Long-term study of Sitka spruce
(Picea sitchensis (Bong.) Carr)
on blanket peat

1. THE RESPONSE TO FERTILISERS AND LIME

E. P. FARRELL

Department of Agricultural Chemistry and Soil Science,
University College Dublin, Belfield, Dublin 4.

ABSTRACT

A nitrogen and phosphorus fertiliser experiment on Sitka spruce (*Picea sitchensis* (Bong.) Carr., which had been running since 1967, was subdivided in 1977. Half of the original experimental plots were left untreated, half received lime and further applications of nitrogen and phosphorus in factorial combination. In the plots of the section unlimed and unfertilised in 1977, the 1967 fertiliser application has shortened the rotation by 6 to 9 years. The section limed and fertilised in 1977 showed growth responses to the new applications of nitrogen and phosphorus. Nevertheless, the indications were that the unlimed trees were superior to those which had been limed. The results indicate that no benefit is to be gained from liming under these circumstances. There is no evidence of nitrogen deficiency in either experiment, but it is possible that further applications of phosphate will prove beneficial.

INTRODUCTION

When this study was begun in 1967, peatland forestry in Ireland was little more than 15 years old. Attitudes towards selection of species were confused and the issue was as controversial as it is today. There was a recognition that contorta pine (*Pinus contorta* var *contorta* Loud.), as it was known, was more tolerant of difficult site conditions than the preferred species Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and the problems of growing the spruce were a cause of serious concern. The need for phosphate was well recognised and a spot application at planting had been standard practice for both species since the early 1950s. Nevertheless, really healthy crops of Sitka were rare and many stands had gone into check, a common condition in young spruce crops on blanket peat, at that time (Parker 1957, McConaghy *et al.* 1960, Dickson 1965). The nature of the problem was not fully understood and the remedy uncertain.

IRISH FORESTRY, 1985, Vol, 42, No. 2: 76-91.

The experiment was established in a crop which appeared to be going into check. In fact, a true check situation never developed. Growth, while it was always poor in untreated plots, continued throughout the life of the experiment. Foliar analysis at the time the experiment was established indicated severe nitrogen deficiency in chlorotic trees scattered throughout the crop. Experience with nitrogenous fertilisers had been generally disappointing (Jack 1965, McConaghy *et al.* 1960, O'Carroll 1967), possibly because checked crops may often have been suffering from deficiencies of both nitrogen and phosphorus. Increased foliar nitrogen concentrations had been reported following application of rock phosphate to checked crops (O'Hare 1967, O'Carroll 1967). While the mechanism of this response was not understood, it did seem a more fruitful approach to the problem.

In the initial period of the experiment, nitrogen and phosphorus were applied in factorial combination at moderate to high levels. The results confirmed the inadequacy of the original spot application of phosphate (85g ground rock phosphate per plant). Plots which did not receive nitrogen or phosphate suffered from deficiencies of both elements and consequent growth stagnation. Both fertilisers produced significant increases in height growth in the early years (Farrell and McAleese 1972). Phosphate had the greatest effect although no additional response was obtained above the lowest level of rock phosphate application (373kg fertiliser per ha).

At the end of the 1976 season it was decided to divide the original experiment in two. Half of the original area, to be known as Experiment 1, was left untreated. In the other half (Experiment 2), all the plots were limed and the effect of new applications of nitrogen and phosphorus examined.

EXPERIMENTAL

The experiment was located on oligotrophic blanket bog at Glenamoy State Forest in north-west Co. Mayo. The climate of the area is extreme maritime, annual rainfall averages 1,400mm, distributed over 270 days. The wind climate is very severe with gales in almost every month.

