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Production and Use of Tubed Seedlings

A J Low

COVER PICTURES

Left Eight-week-old Lodgepole pine tubed seedling ready for planting.

Right Vigorous Lodgepole pine plantation (of coastal Washington provenance) 6½ years after being planted as 8-week-old tubed seedlings on a poorly flushed blanket peat site in Naver Forest, Sutherland. A4420.

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Production and Use of Tubed Seedlings

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SUMMARY

The production and use of tubed conifer seedlings in Britain have been studied between 1968 and 1973 in an extensive research and development programme based initially on Canadian practice. Results from the many nursery and forest experiments are described and form the basis for practical recommendations (see Chapter 6) on raising and planting tubed seedlings.

Using heated polythene greenhouses, seedlings of Lodgepole pine (*Pinus contorta*) and Sitka spruce (*Picea sitchensis*) can readily be grown in small plastic tubes filled with a fertilised peat-sand mixture, and are normally ready for planting eight weeks after sowing. On ploughed peatland, step-planted seedlings are capable of high survival and vigorous early growth, with an effective planting season from mid April to late August. Root development appears satisfactory and, in the case of Lodgepole pine, early stability is better than that of transplant stock. Browsing damage by beasts and birds is the main adverse factor though much less serious than expected, and may necessitate some increase in protection costs. Weed growth is seldom a problem on the poorer upland peats, but may be excessive on flushed peats. Very high planting rates (up to 740 seedlings per man-hour) on previously stepped peat ridges are possible with a specially devised tool. Seedling use could lead to substantial savings in peatland afforestation costs, and large scale "user" trials of tubed seedlings are proceeding satisfactorily in North Scotland.

In contrast, tubed seedlings have proved unsatisfactory for afforestation on ploughed mineral soil, due to severe frost lifting and poor height growth. Similar unsatisfactory results have been obtained in reafforestation trials on a range of mineral soil types.

□

ACKNOWLEDGMENTS

Many Forestry Commission staff members contributed to the research and development work on which this report is based. In particular, I wish to pay tribute to the Silviculture (North) Branch foresters whose sustained hard work and enthusiasm made it possible to carry out a very substantial programme of greenhouse and forest experiments between 1967 and 1973. I am grateful for the co-operation of Work Study Branch staff who devised the special planting tool and planting method, and of North Scotland Conservancy staff who have been involved in the large scale trials. I also wish to thank colleagues at the Northern Research Station and at Alice Holt Lodge for advice and assistance received at various stages of the work.

All the illustrations are drawn from the Forestry Commission collection; photos carry their appropriate identification numbers.

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Chapter 1

INTRODUCTION

By 1966 British nursery techniques for the raising of conventional planting stock (1 year + 1 year transplants or older) had been developed to such an extent in the large post-war nursery research programme that the potential for further improvement appeared relatively small. It was therefore considered that the main opportunity for continued improvement in nursery efficiency and costs lay in the investigation of other types of planting stock grown under more closely controlled conditions (e.g. in greenhouses) than existed in an open nursery; and that container-grown plants in particular offered important handling advantages. At the same time the very large planting programmes being undertaken in upland areas of Britain and the shortage of suitable labour had created a need for a dependable economic method of extending the planting season well beyond the normal limits for conventional stock. This could be achieved to some extent by cold storage of plants (Davies, 1968; Brown, 1971; Low, 1973) but use of container-grown stock appeared to be the most promising means of obtaining a substantial extension to the planting season.

The use of planting stock raised in containers is a long-established forestry practice in tropical and semi-arid regions, where it may be essential in order to ensure satisfactory survival after planting (see, for example, Anon., 1963). In other parts of the world, use of container stock has in the past been restricted by the high costs of production and planting, but by 1966 techniques intended for economic large-scale use in temperate forestry had been devised in various parts of Canada. A particularly promising technique was on trial in Ontario and Alberta, where polythene-covered greenhouses were used to provide suitable conditions for the rapid growth of conifer seedlings raised in small (3 inches long × 0·5 or 0·75 inches diameter) open-ended, side slit plastic tubes (see Plate 1). When only a few weeks old, these tubed seedlings (often referred to as "tubelings") were then used, without removing the tube, for planting on cut-over forest land (Williamson, 1964; Anon., 1967; Carman, 1967). In British Columbia a somewhat similar system was under development, using small bullet-shaped plastic containers for raising seedlings which were planted out in the forest when several months (often at least one year) old (Walters, 1961, 1963).

In relation to British forestry, the main advantages offered by tubed seedlings in comparison with conventional transplant stock appeared to be:

(1) Much easier and more efficient matching of plant production and plant requirements, because of the very short period required to produce plantable seedlings and the possibility of producing several crops in one season.
(2) Much increased nursery output leading to reduced supervisory costs and other overheads.
(3) Elimination of transplanting, thus avoiding a seasonal peak in labour requirement.
(4) Simplified selection of nursery sites because large areas of easily worked land would no longer be required.
(5) Considerable extension of the planting season, by making possible the safe planting of actively growing trees, thus reducing a seasonal peak in labour requirement.
(6) Increased speed of planting due to ease of planting tubes, giving higher output per man-day and reduced planting costs.
(7) More balanced root and shoot growth due to the use of very young planting stock, and improved early growth of species normally subject to post-planting check.

The main disadvantages, all associated with the small size of the tubed seedlings when planted, seemed likely to be:

(1) Greater vulnerability to animal damage.
(2) Unsuitability for weedy sites unless cheap, effective weed control could be achieved.
(3) A somewhat longer establishment period, possibly leading to a slight increase in rotation length.

On balance the potential advantages far outweighed the disadvantages and it was decided to investigate the suitability of tubed seedlings for British conditions, using Ontario practice (Anon., 1967) as a basis from which to develop suitable techniques. Lodgepole pine (*Pinus contorta* Douglas ex Loud.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) were chosen as the principal species for study because of their dominance in the afforestation of upland areas where successful introduction of tubed seedlings could be expected to be of greatest benefit.

The general feasibility of raising tubed seedlings in Britain was confirmed by preliminary trials in 1967. A major research programme was then begun in 1968 with the aim of determining the most satisfactory methods for large-scale production and planting of tubed seedlings, and their limitations for use in British forestry.

An interim report on the project was published when work had been in progress for 3 years (Low, 1971). Since that time, the research work on seedling production has been completed; and much more information has been obtained on the forest performance of tubed seedling stock, which is now being used for large-scale peatland planting trials in the North Scotland Conservancy of the Forestry Commission. The purpose of the present report is to present a definitive account of the research and development work which has been undertaken since 1968.

Chapter 2

PRODUCTION OF TUBED SEEDLINGS

Introduction

Research on the production of tubed seedlings took place during the period 1968–71 at three Forestry Commission research centres in Scotland—Inchnacardoch (Inverness-shire), Newton Nursery (Largh of Moray Forest, Moray) and Tulliallan Nursery (Devilla Forest, Fife). A similar (and substantial) experimental programme was carried out at each location to investigate a range of factors likely to influence germination and growth of seedlings in tubes. For the purpose, a relatively large (12 m × 6 m) polythene-covered greenhouse (similar to that shown in Plate 2) was erected at Inchnacardoch and at Tulliallan, while at Newton a small conventional glasshouse was used. In each house, control of day and night temperatures was provided by means of thermostatically controlled warm air heating and fan ventilation. Until the end of 1970, day and night temperatures were maintained at approximately 21°C and 10°C respectively but in subsequent seasons the night temperature was raised to 15°C. It was found that the degree of temperature control possible varied with the external air temperature and in consequence both day and night temperatures were usually somewhat higher in summer than at other times of the year.

To provide a basis for the investigations, a "standard" technique was adopted, having been based primarily on Ontario tubed seedling production methods. Thin walled polystyrene tubes 7·5 cm long × 1·3 cm internal diameter were filled with a mixture of equal parts by volume of fine grade horticultural sphagnum peat (pH approximately 3·5–4·0) and medium sand to which was added the slow release compound fertiliser "Enmag" and ground limestone at rates of 1·5 kg/m^3 and 0·5 kg/m^3 respectively. One seed, dusted with a thiram-based seed dressing, was sown in each tube and covered with a 3 mm layer of medium seed. After sowing, trays of tubes were watered from below and kept for seven days at a steady temperature of 26°C before being placed in a greenhouse with day and night temperatures of 21°C and 10°C. Watering was carried out as required and a fungicidal captan drench applied at weekly intervals during the first month. The "standard" technique was modified as and when experimental results suggested the desirability of doing so, and led ultimately to the development of the procedure now recommended for tubed seedling production (see Chapter 6, pp. 00–00). Plate 3 shows a typical tray of 8-week-old Sitka spruce seedings grown according to this procedure and ready for transport to the forest.

From Canadian evidence, it was thought probable that seedlings would be large enough for planting out at 8 weeks from sowing, but most experiments were continued until 12 weeks after sowing. Because of their short duration it was frequently possible to repeat individual experiments twice in one season and so obtain rapid confirmation of results. Where appropriate the effects of nursery treatments on growth after planting were studied in forest extension trials.

