Manuring Young Conifers: Experiments in some English Nurseries

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1. Introduction

A study by FAO in 1966 *[1]* 'Wood: World Trends and Prospects' is a useful background against which to view the role of British forest nurseries. The first column of table 1 shows areas under forest in some important timber-producing regions of the north temperate zone; here the contribution made by Britain is very small. However, among the planting plans for the period 1963 to 1967 (second column) it occupies a prominent position. Whereas, for example, Northern Europe has a forest area 25 times that of Britain, its area to be planted is only 10 to 20% larger. Hence, in this country, forest nurseries (where all planting stock has to be raised), form a much more important part of forestry than in countries with large natural forests or with a longer history of man-made forests.

Table 1 Forest areas and planting plans for some Forests of the North Temperate Zone

	Forest area (early nineteen-sixties) million ha	Planting plans 1963–1967 thousand ha
Northern Europe	52.0	190
British Isles	1.9	164
EEC	25.6	408
Central Europe	13.2	13
Southern Europe	32.6	635
Eastern Europe (excl. USSR)	26.5	618
Europe (total)	151.8	2028
USSR	705.9	—
US	205.9	2100
Canada	245.9	—
Japan	23.4	250

In Britain a planned and expanding forestry programme did not begin until after the 1914–1918 war. The emphasis was then – and has been ever since – on the production of softwood (that is wood from coniferous trees such as spruces and pines) to meet some of this country's urgent needs for pitwood, pulpwood, saw-timber and other wood products. (Of the 54000 acres planted in Britain by the Forestry

[1] Reprinted (with minor corrections to Appendix Table 2) from The Fertiliser Society Proceedings No. 94 (1966), London.

Commission in 1965, 53000 were planted with conifers and only 1000 with broad-leaved trees). In parts of the upland areas of Scotland and Wales, spruces will grow two or three times as fast as in Scandinavia *[2]*. A single species, Sitka spruce, *Picea sitchensis,* introduced mainly from British Columbia, constitutes about 40% of all recent Forestry Commission plantings, followed by another North American species, Lodgepole pine, *Pinus contorta* (20%), Scots pine, *Pinus sylvestris* – the only widely planted native conifer (slightly less than 10%), and Norway spruce, *Picea abies* – the most important conifer in Scandinavia (8%). All these conifers and several other species not mentioned above, as well as the few hardwoods, are raised in the Forestry Commission's own nurseries which, in 1965, occupied 1700 acres.

2. History

Successful planting depends to a considerable extent on producing good quality seedlings and transplants in the nurseries. Much of the Forestry Commission's early research work was, therefore, devoted to different aspects of nursery techniques – though less than might have been expected to methods of manuring. R. F. Wood in his 'Historical Notes' in Forestry Commission Bulletin No. 37 *(Benzian [3])* says: 'While steady progress in nursery technique since the early years can be claimed, the same cannot be said for the nutritional side. In fact no important advances in manuring were put into general practice in the Forestry Commission's nurseries between 1920 and the outbreank of the Second World War, though some valuable pointers were obtained by various workers during this period.' Such pointers came, among others, from experiments in Scotland conducted jointly by the Macaulay Institute and the Research Branch of the Forestry Commission and from those of Rayner *[4]* who – in the thirties – grew excellent conifer seedlings (far superior to those raised in the older Forestry Commission nurseries) using compost on the poor acid heathland near Wareham. This led to the establishment of several new nurseries on heathland soils.

Towards the end of the 1939–1945 war, the Forestry Commission planned an extensive planting programme, and had to make sure that planting stock of the right quality and quantity was produced quickly and efficiently. To quote Wood 'The situation plainly called for an immediate extension to the research efforts to investigate the unexplained contrast between the success of the new heathland nurseries and the unsatisfactory performance of the Commission's older nurseries'. A committee was set up under whose auspices the late E. M. Crowther of Rothamsted, in close collaboration with the Research Branch of the Forestry Commission, started the large experimental programme in forest nurseries which I continued after his death. In less than two years, Crowther had reached the conclusion that many of the Commission's older nurseries failed because their soils were not acid enough to grow good quality seedlings of Sitka spruce and some other conifers. The Commission therefore moved seedbeds of sensitive conifers either to a few older nurseries that were on acid soil, or more often, to the new heathland nurseries started as the result of Rayner's work. The soils of these heathland nurseries are usually very light, have small nutrient reserves and buffer capacity and much of our recent work has been concerned with finding methods that will ensure a steady supply of nutrients during the growing season.

3. Experimental Methods

Our work for the period 1945 to 1962 has recently been described in Forestry Commission Bulletin 37 previously quoted *(Benzian [3])*. The details given below, under 'Sites,' 'Crops,' 'Measurements' and 'Design of experiments' are therefore kept very brief and are intended only to draw attention to the changes made since this Bulletin was written.

3.1 *Sites*

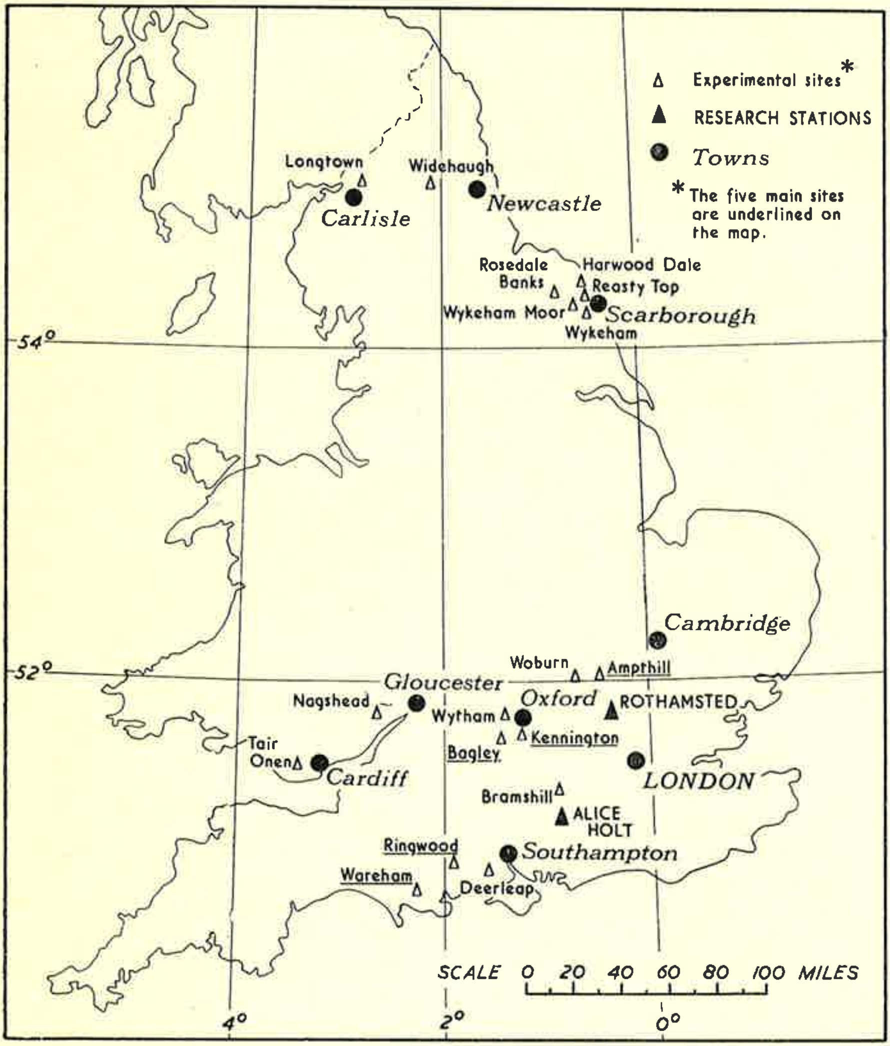
In the late forties experiments were first made in 18 nurseries in England and Wales – some of them research nurseries, others production nurseries. The middle-period experiments (from about 1951 to 1963) were done on half a dozen sites, all within fairly easy reach of the two Research Nurseries: Wareham in Dorset and Kennington near Oxford. (Appendix tables 1 and 2 give soil data for these sites.) Since 1964 experiments have been confined to the two Research Nurseries themselves, except for a few plots at Woburn Experimental Station, Bedfordshire, in the same enclosure as the 'Reference Plots' growing agricultural and horticultural crops. All experimental sites are shown on the map.

The two nurseries to which work is now confined are on very different soils. *Wareham* represents an extreme example of a heathland nursery on sandy podsolic soil of little buffering capacity and small nutrient reserves, and with a natural pH ($CaCl_2$) of between 3.2 and 4.0 – well below optimum even for Sitka spruce. In those sections of this nursery where the pan has been broken or is well below root range, nutrients are rapidly lost by leaching. These seem serious difficulties for intensive cropping, but acidity is more easily remedied than alkalinity, and provided the nutrient shortages can be made good, there are considerable compensations. Thus, the weed-seed population is initially small in heathland nurseries and with suitable management it can be kept down. Furthermore, freely draining sections can be cultivated within a few hours of very heavy rain. Any lessons learnt at Wareham about ways of supplying nutrients safely and steadily throughout the growing season, can be applied not only to other heathland soils, but also to the wetter areas of the west and north.

