Effect of Late-season Top-dressings of N (and K) applied to Conifer Transplants in the Nursery on their Survival and Growth on British Forest Sites

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SUMMARY

At two English forest nurseries, transplants of five conifer species—*Picea sitchensis*, *Picea abies*, *Tsuga heterophylla*, *Abies grandis*, and *Pinus contorta*—were grown with fertilizer supplying N, P, K, and Mg in amounts intended to be adequate for producing healthy green trees with nutrient concentrations in the 'sufficiency range' as determined by earlier experiments. 'Luxury uptake' of nitrogen was obtained with top-dressings of 'Nitro-Chalk' applied in the nursery during early September, when top growth had nearly ceased. Tests of the effect of this extra N on forest establishment were repeated in four successive years under a wide range of soil and climatic conditions, keeping the trees in a cold store during each winter and planting them on forest sites in England, Scotland, or Wales during the following spring. Except for Grand fir, nitrogen advanced bud-break of all species during the first summer after planting and had no deleterious influence on survival. It tended to increase growth of Sitka spruce during the season after planting, but in later years the differences became small in relation to tree size. The effects on other species were small, except for one considerable decrease in the growth response of Grand fir at a single site.

Frost damage of Sitka spruce of Washington origin was severe on a Welsh and a Scottish site where this frost-sensitive provenance would not normally be grown. At the Welsh, but not the Scottish site, the nitrogen treatment increased the damage.

In the few experiments (confined to *Picea sitchensis*) which tested late-season potassium in the nursery, K concentrations were increased from deficiency to barely sufficiency level; growth in the forest was increased in two of the four experiments. The extra K had no effect on frost damage.

INTRODUCTION

In most countries that rely on artificial regeneration for restocking their forests, nursery production of bare-rooted stock has been greatly improved and speeded up in recent years through the development of better methods of nutrition and the control of weeds, pests, and pathogens. Although the young trees now look healthier and are more uniform, surprisingly little is known about the characters which determine success or failure after planting in the forest. Many workers have spoken about the urgent need for such knowledge and have discussed the factors likely to be involved (Armson and Carman, 1961; Kozlowski, 1971; Schubert and Adams, 1971).

An especially controversial topic has been the question of what constitutes the best nutritional status for nursery trees destined for poor soils and for

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sites with unfavourable climates: should such trees be raised under conditions of extreme nutrient deficiency to make them better adapted to the rigours of the new environment, or should they be well supplied with nutrients to allow rapid growth of new plant tissue? The evidence for the first view (still not uncommon today) was traced back by Němec (1948) to the results from a *single* trial on Norway spruce (carried out many years earlier by Helbig, 1920) in which unmanured trees or those manured with N alone equalled or even slightly exceeded in height those with full NPK manuring. But Němec's own results led him to recommend full nursery manuring. Quite recently, Fiedler, Nebe, and Hoffmann (1973) again drew attention to this long-standing controversy, and Hoffmann's (1966) experimental evidence, too, showed that suitable nursery manuring had a beneficial effect. Němec, Hoffmann, and other workers (Holstener-Jørgensen, 1960; Sanada, 1971) did not, however, attempt to distinguish between the effect that manuring had on the *growth* of nursery plants from its effect on their *nutrient concentrations* at the end of the growing season, and trees that were compared in the forest differed initially in more than one respect. This difficulty was discussed by Wakeley (1954) in connection with the production of 'Southern Pines'. He writes that 'nursery stock grades developed to date have attempted to judge these capacities (for survival and growth after planting) by visible characteristics, including size', the so-called '*morphological grades*'. According to Wakeley '. . . more bigness or, presumably, desirable form of seedlings has not always assured planting success. . . . Evidently the effects of non-visible characteristics within seedlings may be as important as the effects of size and external form'. Such non-visible, internal differences he referred to as *physiological grades*. Although methods of morphological grading have been adopted widely in practice, not many experiments have been done to calibrate morphological grades against forest performance, and even fewer on trees with different physiological characteristics—especially those not simultaneously linked to differences in size. However, recently Gürth (1969), in a detailed study on growth and water relations of Norway spruce transplants, examined the performance, after planting, of well-defined morphological grades tested in combination with a comparison of trees kept fresh or deliberately dried out.

Experiments comparing the forest establishment of trees treated differently in the nursery are laborious, slow, and expensive, and in the past have often failed to give useful information because they were not precise enough or because the aims had not been sufficiently clearly defined. Surprisingly little discussion has taken place on how such experiments can best be conducted.

The procedure in our own nursery-to-forest experiments has been to use well-proven methods for raising healthy looking uniform transplants with nutrient concentrations in the optimum range (Benzian and Smith, 1973) and to try to obtain 'luxury' uptake of N (or K) with the help of late-season top-dressings applied in September—when top-growth had nearly ceased. In this way it was hoped to obtain information on the forest behaviour of trees which differed in nutrient concentrations but were comparable in their main morphological characters (though not in intensity of green colour nor in the amount of root growth between early September and the time of lifting in early December). Preliminary experiments—with treatments as well as testing stage confined to the nursery (Benzian and Freeman, 1967)—had shown not only that such increased nutrient concentrations could be achieved, but that they would tend to advance bud-break the following summer, and also increase height and diameter growth during the same season. These results justified extending the work to forest conditions to discover whether the presence of luxury levels of nitrogen (or potassium) in nursery trees would increase the risk of climatic damage after planting in the forests and whether the extra nutrient reserves may even—in some circumstances—improve growth during the initial forest period of special demand. To make the results as widely applicable as possible, trees of five conifer species (the most common ones raised in two nurseries) were taken in four successive years to forest sites in England, Scotland, and Wales, with conditions representative for the species tested—except that, in practice, the frost-sensitive Washington provenance of Sitka spruce is usually confined to the most westerly upland sites.

METHODS USED FOR NURSERY EXPERIMENTS

Sites

All plants were raised in one of two Forestry Commission research nurseries: Wareham (Dorset) and Kennington (near Oxford). Wareham Nursery, on Calluna heathland, is on a sandy podsol derived from flinty drifts over Eocene sands, with a natural pH of 3·5 to 4·0 (measured in 0·01M $CaCl_2$ solution) and an organic carbon content of about 1·5 to 3 per cent. The soil of Kennington Nursery (Kennington Extension), now closed, is a sandy loam derived from thin drift over Corallian deposits, with a natural pH of about 4·5 (in $CaCl_2$) and an organic carbon content of 1 to 2 per cent. The location, soil type, and climate of both nurseries are described more fully by Benzian (1965); analyses of the soils are given by Benzian and Smith (1973).

Crops

Healthy one-year seedlings, well supplied with nutrients, were raised in uniformly treated seedbeds, using the silvicultural techniques in Forestry Commission Bulletin 43 (Aldhous, 1972) and the inorganic-fertilizer regimes described by Benzian and Smith (1973). The seedlings were lifted during the late autumn, graded for height to ensure greater uniformity in the transplant beds, and kept in a cold store during the winter. They were lined out across the experimental transplant beds, 91 cm wide, allowing 5 cm between trees and 20 cm between lines, each of which contained eighteen trees. Transplanting was done during March and early April, except in 1971, when it was delayed until early May for species other than Sitka spruce. The transplants were lifted during the late autumn of the same year; their assessment, storage, and grading before forest planting is described in later sections.

The five species grown and their origins are shown in Table I; all were tested at Wareham, but Sitka spruce only at Kennington (1968–70). Of the two provenances of Sitka spruce tested, Washington (Wa) has the longer growing season; its greater

TABLE I. *Species of conifers grown in experimental transplant beds*

Common name	Abbr.	Botanical name	Origin	Identity number	Years
Sitka spruce	SS	*Picea sitchensis* (Bongard) Carrière	Wa: South Coastal Washington State, USA	61(7972)	1968–71
			QCI: Queen Charlotte Island, B.C., Canada	66(7111)1	1971
Norway spruce	NS	*Picea abies* (Linnaeus) Karsten	St. Viet/Pongau, Austria	63(4362)3	1968–70
Western hemlock	WH	*Tsuga heterophylla* (Rafinesque) Sargent	Nanaimo, British Columbia, Canada	63(7116)5	1968–9
				64(7116)5	1970–1
Grand fir	GF	*Abies grandis* Lindley	Nanaimo, British Columbia, Canada	64(7116)5	1968
			Pe Ell, Washington State, USA	64(7975)7	1969–70
			Louella, Washington State, USA	68(7973)5	1971
Lodgepole pine	LP	*Pinus contorta* Loudon	Washington State (Coastal), USA	65(797)	1970–1

frost tenderness was not considered a serious drawback in the south and west of Britain, and it was, therefore, used in most of our recent nursery nutrition experiments. It was also chosen for the present series of experiments to assess the effects of nursery treatments under more extreme conditions, but trees of Queen Charlotte Island origin (grown in separate beds) were tested, in addition, during 1971.

Design and lay-out

The four types of nursery experiments, their late-season top-dressing treatments and their design are shown below:

Type of experiment	Treatments	Design
N rates	N_0 (in dupl.), N_1, N_2	4 blocks of 4 plots
K rates	K_0 (in dupl.), K_1, K_2	
N×K	none, N, K, NK	
none v. N	N_0, N_2	4 blocks of 2 plots

Details of year, location, species, and rates of application are given in Table II.

To grow the transplants as uniformly as possible, each experiment occupied one or two long beds of equally spaced lines, with the basal fertilizer distributed evenly over the whole area. Before the late-season top-dressings were applied in early September, the beds were split into plots, separated by one line of untreated trees. The size of plots varied from experiment to experiment, ranging from five to eleven lines; the numbers of trees per plot are shown in Table II.

Late-season top-dressing experiments

The late-season treatments of N (as 'Nitro-Chalk') and K (as potassium sulphate) were applied between the lines in early September. The rates of application are shown in the last four columns of Table II.

