The Response of Sitka Spruce to Sulphate of Ammonia and Ground Rock Phosphate on Peat

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ABSTRACT

Major site amelioration is needed to overcome the serious physical and nutritional problems encountered by tree crops on blanket bog. A 4×3 N P factorial experiment was established at Glenamoy in 1967 to examine the response of P'62 Sitka spruce to fertilizers on peat. The trees had received 85 g ground rock phosphate (G.N.A.P.) per plant at planting. G.N.A.P. was applied at levels of 0, 375, 750 and 1,500 kg/ha and sulphate of ammonia (S/A) at 0, 625 and 1,250 kg/ha. The fertilizers were applied in 1967. The 625 kg/ha S/A application was repeated in 1969. Height growth results from the first four years of the experiment and foliar analysis from the first three years are presented here.

The results confirm the need for a second application of phosphate on oligotrophic peat. Significant height growth responses were obtained, but no additional response was observed above the lowest level of G.N.A.P. application. A significant height growth response to S/A was also recorded. Serious leader breakage, which occurred in 1969, was found to be related to total tree height. Foliar N concentrations were significantly increased by both fertilizers. The results indicate that tree growth will be seriously limited below 1.0% N. Concentrations of P were significantly reduced by S/A application. This was a dilution effect due to an increase in needle weight. Both fertilizers significantly reduced foliar K concentrations.

INTRODUCTION

The afforestation of blanket bog in the West of Ireland with Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and contorta pine (*Pinus contorta* Dougl.) represents a movement away from an ecological approach to species selection. No species in general use in Ireland is adapted to the low fertility and poor physical conditions of blanket bog. The physical properties of the peat make the necessary drainage

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difficult. In addition, serious nutritional problems have been encountered. The need for phosphate fertilization of trees on peat at planting time is firmly established (MacDonald, 1945; Zehetmayr, 1954; O'Carroll, 1967; Meshechok, 1968). At present, ground rock phosphate (G.N.A.P.) is applied operationally in Ireland at 627 kg/ha (91 kg P/ha) to new plantations, and also, under certain circumstances, as a second application to existing plantations where growth is considered unsatisfactory.

On blanket bog in Ireland, a single initial application of phosphate is insufficient to meet the nutrient demand of the crop for the whole rotation (Jack, 1965; O'Hare, 1967a). The smaller the application, the shorter will be the period during which growth is maintained (O'Carroll, 1972), particularly with Sitka spruce. Numerous instances of check or growth stagnation have been reported some years after fertilization of crops in Britain and Ireland (Parker, 1957; Parkin, 1957; McConaghy *et al.*, 1960; Dickson, 1965; O'Hare, 1967a). This condition is often associated with low concentrations of foliar nitrogen. Where drainage is adequate, both growth and foliar nitrogen concentrations are usually increased by application of phosphate (Dickson, 1965; O'Carroll, 1967; O'Hare, 1967a; Forestry Commission, 1968).

The response of tree crops on peat to direct application of nitrogenous fertilizers has been inconsistent (Zehetmayr, 1954; Jack, 1965; Heikurainen, 1967; O'Carroll, 1972), though significant responses have been obtained on sites previously fertilized with phosphate (O'Hare, 1967a; O'Carroll, 1972). Nitrogen, with phosphorus and potassium, has given strongly improved growth in Finnish experiments (Heikurainen, 1967). Similar results were obtained with young pines in Sweden (Holmen, 1967). In the latter experiment, a second application of nitrogen, made three years after the first, produced a further response.

The purpose of this experiment was to examine the effects of S/A and G.N.A.P. at high levels of application, on Sitka spruce. In this paper, results from the initial four year period of investigation are presented.

EXPERIMENTAL

The experiment was located at Glenamoy State Forest, situated at Glenamoy in north west Co. Mayo. This is part of the low level blanket bog (Barry, 1969) described as climatic peat by Gardiner and Ryan (1969). The climate of the area is extreme maritime; annual rainfall is 1,400 mm, distributed over 270 days. The wind climate is very severe with gales in almost every month. The *Schoenus nigricans*

L association dominates the natural vegetative cover in the area (O'Hare, 1959). Principal species include *Schoenus nigricans* L. *Molinia caerulea* Moench, *Eriophorum angustifolium* Honck and *E. vaginatum* L. The physical properties of the peat at Glenamoy have been described by Burke (1967). Chemical properties of virgin peat were reported by Walsh and Barry (1958).