The *Schoenus nigricans* L. association dominates the natural flora (O'Hare 1959). Principal species include *Schoenus nigricans* L., *Molinia caerulea* Moench., *Eriophorum angustifolium* Honck., and *E. vaginatum* L. The top 50cm of peat has an ash content of

2.5% and humification 5 to 6 on the Von Post scale (Walsh and Barry, 1958). Bulk density is about 0.09g per cm^3 in the 0-5cm layer and 0.10g per cm^3 at 5-10cm. Saturated hydraulic conductivity is about 1cm per day (Burke 1967).

Preliminary drainage to 1m depth was carried out at 31m spacing in 1954. Prior to afforestation in 1962, the area received double mouldboard ploughing producing a shallow drainage channel and two continuous lines of planting ribbons. The area was planted with Sitka spruce at 1.5m x 1.5m spacing in 1962. The trees received a spot application of 3oz (85g) of ground rock phosphate per plant at planting. The fertilisation experiment comprising 48 x 0.03ha plots was installed in 1967. A randomised block design was employed with four levels of ground rock phosphate and three levels of sulphate of ammonia in factorial combination, replicated four times. All fertilisers were applied broadcast, without incorporation, in April 1967, with a further application of nitrogen to some plots in 1969 (Table 1).

In spring 1977, the original experiment was divided in two. In two of the original four blocks no further treatments were applied (Experiment 1). In the other two blocks (Experiment 2), all plots received an application of 8 tonnes of ground limestone per ha. In addition, nitrogen and phosphorus were applied in the same plots as previously but at different rates and using calcium ammonium nitrate as source of nitrogen and superphosphate as source of phosphorus. Treatments applied in Experiments 1 and 2 are summarised in Table 1.

Height measurements were made in spring 1967 and at the end of the 1967, 1968, 1969, 1970, 1972, 1975 and 1979 growing seasons, and basal area calculated from stem counts and diameter breast height at the close of the 1975, 1979 and 1981 seasons. Samples for foliar analysis were collected in the autumn of the years 1966, 1967, 1968, 1969 1972, 1975 and 1979.

Measurements were initially made inside a buffer strip, two rows of trees wide, in each plot. Due to concern about the spread of fertiliser effects between plots, assessment was confined from 1972 on, to the 16 trees closest to plot centre. Trenches were dug between plots in 1976 to prevent further spread of fertiliser effects along plough ribbons. From 1975 on, the five trees of largest diameter per plot were taken for height measurement and the mean value used as an estimate of top height. Foliage samples were collected and analysed as previously described (Farrell and McAleese 1972).

Table 1. Summary of Treatments Applied in Experiment 1 and Experiment 2 (kg nutrient ha^{-1}). All treatments applied in springtime.

Year	N_0	N_1	N_2	P_0	P_1	P_2	P_3
1967[1,2]	0	132	264	0	55	110	220
1969	0	132	0	0	0	0	0
			Experiment 1				
1977/ 1979			No further treatments applied.				
			Experiment 2				
1977[3,4]	0	75	75	0	35	70	105
1978	0	0	75	0	0	0	0
1979	0	0	75	0	0	0	0

1 N applied as sulphate of ammonia; P as ground rock phosphate.
2 Sulphate of potash (42% K) was applied to all plots at 125kg per ha and copper sulphate (25% Cu) at 11kg per ha.
3 N applied as calcium ammonium nitrate; P as superphosphate.
4 All plots limed at 8t ground limestone per ha.

RESULTS

Experiment 1

By 1972, the response pattern established in the early years of the experiment (Farrell and McAleese 1972) had begun to change. In the plots which make up the present Experiment 1, the influence of applied nitrogen on growth had ceased to be significant and only phosphate was still effective (Table 2). In later years this effect too weakened. The massive effect of phosphate in the 1967-1972 period, which increased height growth by 67% over the control, fell to 17% in 1973-1975 and 23% in 1976-1979. In neither of these later periods was the effect of phosphate statistically significant (Table 2). No significant effect of treatment was observed in basal area increment either (Table 3).