'Nitro-Chalk' (21 per cent N), is a granular mixture of ammonium nitrate and calcium carbonate. The standard fertilizer regime (Benzian and Smith, 1973) included four top-dressings made in late April (or early May), and early in June, July, and August. Where N was applied as experimental late-season treatment, the number of applications was reduced. (For details see below.)

Potassium sulphate K_2SO_4 (41–3 per cent K). We used a coarse Italian product (screened to 2–4 mm particle size), which is easily distributed and does not adhere to the foliage.

Basal manuring

All transplant beds received dressings of phosphorus (11 g P/m^2 1968–9, 6 g P/m^2 1970–1), as either potassic superphosphate or as superphosphate (where K was tested), and magnesium (4 g Mg/m^2) as kieserite, all dug in 8–10 cm deep in the spring before lining out.

The basal dressings of N and K (shown in Table II) were varied with experimental treatments and location. Thus, the experiments destined to receive late-season top-dressings of nitrogen were given the standard amounts of K (11 g/m^2) but had the standard four applications of 'Nitro-Chalk' (each of 3·6 g N/m^2) reduced by one on the poor soil of Wareham and by two on the more fertile soil of Kennington. Experiments testing late-season top-dressings of potassium received the standard

TABLE II. *Amounts of N and K used as basal fertilizer and as late-season top-dressing treatments*

Nursery	Species tested (for abbreviations see Table 1)	Number of trees per plot	Type of experiment	g. element/m²					
				Basal treatments		Late-season treatments			
				N	K	N		K	
						Rate 1	Rate 2	Rate 1	Rate 2
1968									
Kennington	SS	162	N rates	7	11	7	14	—	—
Wareham	SS	162	N rates	11	11	7	14	—	—
Wareham	SS, NS, WH, GF	90	N rates	11	11	7	14	—	—
1969									
Kennington	SS	162	N×K	7	0	—	14	—	14
Wareham	SS	180	N×K	11	0	—	14	—	14
Wareham	SS, NS, WH, GF	198	none v. N	11	11	—	14	—	—
1970									
Kennington	SS	162	N rates	7	11	7	14	—	—
Wareham	SS, NS, WH, GF, LP	198	N rates	11	11	14‡	28‡	—	—
Wareham	SS	198	K rates	14	0	—	—	14‡	28‡
1971									
Wareham	SS (Wa, QCI), WH, GF, LP	198	N rates	11	11	7	14	—	—
Wareham	SS (Wa, QCI)	198	K rates	14	2†	—	—	7	14

‡ Values indicate sum of two applications (Sept. 7 and 21), made necessary by heavy rain shortly after first top-dressing.

† Small basal top-dressing of K to alleviate K-deficiency.

four applications of N, but no basal K. (For an exception in 1971 see below.) Experiments with a factorial test on N×K had their basal dressings adjusted for both nutrients. In June 1971, after 4 inches of rain had fallen in one week, the Sitka spruce transplants of Washington origin but not those from Queen Charlotte Island exhibited—in the K-test experiment—the purpling discoloration typical of K deficiency. As the intention had been to produce plants with K concentrations at the sufficiency level, a small top-dressing of prilled potassium nitrate (2 g K/m^2) was applied. (The QCI trees, which exhibited no purpling, were later found to have received—in error—a basal dressing of K before lining out.)

Measurements and observations

Height and diameter assessments. The trees were assessed three times: (1) for height only—immediately before the late-season top-dressings were applied in early September and (2) again *in situ* in mid-October to see whether the late-season top-dressings had affected height growth. (The second assessment had been omitted during the first year at Wareham, before it was realized that the collar level could not be established with sufficient accuracy during the indoor assessment described under (3) to allow a comparison with the early assessment made *in situ*.) (3) A further assessment, of height and diameter, was made indoors after lifting during mid-December; this served as the basis for 'grading', discussed more fully below.

Determination of dry matter and chemical analyses. During 1970 and 1971 plant samples for analysis were taken just before the trees were lifted for storage in early December—the earliest date then judged suitable by Forestry Commission experimental results and experience. However, during 1968 and 1969 the experimental programme had made it necessary to take the samples earlier, i.e. during late October—a few weeks before lifting. All samples consisted of eight trees; dry matter was determined on tops and roots separately, chemical analyses for the whole tree.

Nitrogen and/or potassium, i.e. the nutrients applied to the plants as experimental late-season top-dressings, were determined quickly so that we could decide whether differences in nutrient concentrations justified testing the contrast in the forest. The samples taken in 1968 and 1969 were subsequently analysed for P, K, Mg, Ca, and Mn to characterize the trees further.

Colour description. Changes in colour which developed as a result of late-season top-dressings were recorded and also scored, if the differences were sufficiently distinct.

Plant preparation and analyses

Plant samples were prepared and analysed as described by Benzian and Smith (1973).

Method of grading

An attempt was made to increase the precision of the forest experiments by reducing the variability of the experimental material through 'grading'. Except in 1972, this was done by discarding extremes of height classes and—within height classes—of diameter, so that no more than 10 to 20 per cent of trees were excluded and the results remained applicable to practice. (Trees without leading shoot or with damage to either root or top were also discarded.) For the 1972 forest experiments, trees were graded by height only and up to 35 per cent of plants were excluded. Table III shows the reduction in the coefficients of variation obtained.

TABLE III. *Effect of grading on coefficients of variation*

	% of population retained after grading	Coefficient of variation %			
		Height		Diameter	
		Before grading	After grading	Before grading	After grading
Kennington					
Sitka spruce (Wa)					
1968	88	4·0	3·0	2·5	1·4
1969	83	1·8	1·2	1·5	1·2
1970	93	2·8	2·4	2·6	2·3
Wareham					
Sitka spruce (Wa)					
1968	81	4·0	3·0	3·8	2·4
1970	86	2·7	1·8	2·5	1·4
1970[1]	88	4·3	3·4	2·1	1·4
1971	66	2·4	0·8	—	—
1971[1]	68	7·3	3·7	—	—
Sitka spruce (QCI)					
1971	64	5·5	1·6	—	—
Norway spruce					
1968	91	3·7	3·6	4·3	3·5
1970	91	6·4	6·1	4·2	3·9
Western hemlock					
1968	87	5·9	4·0	6·8	4·7
1969	87	4·8	3·3	3·2	3·3
1970	88	3·5	3·1	3·7	2·8
Grand fir					
1968	84	4·4	2·8	3·8	2·0
1970	87	3·4	2·9	2·5	2·1
1971	66	5·1	1·9	—	—
Lodgepole pine					
1970	86	2·2	1·5	1·7	1·5
1971	65	3·7	1·6	—	—

[1] K-series.

Storage and handling

The aim had been to adopt the techniques recommended by Brown (1971) for the cold storage of nursery plants in polythene bags and for their movement from store to planting site. Unfortunately, the desired temperatures (+1 to +3 °C) and suitable relative humidities could not always be maintained with the improvised installations available, and grey mycelium was seen on the foliage in some bags after the storage period of four to five months. Plants with and without fungal mycelium were compared in small tests in close association with the main experiments described in this paper; there were no differences in survival or growth.

The need for grading (discussed above) involved more handling of the trees than occurs with normal planting stock, and appears to have caused some damage to the trees, despite such special precautions as keeping the roots between sheets of wet hessian during temporary removal from cold store.

RESULTS OF NURSERY EXPERIMENTS

A comparison between height assessments made *in situ* in October and those made in early September (no detailed results are given) shows that after the application of late-season top-dressings the treated and untreated plants of most species continued to grow slightly: Sitka spruce (Wa) and Western hemlock increased their heights by between 7 and 20 per cent, Lodgepole pine by less than 10 per cent, and Sitka spruce (QCI), Norway spruce, and Grand fir by 3 per cent or less. (No comparable values exist for the Wareham experiments in 1968 because the trees were not measured *in situ* in October, nor for Grand fir in 1969 because of difficulties in defining and measuring the height of the central shoot.)

Despite this slight continued growth, dry-matter weights (Tables IV, V, VI) remained almost unaffected by the September applications—as had been our aim. (The large dry-matter response to potassium in the K-test on Sitka spruce (Wa) in 1971 shown in Table V is an anomaly. Comparison between the October and September height assessments shows that the late-season top-dressing of K had no influence. The large response probably resulted from residues of the previous season's K top-dressings not washed out by winter rain, which was only 442 mm compared with the long-term average of 515 mm. The small top-dressing of KNO_3 given to all plots in June failed to even out the difference.)

Effect of late-season top-dressings on N and K concentrations and on colour of trees

Generally, the %N values (Table IV) in the dry matter of tops plus roots of trees not top-dressed in September agree well with values in the 'sufficiency' range given by Benzian and Smith (1973). The late-season top-dressings of nitrogen increased N concentrations for all species and all years—gains ranging from no more than 5 per cent for both rates of N applied to Western hemlock in 1971 to 85 per cent for the high rate of N applied to Sitka spruce at Kennington in 1968 (with %N of untreated trees, however, a little below sufficiency level). With a single exception, only experiments in which increases in concentration of N exceeded 15 per cent were transferred to the forest for further testing. In 1968 and 1970, this threshold value was exceeded in all nitrogen tests; in 1969 only one species—Western hemlock—qualified, but in 1971 Sitka spruce of both provenances as well as Lodgepole pine met the requirement. Grand fir in 1971, with an increase a little less than 15 per cent, was also included in the forest tests.