Most greenhouse experiments were concerned with raising seedlings of Lodgepole pine (primarily of coastal Washington or Oregon provenance) and Sitka spruce (of Queen Charlotte Islands provenance), but between 1968 and 1970 a small amount of work was done to determine how far methods found suitable for these species could be applied to other conifer species, particularly Grand fir (*Abies grandis* Lindl.). A typical experiment is shown in Plate 4.

The total number of experiments carried out is large (68 in all, not counting repeat sowings) and it is not practicable to describe them in detail. Instead, the treatments tested and results obtained will be summarised for groups of related experiments in the following sub-sections. Unless otherwise stated, experiments were carried out in groups of three—one at each centre. The results of relevant forest extension trials will be described later in Chapter 3.

Fertiliser Regime

Development and testing of appropriate fertiliser regimes formed a very substantial part of the greenhouse research programme. Because of the developmental aspect of the work, the experiments have been grouped according to the season in which they were carried out.

Two fertiliser materials to which frequent reference will be made are "Enmag" and "FL3P" (manufactured respectively by Scottish Agricultural Industries Ltd., and Fison's Ltd.). The former is a solid slow release compound fertiliser containing 5% N, 10·6% P, 8·3% K and 10% Mg., while the latter is a general purpose liquid fertiliser which contains 7% N, 3·1% P and 5·8% K, and is diluted with water prior to use. Both FL3P and the other soluble fertilisers used for top dressing were applied at a rate of 2·5 litres of solution per m^2 of bench area.

(1) **1968 Experiments:** A range of possible fertiliser regimes for Lodgepole pine and Sitka spruce seedling production was investigated in 2 related sets of experiments, using a 1 : 1 mixture of peat and sand

as the soil medium in the tubes. A further single experiment was based on fertilised peat specially prepared by Scottish Agricultural Industries Ltd. (S.A.I.), and in this case no sand was added to the peat prior to filling the tubes. In the first set, the regimes compared were:

(a) "Enmag" at 1·5 kg/m^3 of soil mix, with and without top dressing with ammonium sulphate solution (12 g/litre of water);
(b) Potassic superphosphate (Fison's 48) at 0·75 kg/m^3 of soil mix, top-dressed with solutions of ammonium sulphate (12 g/litre), urea (6 g/litre), or "FL3P" (6 ml/litre);
(c) "FL3P" at 6 ml/litre as a top dressing, with no basal fertiliser.

In each case ground limestone at 0·5 kg/m^3 was added to the peat-sand mix before sowing. Each top-dressing solution was applied three times—4, 6 and 8 weeks after sowing.

There was some indication that germination was best in the "FL3P" treatment which had no fertiliser (other than limestone) added to the soil mix before sowing, but differences between treatments were usually small. As regards seedling height growth and usable out-turn (i.e. the number of seedlings considered fit for planting), results were not consistent but "Enmag" without top-dressing, potassic superphosphate with "FL3P" top-dressing and "FL3P" alone appeared to give the best results. Many Lodgepole pine seedlings and some Sitka spruce seedlings were killed by urea top-dressing and ammonium sulphate also damaged some seedlings of both species: both materials therefore appeared to be unsuitable for top-dressing such young seedlings.

The second set of experiments dealt primarily with nitrogen nutrition and compared:

(a) "Enmag" at 1·5 kg/m^3 of soil mix, without top-dressing (the "standard" treatment);
(b) "Enmag" at 1·5 kg/m^3, top-dressed with solutions of ammonium sulphate at 12 g/litre, urea at 6 g(litre, ammonium nitrate at 9 g/litre or "Nitro-chalk" at 12 g/litre (in effect ammonium nitrate with some calcium in solution);
(c) "Enmag" at 6 kg/m^3, without top-dressing.

As before, ground limestone at 0·5 kg/m^3 was added to the peat-sand mix before sowing and top-dressings were applied 4, 6 and 8 weeks after sowing.

The high rate of "Enmag" (4 times the standard rate) consistently depressed germination and gave reduced height growth and usable out-turn for both species. In most cases the "standard" rate of "Enmag" without top-dressing gave results equal to or better than was obtained with the best top-dressing treatments. As in the first set of experiments many pine and some spruce seedlings were killed by urea application, and some seedlings of both species were killed. by ammonium sulphate application.

In the remaining experiment, for which the S.A.I. peat preparations were used, various types and rates of "Enmag" fertiliser were compared with potassic superphosphate. One of the main objects was to determine whether or not the degree of potassium solubility in the commercially available form of "Enmag" had any harmful effects on seedling growth. The rates used were 1·5 kg/m^3 of normal "Enmag" or amounts of the other materials providing similar quantities of N and/or K, and 4 and 16 times the above rate.

The most important factor which influenced seedling germination and growth was rate of fertiliser application. The highest rate (24 kg/m^3 normal "Enmag" or its equivalent) gave by far the poorest results and was obviously excessive for the conditions of the experiment. Of the other two rates, the lowest (1·5 kg/m^3) gave better germination of both pine and spruce, while the intermediate rate (6 kg/m^3) gave slightly better height growth. (It is interesting to note the difference between results from this experiment and from the first set described above, in which "Enmag" at 6 kg/m^3 gave much poorer results than "Enmag" at 1·5 kg/m^3. The difference may be due to the use of a peat-sand mixture in the first set as compared with undiluted peat in the present case. As regards type of fertiliser, potassic superphosphate gave poorer results, rate for rate, than any of the "Enmag" fertilisers. There is no evidence to suggest that potassium solubility in "Enmag" affected seedling growth.

(2) 1969 Experiments: As in 1968, two related sets of experiments tested various possible fertiliser regimes for Lodgepole pine and Sitka spruce. These were derived primarily from the results of the 1968 trials, and all included the use of ground limestone at 0·5 kg/m^3 in the soil mix. The effect of adding ground limestone to the peat-sand mix was examined in a third set of experiments.

The first set compared three rates of "Enmag" addition—0·5, 1·5 and 2·5 kg/m^3 of soil mix. The two lower rates were tested with and without regular top-dressing using solutions of ammonium nitrate (3 g/litre) or "FL3P" (3 ml/litre). Top-dressings were applied at 2 week intervals, beginning 4 weeks after sowing. A regime without initial fertiliser addition was also included, using "FL3P" (3 ml/litre) applied at weekly intervals from 4 to 10 weeks after sowing. At all 3 nurseries the lowest rate of "Enmag", and "FL3P" alone generally gave the best germination of both pine and spruce, but the differences between these treatments and the middle rate of "Enmag" (the "standard" rate) were often small. The highest rate of "Enmag" consistently depressed germination to a considerable degree. Differences in height growth between the various treatments were not consistent and often small. On average the lowest rate of "Enmag" with top-dressing and the middle rate with or without top-dressing gave the best results. There was little to choose between ammonium nitrate and "FL3P" top-dressing. Numbers of usable seedlings tended to reflect germination differences but were usually less consistent.

In the second set, regimes based on "FL3P" alone and on potassic superphosphate with top-dressing were compared with the "standard" rate of "Enmag" (1·5 kg/m³ of soil mix). Three concentrations of "FL3P" were included—3, 6 and 9 ml/litre. Potassic superphosphate used at 0·75 kg/m³ was tested with dressings of "FL3P" at 3 and 6 ml/litre and of ammonium nitrate at 3 and 6g/litre. All fertiliser solutions were applied at weekly intervals from 4 to 10 weeks after sowing.

Results from these experiments are summarised for both species in Table 1. Germination was usually best in the "FL3P" treatments, which had no fertiliser added to the soil mix before sowing, but differences between these treatments and the others rarely reached significance. In almost every case the standard rate of "Enmag" gave height growth equal to or better than that obtained with any other treatment. There was frequently little to choose between "Enmag" and the three "FL3P" regimes, but the potassic superphosphate regimes tended to give poorer growth, particularly where the top dressing used was ammonium nitrate rather than "FL3P". Numbers of usable seedlings tended to parallel germination numbers with "FL3P" giving slightly better results than the other two types of regime. (*Note:* Seedlings raised using the regimes based on "Enmag", "FL3P" at the lowest rate and potassic superphosphate with "FL3P" top-dressing were planted in forest extension trials which will be described later.)

Results from the two sets of experiments suggested that a slight improvement in usable seedling out-turn might be obtained by adopting a regime based purely on "FL3P" or on a reduced rate of "Enmag" (0·5–1 kg/m³ of soil mix) with "FL3P" top-dressing, instead of the "standard" regime using "Enmag" at 1·5 kg/m³ without top-dressing. However, it was considered that the small benefit to be gained was insufficient to outweigh the greater inconvenience of the alternative regimes.