A clearer picture of productivity trends can be seen by examination of top height in individual treatments (Table 4). In almost every case there is a decline over time in Yield Class as determined by top height-age relationships. However, even the 1979 (age 18) figures may overestimate potential maximum annual volume increment. Yield Class estimation in stands of such varying growth rate can be misleading. In these circumstances, top height increment

Table 2 Experiment 1. Mean Height Increment in the seasons 1967-1972, Top Height Increment 1973-1975 and 1976-1979. Main effect means (m).

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1967-1972	11	2.93	3.21	3.43	0.190	2.13	3.42	3.63	3.59	0.219a
1973-1975	14	1.18	1.57	1.38	0.178	1.22	1.37	1.44	1.47	0.205
1976-1979	18	1.89	2.00	2.32	0.242	1.76	2.06	2.34	2.12	0.250

a $P_0 < P_1, P_2, P_3$ $p < 0.01$

Table 3 Experiment 1. Mean Basal Area Increment (m^2/ha) in the seasons 1976-1979 and 1980-1981. Main Effect Means.

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1976-1979	18	16.6	17.4	18.2	1.70	15.6	16.8	18.0	19.2	1.96
1980-1981	20	6.2	6.8	6.7	0.72	7.1	5.9	6.6	6.5	0.84

may provide a better estimate of true productivity (Edwards and Christie 1981). Top height increment, 1976-1979, indicates a Yield Class of about 8 for the Po plots and 12 to 14 for the phosphate treated plots. Basal area data for 1981 (Table 4) would indicate potential volume production greatly in excess of that indicated by Yield Class. However, but these results should be treated with caution as extrapolation of basal area per ha from the small number of trees used for assessment in the later years of the experiment is subject to a wide margin of error.

It has been suggested that improved nutrient cycling following canopy closure might increase nutrient mineralisation and lead to improved uptake. Foliar nutrient concentrations for 1979, 13 years after phosphate application and 11 to 13 years after nitrogen was last applied, follow a similar pattern to earlier years (Farrell and McAleese 1972) with the effect of applied phosphate on foliar phosphorus and magnesium concentrations still in evidence (Table 5). Examination of variation in mean nutrient concentration since establishment of the experiment in 1967 (Fig 1) shows that foliar phosphorus responded to the fertiliser application in 1967 and then gradually declined. It is interesting to speculate if the increase in nitrogen concentration between 1975 and 1979 might represent a real upturn in nitrogen mineralisation following canopy closure. There is little reason to expect an increase in the rate of forest floor breakdown, at least until after thinning. This was conducted in 1982, but the experiment was terminated at that time and no subsequent results are available.

Experiment 2

The possibility of covariance of growth since the 1977 treatment with growth prior to it was examined using height increment in the period 1973 to 1975 as covariate. The covariate had no influence on height increment in the 1976-1979 period and only a small but significant effect on basal area increment. Basal area increment is presented both as unadjusted and adjusted means.

Phosphate, applied as superphosphate in conjunction with lime, significantly increased height increment in the 1976-1979 period (Table 6). As before, the different levels of applied phosphate had essentially the same effect, even though the P_1 treatment represented an application of only 35kg/ha. The response pattern in basal area was similar, although here a significant effect of nitrogen also was recorded (Table 7).

The long-lived response of foliar phosphorus to applied phosphorus was again manifested (Table 8). Phosphorus also produced an increase in foliar nitrogen concentration. This phenomenon which was observed in the early years of the experiment (Farrell and McAleese 1972) and persisted up to 1972

Table 4. Experiment 1. Top Height (TH), Yield Class (YC) and Basal Area (BA) for Individual Treatments and Main Effect Means.