The experimental site was selected from a Sitka spruce crop planted at 1.5×1.5 m spacing in 1962. The site had been ploughed and G.N.A.P. applied at planting by spot application, at 85 g per plant. In 1967, 48 plots, each 0.03 ha, were installed. A two row wide buffer strip was marked, enclosing the measurement zone in each plot. There were, on average, 45 trees within the measurement zone. A randomized block design was employed with four levels of G.N.A.P. (0, 375, 750 and 1,500 kg/ha, designated Po, P_1, P_2 and P_3 respectively) and three levels of S/A (0, 625 and 1,250 kg/ha; No, N_1, N_2) in factorial combination, replicated four times. These fertilizer applications represented element applications of approximately 0, 55, 110 and 220kg P/ha and 0, 132 and 234 kg N/ha. Sulphate of potash (42% K) was applied to all plots at 125 kg/ha and copper sulphate(25%Cu) at 11 kg/ha. All fertilizers were applied broadcast, without incorporation, in April 1967. In 1969, the 625 kg/ha S/A treatment (N_1) was repeated on those plots which had received it in 1967.

Total height was measured prior to fertilizer application in 1967 (mean tree height was 1.19 m) and again at the end of each growing season to 1970. Height increment was calculated by difference. Height measurements reported for 1969, when a large number of trees suffered leader breakage, and for 1970, are for trees with complete leaders.

Foliage samples (one branch from five trees per plot) were collected in October of each season, 1967-1969. Samples were put in cold storage awaiting transport to the analytical laboratory. At the laboratory, they were dried, ground, and stored in airtight plastic containers. Before analysis, they were dried for 48 hours at 60°C. Two digestion procedures were used: the H_2SO_4/H_2O_2 procedure of Pinevich as modified by Kurkayev (1959) for N, K, Ca, and Mg determinations and the standard $HNO_3/HClO_4$ procedure for P determination. In both cases, 0.2 g oven dry material was used. Determination of N was by titration following standard distillation procedure. Determination of P was by a modification of the vanadomolybdophosphoric yellow colour method described by Jackson (1958). Determination of K was by flame photometry. Atomic absorption was used in the determination of Ca and Mg, using a 12,000 ppm Mg solution to suppress phosphate interference

TABLE 1

Effect of Treatment on Height Increment, 1967-1970

Treatment	Mean Height Increment (m)							
	No	N_1	N_2	Mean	No	N_1	N_2	Mean
		1967				1968		
Po	.14	.37	.38	.22	.28	.37	.38	.34
P_1	.23	.56	.53	.31	.55	.56	.53	.55
P_2	.22	.51	.48	.34	.55	.51	.48	.51
P_3	.24	.47	.47	.34	.53	.47	.47	.49
Mean	.21	.35	.36		.48	.48	.47	
	CV=4.97%				CV%4.91%			
		1969				1970		
Po	.14	.24	.29	.22	.15	.49	.43	.37
P_1	.23	.39	.33	.31	.58	.58	.67	.61
P_2	.22	.37	.42	.34	.73	.67	.82	.73
P_3	.24	.41	.40	.34	.73	.61	.70	.68
Mean	.21	.35	.36		.55	.58	.64	
	CV=6.34%				CV=9.19%			

Effect of Treatment on Cumulative Height Increment, 1967-1970

Treatment	Mean Height Increment (m)			
	No	N_1	N_2	Mean
Po	.80	1.36	1.44	1.20
P_1	1.87	2.02	2.02	1.97
P_2	2.01	1.99	2.25	2.08
P_3	1.99	1.97	2.07	2.01
Mean	1.67	1.83	1.95	

Significant Treatment Comparisons and Interactions:

No vs (N_1+N_2)	'67**	'67-'70**			
Po vs $(P_1+P_2+P_3)$	'67**	'68**	'69**	'70**	'67-'70**
P_1 vs P_2	'70*				
N×P	'70*				

N_1 treatment was repeated in April 1969.
Significance level: *0.05, **0.01.
CV: Coefficient of variation.

in Ca determination. Fresh peat samples were extracted with H_2SO_4 for determination of available nutrients (O'Hare, 1967b). I.B.M. SSP Main Programmes, ANOVA and REGRE, were used for analysis of variance and regression analyses. The arcsine transformation was used on percentage broken shoots (1969) before analysis. Sums of squares for N and P were each divided into mutually orthogonal comparisons.

RESULTS AND DISCUSSION

Effect of fertilizers on growth

In the period under discussion, 1967-'70, the phosphatic fertilizer had a highly significant positive effect on leader growth (Table 1), confirming the need for a second phosphate application for Sitka spruce on oligotrophic peat (Jack, 1965; O'Hare, 1967a). However, the initial phosphate application at Glenamoy, a spot application of 85 g/plant G.N.A.P. may have been considerably less effective than heavier dressings broadcast at planting time on similar sites today. No additional response was observed above the lowest level of G.N.A.P. application (55 kg P/ha).

In comparison with phosphate, the effects of applied S/A on height increment were small. Cumulative height growth was significantly increased by S/A, though annual leader growth showed a significant response only in 1967. The repeated N_1 treatment, made prior to the 1969 season, had no effect on height increment in that season nor in 1970. The most effective nitrogen treatment, therefore, was a single application of 625 kg/ha S/A (132 kg N/ha). A significant $N \times P$ interaction was observed in the 1970 growing season. S/A was considerably less effective in the presence of G.N.A.P. than in its absence.

Following the secondary application of sulphate of ammonia, severe necrosis was observed in three of the four treated plots which had not received phosphate in 1967. The damage was observed in early July. In one plot, close to 50% of the trees were affected. Typically, necrosis was evident on the upper part of the tree, the leading shoot wilted and bent and patches of dead needles were seen elsewhere on the tree. Damage was not apparently related to the age of the needles. Similar observations of damage or mortality as a result of application of sulphate of ammonia have been reported by Benzian (1965, 1966) on nursery trees and by Zehetmayer (1954) and O'Carroll (1972) under forest conditions. Urea applied at the rate of 71 g/plant (approximately 32 g N) resulted in the deaths of up to 48% of the total number of trees in an experiment on peat in Northern Ireland (Brown *et al.*, 1968).

At Glenamoy, both G.N.A.P. and S/A produced significant growth responses in the season of application. This appears to run contrary to the theory of growth predetermination, *viz.*, growth in the current season is largely determined at the time of bud setting in the previous

TABLE 2
Incidence of Broken Leading Shoots (transformed) in the 1969 Season

Treatment	No		N_1		N_2		Mean	
	Degrees	%[1]	Degrees	%[1]	Degrees	%[1]	Degrees	%[1]
Po	10.1	3.0	21.7	13.6	18.8	10.4	16.8	8.4
P_1	36.3	35.0	45.0	50.1	39.8	41.0	40.4	42.0
P_2	35.4	33.6	43.6	47.5	40.2	41.7	39.7	40.9
P_3	36.3	35.0	40.4	42.1	35.1	33.1	37.3	36.7
Mean	29.5	24.3	37.7	37.4	33.5	32.1		
	CV=125.53%							

Analysis of Variance (Degrees)

Source	df	Mean Square	F
N	2	266.901	6.337**
P	3	1,513.949	35.945**
NP	6	18.389	
B	3	324.498	7.704**
Error	33	42.119	

1. % back transformed.
B: Blocks.
Significance level: *0.05, **0.01.