Table 1

EFFECT OF VARIOUS FERTILISER REGIMES ON SEEDLING NUMBERS AND GROWTH IN EXPERIMENTS AT INCHNACARDOCH, NEWTON AND TULLIALLAN IN 1969

Fertiliser regime	Germination % at 4 weeks after sowing			Mean height (cm) at 8 weeks			Usable out-turn % at 8 weeks		
	I.	N.	T.	I.	N.	T.	I.	N.	T.
A. LODGEPOLE PINE									
L_1 —"FL3P" at 3 ml/litre	67	76	76	2·1	2·5	2·5	62	61	78
L_2 —"FL3P" at 6 ml/litre	72	71	78	2·0	2·6	2·5	70	59	80
L_3 —"FL3P" at 9 ml/litre	60	71	80	2·5	2·4	2·5	50	51	64
PL_1 —Potassic superphosphate at 0·75 kg/m³ + "FL3P" as for L_1	47	60	66	2·4	2·4	2·3	42	49	56
PL_2 —Potassic superphosphate at 0·75 kg/m³ + "FL3P" as per L_2	51	71	72	2·1	2·8	2·4	47	60	62
PN_1—Potassic superphosphate at 0·75 kg/m³ + ammonium nitrate at 3 g/litre	44	64	66	2·4	2·4	2·2	41	55	58
PN_2—Potassic superphosphate at 0·75 kg/m³ + ammonium nitrate at 6 g/litre	57	69	64	2·4	2·3	2·1	56	51	44
E —"Enmag" at 1·5 kg/m³	61	67	72	2·6	2·8	2·5	51	60	64
Mean	57	69	72	2·3	2·5	2·4	53	55	64
Overall variation	ns	ns	ns	ns	ns	**	ns	ns	**
B. SITKA SPRUCE									
L_1	70	70	70	1·8	2·1	2·0	58	68	70
L_2	75	67	76	1·7	2·0	2·2	58	56	74
L_3 (For details see above)	68	59	72	1·9	1·8	2·0	57	52	74
PL_1	55	57	56	1·7	1·8	1·8	50	53	58
PL_2	53	63	66	1·5	2·0	1·9	43	57	64
PN_1	57	57	64	1·9	1·8	1·8	51	47	60
PN_2	61	65	56	1·7	1·8	1·6	48	49	50
E	63	66	70	2·0	2·2	2·1	54	61	64
Mean	63	63	66	1·8	1·9	1·9	52	54	64
Overall variation	ns	ns	ns	*	ns	**	ns	ns	*

NOTES: (1) I—Inchnacardoch; N—Newton; T—Tulliallan.
(2) ns—not significant; *—significant at 5% level; **—significant at 1% level.

The third set of experiments was intended to determine whether or not the addition of ground limestone to the soil mix at 0·5 kg/m³ (which had been adopted as part of the "standard" technique) had a beneficial effect on conifer seedling growth. "Enmag" (1·5 kg/m³) and "FL3P" (3 ml/litre) applied at weekly intervals from 3 to 10 weeks after sowing provided two contrasting fertiliser regimes which were compared with and without limestone addition.

Although results at the three centres were not consistent, on average it appeared that the addition of ground limestone improved germination and growth to some extent. This improvement was more noticeable with Lodgepole pine than with Sitka spruce; and with "Enmag" rather than with "FL3P" fertiliser.

(3) 1970 Experiments: A further range of fertiliser regimes was devised from available recommendations for horticultural crops (see e.g. Birch, 1969, 1970 a, b and c; and Sheard, 1969) and from the experimental results obtained during 1969. These regimes were tested in two successive sets of experiments. The need for addition of ground limestone was further investigated, while the effect of adding fritted trace elements was studied in a fourth set of experiments.

In the first set of experiments the fertiliser regimes tested were as follows:

(a) "Enmag" at 1·5 kg/m³ of soil mix ("standard" treatment);
(b) "FL3P" at 3 ml/litre, watered on at weekly intervals from 3 to 10 weeks after sowing (no basal fertiliser addition);
(c) "Nitroform" (urea formaldeyhde) at 0·5 kg/m³, single superphosphate at 1·0 kg/m³ and potassium sulphate at 0·5 kg/m³ of soil mix;
(d) Ammonium sulphate at 0·5 kg/m³, single superphosphate at 1·0 kg/m³ and potassium sulphate at 0·5 kg/m³ of soil mix;
(e) As for (d) but top-dressed with "FL3P" solution (3 ml/litre) 4, 6, 8 and 10 weeks after sowing;
(f) Ammonium sulphate at 0·5 kg/m³ and potassic superphosphate (Fison's Double Season PK) at 1·0 kg/m³ of soil mix;
(g) Ammonium nitrate at 0·25 kg/m³, potassium nitrate at 0·5 kg/m³ and single superphosphate at 1·0 kg/m³ of soil mix;
(h) As for (g), but top-dressed with "FL3P" solution (3 ml/litre) 4, 6, 8 and 10 weeks after sowing.

In each case, ground limestone at 0·5 kg/m³ and trace element frit 253A (see below) at 0·5 kg/m³ were added to the soil mix prior to sowing.

As in previous years, the "FL3P" regime (b) gave the best germination of both pine and spruce, but the results were only slightly poorer for the "Enmag" (a) and "Nitroform" (c) regimes. The ammonium nitrate based regimes (g) and (h) also gave good but less consistent germination, especially for Lodgepole pine. Germination was clearly poorest in the 3 regimes (d), (e) and (f) based on the use of ammonium sulphate, and the results, in conjunction with those obtained in 1968, confirmed the unsuitability of ammonium sulphate as a fertiliser for tubed seedlings. Differences in height growth were less clear cut, but "Emag" was usually one of the best treatments. The regimes including ammonium sulphate and ammonium nitrate often gave the poorest growth, while results were variable with the remaining two regimes. Treatment differences in out-turn of usable seedlings generally reflected differences in germination but were rather less consistent. (*Note:* Seedlings raised using the regimes based on "Enmag", "FL3P" and "Nitroform + potassium sulphate (all with and without addition of trace element frit) were planted in three forest extension trials which will be described later.)

The second set of experiments was sown after completion of the first, and tested a modified range of regimes as follows:

(a) "Enmag" at 1·5 kg/m³ and ground limestone at 1·5 kg/m³ of soil mix;
(b) "FL3P" at 3 ml/litre, watered on at weekly intervals from 3 to 10 weeks after sowing; either ground limestone or ground magnesian limestone at 1·5 kg/m³ of soil mix;
(c) "Nitroform" (urea formaldehyde) at 0·5 k/gm³, single superphosphate at 1·0 kg/m³, potassium sulphate at 0·5 kg/m³ and either ground limestone or ground magnesian limestone at 1·5 kg/m³ of soil mix;
(d) Potassium nitrate at 0·5 kg/m³, single superphosphate at 1·0 kg/m³ and either ground limestone or ground magnesian limestone at 1·5 kg/m³ of soil mix; "FL3P" at 3 ml/litre watered on 4, 6, 8 and 10 weeks after sowing.

In each case element frit 253A at the reduced rate of 0·25 kg/m³ was incorporated into the soil mix. (Both this reduction and the increase in the rate of limestone addition included in the treatments above were made in the light of results from other experiments described below.)

Results for both Lodgepole pine and Sitka spruce in the Inchnacardoch experiment are summarised in Table 2; more or less similar variation between treatments was found in the other two experiments, although there were differences in detail. Considering the experiments as a whole, all four basic regimes gave acceptable results for both species, and differences were often small. Yield of usable seedlings was generally lowest with the urea formaldehyde regime (c), while the "FL3P" treatment (b) most frequently gave the highest germination and usable out-turn. Both "Enmag" and "FL3P" regimes tended to be more consistent in their effects than the potassium nitrate

Table 2

SEEDLING OUT-TURN AND GROWTH PRODUCED BY VARIOUS FERTILISER REGIMES IN EXPERIMENTS AT INCHNACARDOCH (I), NEWTON (N) AND TULLIALLAN (T).

Species	Fertiliser treatment	Germination % at 3 weeks after sowing						Mean height (cm) at 8 weeks						Usable out-turn % at 8 weeks					
		I		N		T		I		N		T		I		N		T	
		L	ML	L	ML	L	ML	L	ML	L	ML	L	ML	L	ML	L	ML	L	ML
Lodgepole pine	"Enmag" (E)	79	—	59	—	76	—	3·7	—	3·0	—	3·1	—	77	—	61	—	66	—
	"FL3P" (L)	83	81	66	67	84	82	3·3	3·9	3·1	3·0	3·0	3·0	85	80	63	69	78	74
	"Nitroform" + superphosphate + potassium sulphate (U)	66	70	47	55	80	74	3·2	3·7	2·3	2·3	2·8	2·7	61	65	46	51	68	64
	Potassium nitrate + superphosphate + "FL3P" (P)	67	79	53	55	74	82	3·3	3·4	2·4	2·4	2·7	2·7	70	77	57	58	68	70
Sitka spruce	E	79	—	53	—	80	—	2·8	—	1·8	—	2·5	—	72	—	67	—	68	—
	L	76	81	63	45	78	86	2·7	3·0	1·9	1·9	2·2	2·4	71	81	68	71	76	82
	U (For details, see above)	76	79	38	44	68	74	2·8	2·7	1·7	1·8	2·3	2·2	67	66	48	54	56	60
	P	85	79	57	58	80	74	3·2	3·2	1·7	1·9	2·3	2·4	83	70	60	62	76	68

Note: L—ground limestone; ML—ground magnesian limestone.

regime (which nevertheless gave the best results for Sitka spruce at Inchnacardoch). In regimes (b), (c) and (d) the use of ground magnesian limestone more often than not gave a slight improvement in performance. (The effect of adding ground magnesian limestone to the "Enmag" regime was not tested because "Enmag" contains a substantial quantity of magnesium.)