Year	1972		1975		1979		1976-1979	1981
Age	11		14		18		Annual	20
	TH	YC	TH	YC	TH	YC	TH Increment	BA
Treatment	(m)		(m)		(m)		(cm)	(m^2 per ha)
$N_0 P_0$	3.1	12	3.9	10	4.9	10	24	23
$N_0 P_1$	4.9	18	6.0	16	8.4	16	60	46
$N_0 P_2$	5.0	18	6.3	16	8.4	16	54	55
$N_0 P_3$	5.3	20	6.8	18	8.3	16	51	50
$N_1 P_0$	3.6	14	5.0	14	6.5	12	37	36
$N_1 P_1$	4.9	18	6.9	18	8.9	16	51	56
$N_1 P_2$	5.3	20	6.9	18	9.2	18	57	46
$N_1 P_3$	5.2	20	6.5	18	8.8	16	55	52
$N_2 P_0$	4.8	18	6.3	16	9.1	18	71	50
$N_2 P_1$	5.5	20	6.5	18	8.2	16	44	44
$N_2 P_2$	5.4	20	6.8	18	9.4	18	65	52
$N_2 P_3$	5.2	20	6.7	18	8.9	16	53	58
Main Effect Means								
N_0	4.6	18	5.7	16	7.6	14	47	43
N_1	5.1	20	6.3	16	8.3	16	50	47
N_2	4.9	18	6.6	18	8.9	16	58	51
P_0	3.7	14	5.1	14	6.8	12	44	36
P_1	5.5	20	6.5	18	8.5	16	52	48
P_2	5.3	20	6.7	18	9.0	18	59	51
P_3	5.0	18	6.7	18	8.8	16	53	53

Yield Class is taken from Top Height — Age curves in Everard (1974).

Table 5 Experiment 1. Foliar Nutrient Concentrations 1979 (age 18 years). Main Effect Means (% DM).

Main Effect	Nutrient Concentration % DM				
	N	P	K	Ca	Mg
N_0	1.45	0.16	0.91	0.48	0.15
N_1	1.52	0.17	0.82	0.44	0.14
N_2	1.49	0.18	0.84	0.51	0.18
SE Treatment Mean	0.10	0.009	0.084	0.026	0.012
P_0	1.40	0.12	0.98	0.43	0.13
P_1	1.58	0.16	0.76	0.50	0.19
P_2	1.41	0.19	0.84	0.46	0.17
P_3	1.56	0.21	0.84	0.51	0.14
SE Treatment Mean	0.12	0.010	0.097	0.030	0.014
		b			a

a $P_0 < P_1, P_2, P_3$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$

has usually been associated with application of rock phosphate rather than superphosphate. However, in view of the complex treatment history of these plots, it is difficult to assess the significance of this result. A significant influence of fertiliser nitrogen on foliar nitrogen concentration was recorded up to 1969 (Farrell and McAleese 1972). A similar effect was observed following the 1977-1979 treatments (Table 8).

Viewed simply, in terms of growth response, the treatments applied in 1977 have proved successful. Basal area increment in the 1976-1981 period (Table 7) shows a 63% increase in the phosphate treated plots over the P_0 treatment. The effect of nitrogen was smaller, a 28% increase in basal area over the 1976-1981 period, but nevertheless significant. It is not possible to say how long this response will be maintained. There is evidence that the response to phosphate was beginning to wane as it was less in the 1980-81 period than in 1976-1979.

Within the context of this experiment, the efficiency of the nitrogen and phosphorus treatments must be judged in association with the lime which was applied to all plots in 1977. In other studies with Sitka spruce on peat, lime has been shown to induce nitrogen deficiency and to retard growth, at least in the short term (Dickson 1972). It was hoped that the ultimate effect of the lime would be to stimulate microbial activity and lead to an increase in the

Table 6 Experiment 2. Mean Height Increment in the Seasons 1967-1972, Top Height Increment 1973-1975 and 1976-1979. Mean Effect Means (m). Means are Unadjusted.