TABLE 3
Analysis of Variance for the Regression of Broken Leading Shoots on Total Height, 1969

Source	df	Mean Squares	F
Due to Regression	1	2,846.20459	27.83**
Deviation about Regression	46	102.26503	
Total	47		

Significance level: *0.05, **0.01.

season and is therefore controlled by conditions in that season. Many workers have not taken measurements until the second season after treatment. Others have failed to observe any significant growth responses in the first season (Dickson, 1969; Brix and Ebell, 1969). The occurrence of a response is apparently linked to the time of fertilizer application. The work of Paarlathi (1967) in Finland and of O'Carroll (1972) indicate that fertilizers applied before March should certainly produce an effect in the current season.

Wind damage was serious during the 1969 growing season. A large number of leading shoots was broken (Table 2). The maximum wind speed recorded during the period was 42 knots (in August) whereas a wind of 86 knots, in January 1968, caused little visible damage to the stand. The effect of both fertilizers on leader breakage was highly significant. This was due to the direct effect of the fertilizers on leader growth. The regression of leader breakage on total height was highly significant in the 1969 season (Table 3). The effect of blocks on leader breakage (Table 2) and on total height (data not presented) were both highly significant in this season. Mean tree height in each block with corresponding mean incidence of leader breakage (degrees) were as follows:

Mean Height (m)	3.29	2.80	2.86	3.07
Leader Breakage (degrees)	38.08	26.47	32.93	36.74

If there is a real relationship between total height and incidence of injury, it may be expected that Sitka spruce crops, having reached a critical height, which would vary with location, would lose a part of their annual leader growth at wind speeds which are by no means rare in the western part of the country. This raises a question concerning the continued use of this species on exposed western sites. However, the considerable variation in growth rates over the area, due to the experimental treatments, may have created an artificial situation. The forest lacked the uniformity which is important for its stability and protection.

Effect of fertilizers on foliar nutrient concentrations

Height increment was excellent with foliar N concentrations as low as 1.08% D.M. (Tables 1 and 4). Previous reports gave concentrations between 1.2 and 2.0% as optimum or adequate for "normal" tree growth (Leyton, 1958a; Tamm 1964; Dickson, 1965; Baule and Fricker, 1970). Maximum or near maximum responses can be obtained on this site at relatively low concentrations of foliar N. Other work at Glenamoy tends to confirm this (O'Hare, 1967a). Growth may be seriously limited below a concentration of 1.0%.

TABLE 4
Effect of Treatment on Foliar N concentrations, 1967-1969

Treatment	Mean Foliar N Concentration (% DM)							
	No	N_1	N_2	Mean	No	N_1	N_2	Mean
		1967				1968		
Po	0.70	1.30	1.39	1.13	0.83	0.94	1.00	0.92
P_1	1.18	1.58	1.85	1.54	1.08	1.16	1.27	1.17
P_2	1.34	1.63	1.82	1.59	1.22	1.27	1.25	1.25
P_3	1.26	1.57	1.73	1.52	1.27	1.40	1.32	1.58
Mean	1.19	1.52	1.70		1.10	1.19	1.21	
	CV=2.90%				CV=2.62%			

		1969			Significant Comparisons
Po	1.01	1.23	1.16	1.13	
P_1	1.12	1.60	1.34	1.35	No vs (N_1+N_2) '67** '69**
P_2	1.27	1.42	1.40	1.37	N_1 vs N_2 '67* '69*
P_3	1.29	1.60	1.36	1.42	Po vs (P_1+P_2+P_3) '67** '68** '69**
Mean	1.17	1.46	1.31		
	CV=2.03%				

Significance level: *0.05, **0.01.
CV: Coefficient of variation.

On this basis, a condition of N deficiency existed under the NoPo treatment in 1967 and 1968.

Both fertilizers produced significant increases in foliar N concentrations (Table 4). The effect of G.N.A.P. was highly significant in all three seasons. As in height increment, there were no significant differences above the 55 kg P/ha level. The effect of S/A was significant only in the season of application. The 1969 application produced a significantly higher foliar N concentration at the N_1 level of application over the N_2 level.