The addition of ground limestone to the soil mix at various rates was studied in the third set of experiments, in which contrasting fertiliser regimes were provided by use of "Enmag" (1·5 kg/m^3) and "FL3P" (3 ml/litre, applied weekly from 3 to 10 weeks after sowing) respectively. In all cases trace element frit 253A was added to the soil mix. When the experiments were first sown, the limestone rates compared were 0, 0·5, 1·5 and 2·5 kg/m^3 and results suggested that this was too narrow a range. Furthermore the rate of trace element frit addition was 0·5 kg/m^3 and it became apparent from these and other experiments that this rate was too high (see below). The experiments were therefore re-sown with the limestone rates under test altered to 0, 2, 4 and 6 kg/m^3 and the basal addition of frit reduced to 0·25 kg/m^3 of soil mix.

Results from the second sowing showed that treatment differences, although frequently significant, were mostly small. However, at Tulliallan the treatment involving omission of limestone from the soil mix gave decidedly lower seedling numbers than the other treatments, particularly when "Enmag" fertilising was used. In general, addition of limestone at 2 or 4 kg/m^3 (which raised the initial pH of the peat-sand mix to about 4·7 and 5·6 respectively) gave the best germination, height growth and out-turn of usable seedlings of both species and with both fertiliser regimes, with little to choose between the two rates. It appeared probable that an intermediate rate of 3 kg/m^3 would be near the optimum (giving a pH (in water) of 5·0–5·5).

The addition of fritted trace elements (Frit 253A) to the soil mix was adopted in 1970 as part of the "standard" treatment. This was done because peat-sand "composts" are likely to be deficient in trace elements (micro-nutrients) unless these are supplied as part of the fertiliser regime (see e.g. Birch, 1970b). Initially, frit was added at a rate of 0·5 kg/m^3 and a set of experiments was carried out to study the effect on germination and growth of Lodgepole pine and Sitka spruce seedlings when frit was included in contrasting fertiliser regimes based on "Enmag" and on "FL3P". Ground limestone was added in each case at 0·5 kg/m^3.

On average, seedling out-turn and growth of both species were appreciably reduced by the addition of frit to the soil mix. Cotyledon "tip-burn" symptoms occurred, particularly with "FL3P" fertiliser and these were attributed to the presence of toxic levels of trace elements. It was concluded that the relatively low pH of the soil mix was leading to excessive solubility of the trace element frit, and that the quantity of frit used was probably too high. The experiments were therefore re-sown with the limestone addition increased to 1·5 kg/m^3 and the frit level halved to 0·25 kg/m^3. Results are summarised in Table 3 which shows that the use of frit tended to reduce germination and seedling out-turn, although the differences seldom reached significance. Height growth differences were usually small and inconsistent although there was some evidence from Tulliallan that the effect of frit was beneficial for Lodgepole pine when used with "Enmag" and for Sitka spruce when used with "FL3P". The changes in frit and limestone levels used eliminated the occurrence of cotyledon tip-burn in all cases except that of Lodgepole pine at Inchnacardoch raised with frit and "FL3P".

(4) 1971 Experiments: The use of trace element frit 253A in relation to fertiliser regime and rate of limestone addition was further investigated in two new experiments at Inchnacardoch and Newton. The basic fertiliser regimes were provided by "Enmag" at 1·5 kg/m^3, and by "FL3P" at 3 ml/litre watered on 3, 4, 5, 6 and 7 weeks after sowing. Each one was tested with and without addition of trace element frit at 0·25 kg/m^3 and with ground limestone rates of 0, 2 and 4 kg/m^3 of soil mix.

Results from the experiment at Inchnacardoch are summarised in Table 4. Those from Tulliallan were basically the same. At both centres, the addition of frit in the absence of ground limestone produced cotyledon tip-burn on both Lodgepole pine and Sitka spruce with both fertiliser regimes. This damage, which was more pronounced with "FL3P" than with "Enmag" fertilisation, did not extend to the primary needles and became inconspicuous within 8 weeks from sowing. Frit addition improved growth slightly (and significantly) for both species at Inchnacardoch, but had little influence on seedling numbers at either centre. Omission of ground limestone resulted in a distinct drop in seedling out-turn for both pine and spruce at Tulliallan and for spruce only at Inchnacardoch; it also led to a generally significant reduction in height growth of both species at both centres (particularly when "Enmag" fertiliser was used). There was little to choose between results obtained using limestone at 2 and 4 kg/m^3. The use of "FL3P" fertiliser gave significantly higher seedling numbers for Sitka spruce at Inchnacardoch and for both species at Tulliallan, although this was almost certainly due in part to the poor results produced by "Enmag" in the absence of limestone. Growth of Lodgepole pine but not Sitka spruce tended to be better with "Enmag" than with "FL3P".

Neither the 1970 nor the 1971 experiments pro-

Table 3

EFFECT OF TRACE ELEMENT FRIT 253A (AT 0·25 KG/M³ OF PEAT-SAND) ON SEEDLING NUMBERS AND GROWTH IN EXPERIMENTS AT INCHNACARDOCH (I), NEWTON (N) AND TULLIALLAN (T) (SECOND SOWING)

Species	Fertiliser treatment	Germination % at 3 weeks after sowing						Mean height (cm) at 8 weeks						Usable out-turn % at 8 weeks					
		I		N		T		I		N		T		I		N		T	
		Frit	O	Frit	O	Frit	O	Frit	O	Frit	O	Frit	O	Frit	O	Frit	O	Frit	O
Lodgepole pine	"Enmag" (E)	78	80	54	68	74	68	3·8	3·6	2·5	2·8	3·6	3·1	79	80	52	62	72	64
	"FL3P" (L)	80	85	65	70	80	82	3·6	3·4	2·4	2·5	3·1	3·1	80	84	59	66	76	76
	Significant differences	—	—	—	—	L>E**	—	—	—	—	—	Inter-action*		—	—	O>F*	—	—	—
Sitka spruce	"Enmag" (E)	77	79	42	60	74	76	3·1	3·1	1·7	2·1	2·5	2·5	74	77	36	52	62	70
	"FL3P" (L)	81	80	56	54	78	86	3·0	3·0	1·7	1·8	2·4	2·6	78	78	31	41	70	84
	Significant differences	—	—	—	—	—	—	—	—	O>F*	—	Inter-action*		—	—	—	—	L>E** O>F*	—

Note: * significant at 5% level; ** significant at 1% level.

Table 4

EFFECT OF DIFFERING FERTILISER REGIMES ON SEEDLING NUMBERS AND GROWTH IN AN EXPERIMENT AT INCHNACARDOCH IN 1970

Species	Fertiliser treatment	Trace elements	Germination % at 3 weeks after sowing				Mean height (cm) at 8 weeks				Usable seedling out- turn % at 8 weeks			
			Limestone rate (kg/m³)			Mean	Limestone rate (kg/m³)			Mean	Limestone rate (kg/m³)			Mean
			0	2	4		0	2	4		0	2	4	
Lodgepole pine	"Enmag"	Frit	94	92	98	94·6	4·3	4·7	4·7	4·6	92	92	96	93·3
		0	98	96	96	96·6	4·1	4·4	4·2	4·2	94	96	96	95·3
	"FL3P"	Frit	94	96	96	95·3	4·2	4·1	3·8	4·0	94	94	96	93·7
		0	98	96	94	96·0	3·8	4·0	4·0	3·9	96	92	90	92·7
	Mean		96·0	95·0	96·0	95·6	4·1	4·3	4·2	4·2	94·0	93·0	94·5	93·8
Sitka spruce	"Enmag"	Frit	80	90	88	86·0	2·6	2·8	2·9	2·8	64	82	82	76·0
		0	70	90	86	82·0	2·5	2·7	2·8	2·7	52	82	78	70·7
	"FL3P"	Frit	92	94	92	92·7	2·5	2·9	2·9	2·8	82	90	90	87·3
		0	86	92	92	90·0	2·5	2·7	2·8	2·7	82	90	90	87·3
	Mean		82·0	91·5	89·5	87·7	2·5	2·8	2·8	2·7	70·0	86·0	85·0	80·3

vided any evidence of a worthwhile benefit during the greenhouse phase resulting from the addition of trace element frit to the soil mix. However, the practice was continued because it appeared to give slightly better height growth in forest trials which will be described later.

Growing Medium

Preliminary trials in 1967 had indicated that a mixture of equal parts by volume of screened horticultural sphagnum peat and lime-free medium sand (i.e. a sand with a high proportion of particles in the 0·6–0·2 mm category) was a suitable medium for filling the tubes. However, in 1968, experiments were carried out to compare the effectiveness of a range of growing media for tubed seedling production. The materials tested were:

(a) Screened fine grade horticultural sphagnum peat (pH 3·5–4·0);
(b) Sphagnum peat and medium sand, two parts: one part by volume;
(c) As for (b), but peat/sand ratio 1 : 1 ("standard" mix);
(d) As for (b), but peat/sand ratio 1 : 2;
(e) John Innes seed compost mixture—2 parts sterilised soil : one part peat : one part sand;
(f) "Levington" peat potting compost (a proprietary preparation of fertilised peat).