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1967-1972	11	2.71	3.11	3.10	0.114	1.61	3.53	3.44	3.31	0.131b
1973-1975	14	1.18	1.55	1.44	0.136	1.36	1.42	1.35	1.44	0.157
1976-1979	18	1.31	1.75	1.70	0.261	0.69	1.82	2.09	1.75	0.302a

a $P_0 < P_1, P_2, P_3$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$

Table 7 Experiment 2. Mean Basal Area Increment (m^2/ha) 1976-1979 and 1980-1981. Main Effect Means. Means Unadjusted and Adjusted using Height Increment 1973-1975 as Covariate.

Season	Age at end of period		N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1976-1979	18	Unadj.	12.5	15.6	16.7	0.99a	9.6	17.1	16.6	16.5	1.15b
		Adj.	12.6	15.5	16.6	1.04a	9.6	17.1	16.6	16.5	1.20b
1980-1981	20	Unadj.	5.2	6.9	7.1	0.51c	4.9	6.9	6.8	7.1	0.59d
		Adj.	5.3	6.8	7.0	0.53	4.9	6.9	6.8	7.0	0.61d
1976-1981	20	Unadj.	17.7	22.6	23.7	1.37c	14.5	24.0	23.4	23.6	1.59b
		Adj.	18.0	22.3	23.7	1.43a	14.5	23.9	23.4	23.5	1.65b

a $N_0 < N_2$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$
c $N_0 < N_1, N_2$ $p < 0.05$
d $P_0 < P_1, P_3$ $p < 0.05$

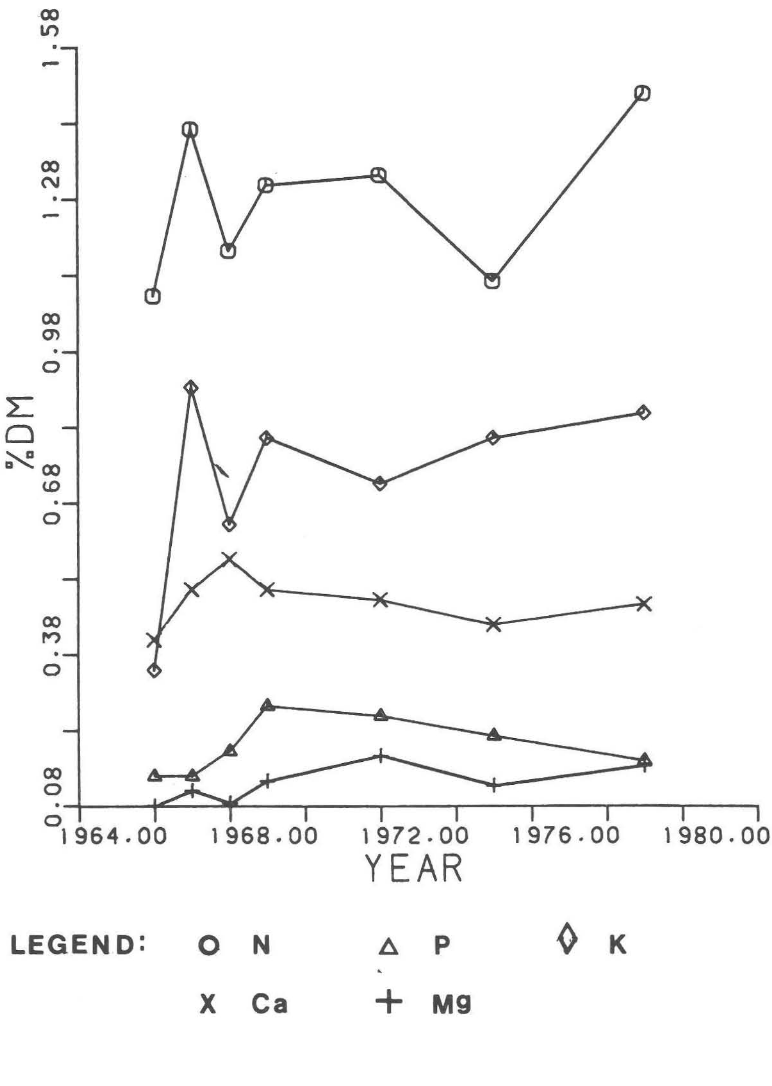

Fig 1 Experiment 1. Foliar Nutrient Concentrations (% DM), Mean of all Plots.