Fig. 1 shows that the shape of the curves depicting increases in N concentrations of Sitka spruce (Wa) was related to the amount of rain that fell during the 15 days after the application of late-season nitrogen: the curves are steeper when rainfall exceeded 50 mm. This relationship appears to be accounted for in part by the differences in N concentrations of the untreated plants whose concentrations tend to be larger in the left-hand graph (<50

TABLE IV. *Effect of late-season top-dressings of nitrogen on dry-matter weights and on N concentrations of transplants (tops+roots)*

	Kennington	Wareham					
	Sitka spruce Wa	Sitka spruce Wa	Sitka spruce QCI	Norway spruce	Western hemlock	Grand fir	Lodgepole pine
Dry matter, g/plant							
1968							
N_0	5·9	6·0	*not*	3·8	4·5	4·9	*not*
N_1	5·6	6·2	*tested*	3·8	4·9	5·2	*tested*
N_2	6·3	5·9		4·1	4·5	4·9	
SE	±0·32	±0·39		—	—	—	
CV%	10·9	13·5		—	—	—	
1969							
N_0	*not*	5·0	*not*	4·1	4·9	5·7	*not*
N_2	*tested*	5·8	*tested*	3·5	5·0	5·2	*tested*
1970							
N_0	*no*	7·2	*not*	3·7	5·1	6·5	9·2
N_1	*data*†	7·4	*tested*	3·9	4·5	5·5	9·1
N_2		6·7		3·6	5·2	6·5	9·2
SE		±0·45		±0·40	±0·45	±0·46	±0·49
CV%		12·7		21·5	17·4	14·7	10·8
1971							
N_0	*not*	7·8	7·4	*not*	4·2	5·0	10·4
N_1	*tested*	7·4	8·1	*tested*	4·1	5·4	10·6
N_2		7·7	7·9		4·2	5·3	10·7
SE		±0·49	±0·38		±0·32	±0·37	±0·72
CV%		12·8	10·0		15·3	14·1	13·5
%N in dry matter							
1968							
N_0	0·81	1·14	*not*	1·43	1·22	1·30	*not*
N_1	1·23	1·46	*tested*	1·82	1·66	1·56	*tested*
N_2	1·50	1·60		1·83	1·75	1·69	
SE	±0·032	±0·030		—	—	—	
CV%	5·8	4·5		—	—	—	
1969							
N_0	*not*	1·10	*not*	1·48	1·14	1·26	*not*
N_2	*tested*	1·24	*tested*	1·70	1·32	1·34	*tested*
1970							
N_0	1·12	1·40	*not*	1·78	1·50	1·46	1·20
N_1	1·37	1·71	*tested*	1·98	1·72	1·63	1·74
N_2	1·39	1·82		2·21	1·88	1·73	1·76
SE	±0·027	±0·034		±0·057	±0·047	±0·046	±0·044
CV%	4·3	4·3		5·8	5·7	5·8	5·9
1971							
N_0	*not*	1·36	1·36	*not*	1·56	1·66	1·30
N_1	*tested*	1·57	1·59	*tested*	1·63	1·80	1·51
N_2		1·59	1·66		1·63	1·87	1·54
SE		±0·029	±0·035		±0·039	±0·031	±0·052
CV%		4·0	4·7		4·9	3·5	7·3

† Dry-weight determinations of roots suspect, but no reason to doubt the validity of %N.

mm). In the years under review, amounts of September rainfall tended to run parallel to those that fell between May and August and as shown by Benzian, Freeman, and Patterson (1972) trees grown during the drier summers have larger %N.

TABLE V. *Effect of late-season top-dressings of potassium on dry-matter weights and on K concentrations in Sitka spruce (Wa) transplants (tops+roots) at Wareham*

	Dry-matter weight, g/tree		% K in dry matter	
	1970	1971	1970	1971
K_0	8·0	7·3	0·55	0·44
K_1	8·6	9·1	0·60	0·62
K_2	8·2	9·0	0·71	0·76
SE	±0·47	±0·60	±0·021	±0·019
CV%	11·4	14·8	7·1	6·8

TABLE VI. *Effect of late-season top-dressings of nitrogen and potassium in factorial combination on dry-matter weight and on N and K concentrations of Sitka spruce transplants (tops+roots) grown in* 1969

	Dry-matter weights		% in dry matter			
	Kennington	Wareham	Kennington		Wareham	
	g/plant	g/plant	N	K	N	K
none	4·3	4·9	0·93	0·82	1·19	0·60
N	4·0	5·6	1·34	0·89	1·29	0·64
K	4·5	4·8	0·99	0·85	1·20	0·68
NK	4·9	4·5	1·30	0·84	1·37	0·71
SE	±0·33	±0·44	±0·030	±0·020	±0·040	±0·030
CV%	14·9	17·7	5·2	4·7	6·3	9·0

Preliminary trials had indicated that it was more difficult to raise K than N concentrations above sufficiency level, and fewer experiments were devoted to tests on K. The results in Table V show that in 1970 and 1971 Sitka spruce without added potassium contained only 0·4 or 0·5 per cent K in dry matter—well below the sufficiency level of about 0·8 per cent—so that instead of reaching 'luxury uptake', the double rate of K raised the concentrations merely to about 0·7 or 0·8 per cent K. (The special circumstances of the 1971 experiments have been mentioned above.) Although the K-test experiments failed to meet our main aim of comparing luxury uptake in trees with sufficiency level, they were transferred to the forest because the substantial increases in K concentrations were thought to merit further observation.

In the factorial test of N×K in 1969 (Table VI), the untreated trees at

Kennington had %K at sufficiency level, but the added K produced no increases; because of the effectiveness of the nitrogen treatment the trees were, however, transferred to the forest. In the parallel experiment at Wareham, neither N nor K concentrations were increased sufficiently to justify such transfer.

The N status of the trees was well reflected in their colours. Trees without late-season N tended to be healthy green, whilst trees which received the

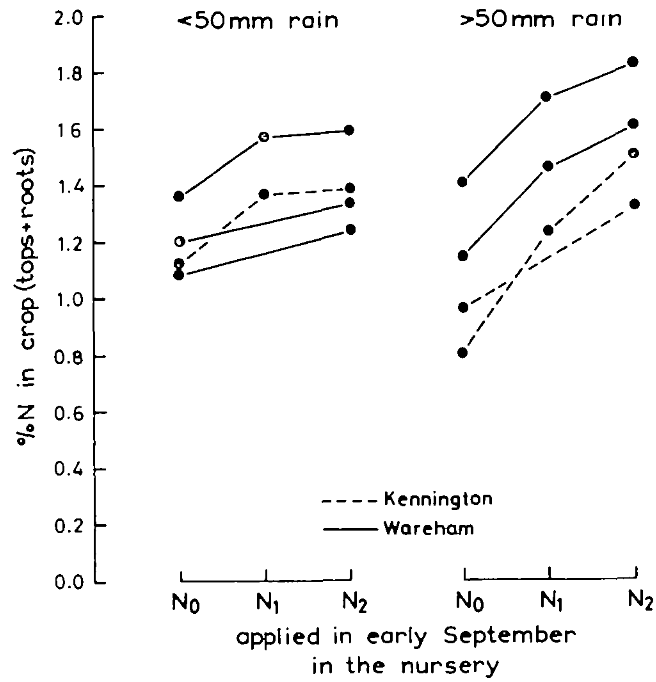


FIG. 1. Relationship between %N in Sitka spruce (tops plus roots) and late-season nitrogen treatments, grouped by rainfall during 15 days following N application.

extra N were darker still (Plate I). Munsell (Munsell, 1929–42) readings for Sitka spruce without late N had a 'Hue' of 7·5 GY, similar to that given by Benzian (1965) for trees well supplied with nitrogen, though 'Chroma' and 'Value' tended to be a little weaker (5/6, 6/6, 7/6, instead of 4/4). Trees with extra N had readings similar to or slightly stronger (4/2, 3/4, 3/2) than those recorded by Benzian.

As the late-season top-dressings had no or only trivial effects on growth and concentrations of nutrients other than N and K, the data shown in Table VII are restricted to those for untreated plots. Only data for trees subsequently transferred to the forests are included. Height and sturdiness (main stem diameters for given heights) of Norway spruce were close to the minimum standard given by Aldhous (1972); with all other species the measurements exceeded these standards. P and Mg concentrations agree well with sufficiency levels given by Benzian and Smith (1973); Ca values are slightly less. The manganese concentrations are also close to those given in their paper.

TABLE VII. *Height, diameter, dry-matter (DM) weights and nutrient concentrations of nursery transplants grown without late-season top-dressing treatments. (This table is confined to experiments transferred to the forest)*

	Height[1] (cm)	Dia.[1] (mm)	DM g/tree		In dry matter of tops + roots					
			Tops (T) + Roots (R)	T/R ratio	%					ppm
					N	P	K	Mg	Ca	Mn
Kennington										
Sitka spruce (Wa)										
1968	30·0	4·5	5·9	2·8	0·81	0·20	0·86	0·080	0·39	1121
1969[2]	26·4	3·9	4·3	3·3	0·93	0·17	0·82	0·086	0·44	1004
1970	23·9	4·0	data suspect[3]		1·12	..	..	..	..	..
Wareham										
Sitka spruce (Wa)										
1968	31·0	4·6	6·1	3·4	1·14	0·23	1·02	0·088	0·50	24
1970	31·6	4·4	7·2	3·4	1·40	..	..	..	..	..
1970[2]	35·0	4·9	8·0	3·0	1·47	..	0·55	..	..	..
1971	33·4	4·4	7·8	3·8	1·36	..	..	..	..	..
1971[2]	30·6	4·3	7·3	3·3	..	..	0·44	..	..	..
Sitka spruce (QCI)										
1971	30·8	4·3	7·4	3·3	1·36	..	..	..	..	..
Norway spruce										
1968	20·3	3·5	3·8	2·3	1·43	0·26	0·83	0·102	0·72	26
1970	16·0	3·6	3·7	1·9	1·78	..	..	..	..	..
Western hemlock										
1968	28·4	3·9	4·5	2 9	1·22	0·23	0·91	0·080	0·42	34
1969	28·0	3·9	4·9	3·3	1·14	0·18	0·90	0·081	0·54	28
1970	27·0	3·8	5·1	2·3	1·50	..	..	..	..	..
Grand fir										
1968	19·3	4·6	4·9	1·9	1·30	0·20	0·94	0·093	0·50	100
1970	21·6	4·6	6·5	1·9	1·46	..	..	..	..	..
1971	20·8	4·2	5·0	2·3	1·66	..	..	..	..	..
Lodgepole pine										
1970	19·2	4·8	9·1	2·7	1·20	..	..	..	..	..
1971	18·2	4·6	10·4	4·1	1·30	..	..	..	..	..