"Enmag" fertiliser and ground limestone were added at rates of 1·5 kg/m^3 and 0·5 kg/m^3 respectively to all except the "Levington" compost which already contained fertiliser and limestone in unspecified quantities.

Results from all three centres were very similar and showed that there was little to choose between the three peat-sand mixtures and the John Innes seed compost mixture as regards germination, height growth, usable out-turn and root development. Pure peat tended to give slightly poorer results, while "Levington" compost proved much inferior to the other soil mixes, possibly because of its relatively high pH. From the handling viewpoint, it was more difficult to fill tubes satisfactorily with pure peat or "Levington" compost than with the other materials. The John Innes mixture suffered from the basic inconvenience of requiring sterilisation of the soil component. (*Note:* Seedlings raised using soil media (a), (c), (e) and (f) were planted during 1968 in forest trials which will be described later.)

Seed Cover Depth and Time of Application

A medium grade of lime-free sand was selected as the most appropriate material for covering seed after sowing. In 1968, a set of experiments compared 5 depths of seed cover—0, 1·6, 3·2, 4·8 and 6·4 mm (actually 0, 1/16, 1/8, 3/16 and $\frac{1}{4}$ in.). Two times of application were also compared—immediately after sowing and after a delay of five days. The latter was included because of its successful use in tubed seedling production in Alberta (Carman, 1967).

Results for the second sowing at the three centres are given in Table 5. In general, the "standard" depth of 3·2 mm was best for both Lodgepole pine and Sitka spruce, closely followed by 1·6 mm, while 4·8 mm usually gave only slightly inferior results. The deepest cover depth (6·4 mm) depressed germination and growth. Omitting seed cover (treatment 0) gave very poor results with high losses after initially good germination, and frequent abnormal seedling development. There were no worthwhile differences related to time of application, and covering at time of sowing is obviously preferable on grounds of convenience.

Tube Length

A further set of experiments in 1968 compared tube lengths of 7·5, 10 and 12·5 cm to determine whether or not any problems would arise if seedlings were raised in tubes longer than the "standard" 7·5 cm size.

Results from the three nurseries were not entirely consistent, but in general there appeared to be little difference between the 7·5 and 10 cm lengths, while the 12·5 cm length tended to give somewhat poorer germination and growth. It seemed possible at the time that the longest tubes dried out more rapidly after watering than the shorter sizes or alternatively that trays of the shorter sizes in the experiments benefited to some extent from shading by trays of the longest size.

Root Control by Copper Paint

It is common to find vigorous roots emerging from tube bases before seedlings are ready for planting, and these roots are usually broken during the planting operation. Work in Canada (Saul, 1968) indicated that this root emergence and subsequent loss could be prevented by applying copper paint to the bases of the trays used to hold the tubes, and a trial was carried out at Tulliallan in 1968 to confirm this for Lodgepole pine and Sitka spruce. It was found that two different brands of copper paint effectively prevented root emergence of both species for the duration of the experiment (12 weeks from sowing). Apart from a slight height reduction in Lodgepole pine seedlings when 12 weeks old, there was apparently little effect on shoot growth or on the root/shoot ratio of the seedlings.

Despite the apparent lack of any harmful effects resulting from the copper paint treatment, it was decided at the time not to use such treatment as standard practice until more was known about its effect on growth after planting in the forest. The results of the forest extension trials involved will be described later. However, recent Canadian work has

Table 5

EFFECT OF SEED COVER DEPTH AND TIME OF APPLICATION ON SEEDLING NUMBERS AND GROWTH IN EXPERIMENTS DURING 1968

Species	Depth of sand cover (mm)	Germination % at 4 weeks after sowing						Mean height (cm) at 8 weeks						Usable seedling out-turn % at 8 weeks					
		Inchna-cardoch		Newton		Tulliallan		Inchna-cardoch		Newton		Tulliallan		Inchna-cardoch		Newton		Tulliallan	
		ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D
Lodgepole pine	0	72	77	73	73	40	34	1·8	2·0	2·5	2·7	3·4	3·4	(Not assessed)		34	35	32	28
	1·6	71	63	77	78	80	76	2·6	2·6	2·5	2·4	3·1	3·3			68	65	66	70
	3·2	67	59	86	75	82	74	2·8	2·7	2·5	2·2	3·1	3·1	—	—	81	63	78	72
	4·8	57	55	71	57	70	76	2·6	2·6	1·8	1·7	2·6	2·7	—	—	67	52	64	72
	6·4	51	59	47	33	64	62	2·5	2·5	1·5	1·5	2·4	2·6	—	—	40	28	52	58
	Mean	64	63	71	63	66	64	2·5	2·5	2·1	2·1	2·9	3·0	—	—	58	48	58	60
Sitka spruce	0	74	67	80	66	32	28	1·9	2·3	2·3	2·3	2·7	2·8	(Not assessed)		42	24	14	16
	1·6	62	67	81	75	72	68	2·0	2·2	2·4	2·5	2·7	2·8			67	65	66	62
	3·2	64	58	71	72	70	78	2·5	2·3	2·2	2·0	2·6	2·6	—	—	65	61	66	68
	4·8	56	54	54	53	68	70	2·1	2·3	1·7	1·7	2·3	2·4	—	—	47	45	62	66
	6·4	49	63	35	32	60	66	1·9	2·3	1·4	1·6	2·2	2·2	—	—	31	31	58	66
	Mean	61	62	64	59	60	62	2·1	2·3	2·0	2·0	2·5	2·6	—	—	50	45	53	54

Note: ND—Sand applied immediately after sowing; D—Sand applied after a delay of 5 days.

cast doubt on the desirability of using copper paint to control root growth in the greenhouse (Hocking, 1972). Lodgepole pine seedlings raised in copper painted trays were found to have a very high content of copper in their roots, and showed some inhibition of shoot growth. Control of root growth by growing seedlings in trays with perforated bases over an air space has recently been recommended by Scarratt (1972a) as being more effective than use of copper paint.

Fungicidal Treatment

The use of thiram seed dressing and post-germination drenching with captan were adopted in 1968 from common horticultural practice as part of the "standard" technique. To test the effects of these treatments on seedling growth, experiments were sown at the beginning and end of the 1969 growing season, and again at the beginning of the 1970 growing season. Seed was sown with and without a dressing of thiram (added to the dry seed at 1% by weight). Subsequently trays either received no further fungicidal treatment or were drenched (2·5 litre/m^2) with captan suspension (at the manufacturer's recommended concentration of 0·1% active ingredient) at 2 and 4 weeks or at 1, 2, 3 and 4 weeks after sowing.

During the course of the experiments sown at the beginning of both growing seasons, the humid, relatively cool conditions in the greenhouses were expected to favour fungal damage. However, although relative treatment differences were somewhat variable, omission of both seed dressing and drenching frequently gave as good results as any other treatment at all three centres. There was rarely any evidence of a positive benefit resulting from use of either fungicide. In a number of cases both seed dressing and to a lesser extent drenching caused a significant reduction in seedling numbers and heights; the more frequent captan drenching produced more obvious reductions than the less frequent. As far as captan treatment is concerned the results obtained agree with those of Denne and Atkinson (1973) who found that captan drenching reduced growth of young Scots pine (*Pinus sylvestris* L.), Sitka spruce, and Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings.

Following completion of the experiments, use of a thiram-based seed dressing was omitted from the "standard" treatment. Drenching with captan continued to be used as a regular prophylactic measure 2 and 4 weeks after sowing, but it is now considered that drenching should be used only when conditions in the greenhouse appear particularly conducive to fungal attack.

Use of Graded Seed

In the production of tubed seedlings, it is important to obtain rapid germination of the maximum possible number of seeds sown. Use of weight-graded seed of both Lodgepole pine and Sitka spruce was tested as a possible aid to achieving this aim. Contrasting seed grades were produced for the purpose by fractionating bulk seed lots on a vibrating gravity table. Experiments in 1969 compared three grades (heavy, medium and light) with normal ungraded seed. In all cases either the heavy or the medium grade gave the best germination, although the difference between these and the normal ungraded seed was often small and not statistically significant. The light grade usually gave distinctly poorer germination, particularly in the case of Lodgepole pine. A similar pattern of variation was shown by numbers of usable seedlings 8 weeks after sowing. Height growth differences were usually less pronounced and more variable, but on average the heavy and medium seed again gave the best preformance, with normal ungraded seed only slightly poorer.

A further set of experiments in 1970 compared 6 grades of seed, normal ungraded seed and seed from which the lightest fraction (approximately 1/5th by volume) had been removed by gravity table treatment. For both species, germination and number of usable seedlings was consistently (and significantly) lower for the lightest grade than for the other treatments, and the second lightest grade also tended to give poorer results for Sitka spruce. There was relatively little difference between the remaining four grades, normal seed and seed with the light fraction removed. Height growth differences were somewhat inconsistent, but there was some indication of a decreasing trend from the heaviest to the lightest grade.