Kennington Nursery – on a sandy loam soil – has three parts: one – Old Kennington, more than 40 years old with neutral or near-neutral soils, provides one of the classical examples of 'stunted growth' of Sitka spruce which will be mentioned only briefly in this paper. The soils of the two newer parts (Kennington Extension and Kennington Three) have a pH near the optimum for Sitka spruce; they contain more nutrients than the Wareham soil, the clay content is greater, and any spells of wet weather halt cultivation for much longer than at Wareham.

3.2 *Crops*

The commonest practice for raising coniferous planting stock in British nurseries is to sow in the spring and transplant the seedlings after one or two growing seasons either in the same or in another nursery. The transplants in turn spend one or two years in the nursery before they are planted out in the forest. Nursery operations are expensive and the aim is to produce in the shortest possible time young trees suitable



Map. Location of experimental sites.

Fig. 1: Map. Location of experimental sites.

for planting. In our experiments we have standardised on one-year seedlings and 'one-plus-one' transplants (one growing season in the seedbed and one growing season in the transplant bed). The smallest suitable seedling is well defined: from 1½ inches in height upwards it is referred to as 'usable', because it can be transplanted by hand or machine. The precise height of transplants matters much less and there is little clear evidence in this country as to which easily defined characteristics are correlated with survival and growth in the forest. (See below under 'Measure-

Fig.2: Experimental plots of seedlings (Sitka spruce) in the foreground and of transplants (Sitka spruce on the left, Norway spruce on the right) in the background.

ments.) Until recently most of our work was done on seedbeds, but with the realization that transplants of some species are less resistant to damage from fertilizer salts than Sitka spruce, more tests than before are now devoted to these older plants.

Sitka spruce, *Picea sitchensis,* the most widely planted conifer remains the principal experimental species. Other commonly planted conifers have occasionally been included in our experiments, but in recent years more work has been done on Norway spruce, *Picea abies,* because transplants of this species were found to be salt-sensitive (Fig. 2).

3 3 *Measurements*

For all experiments, height is measured in the nursery before the plants are lifted. Height of *seedlings* is a useful measurement not only because in practice plants are graded according to their size, but because the height of many conifers (though not pines) is closely correlated with weight. As mentioned above, small differences in height of *transplants* are less important; neither is correlation between height and weight very close for these older plants, and additional measurements, such as stem diameter at soil surface, will have to be made in future. At the end of the growing season, plant samples are taken from many experiments to measure the dry weight (of roots and tops separately) and for chemical analysis (usually of the whole plant).

During the last three years (1964–1966), seedling tops have been repeatedly sampled for analysis *during* the growing season to obtain information on nutrient uptake from soluble and from slow-release fertilizers.

3.4 *Design of experiments*

During the exploratory phase of our work, factorial designs proved to have great merits. More recently, with the shift of emphasis to comparisons between forms of fertilizer supplying more than one nutrient element, randomized blocks have been used. However, several of the older factorial experiments (with a wide range of nutrient contents in soil and plant) have been retained to help with the interpretation of tests on novel forms of fertilizer.

4. *The Nutrition of Young Conifers*

4.1 *Soil-less cultures*

The nutritional needs of young conifers can be studied by the same methods as those used for other crops. Some aspects are best investigated in water-, sand- or other soil-less cultures *(Hewitt [5])* and the results from such work help to interpret experiments done in the more complex conditions of forest nurseries.
Some excellent work with soil-less cultures has been done by, for example, *Ingestad [6]* of Sweden and *Evers [7]* of Germany. Figure 3 (after *Ingestad*), shows for the major nutrients, growth and nutrient concentrations in the crop in relation to increasing nutrient concentrations in the solution. The spruce seedlings were grown under controlled temperature and light conditions and the samples taken at a time of rapid growth.

4.2 *Mycorrhiza*

Rayner who, using compost, grew very good conifers on the poor heathland soil near Wareham, held the view that the main role of compost was not to supply nutrients but to stimulate mycorrhizal infection of conifer roots. Since then much work has been done on mycorrhiza using new techniques. *Hewitt* points out the need to study the relation of mycorrhiza to micro-nutrient uptakes, but whatever importance they may have on impoverished forest sites, it seems unlikely that they are important with the nutrient conditions aimed at in present-day forest-nursery manuring.

4.3 *Results of our nursery experiments*

The results from our own experiments, can conveniently be discussed under four heads: Soil reaction; Learning to use soluble fertilizers; Comparing compost and soluble fertilizer in many short-term and in two long-term experiments on two contrasted soils; Avoiding or making good leaching losses by using slow-release fertilizer and/or repeated topdressings.

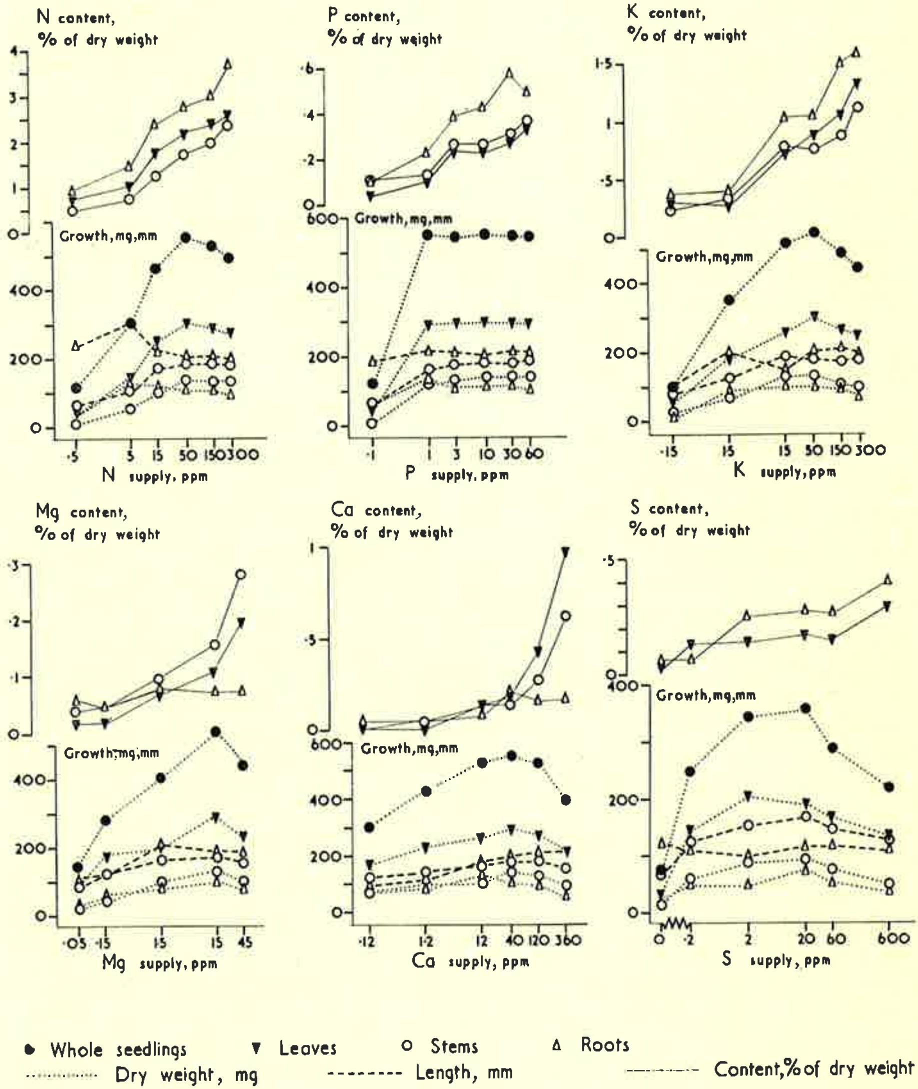


Fig.3: Growth and nutrient concentrations of Norway spruce *(Picea abies)* grown in nutrient solutions (after Ingestad [*6*]).

4.3.1 *Soil Reaction*

Seedlings of several of the commonly grown conifers are very sensitive to soil reaction and grow best on acid soils. For some species, optimum growth is confined to a very narrow range, as is shown in figures 4 and 5. The graphs are based on results from the 'pH range trials' at Wareham and Kennington Extension where pH

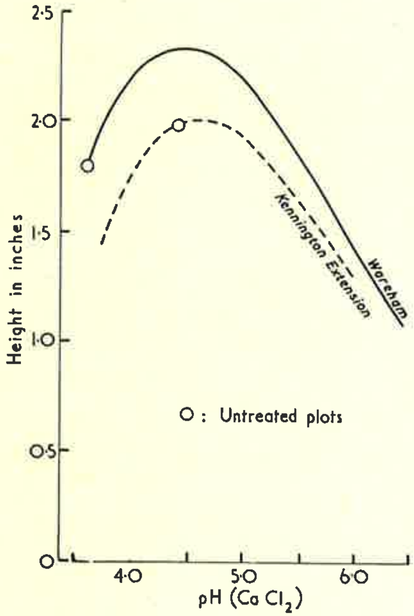


Fig.4: pH values of soils and heights of Sitka spruce seedlings averaged over nine-year period – 1951–1959 – in pH trials at Wareham and Kennington Extension.