Table 8 Experiment 2. Foliar Nutrient Concentration 1975 (age 14 years) and 1979 (age 18 years). Lime and Fertiliser Treatments Applied 1977. Main Effect Means (% DM).

Main Effect	Nutrient Concentration (% DM)									
	N		P		K		Ca		Mg	
	1975	1979	1975	1979	1975	1979	1975	1979	1975	1979
N_0	0.92	1.28	0.21	0.17	0.81	0.81	0.41	0.62	0.11	0.16
N_1	1.07	1.44	0.20	0.19	0.76	0.81	0.38	0.64	0.11	0.16
N_2	1.05	1.68	0.21	0.19	0.77	0.71	0.38	0.58	0.12	0.14
SE Treatment Mean	0.046	0.066	0.12	0.008	0.044	0.050	0.020	0.031	0.006	0.011
		b								
P_0	0.93	1.26	0.10	0.11	0.86	0.87	0.34	0.59	0.10	0.14
P_1	0.96	1.57	0.23	0.20	0.79	0.80	0.39	0.58	0.11	0.16
P_2	1.13	1.55	0.23	0.22	0.73	0.72	0.41	0.64	0.13	0.18
P_3	1.03	1.48	0.27	0.21	0.75	0.73	0.42	0.63	0.12	0.15
SE Treatment Mean	0.053	0.076	0.14	0.009	0.051	0.059	0.023	0.036	0.007	0.013
		c	a	a						

a $P_0 < P_1, P_2, P_3 \quad p < 0.01$
b $N_0 < N_1, N_2 \quad p < 0.01$
c $P_0 < P_1, P_2, P_3 \quad p < 0.05$

mineralisation of nitrogen and phosphorus. During the build up of the microbial population, competition for nitrogen would be severe and it was hoped that the fertiliser treatments would reduce the deleterious effects of competition on the tree crop. However, the results do not fully support this model. Levels of foliar nitrogen increased in the period 1976-1979 both in Experiment 2 where lime was applied in 1977 (Table 8) and in Experiment 1 where there was no intervention (Figure 1). Even the N_0P_0 treatment in Experiment 2 which had a mean foliar nitrogen concentration of 0.84% in 1975 showed a concentration of 1.24% in 1979. Corresponding nitrogen concentrations for the N_0P_0 treatment in Experiment 1 were 0.85% in 1975 and 1.30% in 1979.

Comparison of Experiments 1 and 2

The study was not primarily designed to test the effect of lime alone. However, it is likely that growth was in fact retarded as a result of lime application. The only true comparison to test the effect of lime is between the N_0P_0 plots in each experiment. However, variation in growth rates between plots which have received very low levels of fertiliser is often very high and this is the case with these plots making direct comparison of little value. Nevertheless, despite the stimulation produced by the fertiliser treatments in Experiment 2, top height increment over all plots in this experiment was significantly less than in Experiment 1 in the 1976-1979 seasons (Table 9). A similar trend can be seen in basal area increment, although it should be pointed out that a higher, though not significantly so, total basal area was recorded in Experiment 1 two years prior to application of lime in Experiment 2.

Apart from the increase in foliar calcium concentrations following liming (Table 8), no significant differences were recorded in foliar nutrients between experiments. While the possibility of a long-term effect of liming cannot be discounted, it seems unlikely as the lime did not become thoroughly incorporated with the peat.

DISCUSSION

At initial spacing of 1.5 x 1.5m, a spot application of 85g of rock phosphate per tree represents an application of about 378kg fertiliser or 55kg P per ha, almost identical to the rate recommended today. The fact that the crop was in distress five years after planting is a remarkable testimony to the advantage of broadcast over spot application of fertiliser.