Ackerman and Gorman (1969) had found in Canada that early growth of Lodgepole pine and White spruce (*Picea glauca* (Moench.) Voss) seedlings was influenced to some extent by seed weight. In the present study it was therefore surprising to find that, apart from the poorer performance of the lightest seed, there were no important differences between the various seed grades tested. However it later became apparent that the grading method used in preparation for the present study had probably not produced sufficiently discrete grades in that the seed weight ranges overlapped considerably; only the lightest grade was likely to be consistently reproducible.

From the results there appeared to be some possibility of obtaining a small improvement in tubed seedling germination and out-turn through the use of seedlots from which the lightest fraction had been removed. It was therefore decided to adopt the use of such seed in the "standard" technique because even a small gain is of value when only one seed is sown in each tube.

Use of Pelleted Seed

Seed pelleting was developed in horticulture to facilitate the handling of small and/or irregularly shaped seed. Each seed is coated with an inert clay-like substance to increase its size and produce a rounded shape suitable for precision sowing by machine. In view of the small size of Lodgepole pine and Sitka spruce seed and the desirability of developing mechanical sowing equipment for tubed seedling work, arrangements were made for some seed of both species to be pelleted commercially prior to sowing in tubes during 1969.

In comparison with normal seed the use of pelleted seed substantially reduced total germination (often by as much as 50%). The start of germination was slightly delayed and seedling growth was somewhat poorer. Laboratory examination of samples from the same batches of pelleted seed demonstrated that the reduction in germination was not due to damage sustained during the pelleting process. Furthermore, when sown in open nursery seedbeds, the pelleted seed gave results only marginally poorer than those for unpelleted seed.

Two further small trials in 1970 compared normal Sitka spruce seed and two types of pelleted seed: (a) "Full coat" pelleted (similar to the pelleting tested in 1969; and (b) "mini-pelleted", with a much thinner coating of the pelleting material. In these trials the poor germination in tubes of full-pelleted seed was confirmed. Results for mini-pelleted seed fell between those for full pelleted and unpelleted seed.

Trials of Other Conifer Species in Tubes

(1) Grand fir: In 1968, the scope of tubed seedling forest trials was extended to include replanting of felled areas. Because of the potential usefulness of Grand fir (*Abies grandis*) on such sites, a preliminary study was made of its behaviour when sown in tubes. As was anticipated, the start of germination was much delayed in comparison with Lodgepole pine and Sitka spruce, and, once started, proceeded very slowly and irregularly. Approximately 12% of unstratified seed germinated, while seed given cold-wet stratification (pre-chilling) in a refrigerator for two weeks prior to sowing gave negligible germination. A considerable number of the seedlings which germinated died later from what appeared to be fungal damage despite regular use of a captan drench.

A further trial of Grand fir in 1969 confirmed the difficulty of raising this species in tubes, although results were better than those obtained in 1968. Seed pre-chilled for 3 weeks before sowing gave considerably faster and higher germination than untreated seed. Germination was considerably better with 6 mm of seed cover than with 12 mm, and liquid fertilising with "FL3P" gave somewhat better results than "Enmag" added before sowing. However the most striking feature was the high seedling mortality which occurred soon after germination, and was frequently associated with stem breakage of the emerging seedlings. It may well be that the standard 1·3 cm diameter tube was too narrow to allow the germinating Grand fir seedling sufficient freedom of movement for satisfactory emergence from the soil; such stem breakage was rare in the case of some seedlings raised in 1·8 cm diameter tubes for forest use.

(2) Other Species: The germination and growth in tubes of Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville), Norway spruce (*Picea abies* (L.) Karst.), Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) and Western hemlock were investigated in a general trial, using two fertiliser regimes (based on "Enmag" at 1·5 kg/m^3 of soil mix and on "FL3P" at 3 ml/litre) and two depths of seed cover (3 and 6 mm). For all four species there were no outstanding differences between the fertiliser treatments but in each case the deeper seed cover reduced both germination and growth (see Table 6). The results indicated that there should be no major problem in raising Corsican pine and Norway spruce in tubes using the "standard" technique; both species germinated rapidly and evenly, grew vigorously and gave a high out-turn usable seedlings. Douglas fir seemed likely to be a more difficult species to raise in this way because of its slow germination and considerably lower seedling out-turn. Germination of Western hemlock was very poor, confirming what had already been found when attempting to produce seedlings of this species for forest experiments.

Table 6 GERMINATION, GROWTH AND OUT-TURN OF CORSICAN PINE, NORWAY SPRUCE, DOUGLAS FIR AND WESTERN HEMLOCK SOWN IN TUBES

Species	Fertiliser regime	Germination % at 4 weeks after sowing		Mean height (cm) at 8 weeks		Usable out-turn % at 8 weeks	
		Seed cover depth		Seed cover depth		Seed cover depth	
		3 mm	6 mm	3 mm	6 mm	3 mm	6 mm
Corsican pine	"Enmag"	90	70	3·1	2·4	84	65
	"FL3P"	79	81	2·8	2·3	74	77
Norway spruce	"Enmag"	68	59	2·2	2·2	62	52
	"FL3P"	74	66	2·2	1·9	68	53
Douglas fir	"Enmag"	54	26	3·7	2·4	51	39
	"FL3P"	55	26	3·1	2·3	50	22
Western hemlock	"Enmag"	20	7	1·1	1·0	18	6
	"FL3P"	21	4	1·1	12·	13	4

Chapter 3

FOREST TRIALS OF TUBED SEEDLINGS

Introduction

The earliest forest trials of tubed seedlings in Britain (six in all) were planted near the end of the 1967 growing season at two forests in North Scotland. Since then, 71 more experiments have been planted (59 of them between 1968 and 1970), mainly at forests in North, West, and South Scotland Conservancies, with a few in North East and East England and in Wales. Most of the work has been concerned with the possible use of tubed seedlings for the afforestation of ploughed peatland in upland areas. However, between 1968 and 1970 12 trials were planted on ploughed upland mineral soils; and some attention was also given to the performance of tubed seedling stock when used for regeneration planting, particularly on clear-felled spruce sites.

In almost all cases, simple randomised block designs were used, with double line plots (2 × 20 or 2 × 25 plants along adjacent plough ridges) on ploughed ground and rectangular 20–40 plant plots on regeneration sites. The species used were Lodgepole pine (almost entirely of coastal Washington or Oregon provenances) and Sitka spruce (of Queen Charlotte Islands provenance) in afforestation trials, and Sitka spruce, Norway spruce, Western hemlock, Grand fir and Corsican pine in regeneration trials. Factors tested in the experiments include date of planting, seedling age at time of planting, tube length, method of planting, position of planting, method of step cutting, forest fertiliser regime and use of herbicides for weed control, as well as greenhouse treatments such as fertiliser regime, soil mixture in the tube, and control of root growth by copper paint. Until 1971, almost all planting was done using a simple steel dibble. Initially the length of the dibble saw such as to leave approximately 1 cm of the tube protruding from the soil surface; but since 1968 it has been considered desirable to insert tubes completely into the soil, preferably with the top edge slightly below the soil level, so as to make them less conspicuous to animals. From 1971 onwards, planting has been done using a specially devised peat planting tool which will be described later. On peat sites almost all planting has been done in "steps" cut in the sides of single mouldboard plough ridges (Plate 5).

In 1971, large scale "user" trials of tubed seedlings for peatland afforestation were begun in the North (Scotland) Conservancy. These trials are continuing on an increasing scale and approximately 600,000 seedlings were planted during the 1973 growing season.

As in the case of the nursery research programme, it is not possible to describe in detail the large number of experiments involved. Information on them has been summarised in the following sections.

AFFORESTATION EXPERIMENTS ON PEAT

Five major locations were used for the experiments planted on ploughed peatland: Naver Forest (Sutherland), Shin Forest (Sutherland), Farigaig Forest (Inverness-shire), Tighnabruaich Forest (Argyll) and Selm Muir Forest (Midlothian). Experiments were also planted at Rumster Forest (Caithness), Minard Forest (Argyll), Lleyn Forest (Caernarvonshire) and Tywi Forest (Mid Wales). The selected sites lay either on poorly flushed blanket bog or on unflushed hill peat, with the ground vegetation consisting of *Calluna vulgaris*, *Trichophorum caespitosum*, *Molinia coerulea*, *Eriophorum* species, *Erica tetralix* and *Sphagnum* species in varying proportions. (Occasionally the peat depth was less than 45 cm and in strict accordance with Forestry Commission site survey practice the soil would have been classed as a peaty gley rather than a peat. However, for tubed seedling purposes, all sites on which the plough ridges consisted entirely of peat were included as peat sites.) In each case the application of phosphate fertiliser at time of planting was considered essential for successful establishment of a tree crop. Sites ranged in elevation from 500 to 1,200 ft above sea level. Many were subject to a considerable degree of wind exposure and none could be regarded as sheltered.