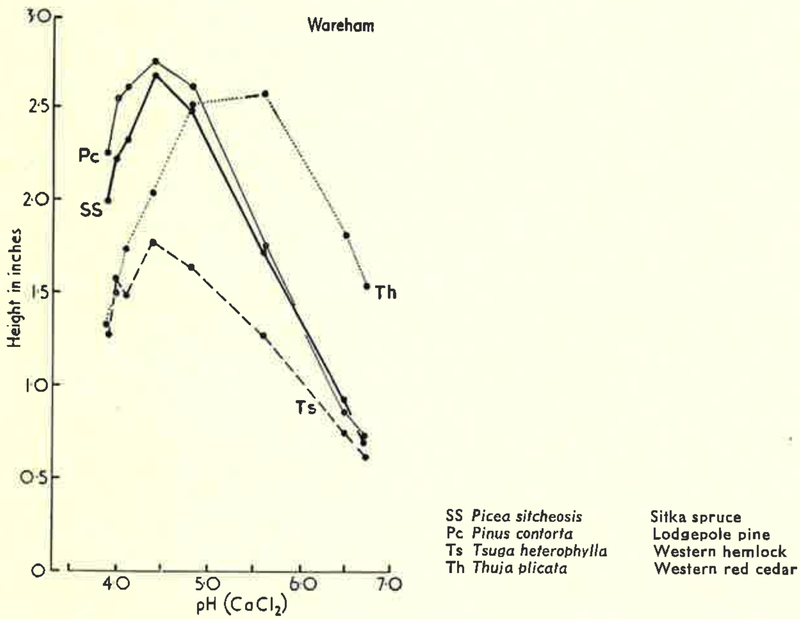


Fig.5: pH values of soils and heights of four conifer species in Wareham pH trial 1957–1959.

was gradually raised by adding increasing amounts of calcium carbonate, and at Kennington Extension was also decreased by adding sulphur or aluminium sulphate. In figure 4, plotting seedling heights against pH values (measured in $CaCl_2$), the curves for both nurseries rise steeply to a well-defined maximum close to pH 4.5, above which growth declines steadily. Figure 5 shows, in addition to Sitka spruce, three other species, two of which (Lodgepole pine, *Pinus contorta* and Western hemlock, *Tsuga heterophylla*) match Sitka closely, with a third *(Thuja plicata)* having a well defined maximum more than one pH unit higher.

Maintaining soil reactions appropriate to individual crops, is one of the nursery forester's most important tasks. The loss of productivity of many of the Forestry Commission's older nurseries (often referred to in the past as 'conifer sickness') was brought about not only by overliming or applying calcareous seedcovers, but also by using low-grade basic slag. Such dangers are now clearly recognised and avoided.

Experiments have shown that the growth-inhibiting factor or factors leading to 'stunting' of conifers at such nurseries on high-pH soils as Ampthill or Old Kennington, can be removed either with the help of acidifying agents or partial sterilants (formalin, chloropicrin and others). These methods are used in a few production nurseries, but nowadays nurseries on neutral or near-neutral soils are cropped mainly with broadleaved trees whilst the more sensitive conifers are confined to acid nurseries.

4.3.2 *Learning to use soluble fertilizers*

The small size of conifer seedlings tends to make observers underrate the amount of dry matter they produce and the quantities of nutrients they remove. Table 2 gives values for some common British agricultural crops and 12-year averages for Sitka spruce seedlings and transplants grown with soluble fertilizers on the very poor soil of Wareham and richer soil of Kennington. (The yields for agricultural crops are large but they can none the less be reliably obtained at Rothamsted *[8]*. As will be shown later, too little fertilizer was used at Wareham for satisfactory growth of Sitka spruce.)

In a so-called 'Maximum Productivity Trial' at Wareham, Sitka spruce seedlings and transplants were grown alongside Italian ryegrass in 1965. All crops received incremental dressings of N and more adequate supplies of P, K and Mg than had been applied to the above mentioned long-term experiments. The largest amount of dry matter produced was 10500 lbs. for four cuts of ryegrass, 5100 lbs. per acre for seedlings (tops plus roots) and 4800 for transplants (tops plus roots). *(Coulter, Benzian [9])*.

Except for the two long-term rotation experiments, the detailed results of our manuring experiments up to the early sixties are given in Forestry Commission Bulletin 37. Therefore, only the main conclusions will be mentioned from the many tests on forms of fertilizer, and rates, methods and times of application.

One important feature distinguishing conifer seedlings from many agricultural crops is that they make most of their growth late in the season – in August and September. On light soils much N, K, Mg and even P can be lost in wet years before the crop is large enough to take up the nutrients. Sitka spruce develops deficiency symp-

Table 2 Amounts of different nutrients removed by some common British agricultural crops and by seedlings and transplants of Sitka spruce *(Picea sitchensis)*

		Tons per acre Dry matter	Pounds per acre N	P	K	Mg	Ca
Agricultural Crops							
wheat (total crop)		5	120	20	150[1]	25	40
potatoes (tubers only)		5	250	40	250	10	10
sugar beet (total crop)		5	180	25	250	25	30
red clover		4	250	50	180	20	100
grass		5	250	40	250	25	75
Sitka Spruce (tops + roots)							
seedlings	Wareham	1.3	44	7	20	4	18
	Kennington	1.6	69	11	43	4	22
transplants	Wareham	1.8	63	10	37	5	22
	Kennington	3.0	100	14	60	7	39

[1] Max. uptake, only half in harvested crop usually.

toms of diagnostic value for N, K and Mg, and visual observations can be of great help in following release of nutrients from fertilizers or their losses throughout the season.

Nitrogen

Responses to nitrogen differed greatly from year to year (figure 6). Soluble nitrogen fertilizers could be applied safely as repeated topdressings during the growing season. Risk of damage to the plant was slight, provided the foliage was dry. When used for only a few years, ammonium sulphate, 'Nitro-Chalk' and calcium nitrate gave closely parallel results on acid soils, though ammonium sulphate was much better on neutral or near-neutral soils. For continued use on acid soils 'Nitro-Chalk' was best.

Although to topdress repeatedly is laborious, this method has the advantage that amounts of fertilizer and timing can be easily modified to match them to the needs of different soils, crops and rainfall.

Phosphorus

Responses to phosphorus applied to seedbeds differed greatly between the 14 nurseries, ranging from none to about 200%. Figure 7 shows for six nurseries seedling height in relation to graded additions of P applied as single superphosphate. There is, however, some difficulty in the precise interpretation of the results. At Bagley near Oxford – and possibly at Wareham – calcium as well as phosphorus probably contributed to the increase in plant height. This difficulty in interpretation is a recurrent problem on very poor soils, as many of the common fertilizers supply nutrients other than those specifically being studied.

The three forms of phosphorus principally tested were: Bessemer basic slag, Gafsa rock phosphate and superphosphate (single). On moderately acid soils, basic slag and rock phosphate were inferior to superphosphate; on very acid soils they sometimes equalled superphosphate but neither was ever better than superphos-

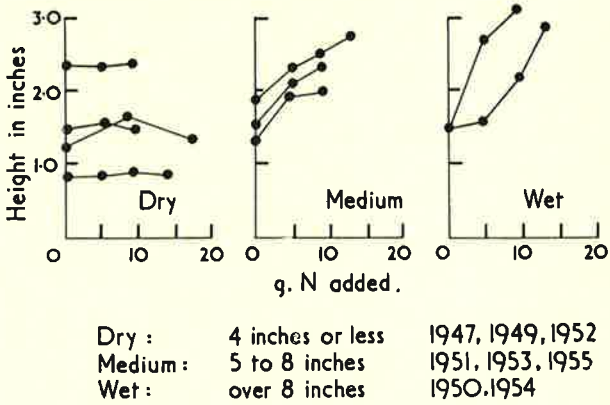


Fig. 6: Summer rainfall (total for June, July and August) and responses of Sitka spruce seedlings to graded additions of topdressed nitrogen at Wareham.