[1] Assessed indoors after lifting. [2] K-test or N × K test. [3] See Table IV footnote 1.

METHODS USED FOR FOREST EXPERIMENTS

Table VIII lists all forest experiments. Originally they were intended to last four years, but as early results indicated that little information would be lost if no assessments were made after the autumn of 1973, no experiments were continued beyond that date. This should have allowed the 1969 and 1970 plantings to run for the full four growing seasons, the 1971 plantings for three, and the 1972 plantings for two.

TABLE VIII. *List of forest experiments*

(For abbreviation of names of species see Table I.)

Planting year and forest	Nursery treatments	Nursery origin and species[1]			Duration in years	Number of trees/plot
		Kennington	Wareham			
1969 Aberhirnant	N rates	SS	SS	....	4	18 or 36
Rheidol	N rates	SS	SS .. NS	WH GF	4	18 or 36
Bedgebury	N rates	..	.. .. NS	WH GF	4 (GF 1)	18
1970 Beddgelert	N×K	SS	.. .. ..	....	4	36
Glenbreck	N×K	SS	.. .. ..	....	4	36
Rockingham	none v. N	..	.. .. ..	WH ..	2	60
Thetford	none v. N	..	.. .. ..	WH ..	2	60
1971 Gwydyr	N rates	SS	SS LP ..	....	SS 1, LP 3	36
	K rates	..	SS	....	1	36
Selm Muir	N rates	SS	SS LP	....	2	48
	K rates	..	SS	....	2	48
Haldon	N rates	..	.. .. ..	WH GF	3	40
Rockingham	N rates	..	.. .. NS	WH GF	3	40
1972 Dovey	N rates	..	SS[2]LP	....	2	32 or 44
	K rates	..	SS	....	2	44
Irfon	N rates	..	SS[2]LP..	....	2	32 or 44
	K rates	..	SS	....	2	44
Rockingham	N rates	..	.. .. ..	.... GF	2	44
Wareham	N rates	..	.. .. ..	.... GF	2	44

[1] *Sitka spruce of Washington provenance except where otherwise stated.*
[2] Two separate experiments—one with Washington provenance, one with QCI.

However, several experiments had to be stopped sooner because of severe damage to crops from frost, drought, or pests.

Sites

The location of the experimental sites is shown in Fig. 2 (map), the description in Appendix Tables A and B, and some physical and chemical properties of the soils and peats in Appendix Tables C, D, and E. Each experimental area was selected and orientated to provide as uniform conditions as possible of soil, slope, aspect and drainage.

Upland sites (Appendix Table A). The eight sites ranged widely in exposure, but almost all had climatic conditions representative of upland planting land. The exception was Rheidol which, despite its elevation of 244 m, was more sheltered, so that in addition to Sitka spruce three species more sensitive to exposure (Norway spruce, Grand fir, and Western hemlock) could be planted.

Mineral soils and peats are both common on upland sites, but as the two principal upland species—Sitka spruce and Lodgepole pine—are established more easily on peat, only two such sites were included amongst the eight.

Lowland sites (Appendix Table B). These sites had little in common beyond their lack of exposure. Spring and autumn frosts occurred frequently at some of the forests. The soils varied more widely in particle-size distribution and chemical composition than the mineral soils of the upland sites.

FIG. 2. Location of experimental sites.

Silvicultural methods

Generally, the methods adopted were similar to those that are standard practice in the respective areas ('Forestry Practice', F. C. Bull. 14, Eighth Edition 1964). All upland sites were ploughed using implements designed to delay recolonization by weeds and to aid drainage and rooting where needed. On lowland sites, woody growth was removed mechanically, and at Rockingham (1970) ammonium sulphamate was applied to stumps before planting to prevent early regrowth. Only Thetford was ploughed (approx. 2 m between furrows). At Bedgebury, 'buffer' trees—of the same origin as the experimental trees—were planted on either side of the many remaining stumps; at other lowland sites, spacing within rows was varied to avoid them. On all lowland sites, especially Rockingham and Haldon, rapid recolonization with vigorous weeds caused the usual competition with the young trees, despite regular hand weeding.

Planting took place between late March and late April, except at Irfon (1972) where it was delayed until late May.

Manuring

Forms and rates of fertilizer application for the upland sites followed local practice. Of the 'lowland' sites, only the very P-deficient Bedgebury soil was manured. The forms of phosphorus fertilizer (with rates in kg P/ha shown in parenthesis) were: triple superphosphate for Aberhirnant (43), Rheidol (16), Beddgelert (60); single superphosphate for Bedgebury (48); Gafsa rock phosphate—unground for Glenbreck (13), and Selm Muir (45), ground for Gwydyr (50). Gwydyr was the only site which received, in addition, K (100 kg K/ha) as potassium chloride. Fertilizers were applied either around or close to each tree, or broadcast between furrows. At Rheidol, faulty application caused damage to the foliage, especially of Western hemlock.

Crops

The conifer species tested and their origins are described above in 'Methods used for nursery experiments'. On arrival at the planting site, most trees were described by the forester as 'good', 'very good', or 'excellent'. The exceptions were: 1969 Bedgebury, where roots of all species were thought not moist enough, and Rockingham and Haldon (both 1971), where the Grand fir was considered sparsely rooted. Many of the Grand fir planted in 1971 had 'blind' buds, but most of the affected trees ended the first season in the forest with normal leaders. (Late-season N treatments had no effect on the occurrence of the symptom.) Individual bags of Lodgepole pine were noted as unsatisfactory or mouldy at Selm Muir 1971 (Block II, N_1), Dovey 1972 (Block III, N_2) and, especially, at Irfon 1972 (Block I, N_2), where fungal infection was associated with prolonged storage because of late planting and a 10-day interval between receipt of trees and removal from the bags.

In 1972, during the first summer after planting, many Lodgepole pine plants had leaders with poorly developed needles—often giving a 'bottle-brush' appearance. Comparable abnormalities were observed at the two widely separated planting sites: Gwydyr and Selm Muir. The foresters attributed the symptoms—tentatively—to a variety of causes, such as attack by grouse (Gwydyr) or browsing by hares and sheep or to insect damage (Selm Muir). Similar symptoms occurred again in 1973 at Dovey and Irfon. Our experimental nursery treatments had no effect on the abnormal needle developments.

Design and lay-out

The nursery experiments were transferred to the forest, block by block, without changing the randomization within blocks, but in some of the first years' experiments one or two blocks had to be omitted because mould had developed in several bags during storage. On every site care was taken to associate differences of terrain with blocks, minimizing differences within blocks.

Planting distances, between rows and between trees within the row, were 1·5 or 2 m, following local practice, except in 1972, when spacing within the row was reduced to 1 m. The number of trees per 1-row or 2-row plots (Table VIII) ranged from 36 to 60, but a few experiments in 1969 had only eighteen trees. The experiments were surrounded on the outside by, usually, two rows of guard trees of the appropriate species of the same origin.

Measurements and observations

From 1970 onwards, trees in all new experiments had their initial height and diameter measured (just above ground level) shortly after planting; this ensured that differences in planting depth were accounted for. (During the first year, 1969, we had to rely on the indoor measurements made after lifting.) Heights were then measured at the end of each growing season—up to four seasons after planting for the oldest experiments. Diameter measurements were omitted in a few experiments which had been badly damaged by frost, drought, or pests.

Bud-break scores were obtained for most experiments during the first growing season to see whether the late-season top-dressings had altered the date of flushing. It was not always possible to reach remote planting sites when differences were largest.

All experiments were inspected at frequent intervals during the first two growing seasons, to record (and score where possible) any colour symptoms or other abnormalities, such as poorly developed leaders, needle loss or damage from drought, frost or pests, which could have reflected differences between treatments.

Soil and peat analyses

For the mineral soils, samples were taken 23 cm deep with a semi-cylindrical sampling tool (2 cm diameter) from the undisturbed soil, as close as possible to the planting position; at Thetford the sample was taken from the bottom of the shallow furrow. Blocks were sampled individually and pH was determined for all. Detailed analyses were confined to one composite sample per experiment or per site. The two peat sites—Gwydyr and Selm Muir—were sampled to 45 cm, each sample made up from three 15 cm cores representing three consecutive horizons.

The soil samples were analysed as described by Benzian, Freeman, and Patterson (1972), except that organic carbon determinations were made by the Tinsley method (Tinsley, 1950). In the peat samples the elements N, P, K, Ca, Mg were determined in a sulphuric acid/selenium digest of the peat. N was determined by the method of Crooke and Simpson (1971) and P by colorimetry. K and Na were determined by flame emission spectrophotometry and Ca, Mg by atomic absorption spectrophotometry.

RESULTS OF FOREST EXPERIMENTS

Bud break

During the early summer of each first growing season (except 1972), bud-break scores were recorded for all experiments using the method described by Lines and Mitchell (1966). A score of 1 denotes buds in winter stage, 2—buds swollen but not yet open, 3—buds burst, showing tips of individual needles, and 4—buds fully flushed. Plate II, Figs. 3a, b, c, and d depict these four stages for Sitka spruce.