Planting Season

To define the effective planting season for Lodgepole pine and Sitka spruce tubed seedling stock on peatland, 11 experiments were planted between 1968 and 1971 at forests in North, West and South Scotland. The results of planting at monthly intervals from mid May to mid October were compared in two experiments planted during 1968 at Naver and Tighnabruaich Forests. During 1969, planting dates from mid April to mid October were tested in three experiments at Shin, Tighnabruaich and Selm Muir Forests. In both these years, all seedlings planted were growing actively (i.e. were non-dormant) when planted. Four experiments planted during 1970 (at Shin, Farigaig, Selm Muir and Minard Forests) included the use of dormant seedlings; these were planted in mid March and mid April, and were compared with non-dormant stock planted from mid April to mid October. Finally, during 1971 the performance of dormant stock planted in March and April were further investigated in two experiments at Farigaig and Selm Muir, and compared with non-dormant stock planted between April and June (Selm Muir) or April and August (Farigaig). In both seasons the dormant seedlings used were raised during the preceding autumn, allowed to become dormant in November, 8 weeks after sowing, and overwintered out of doors until planted.

All the experiments except the two planted in 1971 involved the use of 8 week and 12 week old seedlings on each planting date. However, the effect of seedling age on survival and growth in these and other experiments will be discussed in a later sub-section.

Figures 1–4 illustrate results obtained for Lodgepole pine and Sitka spruce in several of the experiments. However, the following description of results is based on data from all 11 experiments involved and not just those illustrated. Except where otherwise specified it refers to both Lodgepole pine and Sitka spruce because the overall pattern has been similar for the two species.

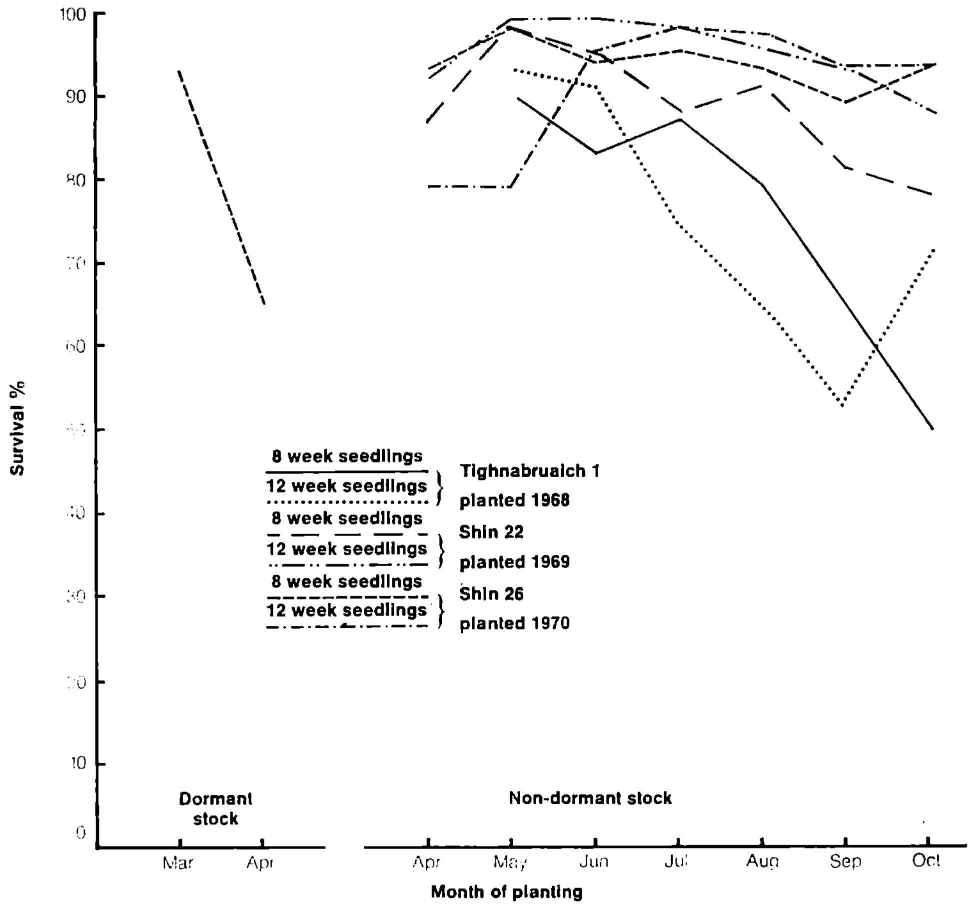

Figure 1. Effect of planting date on survival of Lodgepole pine after the second winter.

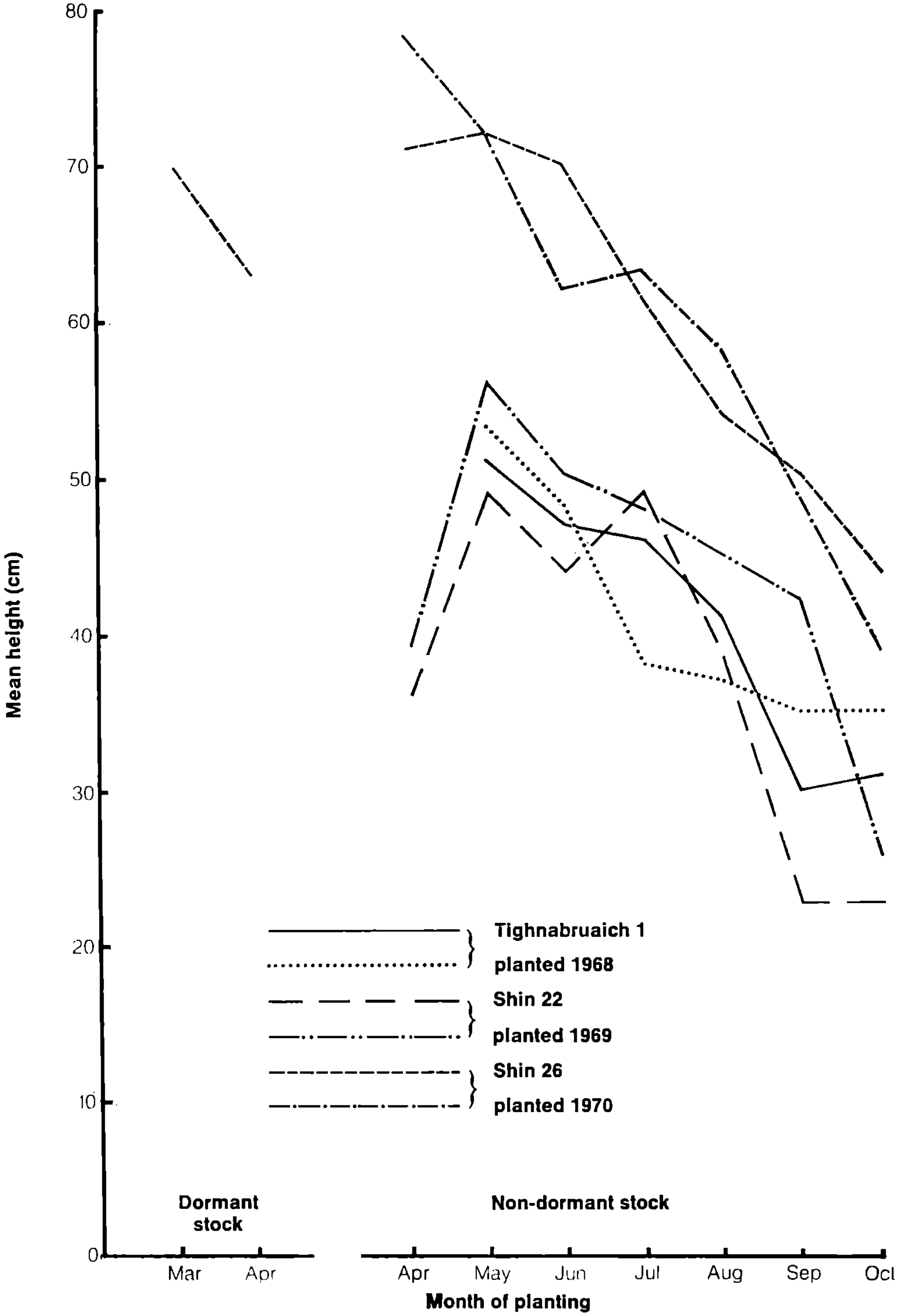

Figure 2. Effect of planting date on mean height of Lodgepole pine after 4 growing seasons.