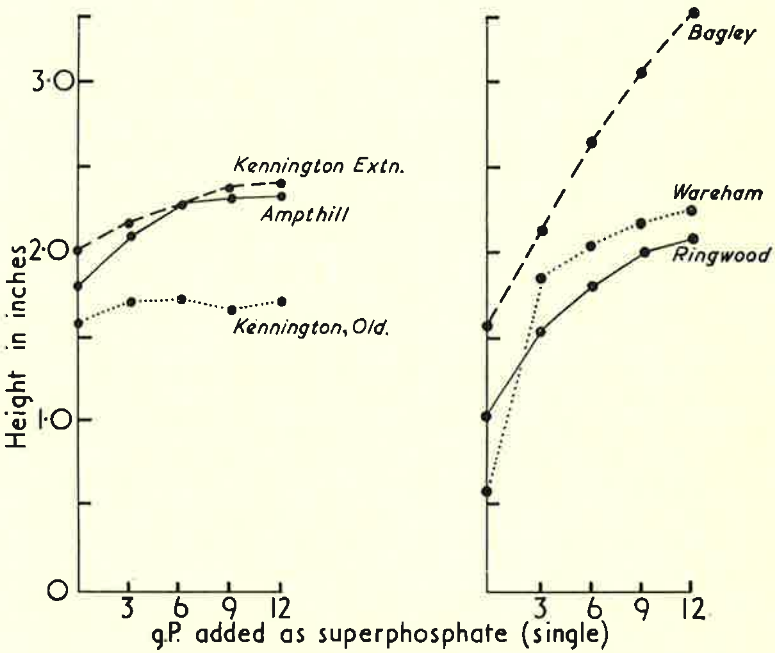


Fig. 7: Phosphorus response curves for Sitka spruce seedlings at six nurseries.

phate, either for seedlings or transplants of Sitka spruce. This is a surprising result for two reasons. Firstly, there had been several instances where superphosphate had caused severe damage to newly planted trees in Forestry Commission experiments. Recent evidence *[10]* has provided the explanation: superphosphate may under some conditions cause scorch of *transplants* of certain conifers such as Norway spruce and some species of *Abies*. Such damage has not been observed on Sitka spruce transplants or on *seedlings* of any of the conifers tested.

The second reason why the good results from superphosphate on Wareham soil are surprising is that according to *Mattingly [11]* only 7% of the phosphate applied as superphosphate to plots at Wareham between 1955 and 1963 was retained by the surface horizon, whereas the figures for Gafsa rock phosphate and basic slag were 67 and 41% respectively. *Mattingly* says 'The average annual rainfall at Wareham (about 35 in.) seems enough to leach more than 90% of the applied water-soluble phosphate from the top 6 in. of soil'. However, most of this leaching undoubtedly occurred in the winter months, whereas in recent years heavier spring and early summer rainfall will have played a part. Thus, during the 18 years of experimentation reported in Bulletin 37 (1945 to 1962), the rainfall for either April or May exceeded 4 in. only three times, whereas in the short period between 1963 and 1966 it did so four times. There has been some evidence during the last few years of losses of phosphorus (from superphosphate) occurring early in the season in those sections of Wareham Nursery where leaching is especially severe.

Potassium

In the 14 nurseries in which K was tested on seedbeds, responses ranged from none to a little over 60%. Potassium salts can quickly be lost through leaching from sandy heathland soils, and the responses from potassium may have been underestimated by relying too much on applications made before sowing. *Bolton* and *Coulter [12]*, in investigating the distribution of cations in the four major podsol horizons (of plots in the same experiment as that studied by *Mattingly*) found that 23% of the applied potassium had been taken up by the crop, 7% had remained in the top 23 in. of the profile and 70% of the applied potassium had leached from the profile.

Potassium chloride and sulphate gave similar results – with seedlings as well as transplants of Sitka spruce. This seemed surprising, as in 1939 *Němec [13]* had reported chloride damage to spruce transplants. The reason is that his work was done with Norway spruce, *Picea abies,* the spruce species grown widely on the continent. In some seasons, chloride causes a bright rusty scorch in Norway spruce whilst Sitka remains green. As with superphosphate, only the transplants proved 'salt-sensitive'.

Interactions between N, P and K

Factorial experiments allow the influence of one nutrient upon another to be studied. Table 3 shows, for two seedbed experiments on Sitka spruce, the great disparity between responses to each nutrient applied alone (column A) and in the presence of the other two (column B). Thus, although nitrogen by itself decreased

Table 3 Responses to nitrogen, phosphorus and potassium, each alone and in combination with the other two, at Bagley and Wareham

	Height in inches dry summers		wet summers	
	alone A	in presence of other nutrients B	alone A	in presence of other nutrients B
Bagley				
Responses to				
nitrogen	—0.24	0.00	—0.15	0.59
phosphorus	0.24	0.72	0.16	0.78
potassium	0.06	0.50	0.13	0.65
Wareham				
Responses to				
nitrogen	—0.38	—0.08	—0.13	0.83
phosphorus	0.69	1.33	0.47	1.55
potassium	—0.09	0.85	—0.20	0.88

growth considerably in dry, and even slightly in wet seasons, with P and K it did no harm in dry seasons and increased heights in wet ones. Phosphorus applied together with N and K, gave between twice and four times the increase obtained with phosphorus alone. Responses to potassium alone were small (positive at Bagley, negative at Wareham), but with N and P they were positive and large throughout.

Magnesium

Growth responses to magnesium were confined to wet seasons even at Wareham, but the characteristic yellow symptoms of magnesium deficiency developed consistently during the late autumn in several nurseries. The symptoms could be prevented by magnesium sulphate (applied as Epsom salts or kieserite) or dolomitic limestone, but soluble salts applied before sowing did not prevent deficiency symptoms from appearing after very wet summers.

4.3.3 Comparing compost and soluble fertilizers in many short-term experiments and in two long-term experiments on two contrasted soils

Short-term experiments

When our work began, composts (originally made in ways developed by *Rayner*) were used widely, often exclusively, in the Forestry Commission's nurseries. Among the questions that needed answering urgently were: Do composts act chiefly as sources of nutrients or do they have some unique qualities (such as encouraging mycorrhizal infection or of rendering plants more resistant to attack by pests and pathogens) which would make it risky to replace them by fertilizers? In practice, composts had been made from a wide range of variable raw materials, with little knowledge of their contents of nutrients and of possibly even harmful ingredients. Moreover, compost-making was very costly and laborious.

Our earliest experiments tested composts and other bulky manures – differing widely in their nutrient contents – in factorial combination with nitrogen, phosphorus and potassium applied as fertilizers. In some experiments the effects of the bulky organic manures were well related to their chemical composition, especially to their potassium contents.

After we had learned how to use soluble fertilizers, it became possible to compare in many seedbed experiments (most of them short-term) responses by Sitka spruce to soluble fertilizers with those to a 'standard' compost made from bracken *(Pteridium aquilinum)* and hopwaste, a by-product of the brewing industry (hops = *Humulus lupulus*). The compost supplied more total nutrients than the fertilizer – about three times as much N, slightly more P, and twice as much K. Figure 8 compares effects on plant height and figure 9 on plant number. In 110 comparisons made in five nurseries between 1947 and 1957, fertilizer was clearly superior to compost, with 80 points out of the 110 above, that is on the fertilizer side, of the 'equality' line. For plant number, differences were smaller, but again the distribution of points was 80 to 30 in favour of fertilizers.

Long-term experiments

In 1951, two long-term rotation experiments of about 350 plots each cropped with Sitka spruce seedlings or transplants, were started in nurseries at Wareham and Kennington (Three). (Their design and lay-out is described in *Rep. For. Res. For. Comm.* for 1952–1953, p. 84–100.) The experiments compared continuous conifer cropping with a rotation in which one conifer crop in three was replaced by either bare fallow or a 'green' crop (rye, ryegrass or yellow lupins); they also compared annual applications of compost made from bracken and hopwaste with fertilizers consisting of 'Nitro-Chalk' (a granular mixture of ammonium nitrate and calcium carbonate), potassic superphosphate (a compound fertilizer consisting of superphosphate and potassium chloride) and kieserite $MgSO_4.H_2O$). The site chosen for the Wareham experiment – cleared from heather and pine scrub – was on a sloping site much more exposed than the other sections of this nursery; the soil there was poorer and leaching greater. The Kennington site was on good agricultural land which had been under arable cropping.

Table 4 Amounts of nutrients supplied by fertilizers in long-term experiments at Kennington (Three) and Wareham

N as 'Nitro-Chalk' applied either in two topdressings (Kennington 1954–1960, Wareham 1954–1958) or three topdressings (remaining periods)
P, K } as potassic superphosphate applied before sowing (all years)
Mg as kieserite applied before sowing (all years)

	Total average amounts applied per year in g. element per sq. yd.				
	N seebdeds	N transplants	P	K	Mg
Kennington and Wareham					
1954–1957	9	6	8	9	3
1958–1961	11	8	9	9	3
1962–1965	14	9	9	9	3

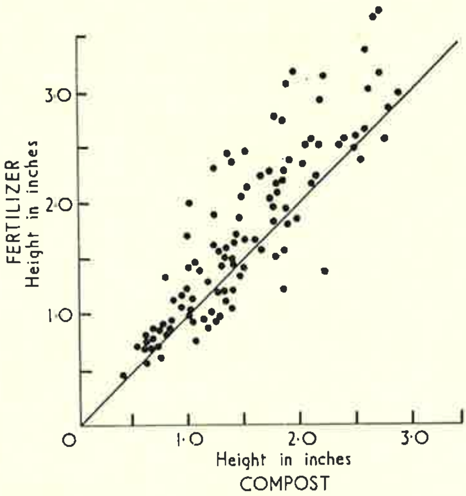


Fig.8: Comparison of compost and fertilizer (all nurseries, 1947–1957). Heights of Sitka spruce seedlings.