Fig. 4, confined to Sitka spruce, shows that late-season application of nitrogen speeded up flushing of that species with remarkable consistency: with one exception, the larger the amount of N applied, the more advanced the buds. (What matters in this diagram is the slope of the curves and not the absolute

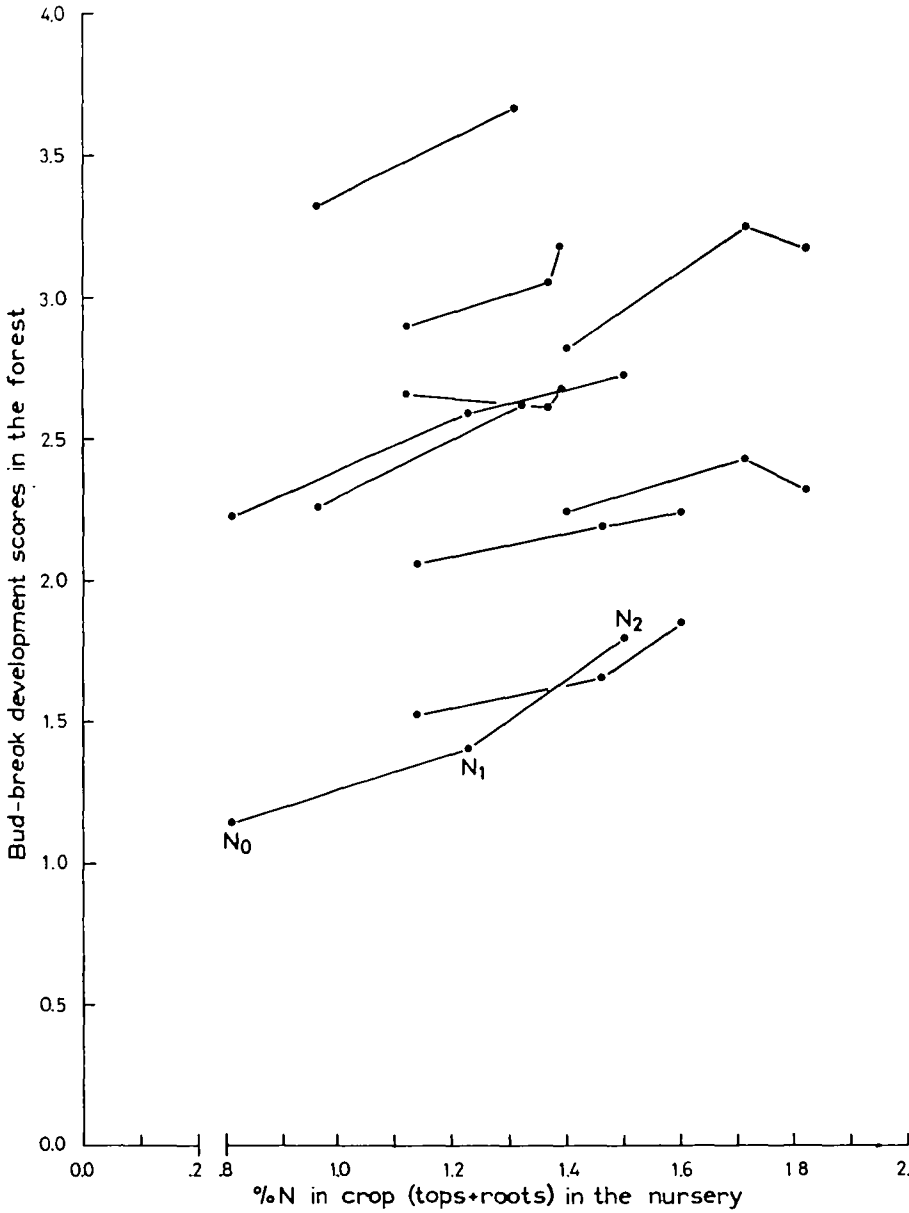


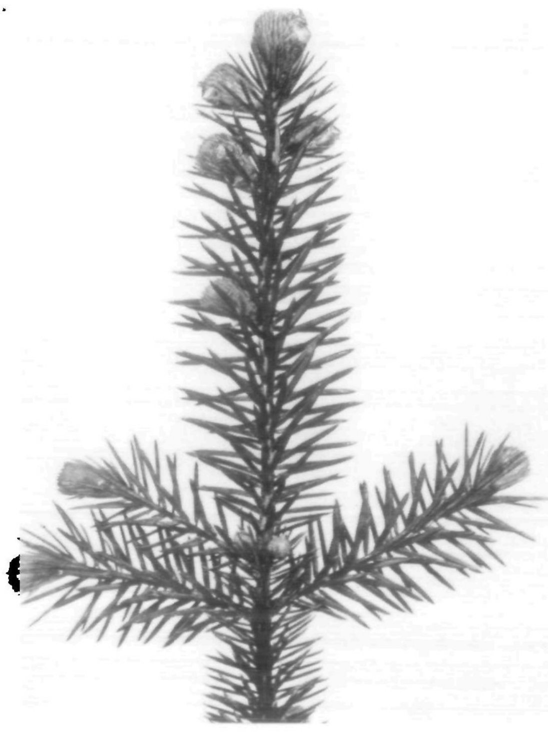
FIG. 4. Relationship between bud-break scores in Sitka spruce (*Picea sitchensis*) forest experiments and %N in the crops before lifting in the nursery.

Layout of nursery experiments of Sitka spruce *Picea sitchensis* transplants at Kennington (photographed in October) showing similarity in size and slight differences in colour between plots with and without late-season top-dressings of nitrogen.

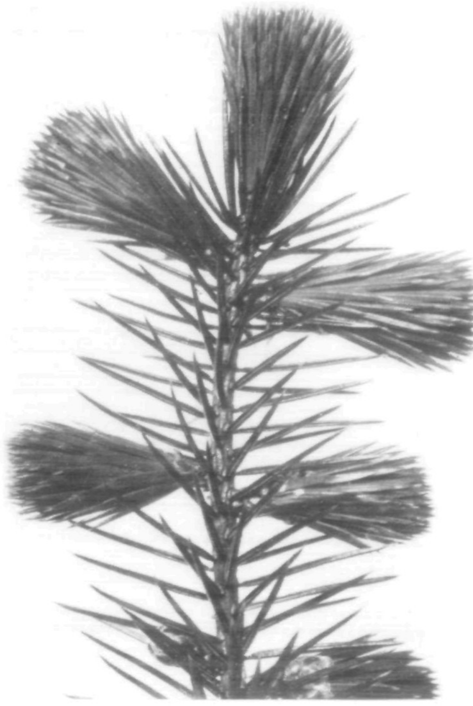
PLATE I

3*a*

3*b*



3*c*



3*d*

Stages of bud-break in Sitka spruce (after Lines and Mitchell, 1966). Fig. 3*a* Buds dormant; Fig. 3*b* Buds swollen; Fig. 3*c* Buds just open; Fig. 3*d* Needles free.

PLATE II

values of the scores, which merely reflect the stage of development reached when the observations were made.) N treatments affected the buds of Norway spruce and Western hemlock in a similar way, and—less clearly—those of Lodgepole pine (scored only in a single year). By contrast, nitrogen retarded bud break in two of the four Grand fir experiments—especially at Rockingham.

The effects of potassium were small and variable.

TABLE IX. *Relationship between late-season top-dressings of N applied in the nursery and growth in the forest*

Planting year and forest	Sitka spruce *Picea sitchensis*										
	Nursery			Forest. Assessed at end of *first growing season*							
	Origin/ proven.	%N in DM (T+R)		Height (cm)				Diameter (mm)			
		N_0	[1]Effect of N	N_0	[1]Effect of N	[2]SE±	CV%	N_0	[1]Effect of N	[2]SE±	CV%
1969											
Aberhirnant	KE/Wa	0·81	0·56	30·0	3·8**	0·63	4·0	4·5	0·9**	0·13	5·2
	W/Wa	1·14	0·39	28·3	1·3*	0·68	5·1	4·7	0·6**	0·17	7·4
Rheidol	KE/Wa	0·81	0·56	31·6	5·7**	0·78	4·5	4·1	0·5**	0·07	3·2
	W/Wa	1·14	0·39	33·1	3·2*	1·19	7·6	4·5	0·3	0·15	7·1
1970											
Beddgelert[3]	KE/Wa	0·96	0·36	31·2	0·0	0·64	4·1	6·8	0·2	0·26	7·6
Glenbreck[3]	KE/Wa	0·96	0·36	23·0	1·8*	0·71	6·0	5·0	0·2	0·12	4·8
1971											
Gwydyr	KE/Wa	1·12	0·26	24·4	0·0	0·52	4·2	4·7	0·1	0·12	4·8
	W/Wa	1·40	0·36	31·2	2·2**	0·42	2·6	5·3	0·6**	0·09	3·3
Selm Muir	KE/Wa	1·12	0·26	35·2	−0·9	1·43	8·2	7·5	0·2	0·26	6·7
	W/Wa	1·40	0·36	35·8	−0·6	1·02	5·8	7·2	−0·2	0·23	6·4
1972											
Dovey	W/Wa	1·36	0·22	34·6	0·5	0·79	4·5	5·6	0·3*	0·12	4·2
	W/QCI	1·36	0·26	34·9	0·6	0·61	3·5	6·0	0·1	0·06	2·1
Irfon	W/Wa	1·36	0·22	33·2	1·6**	0·39	2·3	4·3	0·2	0·09	4·2
	W/QCI	1·36	0·26	32·7	0·6	0·74	4·5	4·3	0·0	0·11	5·1

[1] Levels of N averaged. [2] SE of effect. [3] K-treatment averaged. *, **, see p. 173.

Forest growth

Results for growth in the forest (height and diameter) are given in two sets of tables: (1) based on measurements made at the end of the first growing season—Tables IX, XI, XIII, and (2) derived from the last assessment—Tables X, XII, XIV. (Experiments concluded after one year are omitted from the second set.)

N treatments. As no systematic differences resulted from the two rates of nursery-nitrogen application, only the average N effect is shown. For ease of comparison, %N in the nursery crop is set out similarly alongside. During the first season after planting, nitrogen applied in the nursery produced well-defined increases in height—of up to 18 per cent—in half of all the Sitka spruce experiments (Table IX), and no substantial decreases in any. Results for diameter measurements were broadly similar. No clear relationship is evident between height increases and any climatic or soil characteristics of the forest sites, nor with the amount of extra N taken up by the crop in the nursery. However, it is noteworthy that even for nursery trees with as much as 1·4 per cent tissue N, some benefit was derived from late-season top-dressings. When the experiments were assessed for the last time (Table X), increases in growth were still apparent in several of the experiments, but these increases had become less important in relation to the size of the trees.