Table 9 Comparison of Means over all Treatments of Top Height, Top Height Increment, Basal Area and Basal Area Increment 1972-1981 between Experiment 1 and Experiment 2.

Season	Age at end of period	Experiment 1	Experiment 2	t value
Top Height				
1972	11	4.9	4.9	0.11
1975	14	6.2	6.2	0.15
1979	18	8.3	7.9	0.92
Top Height Increment (m)				
1973-1975	14	1.4	1.4	0.15
1976-1979	18	2.1	1.6	2.19*
Basal Area (m^2/ha)				
1975	14	23.1	21.6	0.56
1979	18	40.5	36.6	1.07
1981	20	47.0	43.0	1.02
Basal Area Increment (m^2/ha)				
1975-1979	18	17.9	14.9	1.85
1980-1981	20	6.6	6.4	0.29

* p 0.05

High rates of phosphate were used in the 1967 treatments, the intention being to investigate the possibility of a greater duration of response to the heavier rates. The higher rates of application often gave a slightly greater growth response but the differences were never significant and could hardly give an economic return on the increased investment. In this regard, it is rather disturbing to see that an increase in height growth of 23% over the control, as was recorded in 1976-1979 in Experiment 1, should fail to reach statistical significance. A corresponding increase in volume increment would be very attractive financially. The lack of significance is due to the high level of experimental error (coefficient of variation in this case was 33%), which was in part a consequence of the low level of replication following the division of the original experiment in 1977.

In comparison with phosphate, the response to nitrogen in Experiment 1 was small. Nevertheless, basal area in the N_2 plots in

1981 was $8m^2$ per ha greater than in the No plots (Table 4), a 19% increase. This difference was far from being statistically significant. However, it follows exactly a trend established in 1975 and repeated in 1979 (data not presented), and as such appears to represent the residue of the small but significant effect of nitrogen on height increment measured in the years following fertiliser application 15 to 17 years previously.

The effect of fertilisers in Experiment 1 has been to temporarily increase the growth rate in the treated plots. A continuing long-term response is not to be expected. The fact that Yield Class was greater than in the untreated plots at the end of the experiment tells us merely that a real increase was obtained and that as a result the crop is closer to maturity. Rather than consider the effect of the fertiliser in terms of an increase in Yield Class, it is more appropriate to compare treatments in terms of their relative stage of development (Everard 1974, Miller 1981). Thus, at year 18 the top height-age relationship indicates that the control plots in Experiment 1 are Yield Class 10. Top height averaged over all phosphate treated plots was 8.8m, the height a Yield Class 10 crop would achieve at 24 to 27 years. Expected top height increment in a Yield Class 10 Sitka spruce stand of top height 8.8m is about 48cm per annum (Edwards and Christie 1981). Annual leader length in the phosphate treated plots 1976-1979, was considerably greater than this (55cm). Assuming that top height increment does not fall below the level commensurate with a stand of Yield Class 10 at that stage of development, the rotation has been shortened by a minimum 6 to 9 years and this is the most sensible criterion of successful fertiliser treatment.

Applying lime to this crop holds little promise of success. Growth in comparison to the unlimed plots of Experiment 1 was, if anything, slightly retarded by the lime. The influence of the lime and fertilisers on the peat will be dealt with in a later paper but the effect of the lime on peat pH was small. There was an increase in pH of the forest floor from pH 4.5 to pH 7.0 in some plots, but the lime proved to be poorly mobile and its influence was not seen below 5cm in the peat. Lime may produce beneficial results after a number of years (Dickson 1984), or if it can be fully incorporated with the peat (Dickson 1977), but this is of course impossible in an established crop. Even when incorporation is possible, the evidence suggests that the lime should be worked into the peat several years before planting (Dickson 1977).