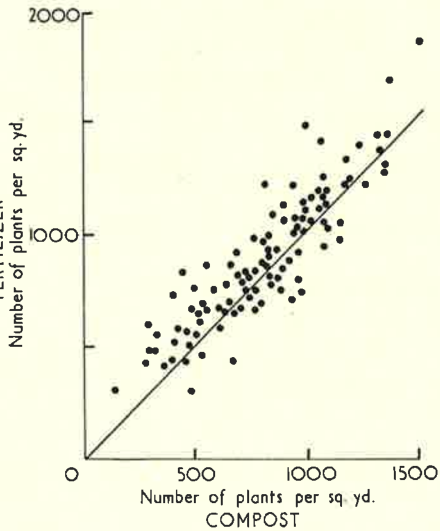


Fig.9: Comparison of compost and fertilizer (all nurseries, 1947–1957). Numbers of Sitka spruce seedlings.

These complex rotation experiments were supported at both nurseries by two ancillary experiments, one cropped annually with Sitka spruce seedlings, the other with Sitka spruce transplants. The treatments were: unmanured, fertilizer alone, compost alone, fertilizer plus compost. Table 4 shows forms and rates of fertilizer used, table 5, the composition of composts (made from 75% bracken and 25% hop-waste) and table 6 the amounts of N, P, K and Mg supplied by the composts.

Table 5 Analyses of composts used in long-term experiments at Kennington (Three) and Wareham

	% in fresh material Moisture	% in dry matter Org. matter	Ash	N total	N inorg.	P	K	Mg
Kennington								
1954–1957	79	78	22	4.1	0.2	0.9	2.3	0.4
1958–1961	79	73	27	3.7	0.3	0.6	2.2	n.d.
1962–1965	79	77	23	3.8	0.4	0.6	2.1	n.d.
Mean	79	76	24	3.9	0.3	0.7	2.2	(0.4)
Wareham								
1954–1957	83	87	13	3.9	0.1	0.5	1.8	0.3
1958–1961	82	81	19	4.2	0.4	0.5	1.7	n.d.
1962–1965	83	90	10	4.4	0.4	0.4	2.1	n.d.
Mean	82	86	14	4.1	0.3	0.5	1.9	(0.3)

(n.d. = not determined.)

Table 6 Amounts of nutrients supplied by compost in long-term experiments at Kennington (Three) and Wareham

	Amounts applied per year to seedbeds and transplants kg per sq.yd. of fresh product applied before sowing	g element per sq.yd. N total	N inorg.	P	K	Mg
Kennington						
1954–1957	4.5	39.2	1.8	8.6	22.0	3.7
1958–1961	4.5	34.4	2.9	6.0	20.0	n.d.
1962–1965	4.5	35.7	3.6	5.6	20.2	n.d.
Mean	4.5	36.4	2.8	6.7	20.7	(3.7)
Wareham						
1954–1957	4.5	30.6	0.7	4.0	13.2	2.6
1958–1961	5.6	42.2	3.7	5.4	17.3	n.d.
1962–1965	6.8	52.2	4.3	5.1	24.5	n.d.
Mean	5.6	41.6	2.9	4.8	18.4	(2.6)

(n.d. = not determined.)

It took three years for all parts of the Rotation Experiment proper to be started and the results for the ancillary tests presented here are, therefore, also confined do the 12-year period 1954–1965.

The difficulties encountered in running these experiments and interpreting the results are only too familiar to experimenters who have attempted similar tests with other crops. Either the amounts of nutrient originally chosen are retained, when – if they were too small – plants suffer increasingly from nutrient shortages, or – if the amounts are increased – it may be difficult to separate the effects caused by such increases from changes with time brought about by other factors.

Another difficulty in testing bulky organic manures and fertilizers is to find a useful basis of comparison between the two types of material. The *fertilizers* we used consisted of 'Nitro-Chalk' applied as topdressings and potassic superphosphate plus kieserite, applied before sowing. Amounts of P were increased at both nurseries in 1955 and amounts of N at Wareham in 1959 and at Kennington in 1961. Deficiency symptoms at Wareham clearly showed that even three topdressings of N were not enough in wet summers, that much of the K was leached out before the crop (particularly seedlings) could use it, and that in some years the seedlings may also have suffered from shortage of Mg. Phosphorus shortage does not cause easily recognisable deficiency symptoms, but *Mattingly's* evidence indicates that in some seasons losses of P may well have been enough to have affected growth. Deficiency symptoms were never observed on fertilizer plots at Kennington.

Seedlings and transplants on fertilizer plots at Wareham (but not at Kennington) developed copper deficiency symptoms in many seasons (*Warren* and *Benzian [14]*).

The type of *compost* chosen was one which could be expected to supply fair amounts of N and P (from hops) and K (from bracken); the raw materials could be obtained in many parts of the country, and composts of somewhat similar composition were used in some production nurseries. The amount applied (4.5 kg per sq. yd. or approx. 20 t per acre) was not unlike that used in many production nurseries, although these nurseries would not have applied so much annually. At Kennington the same amount was applied throughout, but at Wareham the compost dressing was increased by half in 1960 to coincide with larger fertilizer supplies of N and P. Even these heavy compost dressings at Wareham of approx. 30 t per acre (which made it difficult to consolidate the beds), were undoubtedly too small for such a responsive site. Potassium supplies were ample at both nurseries and K deficiency symptoms were never observed on compost-treated plots. Nitrogen deficiency symptoms, however, developed on compost plots at Wareham in most years and were severe in wet seasons. No copper deficiency occurred on compost plots at Wareham, because the compost was made with hopwaste from a brewery with copper installation. Thus, judging by the appearance of the crop and experience gained from results of other experiments on nearby sites, fertilizer and compost have supplied adequate amounts of nutrients at Kennington. At Wareham, however, the compost supplied too little N and P, and the fertilizer in many seasons too little N, K, Mg and Cu, and possibly even P.

The results for the seedling experiments are summarized in tables 7 and 9, for transplants in table 10. In all tables the 12-year period has been split into three 4-year periods to bring out any trends with time.

Seedlings. Table 7 shows measurements on seedlings made in the nursery – height, plant number, and number of usables. At Kennington, seedlings on fertilizer plots were considerably larger than those on compost plots in all three periods. There was no benefit whatever from adding compost to the fertilizer. Even in the third period, height was not increased after continued annual applications of about 20 t per acre of compost. Productivity did not decline on this site; fertilizer-grown seedlings in the third periods were similar to those in the first.

At Wareham the results were quite different. During the early period, fertilizer-grown seedlings were as superior to compost-grown plants as at Kennington, but during the middle and late period fertilizer-treated seedlings were no better than those grown with compost. Using compost and fertilizer together had increasingly greater advantages throughout the 12-year period; with this treatment productivity declined only a little.

Table 7 Nursery measurements of seedlings in long-term experiments on compost and fertilizer

	Kennington 1954 –1957	1958 –1961	1962 –1965	Wareham 1954 –1957	1958 –1961	1962 –1965
Height in inches						
unmanured	1.3	1.2	0.8	0.3	0.5	0.5
fertilizer	2.0	2.7	2.1	2.1	1.7	1.4
compost	1.4	1.9	1.6	1.5	1.6	1.4
both	1.6	2.6	2.1	2.4	2.3	2.1
Number of plants per sq.yd.						
unmanured	1020	1040	1240	1210	910	1290
fertilizer	950	1000	1230	1080	1000	1350
compost	810	830	1250	980	890	1280
both	800	890	1210	990	960	1240
Number of usables (>1.5 in.)						
unmanured	291	310	90	0	13	6
fertilizer	474	804	908	739	518	490
compost	299	484	610	433	385	486
both	368	718	860	794	720	852

As mentioned previously, losses of nutrients by leaching are particularly large on the site of the Rotation Experiment. By contrast, in a different part of Wareham nursery where losses are less, productivity has been maintained on continuously cropped plots given soluble fertilizers similar to those used in the Rotation Experiment (table 8).

Table 8 Nursery measurements of seedlings grown on fertilizer-treated plots in Section E of Wareham Nursery where productivity has been maintained over long periods

	Height in inches	Number of plants per sq. yd.	Number of usables (>1.5 in.)
1954–1957	2.29	1088	793
1958–1961	2.62	1004	856
1962–1965	2.35	1396	1002

Table 9 shows for whole seedlings (tops + roots), dry matter and N, P and K per cent. in crop. (At Wareham the unmanured plots could not be sampled, because the seedlings were too small.) At Kennington, omitting the unmanured plots, more dry

Table 9 Dry matter and nutrient concentrations of seedlings in long-term experiments on compost and fertilizer

	Kennington 1954 –1957	1958 –1961	1962 –1965	Wareham 1954 –1957	1958 –1961	1962 –1965
Dry matter mg per plant (tops + roots)						
unmanured	175	142	94	not sampled		
fertilizer	306	342	297	264	278	177
compost	282	316	246	204	279	218
both	306	360	344	326	386	304
Per cent. element in dry matter of total crop						
Nitrogen						
unmanured	1.9	1.8	1.7	not sampled		
fertilizer	1.9	1.8	2.1	1.5	1.6	1.4
compost	2.2	2.1	2.1	1.6	1.8	1.6
both	2.1	2.0	2.2	1.6	1.7	1.6
Phosphorus						
unmanured	0.31	0.26	0.26	not sampled		
fertilizer	0.32	0.31	0.29	0.24	0.24	0.24
compost	0.33	0.31	0.28	0.32	0.31	0.26
both	0.33	0.30	0.30	0.28	0.27	0.24
Potassium						
unmanured	0.8	0.6	0.8	not sampled		
fertilizer	1.2	1.2	1.2	0.8	0.6	0.6
compost	1.6	1.5	1.4	1.3	1.2	1.3
both	1.5	1.4	1.5	1.0	0.9	1.0

matter was produced by fertilizer, than by compost-grown seedlings, but nutrien- concentrations differed little either between treatments or periods, and these figure- provide no explanation for the poor performance of compost. At Wareham nutrient concentrations tended to be considerably less than at Kennington. Differences between treatments were small for N and P, but the K concentrations in compost-grown seedlings were twice those in fertilizer-grown seedlings.