TABLE X. *Relationship between late-season top-dressings of N applied in the nursery and growth in the forest*

Planting year and forest	Sitka spruce *Picea sitchensis*									
	Nursery	Forest. Assessed at end of *last growing season*								
	Origin/ proven.	Duration in years	Height (cm)				Diameter (mm)			
			N_0	[1]Effect of N	[2]SE±	CV%	N_0	[1]Effect of N	[2]SE±	CV%
1969										
Aberhirnant	KE/Wa	4	92·8	4·8*	1·59	3·3	23·0	2·1**	0·31	2·6
	W/Wa	4	86·8	6·0*	2·58	6·4	23·3	0·9	0·85	8·0
Rheidol	KE/Wa	4	118·5	1·1	4·37	7·3	20·0	0·5	1·06	10·4
	W/Wa	4	114·7	3·5	3·11	6·0	19·8	0·1	0·95	10·7
1970										
Beddgelert[3]	KE/Wa	3	84·3	3·6	3·59	8·3	21·8	0·7	0·87	7·8
Glenbreck[3]	KE/Wa	3	86·7	4·8	3·12	7·0	20·9	0·9	0·77	7·2
1971										
Selm Muir	KE/Wa	2	41·1	−1·8	1·66	8·3	9·4	0·1	0·41	8·7
	W/Wa	2	46·0	−0·1	1·13	4·9	9·7	−0·2	0·21	4·3
1972										
Dovey	W/Wa	2	59·0	−0·6	2·17	7·4	9·8	0·2	0·32	6·4
	W/QCI	2	58·4	−0·4	1·35	4·6	10·6	0·0	0·30	5·7
Irfon	W/Wa	2	45·4	−0·6	0·67	3·0	7·8	0·0	0·21	5·4
	W/QCI	2	43·3	0·0	1·25	5·8	7·9	−0·2	0·28	7·3

[1] Levels of N averaged. [2] SE of effect. [3] K-treatment averaged.

The extra N given in the nursery had little influence on the forest growth of Norway spruce or Western hemlock, though most of the small effects were positive. Results for Grand fir and Lodgepole pine were less consistent. The one clear-cut negative effect with Grand fir at Rockingham had been foreshadowed by retardation of bud development (Tables XI, XII).

K treatments. For reasons explained in the section 'Results of Nursery Experiments', the late-season K tests differed fundamentally from those of the N tests in that the trees without added potassium contained only 0·4 or 0·5 per cent K in dry matter—considerably below the sufficiency level of about 0·8 per cent K, and that those with the extra potassium had tissue concentrations raised only to about 0·7 and 0·8 per cent K. Tables XIII and XIV show that of the four experiments, the two planted in 1972—with larger increases in K concentrations resulting from nursery treatments—benefited considerably during the first growing season: by the time of the last assessment differences had evened out. The nursery treatments had little or no effect in the experiments planted in 1971.

TABLE XI. *Relationship between late-season top-dressings of N applied in the nursery (Wareham) and growth in the forest*

	Nursery		Forest. Assessed at end of *first growing season*							
	%N in DM (T+R)		Height (cm)				Diameter (mm)			
	N_0	[1]Effect of N	N_0	[1]Effect of N	[2]SE±	CV%	N_0	[1]Effect of N	[2]SE±	CV%
NORWAY SPRUCE										
1969										
Rheidol	1·43	0·40	25·7	0·5	0·66	4·4	4·4	0·2	0·17	6·6
Bedgebury	1·43	0·40	22·5	0·9	0·96	7·2	4·2	0·1	0·21	8·5
1971										
Rockingham	1·78	0·32	24·3	0·7	0·95	7·7	4·2	0·1	0·14	6·9
WESTERN HEMLOCK										
1969										
Rheidol	1·22	0·48	32·5	2·3	1·31	7·8	3·7	0·2	0·18	9·4
Bedgebury	1·22	0·48	28·3	0·2	1·72	12·1	4·9	0·8*	0·27	10·2
1970										
Rockingham	1·14	0·18	19·2	−0·1	1·74	12·9	4·2	0·5	0·25	8·2
Thetford	1·14	0·18	26·8	1·4	0·76	3·9	6·8	0·4	0·36	7·3
1971										
Haldon	1·50	0·30	44·7	1·2	0·92	4·1	5·6	0·2	0·18	6·4
Rockingham	1·50	0·30	38·9	1·2	1·07	5·4	4·1	0·2	0·19	9·0
GRAND FIR										
1969										
Rheidol	1·30	0·32	20·9	4·6**	1·13	9·8	4·6	0·6*	0·21	8·6
1971										
Haldon[3]	1·46	0·22	28·0	−0·8	0·62	3·9	6·3	−0·0	0·13	3·5
Rockingham	1·46	0·22	23·9	−2·5*	1·09	9·6	5·0	−0·1	0·10	4·2
1972										
Rockingham	1·66	0·18	22·1	1·2	1·00	8·8	4·2	0·2	0·17	7·9
Wareham	1·66	0·18	22·2	0·7	0·88	7·8	4·5	−0·1	0·18	8·1
LODGEPOLE PINE										
1971										
Gwydyr[3]	1·20	0·55	30·2	1·3	1·18	6·6	6·7	0·5*	0·20	4·9
Selm Muir[3]	1·20	0·55	25·4	2·0	1·08	7·1	7·3	0·4	0·22	5·1
1972										
Dovey[3]	1·30	0·22	27·4	0·1	1·44	9·1	6·6	0·1	0·16	4·2
Irfon[3]	1·30	0·22	24·6	1·6	0·78	5·3	5·1	0·2	0·13	1·9

[1] Levels of N averaged. [2] SE of effect. [3] Excluding anomalous blocks.

In Tables IX–XIII: *, difference significant at 5% level; **, difference significant at 1% level.

TABLE XII. *Relationship between late-season top-dressings of N applied in the nursery and growth in the forest*

	Forest. Assessed at end of *last growing season*								
	Duration in years	Height (cm)				Diameter (mm)			
		N_0	[1]Effect of N	[2]SE±	CV%	N_0	[1]Effect of N	[2]SE±	CV%
NORWAY SPRUCE									
1969									
Rheidol	4	69·2	−4·0	2·88	7·4	13·7	−1·4	0·69	9·2
Bedgebury	4	47·6	1·6	3·59	12·8	12·2	1·0	0·76	10·4
1971									
Rockingham	3	44·4	3·4	2·66	11·6	8·5	0·3	0·56	13·0
WESTERN HEMLOCK									
1969									
Rheidol	4	101·2	3·1	3·66	7·1	14·8	0·3	0·46	6·2
Bedgebury	4	45·9	2·3	4·83	20·5	21·9	0·4	1·75	15·9
1970[3]									
Thetford	2	37·4	1·2	7·36	27·4		not assessed		
1971									
Haldon	3	151·2	5·7	4·26	5·5	19·8	0·6	0·79	7·9
Rockingham	3	61·5	5·9	4·30	13·3	9·0	0·4	0·49	10·6
GRAND FIR									
1969									
Rheidol	4	60·6	8·1	4·08	12·6	11·4	2·1*	0·93	14·9
1971									
Haldon[4]	3	88·8	−1·4	1·30	2·6	18·2	−0·8*	0·57	5·5
Rockingham	3	46·5	−6·2*	2·68	12·3	9·6	−0·1	0·55	12·2
1972									
Rockingham	2	22·6	1·1	1·01	8·7	4·8	0·0	0·15	6·2
Wareham	2	45·7	0·0	2·40	10·5	10·2	−0·2	0·35	7·0
LODGEPOLE PINE									
1971									
Gwydyr[4]	3	88·7	−4·4*	1·39	2·8	23·0	−0·3	0·50	3·8
Selm Muir[4]	2	36·4	3·1	1·89	8·6	9·6	1·0	0·41	7·0
1972									
Dovey[4]	2	62·0	0·6	2·66	7·4	13·5	0·5	0·53	6·7
Irfon[4]	2	43·1	3·7*	1·32	5·1	9·8	0·7*	0·23	4·0

[1] Levels of N averaged.
[2] SE of effect.
[3] Rockingham omitted because of poor survival.
[4] Excluding anomalous blocks.

TABLE XIII. *Relationship between late-season top-dressings of K applied in the nursery (Wareham) and growth in the forest*

	Sitka spruce *Picea sitchensis*									
	Nursery		Forest. Assessed at end of *first growing season*							
	%K in DM (T+R)		Height (cm)				Diameter (mm)			
	K_0	[1]Effect of K	K_0	[1]Effect of K	[2]SE±	CV%	K_0	[1]Effect of K	[2]SE±	CV%
1971										
Gwydyr	0·55	0·10	31·6	0·0	0·67	4·3	5·8	0·0	0·13	4·4
Selm Muir	0·55	0·10	38·5	−0·8	0·76	4·0	7·3	0·0	0·54	3·6
1972										
Dovey	0·44	0·25	32·7	3·2**	0·79	4·6	5·3	0·3**	0·06	2·2
Irfon	0·44	0·25	32·1	2·8*	1·07	6·4	3·8	0·3*	0·12	5·8

[1] Levels of K averaged. [2] SE of effect.

TABLE XIV. *Relationship between late-season top-dressings of K applied in the nursery and growth in the forest*

	Sitka spruce *Picea sitchensis*								
	Forest. Assessed at end of *last growing season*								
	Duration in years	Height (cm)				Diameter (mm)			
		K_0	[1]Effect of K	[2]SE±	CV%	K_0	[1]Effect of K	[2]SE±	CV%
1971									
Selm Muir	2	48·6	−0·4	1·12	4·6	9·7	0·3	0·25	5·2
1972									
Dovey	2	57·7	2·6	1·53	5·2	10·2	0·2	0·37	7·3
Irfon	2	43·0	0·4	1·41	6·5	7·3	0·0	0·20	5·5

[1] Levels of K averaged. [2] SE of effect.