Foliar analysis in 1979 did not indicate a deficiency of nitrogen in either experiment. Despite the fact that applied nitrogen has been shown to be beneficial in the early years on low level blanket peat

(Carey M.L., Personal Communication) and essential on high level blanket peat (Dickson and Savill 1974), there is no evidence that additional nitrogen will be required on this site to maintain growth. The gradual decline in foliar phosphorus concentrations, however, suggest that a further application of this element might well produce a growth response.

ACKNOWLEDGEMENTS

Many people have helped in this study over the years. Thanks are due to the Forest and Wildlife Service for providing the site and a great deal of assistance in the field. In particular I wish to thank Joe Freeman, P. J. Lyons, Cyril Flynn, Mick Forde, Joe Fenton and Philip Comer for their help. Annette Callaghan was responsible for the laboratory work and Iris Neylan prepared the typescript.

REFERENCES

BURKE, W. 1967. Principles of drainage with special reference to peat. Irish For. 24(1):1-7.

DICKSON, D. A. 1965. The effect of nitrogenous and phosphatic fertilisers on the growth of checked trees on deep peat. Record of Agricultural Research 14 (part 2):61-71.

DICKSON, D. A. 1972. Effects of limestone, phosphate and potash on the early growth and nutrient uptake of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) planted on deep peat in Northern Ireland. Proc. Fourth Int. Peat Cong. Otaniemi, Finland, Vol. 3: 479-488.

DICKSON, D. A. 1977. Nutrition of Sitka spruce on peat — problems and speculations. Irish For. 34:31-39.

DICKSON, D. A. 1984. Effects of ground limestone and urea on growth of Sitka spruce planted on deep oligotrophic blanket peat in Northern Ireland. Proc. 7th Int. Peat Cong. Dublin, Vol. 3:255-263.

DICKSON, D. A. and P. S. SAVILL. 1974. Early growth of *Picea sitchensis* (Bong.) Carr. on deep oligotrophic peat in Northern Ireland. Forestry 47:57-88.

EDWARDS, P. N. and J. M. CHRISTIE. 1981. Yield models for forest management. Forestry Commission Booklet No. 48.

EVERARD, J. E. 1974. Fertilisers in the establishment of conifers in Wales and Southern England. Forestry Commission Booklet No. 41.

FARRELL, E. P. and D. M. McALEESE. 1972. The response of Sitka spruce to sulphate of ammonia and ground rock phosphate on peat. Irish For. 29(2):14-28.

JACK, W. H. 1965. Experiments on tree growing on peat in Nothern Ireland. Forestry 28:20-40.

McCONAGHY, S., J. S. V. McALLISTER, J. F. PARKIN and R. E. PARKER. 1960. The growth of Sitka spruce on deep peat in Northern Ireland. I. The effect of fertilisers and other treatments on the growth of young trees. Res. and Expt. Rec., Min. for Agriculture, Northern Ireland 10:151-162.

MILLER, Hugh G. 1981. Forest fertilisation: some guiding concepts. Forestry 54:157-167.

O'CARROLL, N. 1967. Forest fertilisation in the Republic of Ireland. Proc. Colloquium on Forest Fertilisation, Jyväskylä, Finland, 271-274.

O'HARE, P. J. 1959. An ecological study of certain blanket bogs in Co. Mayo. M.Agr.Sc. thesis, Univ. College Dublin. Unpubl.

O'HARE, P. J. 1967. Leader growth and foliar composition in Sitka spruce in relation to fertiliser application on blanket peat. Proc. Colloquium on Forest Fertilisation, Jyväskylä, Finland, 111-121.

PARKER, R. E. 1957. Some problems arising in the afforestation of peat-land in Northern Ireland. Irish For. 14:118-121.

WALSH, T. and T. M. BARRY. 1958. The chemical composition of some Irish peats. Proc. Roy. Irish Acad. 59(B):305-328.