Transplants. Table 10 gives heights, dry matter, and nutrient concentrations of transplants. For these older plants there was a slight benefit from continuous compost applications. Whereas initially fertilizer-grown plants were taller and heavier, compost-grown plants had a slight advantage in the middle and late period. Compost and fertilizer used together produced the best plants in most comparisons.

The nutrient concentrations in the crop (omitting unmanured plots) were very much more uniform than those in seedlings. There were no consistent differences between nurseries, except that P per cent. was a little more at Wareham, and none between treatments, except for somewhat greater K concentrations on plots that had received compost.

Seedlings and transplants. To sum up: For seedlings at Kennington fertilizer was consistently superior to compost. This is not very easy to understand, unless the compost failed to supply enough nitrogen during the whole of the growing season, without letting the N supply fall to the level when deficiency symptoms develop. For seedlings at Wareham neither compost nor fertilizer supplied sufficient nutrients,

Table 10 Height, dry matter and nutrient concentrations of transplants in long-term experiments on compost and fertilizer

	Kennington 1954–1957	Kennington 1958–1961	Kennington 1962–1965	Wareham 1954–1957	Wareham 1958–1961	Wareham 1962–1965
Height in inches						
unmanured	8.5	8.7	8.0	3.5	4.0	3.9
fertilizer	10.9	12.4	10.7	9.0	8.9	7.5
compost	10.6	13.3	11.2	8.2	9.5	8.2
both	11.0	14.2	11.7	10.0	9.5	8.5
Dry matter g per plant (tops + roots)						
unmanured	4.4	5.3	4.5	1.2	1.2	1.1
fertilizer	6.8	8.7	7.7	5.2	5.1	3.8
compost	6.4	9.8	7.9	4.7	5.9	4.8
both	6.7	11.1	9.0	6.1	6.0	4.9
Per cent. element in dry matter of total crop						
Nitrogen						
unmanured	1.3	1.2	1.4	1.2	1.5	1.6
fertilizer	1.4	1.4	1.7	1.3	1.5	1.8
compost	1.5	1.5	1.8	1.3	1.5	1.6
both	1.5	1.5	2.0	1.3	1.5	1.8
Phosphorus						
unmanured	0.22	0.21	0.21	0.07	0.13	0.14
fertilizer	0.21	0.21	0.22	0.22	0.24	0.26
compost	0.23	0.22	0.24	0.22	0.23	0.26
both	0.23	0.23	0.23	0.22	0.24	0.27
Potassium						
unmanured	0.6	0.5	0.7	0.6	0.6	0.6
fertilizer	0.9	0.8	1.0	0.8	0.8	1.0
compost	1.0	1.1	1.3	1.0	1.2	1.3
both	1.0	1.1	1.2	0.9	1.0	1.2

but the two materials differed in the type and timing of shortages. Seedlings grown with compost plus fertilizer received a steadier supply of N and P (though probably not quite enough), and sufficient K, Mg and Cu; there was very little loss of productivity on these plots. For transplants, compost gained slightly on fertilizers at both nurseries, and compost plus fertilizer gave the best results throughout. There may be several reasons for this. Transplants are more salt-sensitive than seedlings. Although damage is rarely observed on Sitka, there has been some evidence that chloride has a deleterious effect on its growth *(Benzian,* 1965 *[10])*. Transplants are also likely to have benefited from the nitrogen released early in the season from compost. With the help of the new slow-release fertilizers (discussed in the next section) we may approach more closely to the stage when it will become possible to say whether, under the conditions described, compost acts almost exclusively as a source of nutrients or whether it has some slight additional biological or physical effects. The evidence so far obtained indicates clearly that any such additional effects are small.

Reverting to the question posed at the beginning of this section, *Levisohn [15]* found no evidence that compost and fertilizer 'affected mycorrhiza-formation in consistently different directions'. As to pests or diseases, there were no indications of an increase with either treatment after continuous cropping for 15 years. In one or two seasons there were widespread occurrences of wilting of transplants and browning of seedlings at Kennington; these troubles were almost completely confined to compost plots. (Although the precise cause could not be established, fungal attack was suspected.)

4.3.4 *Avoiding or Making Good Leaching Losses by Using Slow-Release Fertilizers and/or Repeated Topdressings*

From the beginning of our work we have sought materials that would release nutrients gradually and safely, matching the needs of the growing plants. Bulletin 37 gives results for such materials. To choose two examples: formalised casein (button waste) proved a useful source of slow-release N and the mineral glauconite of slow-release K.

Interest in such products has recently increased and some slow-release fertilizers are now in full-scale production or have been made on a pilot scale. The products tested by us in recent experiments are: Isobutylidene diurea (IBDU) as a source of N, potassium metaphosphate as a source of P and K, and magnesium ammonium phosphate as a source of N, P and Mg.

Isobutylidene diurea

In a paper to this Society last year *Hamamoto [16]* described its properties and early experimental results. Our first test consisted of a small trial with Sitka seedlings at Wareham in 1965. IBDU of particle size 0.8 to 1.4 mm dug in in late March was compared at two amounts (9 and 18 g N per sq. yd.) with three summer topdressings of 'Nitro-Chalk' supplying similar total amounts of N. Early in the season the colour of the plants given IBDU was excellent but later they became slightly pale. However, at the end of the season seedlings were taller on IBDU than on 'Nitro-Chalk' plots.

	Height in inches
No nitrogen	0.4
'Nitro-Chalk'	
9 g N	1.4
18 g N	1.6
IBDU (0.8 to 1.4 mm)	
9 g N	1.6
18 g N	2.1
S.E.	±0.17

In 1966 two particle sizes of IBDU (0.8 to 1.4, and 1.5 to 2.4 mm) were compared at Wareham and Kennington Extension with formalised casein and 'Nitro-Chalk' (table 11). IBDU and formalized casein were applied before sowing; 'Nitro-Chalk' was topdressed on four occasions: at the beginning of June, July, August and September. All materials were tested at four rates of nitrogen: 6, 12, 18 and 24 g N per sq. yd., and both experiments had a basal dressing of potassium metaphosphate and kieserite.

Table 11 Comparison at two nurseries of four nitrogen forms applied to Sitka spruce seedlings, 1966

'Nitro-Chalk' applied in four equal topdressings
Formalized casein and IBDU: applied before sowing in early March.

low N = mean of 6 and 12 g N per sq. yd.
high N = mean of 18 and 24 g N per sq. yd.

	Height in inches Wareham		Kennington Extension	
No nitrogen	0.4		1.1	
	low N	high N	low N	high N
'Nitro-Chalk'	1.8	3.0	2.2	2.8
Formalized casein	1.6	2.7	2.3	2.9
IBDU (0.8–1.4 mm)	1.4	2.9	1.9	2.7
IBDU (1.5–2.4 mm)	2.0	2.8	2.0	2.6
S.E.	±0.11		±0.12	

Table 11 shows that preliminary results with IBDU are promising. The high rate of nitrogen gave for all N fertilizers a 2½-fold increase in seedling height at Kennington Extension and a 7-fold increase at Wareham, with only small differences between N forms.

At Wareham, colour differences of seedlings were large at the time when the final height assessments were made in the autumn. The 'Nitro-Chalk' plots were best, closely followed by coarse IBDU; the formalized casein plots and medium-fraction IBDU plots were much paler. At Kennington Extension the differences were smaller – with 'Nitro-Chalk' again best, followed by formalized casein, and then by the two fractions of IBDU.

The different nitrogen forms gave similar results for plant number, both in 1965 and 1966.

Because of exceptionally heavy rain in July 1965, and in April and August 1966 – especially at Wareham, conditions may have favoured IBDU and it will need further testing to find its value in drier years.