The increase in foliar N concentrations with phosphate application was not accompanied by a significant increase in dilute H_2SO_4 extractable N in the peat (Table 5). This may have been due to the extreme variation in peat N concentrations within plots. Kaila (1958) has measured increased N mineralization in acid peat with superphosphate application. The evidence suggests that the causative factor is calcium (Forestry Commission, 1967; Atterson, 1969). This is present in all commercial phosphatic fertilizers (G.N.A.P.

TABLE 5

Effect of Treatment on available N and K content of Peat, 0-15 cm Depth, 1969

Treat-ment	(N Content (ppm wet peat)				K Content (ppm wet peat)			
	No	N_1	N_2	Mean	No	N_1	N_2	Mean
Po	62.1	145.4	97.2	101.5	30.0	27.4	28.4	28.6
P_1	86.6	166.6	91.5	114.9	23.4	23.9	22.1	23.2
P_2	109.4	117.6	132.3	119.8	30.1	22.4	18.3	23.6
P_3	91.5	163.3	104.5	119.8	21.6	20.0	22.3	21.3
Mean	87.4	148.2	106.4		26.3	23.4	22.8	
	CV=1,288.20%				CV=53.45%			

Significant Treatment Comparisons and Interaction

	N Content	K Content
No vs (N_1+N_2)	**	**
N_1 vs N_2	**	NS
Po vs (P_1+P_2+P_3)	NS	**
N×P	NS	*

Significance level: *0.05, **0.01.
NS: Non significant.
CV: Coefficient of variation.

is 37.0% Ca) and probably results in an increase in microbial activity (Zöttl, 1963). However, applied Ca may not be the only causative factor. Work with loblolly pine (*Pinus taeda* L.) seedlings in solution culture suggests a decreased ability of that species to absorb or utilize N at very low P concentrations in solution (Fowells and Krauss, 1959).

In 1967 and 1968, foliar P concentrations in the non-phosphate treated plots (Po) were considerably below the 0.12-0.13% P limiting range cited by Baule and Fricker (1970). The response to applied phosphate was highly significant in all seasons (Table 6). S/A significantly reduced foliar P concentrations but this was a dilution effect due to an increase in needle weight. A reversed trend was observed when foliar P was expressed on a weight per 100 needle

TABLE 6
Effect of Treatment on Foliar P Concentrations, 1967-1969

	Mean Foliar P Concentration (% DM)							
Treatment	No	N_1	N_2	Mean	No	N_1	N_2	Mean
		1967				1968		
Po	0.07	0.09	0.08	0.08	0.11	0.08	0.10	0.09
P_1	0.17	0.13	0.18	0.16	0.17	0.23	0.24	0.21
P_2	0.26	0.17	0.15	0.19	0.23	0.21	0.18	0.21
P_3	0.20	0.20	0.14	0.18	0.26	0.21	0.22	0.23
Mean	0.17	0.14	0.14		0.19	0.18	0.18	
	CV=0.88%				CV=1.02%			

		1969			Significant Comparisons	
Po	0.13	0.13	0.16	0.14	No vs (N_1+N_2)	'67**
P_1	0.24	0.28	0.33	0.28	Po vs $(P_1+P_2+P_3)$	'67** '68** '69**
P_1	0.30	0.29	0.31	0.30	(P_1+P_2) vs P_3	'69**
P_3	0.32	0.35	0.38	0.35	P_1 vs P_2	'67*
Mean	0.25	0.26	0.29			
	CV=0.93%					

Significance level: *0.05, **0.01.
CV: Coefficient of variation.

TABLE 7
Effect of Treatment on Foliar P. Content, 1967

Treatment	Mean Foliar P Content (mg/100 needles)			
	No	N_1	N_2	Mean
Po	0.20	0.33	0.27	0.27
P_1	0.46	0.48	0.64	0.53
P_2	0.70	0.76	0.55	0.67
P_3	0.61	0.71	0.67	0.66
Mean	0.49	0.57	0.53	
	CV=5.15%			

Significant Comparisons:
Po vs $(P_1+P_2+P_3)$**

Significance level: *0.05, **0.01.
CV:Coefficient of variation.

basis (Table 7). Mean needle weights (mg) per 100 needles at each treatment for 1967 were as follows:

No	N_1	N_2	Po	P_1	P_2	P_3
288	391	388	339	336	369	379

The response of needle weight to applied S/A was highly significant. Leyton (1958b) reported a reduction in foliar P concentration with nitrogen application in Japanese larch (*Larix leptolepis* Gordon). In this case there was a reduction in the absolute content of P in the needles which, he claimed, was the result of a direct antagonistic effect of the nitrogenous fertilizer.

