied appear suitable both are more expensive per unit of P than the rock phosphate more commonly used in forestry.

The pH of the soil is within the range found for oligotrophic peat where rock phosphate has been found to be effective (Dickson, 1971) and unless the high P concentration of triple-superphosphate is found to outweigh its extra price rock phosphate would be a more suitable fertiliser. Rates of application should be at least 480 kg per hectare rock phosphate (14% P) for Scots pine and about 330 kg per hectare for an inland provenance of lodgepole pine.

On present evidence application of nitrogen or potash is not justified.

The economics of treating the crop described are complicated by the very long period (25 years) between planting and time of treatment. Effectively, however, application of phosphate to a crop moribund in 1963 has produced a viable, closed canopy plantation by 1973. Without treatment many of the Scots pine were by then dead and the lodgepole pine were in very poor condition. Even if, as seems possible, further phosphate input is necessary before crop maturity this can be done relatively easily by helicopter and the longevity of growth response to a single phosphate application suggests that total fertilising costs for the treatment recommended will not be excessive.

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