Potassium metaphosphate

A fertilizer supplying both P and K in slow-release form without deleterious accompanying anions would have clear advantages; potassium metaphosphate promised to be such a material. The product we tested was described by *Harris [17]* in a paper to this Society. Experiments with Sitka seedlings (started at Wareham in 1964 and at Kennington in 1966) and with Sitka and Norway spruce transplants (started at both nurseries in 1964) were of similar design, comparing potassium metaphosphate (particle size 0.5 to 2 mm) with (a) potassic superphosphate alone (b) potassic superphosphate supplemented with topdressings of prilled potassium nitrate and (c)

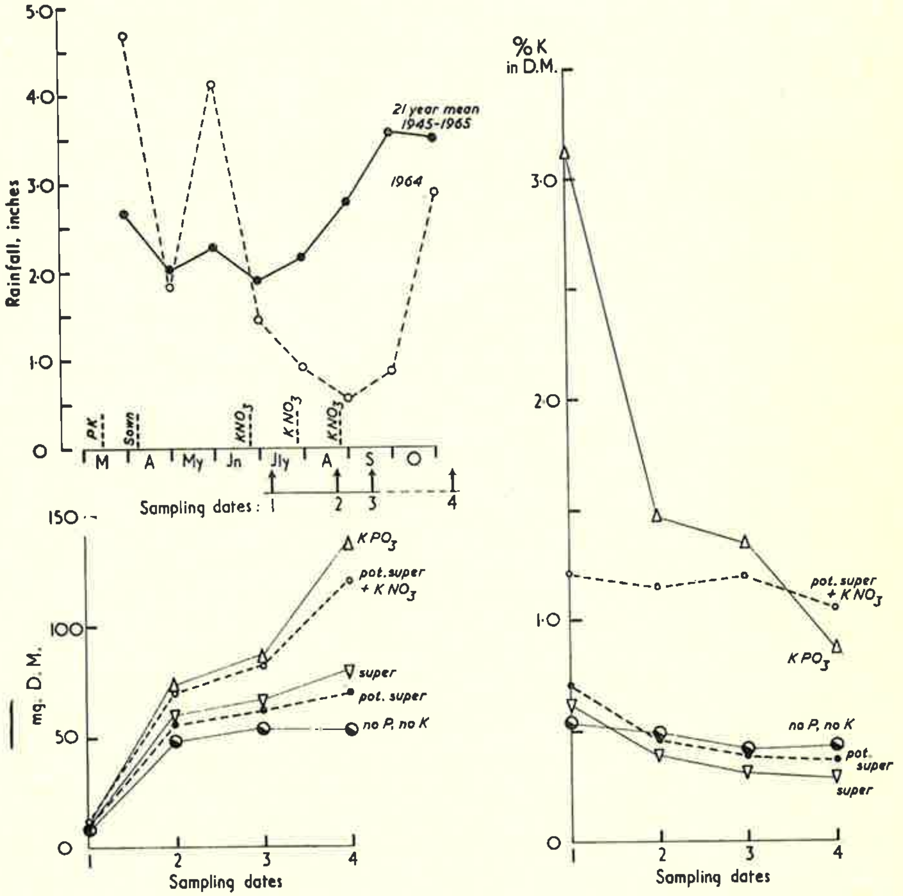


Fig.10: The effects of PK fertilizers on dry matter production and potassium concentrations of Sitka spruce seedlings at Wareham in 1964.

potassium dihydrogen phosphate which is soluble but free from chloride or sulphate ions. The experiment also included superphosphate plots without K. All plots had a basal dressing of N and Mg.

The Wareham seedlings (tops only) were sampled four times – three times during and once at the end of each growing season – to measure uptake of P, K, Ca and Mg. Preliminary end-of-season results for 1964 and 1965 have been published *[18, 19]*. Dry matter production and per cent K in crop for four sampling dates in 1964 and 1965 are shown in figures 10 and 11, and for the first two dates in 1966 in figure 12 (potassium dihydrogen phosphate has been omitted from these figures). The results are well related to rainfall, shown in the same diagrams.

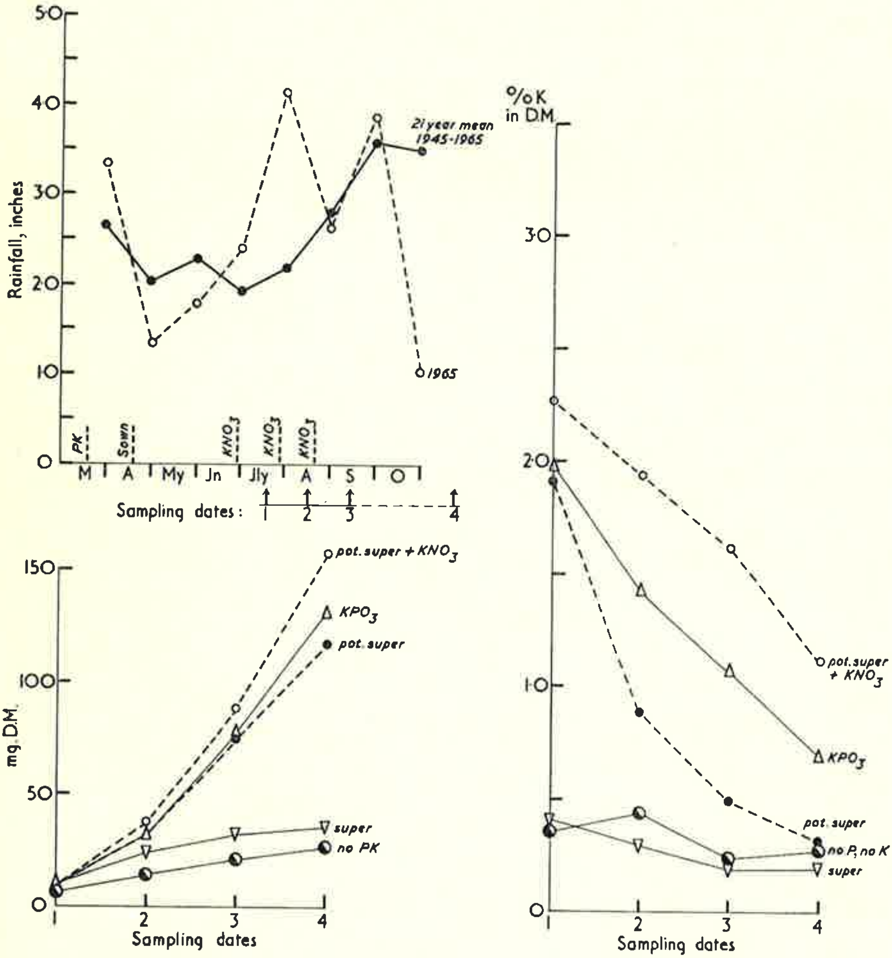


Fig. 11: The effects of PK fertilizers on dry matter production and potassium concentrations of Sitka spruce seedlings at Wareham in 1965.

In 1964 much K was lost during heavy rain in March and May; plants grown with potassic superphosphate produced only slightly more dry matter and had no larger K concentrations than those grown with superphosphate alone. Repeated topdressings with potassium nitrate maintained K concentrations. Potassium metaphosphate gave larger K concentrations in the early period but was close to potassic superphosphate supplemented by potassium nitrate (about 1 % K in dry matter) at the end of the period.

In 1965, after a much drier spring and early summer, potassic superphosphate by itself gave K concentrations close to those of potassium metaphosphate and of potassic super with KNO_3 early in the season, but dropped to very low values late in the season.

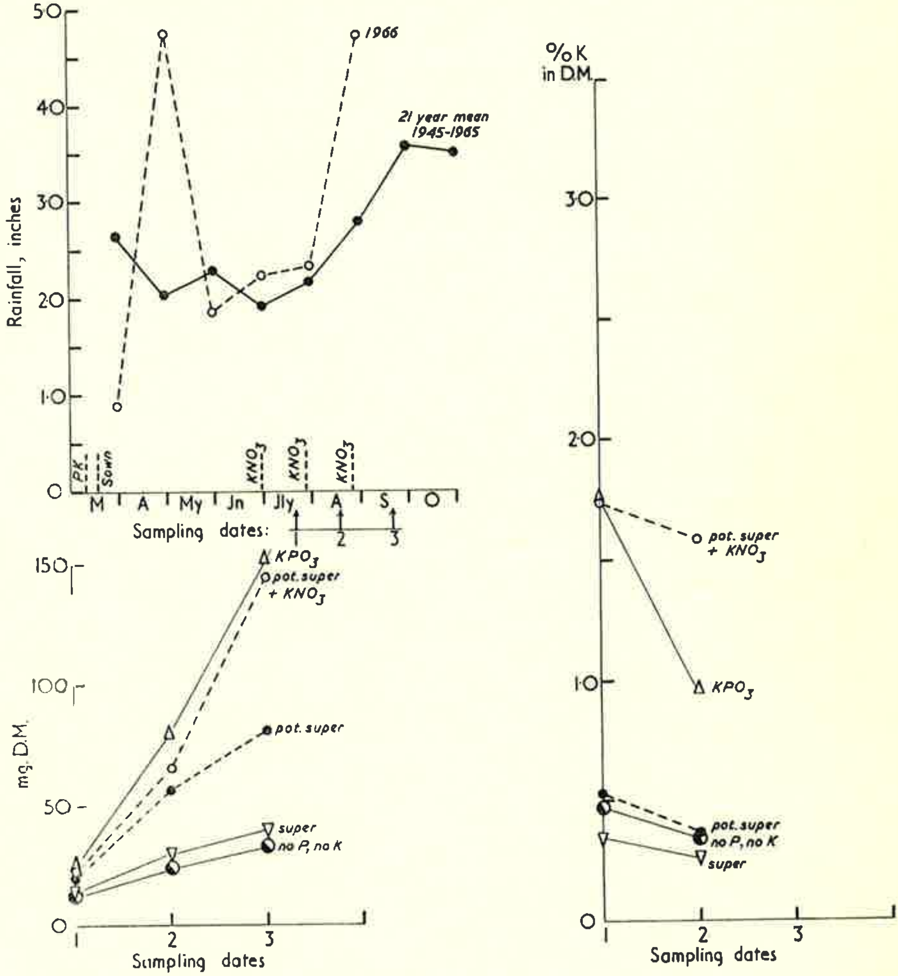


Fig.12: The effects of PK fertilizers on dry matter production and potassium concentrations of Sitka spruce seedlings at Wareham in the early part of 1966.