Survival

Fig. 5 shows for all N-test experiments percentage survival at the last assessment. (For duration of experiments see Table VIII.) *Sitka spruce* suffered very few losses; thirteen out of the fourteen experiments had survivals between 95 and 100 per cent. At Beddgelert—the single exception—with survivals of about 84 per cent, deaths were caused by sharp fragments of shale rubbing against the root collar. Survival in the K-test experiments (not shown) was equally high and was not affected by nursery treatments.

Norway spruce survived well in two experiments. In the third, Bedgebury (By), losses—not influenced by nursery treatment—were heavy; among the adverse conditions were an abnormally dry first autumn (September less than 50 per cent of average rainfall, October less than 10 per cent).

Survivals of *Western hemlock* were between 90 and 100 per cent at Rheidol and between 80 and 90 per cent at three of the five lowland sites. The heavy losses at Bedgebury and even heavier ones at Rockingham were probably

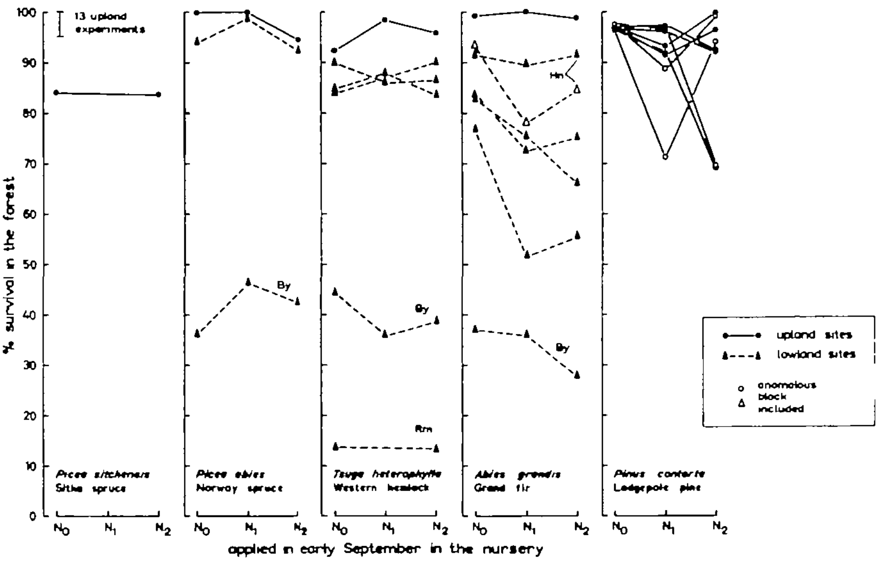


FIG. 5. Relationship between percentage survival in the forest (at the last assessment) and late-season N treatments applied in the nursery.

associated with abnormally dry spells during the first growing season, aggravated by competition from vigorous ground vegetation and (at Rockingham) late-spring frost; nursery treatments again had little if any effect.

In contrast to the spruces and hemlock, *Grand fir* shows a clear tendency towards heavier losses of the N-treated plants, except at Rheidol where deaths were negligible. Survivals on the remaining sites, expressed as angular transformations, are given below:

Planted	Site	N_0	[1]Effect of N	SE±
1969	Bedgebury	37·1	−3·2	3·54
1971	Haldon			
	all blocks	79·1	−12·6	3·27
	exc. block II	77·0	3·8	5·33
	Rockingham	61·8	−14·5	6·60
1972	Rockingham	63·8	−2·8	1·64
	Wareham	66·9	−9·5	3·67

[1] Levels of N averaged.

(At Haldon (Hn), most of the losses were confined to one plot in Block II, and results are shown with and without this block.)

All four curves for the *Lodgepole pine* experiments have a pronounced dip—two corresponding to N_1 and two to N_2 treatments. In both years these deaths occurred in corresponding plots of the two parallel forest experiments, i.e. among trees which had been stored in a single bag. It cannot be ruled out, therefore, that the cause lies in the unsatisfactory storage conditions referred to above, which may have had a more damaging effect on plants treated with nitrogen late in the season. If the respective blocks are excluded, survivals range from 90 to 100 per cent, with no deleterious effects from the nitrogen treatments.

Frost damage and other abnormalities

During the first two growing seasons of the experiments, foresters recorded detailed observations of all abnormalities, where possible supported by counts or visual scores for individual trees.

Frost damage of Sitka spruce of Washington origin was severe at Gwydyr and Selm Muir, two sites where this frost-sensitive provenance would not normally be grown. At Gwydyr, a June frost during the second growing season injured 30 to 40 per cent of all trees in one nitrogen experiment and 70 to 80 per cent in another; the extra nursery N aggravated the damage in both. At Selm Muir, frost injuries recorded at the end of the first growing season were about 60 per cent and 90 per cent respectively, with no effect of nursery treatment in either experiment. Angular transformations of the results are shown below:

	Nursery origin	N_0	[1]Effect of N	SE±
Gwydyr	Kennington	29·8	7·1	3·07
	Wareham	59·3	8·0	2·70
Selm Muir	Kennington	75·3	1·7	3·58
	Wareham	50·0	1·2	3·12

[1] Levels of N averaged.

Potassium applied in the nursery had no influence on frost damage at Gwydyr or Selm Muir.

Frost damage of less severity was recorded, at the lowland sites, for Norway spruce, Western hemlock, and Grand fir, but in no instance was the injury increased by late-season nitrogen applied in the nursery.

Insect damage. The only severe insect attack observed in this series of experiments was from pine weevil *Hylobius abietis* at Thetford; it occurred in early October 1970—the end of the first growing season—and caused so much damage to Western hemlock that the experiment had to be concluded prematurely. The late-season N applied in the nursery had no influence on the severity of the attack.

Other observations. Late-season top-dressings of nursery-N had no effect on the development of abnormalities in shoot development, such as absence of leaders of Grand fir, and multiple or broken leaders of Sitka spruce, but it halved 'lammas' growth at Glenbreck. Nitrogen also decreased needle cast and needle browning of Western hemlock at Bedgebury.

DISCUSSION AND CONCLUSIONS

The methods adopted for this series of experiments have proved their worth in several respects but have also revealed some weaknesses.

In the nursery, late-season top-dressings of nitrogen increased N concentrations with all species in all years, but not always sufficiently to justify testing the effect in the forest. We would have been even more successful had we watered the beds, but many British nurseries have no irrigation equipment, and we wanted to adhere to normal practice as much as possible. We failed to obtain 'luxury uptake' of potassium, although this had been achieved in our preliminary experiments with seedlings (Benzian and Freeman, 1967). Inadequate storage conditions in the nursery were in all probability responsible for poor survival on a few individual experimental plots in the forest.

Forest trials tend to be very variable; by using techniques developed over many years and by eliminating a small proportion of trees with extreme height and diameter measurements, the experimental error was kept small, and the precision of the forest experiments allowed us to draw firm conclusions. (However, there is some evidence from small associated trials in 1972 and 1973 on Sitka spruce, Grand fir, and Lodgepole pine that interrupting the continuous storage period to 'grade' the trees had some deleterious effect on subsequent growth—especially of Lodgepole pine and Grand fir.) Bud-break scores, recorded in the forest during the first growing season, were often well related to levels of N concentrations in nursery plants, showing clearly that even small effects of nursery treatments could be detected after planting.

The results for this series of nursery-to-forest experiments have confirmed our view that such tests need to be done separately for individual species: of the five species included in our experiments, late-season nitrogen had an adverse effect on the survival of only one—Grand fir. Extra nursery nitrogen promoted growth of Sitka spruce during the first growing season of most experiments, and although the magnitude of the effects could not be related to specific site characters, it was important to know that improvements could occur —in different seasons—over such a wide range of soil and climatic conditions.

Several workers in the United States have also attempted to improve planting stock by 'pre-lifting' applications of fertilizer, but—with few exceptions—without determining nutrient concentrations in the nursery plants; no comparisons appear to have been made between trees with N at 'sufficiency' and at 'luxury' level. Anderson and Gessel (1966) top-dressed Douglas fir (*Pseudotsuga menziesii*) seedlings in September with ammonium sulphate and compared them with untreated seedlings after planting on a forest site. The nitrogen treatment improved growth and had no deleterious effect on survival. In the words of the authors '. . . the fact that the nursery treatment did not reduce survival is in itself significant, since application of nitrogen fertilizer late in the growing season is contrary to accepted practice'. Ursic (1956), using Loblolly pine (*Pinus taeda*) seedlings as test crop, applied top-dressings of nitrogen plus potassium during January, before the crop was lifted in February; he found that the fertilizer diminished survival but did not affect growth. Shoulders (1959) warned about the risks involved in making pre-lifting application of nitrogen to Longleaf-, Loblolly-, and Slash-pine seed-beds without adequate knowledge of the needs of plants at the particular time of fertilizing and the nutrient status of the soils to which they are transferred. However, his findings bear little relation to our conditions, as in his words 'the top-dressings induced growth of seedlings in the nursery beds during the mild winter of 1956–57, and by lifting time many of the buds had burst'. Switzer and Nelson (1963) used regression analysis to investigate the relationship (for Loblolly pine) between the effects of nitrogen treatments applied in the nursery on seedling size and %N in crop, and their height after planting in the forest. Their results indicated that growth could be reasonably predicted from a number of size characteristics, but that slightly better relationships were obtained when combinations of size and nitrogen status were employed.

The practical implications of our own experiments are that there is no reason why (except with Grand fir) nurserymen should deliberately limit the nitrogen supply to trees of the conifer species tested for fear of increasing the risk of climatic damage in the forest after planting. In fact, luxury uptake of N by nursery transplants late in the growing season may well give small increases in growth in the first season after planting, especially with Sitka spruce.