Foliar K concentrations and peat concentrations of dilute H_2SO_4 extractable K were significantly reduced by both fertilizers (Tables 5 and 8). The reduction due to G.N.A.P. was highly significant in 1968 and 1969. Carlisle and White (1962) reported a case of K

TABLE 8
Effect of Treatment of Foliar K Concentrations, 1967-1969

	Mean Foliar K Concentrations (% DM)							
Treatment	No	N_1	N_2	Mean	No	N_1	N_2	Mean
	1967				1968			
Po	1.05	0.90	0.83	0.93	0.78	0.79	0.67	0.74
P_1	1.02	0.95	0.97	0.98	0.73	0.62	0.63	0.66
P_2	1.02	0.89	0.82	0.91	0.73	0.65	0.53	0.64
P_3	1.01	0.82	0.80	0.87	0.68	0.58	0.49	0.58
Mean	1.02	0.89	0.85		0.73	0.66	0.58	
	CV=1.04%				CV=1.07%			

	1969				Significant Comparisons
Po	0.92	0.88	0.82	0.87	
					No vs (N_1+N_2) 67** 68** 69*
P_1	0.83	0.78	0.69	0.77	
P_2	0.85	0.74	0.74	0.78	N_1 vs N_2 68**
P_3	0.89	0.69	0.73	0.77	Po vs (P_1+P_2+P_3) 68** 69*
Mean	0.87	0.77	0.75		(P_1+P_2) vs P_3 '67* '68*
	CV=0.83%				

Significence level: *0.05, **0.01.
CV: Coefficient of variation.

deficiency in Scots pine (*Pinus sylvestris* L.) resulting from G.N.A.P. application on a deep peat site in Britain. This was attributed to an antagonistic effect of calcium in the phosphatic fertilizer.

Foliar Ca concentrations ranged from 0.40 to 0.69% D.M. They were significantly increased in the 1968 and 1969 seasons by G.N.A.P. application. Foliar Mg concentrations ranged from 0.07 to 0.16% D.M. Applied phosphate resulted in a significant increase in concentrations. In 1967, application of S/A resulted in a highly significant reduction in Mg concentration. However, the effect was so small, 0.13 to 0.10%, that it is doubtful if it has any biological significance.

CONCLUSIONS

Ultimately, the success of our peatland forests will be measured by the contribution they make to a sector of our society. This contribution will depend in part on the volume of merchantable wood which they produce. The results of this study add to the information available for the management of these forests to their full potential.

The need for a second application of phosphate after planting on this site is confirmed. The response to this application was still strongly evident in 1970 and the results suggest that it will persist for some years more. Canopy closure, which is not yet completed, will greatly alter the pattern of nutrient cycling developed in the stand. Few of our peatland forest crops have yet closed canopy and it is impossible to say how this will affect the nutrient status of the crops.

The incidence of leader breakage in 1969 must be of concern though no firm conclusions can be drawn from it.

The effect of G.N.A.P. in increasing foliar N concentrations emphasises the heterogenous nature of this material. It is an ideal fertilizer for use at this early stage in our knowledge of tree nutrition on peat. As a water insoluble calcium phosphate, it may be expected to become slowly available under acid conditions. The low iron and aluminium content of Irish peats (Walsh and Barry, 1958) should restrict subsequent phosphate immobilization to a fraction of that encountered in strongly acid mineral soils. In addition, it contains a number of essential plant nutrients though little information is available on synergistic or antagonistic relationships developed between components of G.N.A.P. and other nutrients present in the peat. Both G.N.A.P. and S/A caused a reduction in foliar and peat K concentrations. This raises the possibility of incipient K deficiency in some crops.

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