In the early part of 1966 seedlings with potassium metaphosphate and with potassic superphosphate supplemented by potassium nitrate produced similar amounts of dry matter, but those with potassic super alone, much less. Exceptionally heavy April rainfall had caused much loss of soluble K, and on sampling date 2, seedlings with potassic superphosphate had K concentrations no larger than those with superphosphate only. Again, seedlings grown with potassium metaphosphate and potassic superphosphate plus potassium nitrate had larger K concentrations.

Treatment differences were small with transplants, except that in 1964 Norway spruce at Wareham developed scorch symptoms with potassic superphosphate but remained healthy with potassium metaphosphate.

Magnesium ammonium phosphate

The product used in our experiments was described by *Bridger* et al. [20].

It is very difficult to design experiments that will test adequately fertilizers which supply three essential nutrients, especially under conditions where the rate of release of each one of these nutrients matters and their interaction is important. A further difficulty lies in the nutrient ratios of magnesium ammonium phosphate: 8% N, 17.5% P and 14% Mg, whereas the amounts commonly applied in our experiments are 12 to 18 g N, 9 g P and 3 g Mg per sq. yd.

Magnesium ammonium phosphate was included in a few small trials. It was tested either (a) at three rates – principally as a source of nitrogen or (b) as a constituent of a 'slow-release' fertilizer in combination with potassium metaphosphate. In the experiments mentioned under (a) above, magnesium ammonium phosphate was given in amounts supplying 4.5, 9, 18 g N per sq. yd. (and hence, 8, 16, 32 g P and 4.5, 9, 18 g Mg. per sq. yd.), and compared with a standard soluble fertilizer consisting of three or four topdressings of 'Nitro-Chalk' (13½ g N per sq. yd. in 1964, 18 g N in 1966), superphosphate (9 g P) and kieserite (3 g Mg). Identical amounts of K were applied to plots with magnesium ammonium phosphate and those with standard soluble fertilizer. The transplant experiments were of similar design but had slightly smaller dressings of 'Nitro-Chalk'.

Seedlings (Sitka spruce). For comparable amounts of nitrogen, plants at Wareham in 1964 were much taller on magnesium ammonium phosphate plots than on soluble-fertilizer plots but only very slightly taller in 1966. The interpretation of these results is not easy, as responses to N cannot be separated from those to P, and possibly, Mg. Observations made during the growing season indicated that nitrogen was released early: the plants started to look severely N-deficient by midsummer.

Transplants (Sitka and Norway spruce). In 1964 Sitka and Norway spruce transplants were taller with rates 1 and 2 of magnesium ammonium phosphate than with standard soluble fertilizer; in 1966 they were similar. In both years and for both species plants with rate 3 of magnesium ammonium phosphate were consistently smaller than those with rate 1 or 2.

Magnesium ammonium phosphate was also tested as part of a 'slow-release' fertilizer mixture (with potassium metaphosphate), used in amounts supplying either 3 g P or 6 g P, and hence 1.5 g N and 2.5 g Mg, or 3 g N and 5 g Mg respectively. At these rates, it provided a 'starter' dose of nitrogen and sufficient magnesium in seasons when many plants with 3 g Mg as kieserite had developed characteristic magnesium deficiency symptoms.

Summary

1. In Britain, all young conifers needed by the Forestry Commission for afforestation are raised in the Commission's own nurseries, which in 1965 occupied 1700 acres.

2. The paper summarises briefly results of manurial experiments done jointly by Rothamsted and the Research Branch of the Forestry Commission since 1945.

3. The main experimental species, Sitka spruce *Picea sitchensis*, and other commonly planted conifers were found to be sensitive to soil reaction and grew best on acid soils.

4. Soluble fertilizers such as 'Nitro-Chalk,' superphosphate, potassium chloride and magnesium sulphate could be used safely for seedlings of all species tested, but superphosphate and potassium chloride occasionally damaged transplants of Norway spruce, *Picea abies*.

5. In short-term comparisons between soluble fertilizers and composts (with compost supplying considerably more N and K and slightly more P), fertilizer gave better results in 80 out of 110 experiments. In two long-term experiments – one on a heathland site (Wareham, Dorset) the other on farming land (Kennington nr. Oxford) compost and soluble fertilizer were tested singly and together. In *seedling* experiments at Kennington, fertilizer was not only consistently superior to compost but growth was not even improved further if compost and fertilizer were applied together. On the poor, severely leached Wareham soil, neither compost alone nor fertilizer alone supplied sufficient nutrients for seedlings towards the end of the 12-year period, but there was very little decline in productivity on plots with compost plus fertilizer. For *transplants*, fertilizer was better initially, but later composts had the advantage; compost plus fertilizer was best throughout.

6. Soluble fertilizer applied before sowing or transplanting may be rapidly lost by leaching from the light sandy soils where many of the Forestry Commission's young conifers are grown. Losses of N and K could be made good by repeated topdressings of 'Nitro-Chalk' and potassium nitrate.

7. For use in forest nurseries, the ideal fertilizer would release nutrients gradually to match the needs of the slow-growing conifer seedlings, and would not contain any soluble salts which might harm sensitive transplants. Three slow-release fertilizers were tested: Isobutylidene diurea (supplying N), potassium metaphosphate (supplying P and K) and magnesium ammonium phosphate (supplying N, P, Mg.). Early results with isobutylidene diurea in two wet seasons have been promising. Potassium metaphosphate had special merits for seedlings on the light podsolic soil of Wareham. The three-constituent material – magnesium ammonium phosphate – with its unusual proportions of N, P and Mg, was difficult to test, but appeared to release most of its nitrogen early in the season.

Outlook

Compared with agriculture, production costs for nursery seedbeds are high. Whereas, at current agricultural manuring levels, fertilizer cost may represent as much as a quarter of the production cost for cereals and a sixth for potatoes, the comparable value for Sitka spruce seedlings (based on current practice of production nurseries) is below 3 per cent.

Of slow-release fertilizers so far tested, potassium metaphosphate appears to be a useful material for sandy heathland soils. A mixture (on the basis of equal amounts of P) of potassium metaphosphate with magnesium ammonium phosphate would provide a 'starter dose' of N, and a supply of P, K and Mg throughout the growing season. If promising early results with IBDU are later confirmed, all major nutrients could be applied before sowing or transplanting, saving labour and avoiding risk of damage to the crop.

Acknowledgements

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Appendix

Appendix Table 1 Mechanical composition of some nursery soils (ploughed layer)

	Size distribution of mineral particles (limiting diameters in mm) coarse sand 2–0.2%	fine sand 0.2–0.02%	silt 0.02–0.002%	clay < 0.002%
Wareham, Dorset	54	37	7	2
Ringwood, Hants.				
Section 7	43	45	7	5
Kennington, nr. Oxford				
Old, Section 3	65	17	6	12
Extension, Section C	71	14	4	11
Three (Rotation Expt.)	63	17	6	13
Bagley, nr. Oxford				
Section 4	68	19	7	6
Ampthill, Beds.				
Section 1	77	12	4	7
Woburn, Beds.				
Reference Plots (Stackyard)	44	36	9	11

Appendix Table 2 Chemical analyses of some nursery soils (– not determined)

	Sample No. (TE/A)	pH in 0.01 M $CaCl_2$	% Org. C	Total element, p.p.m. N	P	K	Ca
Wareham, Dorset							
Sections A, B, C	7581	3.2	2.6	1010	–	–	–
D, E, F	7583	3.3	3.6	1640	190	1300	320
J	7582	3.3	1.9	770	–	–	–
Rotation Expts. NW	7584	3.3	2.9	930	70	–	–
SE	7462	3.4	1.9	750	–	1000	200
Ringwood, Hants.							
Section 7 (north)	7574	4.9	0.7	700	520	3600	770
Kennington, nr. Oxford							
Old, Section 8	7569	6.2	1.5	1610	1300	5500	4100
Extension, Sections A, B, C	7576	5.2	1.8	1260	710	3500	1400
Three (Rotation Expt.)	7577	5.1	1.2	1120	530	4400	1100
Bagley, nr. Oxford							
Section 4	7580	3.1	3.7	1920	380	5200	350
Ampthill, Beds.							
Section 1	7573	5.5	1.2	940	720	2800	1600
Woburn, Beds.							
Reference Plots (Stackyard)	no No.	4.5	0.7	1000	860	6700	2200