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APPENDIX TABLE A. *Properties of upland sites*

	Forest and location	Rain (mm)[1] Mean annual	Temp. (°C)[2] Mean Jan.	July	Elevation (m)	Topex[3] value	Relief of *a* site *b* surrounding land	Geology and soil	Vegetation and history
1969	Aberhirnant SH 976 287 Merioneth	2,083	1·0	11·3	518	52–55	*a* Uniform 14° slope to west *b* Mountainous	Intergrade brown earth to ironpan soil with about 15 cm of peat, on Ashgill and Caradoc series of Ordovician	Previously poor hill grazing. *Calluna* dominant with abundant *Vaccinium myrtillus*
	Rheidol SN 713 853 Cardigan	1,549	3·3	13·7	244	123–5	*a* Flat (valley bottom) *b* Hilly/mountainous	Shallow upland brown earth on Tarannon and Llandovery series (slaty shales) of Silurian	Previously ploughed and latterly grazed by sheep or cattle. Mainly fine and soft grasses with some *Juncus* spp.
1970	Beddgelert SH 545 592 Caernarvon	1,930	1·4	12·3	350	38–9	*a* Flat *b* Hilly/mountainous	Intergrade brown earth to ironpan with about 10 cm of peat, on Pre-cambrian rocks	Previously poor hill grazing. *Trichophorum caespitosum*, *Deschampsium flexuosa* and *Calluna* all frequent
	Glenbreck NT 125 263 Peebles	1,524	1·4	10·5	442	59–60	*a* Uniform 30° slope to WSW *b* Hilly/mountainous	Ironpan soil with about 20 cm of peat, on Tarannon and Llandovery series (greywacke and slaty shales) of Silurian	Previously poor hill grazing/grouse moor. *Molinia* dominant with frequent *Nardus stricta*, *Vaccinium myrtillus*, *Calluna* and *Trichophorum caespitosum*
1971	Gwydyr SH 778 515 Caernarvon	2,057	1·7	12·7	320	22–33	*a* Flat *b* Hilly/mountainous	Molinia bog (site M) and non-flushed Sphagnum bog (site S) on Ordovician slates and shales	Previously poor hill grazing. Mainly *Molinia*, with frequent *Calluna* and *Sphagnum* spp.
	Selm Muir NT 056 596 Midlothian	1,003	1·7	12·1	259	10–11	*a* Flat *b* Hilly	Intergrade Molinia bog to non-flushed Sphagnum bog on calciferous sandstones of Ludlow and Wenlock series of Silurian	Previously poor hill grazing/grouse moor. *Molinia*, *Calluna*, *Deschampsia flexuosa* and *Polytrichum* spp. frequent, with some *Erica tetralix*
1972	Dovey SH 796 073 Montgomery	1,854	3·1	13·5	274	72–100	*a* Undulating 5 to 15° slope to SE *b* Hilly	Upland brown earth on Tarannon and Llandovery series (shales) of Silurian	Previously good hill grazing. Predominantly fine and soft grasses (e.g. *Agrostis* and *Holcus* spp.)
	Irfon SN 813 430 Carmarthenshire	1,549	3·0	13·9	200	57–77	*a* Uniform 20° slope to south *b* Hilly	Upland brown earth on Ashgill and Caradoc series (shales) of Silurian	Previously good hill grazing. Predominantly fine and soft grasses (e.g. *Agrostis* and *Holcus* spp.)

[1,2] See footnotes on Appendix Table B.

[3] 'Topex' = assessment of relative topographic exposure of a site made by measuring the angle of inclination of the horizon at the eight major points of the compass. The sum of the eight angles gives the 'Topex value' (Pyatt, Harrison, and Ford, 1969).

APPENDIX TABLE B. *Properties of lowland sites*

	Forest and location	Rain (mm)[1] Mean annual	Temp. (°C)[2] Mean Jan.	July	Elevation (m)	Relief of *a* site *b* surrounding land	Geology and soil	Vegetation and history
1969	Bedgebury TQ 727 337 Kent	838	2·9	15·7	91	*a* Flat *b* Undulating	Surface water gley on Tunbridge Wells Sands of Hastings beds of Cretaceous	Previously birch scrub cleared for experiment. Existing vegetation scattered bracken and grass
1970	Rockingham SP 947 880 Northants.	610	2·9	15·6	99	*a* Flat *b* Flat	Surface water gley on Upper Lias of Jurassic	Previously oak scrub. Existing vegetation predominantly *Deschampsia caespitosa* and other grasses
	Thetford TL 817 834 Suffolk	635	2·4	15·1	84	*a* Flat *b* Flat	Argillic brown earth (Worlington series) on deep sand over Chalk	Previously a conifer crop. Existing vegetation predominantly bracken with scattered grass and *Calluna*
1971	Haldon SX 871 824 Devon	1,016	4·8	15·7	99	*a* Uniform 26° slope to WSW *b* Hilly	Imperfectly drained brown earth on Upper Culm Measures of Carboniferous	Previously conifer woodland. Predominantly bramble, with frequent bracken, and 'rich' herbs (e.g. bluebell and dog's mercury)
	Rockingham SP 953 977 Northants	610	2·9	15·6	91	*a* Flat—in slight hollow *b* Undulating	Imperfectly drained brown earth on Upper Lias clay of Jurassic	Previously mixed broadleaved woodland. Bracken dominant, with occasional *Juncus* and grass species
1972	Rockingham SP 989 988 Northants.	597	2·9	15·6	85	*a* Flat *b* Flat	Surface water gley on Upper Lias clay of Jurassic	Previously old mixed woodland. Predominantly *Deschampsia caespitosa* and other grasses
	Wareham SY 853 838 Dorset	914	3·0	15·0	84	*a* Uniform 10° slope to west *b* Undulating	Imperfectly drained brown earth on London Clay of Eocene	Previously mixed broadleaved woodland. A very wide mixture of ground species, including bramble, bracken, bluebell, willow herb and some grasses and *Juncus* spp.

[1] Estimated for individual sites from a 1:250,000-scale map of rainfall distribution over the British Isles for the period 1916–50.
[2] Estimates based on data from nearest comparable climatological station; adjustments for altitude of upland sites made by using average 'lapse rate' for Wales.

APPENDIX TABLE C. *Particle-size analysis of mineral soils*

		% of whole soil sampled	% of oven-dry inorganic fraction less than 2 mm		
		Stones >2 mm	Sand 2·0–0·05 mm	Silt 0·05–0·002 mm	Clay <0·002 mm
Upland sites					
1969	Aberhirnant	n.d.[1]	13·4	55·0	31·6
	Rheidol	n.d.	24·8	45·2	29·9
1970	Beddgelert	20·2	56·9	22·9	20·2
	Glenbreck	20·9	66·4	21·0	12·6
1972	Dovey	39·5	28·7	44·9	26·4
	Irfon	40·9	38·4	39·0	22·5
Lowland sites					
1969	Bedgebury	n.d.	31·3	65·9	2·8
1970	Rockingham	16·2	25·8	38·2	35·9
	Thetford	1·5	87·8	6·6	5·6
1971	Haldon	19·3	27·4	43·6	29·0
	Rockingham	2·3	39·7	40·4	19·9
1972	Rockingham	none	25·3	33·9	40·8
	Wareham	none	66·9	21·4	11·7

[1] n.d. not determined.

APPENDIX TABLE E. *Chemical analyses of peats*

	Depth (cm)	Bulk density g (oven-dry)/ml (fresh peat)	In fresh peat: % dry matter	In oven-dry peat: % ash	Total elements: % N	mg/kg: P	K	Mg	Ca
Upland sites									
1971 Gwydyr[1]									
Site M	0–15	0·126	16·6	4·85	2·13	760	570	640	3,540
	15–30	0·120	15·3	14·15	1·85	470	300	670	4,340
Site S	0–15	0·078	9·8	3·53	2·04	250	440	1,130	880
	15–30	0·079	8·6	2·08	2·03	190	260	860	166
Selm Muir	0–15	0·118	13·6	4·77	2·02	540	220	680	1,710
	15–30	0·110	11·9	2·36	1·85	420	90	1,020	2,630

[1] Two different peat types were included:
Site M Molinia bog—Lodgepole pine experiment.
Site S non-flushed Sphagnum bog—Sitka spruce experiments.

Appendix Table D. *Chemical analyses of soils*

		pH in		In air-dry soil									
				Organic carbon[1]	Total elements						Exchangeable		
		H_2O	0·01 M $CaCl_2$	%	%	mg/kg					mg/kg		
					N	P	K	Mg	Ca	Mn	K	Mg	Ca
Upland sites													
1969	Rheidol	4·5	4·3	2·9	0·283	918	22,950	6,020	462	1,540	59	28	320
	Aberhirnant	3·6	3·3	12·7	0·658	650	19,950	2,080	225	74	107	65	150
1970	Beddgelert	4·0	3·1	15·6	0·922	920	not determined				271	142	132
	Glenbreck	3·8	3·1	13·0	1·005	1,020	not determined				231	129	112
1971	Gwydyr	see Appendix Table E											
	Selm Muir	see Appendix Table E											
1972	Dovey	5·0	4·3	6·0	0·458	1,280	not determined				125	69	620
	Irfon	5·2	4·5	3·8	0·342	1,260	not determined				123	82	900
Lowland sites													
1969	Bedgebury	3·6	2·9	6·3	0·123	110	840	145	100	25	49	26	72
1970	Rockingham	5·1	4·6	3·8	0·342	780	not determined				191	200	3,050
	Thetford	3·8	3·0	2·2	0·093	330	not determined				23	1	70
1971	Haldon	4·5	3·8	3·7	0·260	560	not determined				139	50	294
	Rockingham	4·5	3·8	2·2	0·123	410	not determined				74	61	760
1972	Rockingham	6·0	5·2	4·1	0·390	570	not determined				253	356	4,010
	Wareham	3·8	3·1	7·5	0·270	380	not determined				89	56	230

[1] Determined by Tinsley (1950) method.