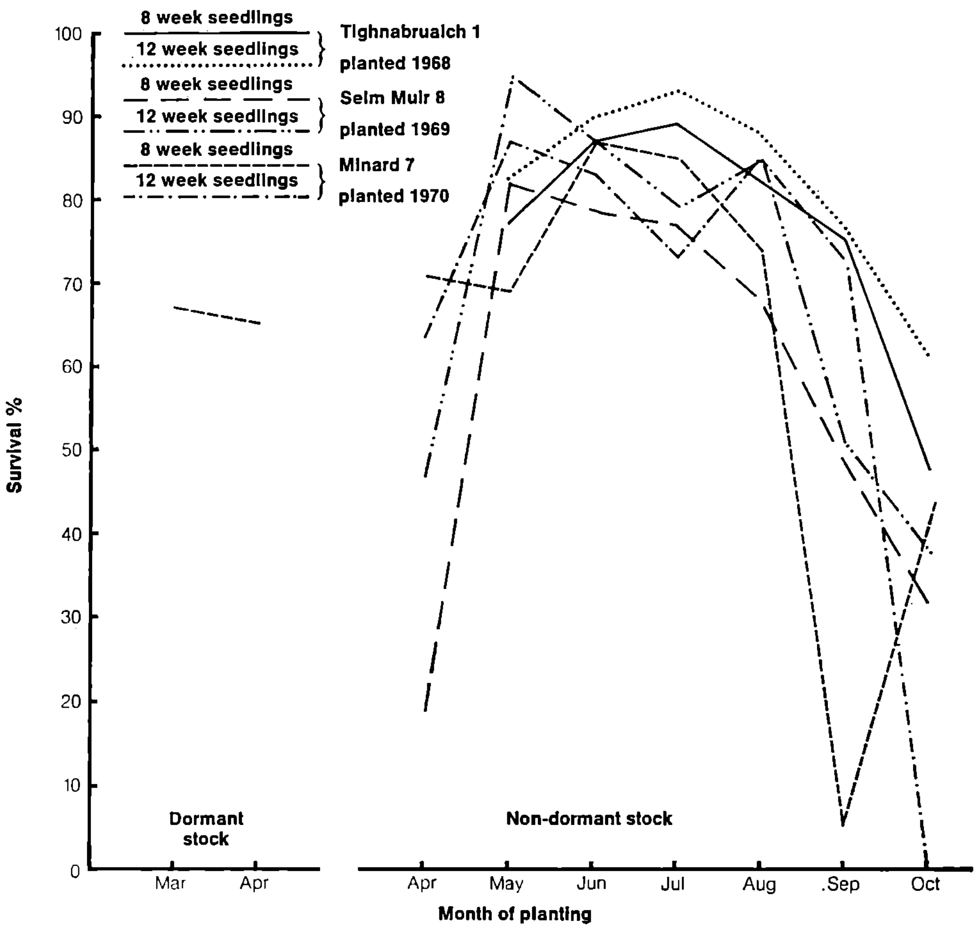

Figure 3. Effect of planting date on survival of Sitka spruce after the second winter.

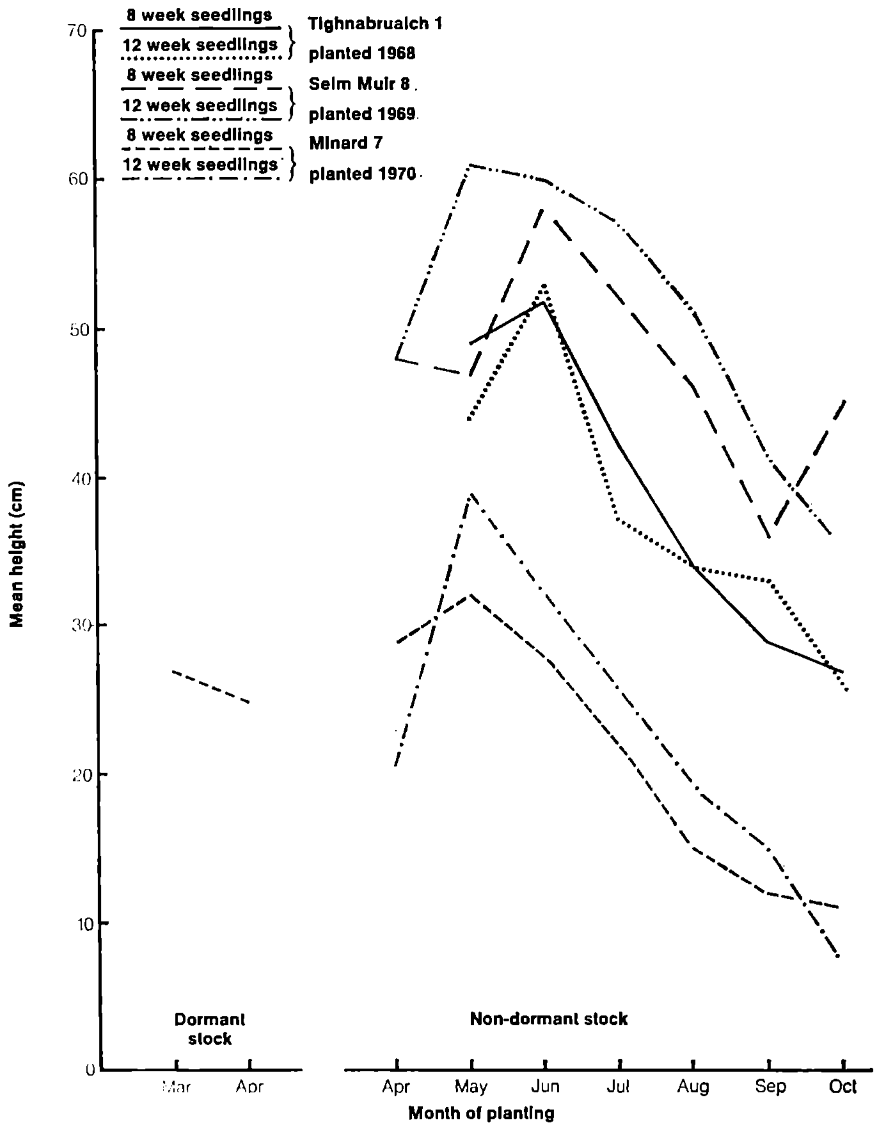

Figure 4. Effect of planting date on mean height of Sitka spruce after 4 growing seasons. (Note: Growth in all treatments at Minard has been retarded by browsing damage).

Considering first the use of non-dormant seedlings, survival has generally been highest for planting between May and July (often over 90% after the second winter, and seldom less than 80%), somewhat lower for April and August, and progressively poorer for September and October. Results for planting early (April) and late (August–October) in the growing season have varied more widely between experiments than those for May–July planting, and almost certainly reflect climatic differences between sites and years. For example, in several experiments planted during 1970, survival was only slightly poorer for planting from August to October than for mid-summer planting. This result was probably associated with the mild winters of 1970–1971 and 1971–1972. In a number of instances damage by late spring frosts reduced survival of seedlings planted in mid-April (particularly in the case of Sitka spruce). It appeared that the occurrence of strong cold winds was also liable to reduce survival of spring planted seedlings.

Height growth has to some extent followed a similar pattern in that the best results have been obtained for planting between May and July, and the poorest for planting in September and October (see Plate 6). However, a more definite decreasing trend from May to October is apparent in most experiments. By the end of the fourth growing season, the mean height of October planted seedlings was seldom much more than half that of seedlings planted in May and June. Results for April planting have been variable, sometimes rivalling those for May planting and sometimes decidedly poorer. In the latter case, poor growth has been due either to spring frost damage, or to seedlings having stopped growing and developed terminal buds soon after planting if cold weather persisted at the time.

Dormant seedlings planted in mid March and mid April were included in the 1970 and 1971 experiments to see if their use would provide a means of avoiding the variable survival and growth shown by non-dormant seedlings planted in April. In fact, results for dormant stock have also shown considerable variation. Somewhat surprisingly, survival of dormant seedlings planted in March and April has on balance been only marginally better than that of April-planted non-dormant stock, and consequently poorer than that for seedlings planted in May–July. Average height growth has on the whole been less variable than survival; it tended to be slightly better for seedlings planted when dormant (both months of planting) than for non-dormant seedlings planted in April, and has usually been comparable with that for May-planted seedlings. However, in plots planted with dormant stock there often appeared to be a wider range of individual tree heights than in plots planted with non-dormant stock, and this was probably related to erratic flushing of dormant stock in the season of planting.

At most of the experimental locations, survival and height data indicate an effective planting season for non-dormant seedlings from mid April to late August, with the optimum period from May to July inclusive. Dormant seedlings could if necessary be used for early planting in both March and April, but survival may not be very reliable (and there are also potential problems in raising and over-wintering large numbers of seedlings). In areas prone to late spring frosts or to severe weather conditions in spring, April planting of non-dormant stock appears undesirable, particularly for Sitka spruce seedlings.

Seedling Age at Time of Planting

Canadian experience with several coniferous species and the results of preliminary trials in Britain suggested that seedlings would probably be sufficiently well developed for successful forest planting 8 weeks after sowing. To determine whether there was any advantage in using older and therefore larger plants, 8-week and 12-week-old seedlings were compared in the majority of the planting season experiments, and in a few of the experiments concerned with other aspects of tubed seedling use. The results for both seedling ages in several of the planting season experiments have been included in Figures 1–4, but easier comparison is possible in Figures 5–8. These show for each month of planting the extent to which survival and mean height were higher or lower for 8 week than for 12 week old stock. A positive difference indicates that the result was better for 8 week than for 12 week old seedlings, and a negative one that the reverse was true.

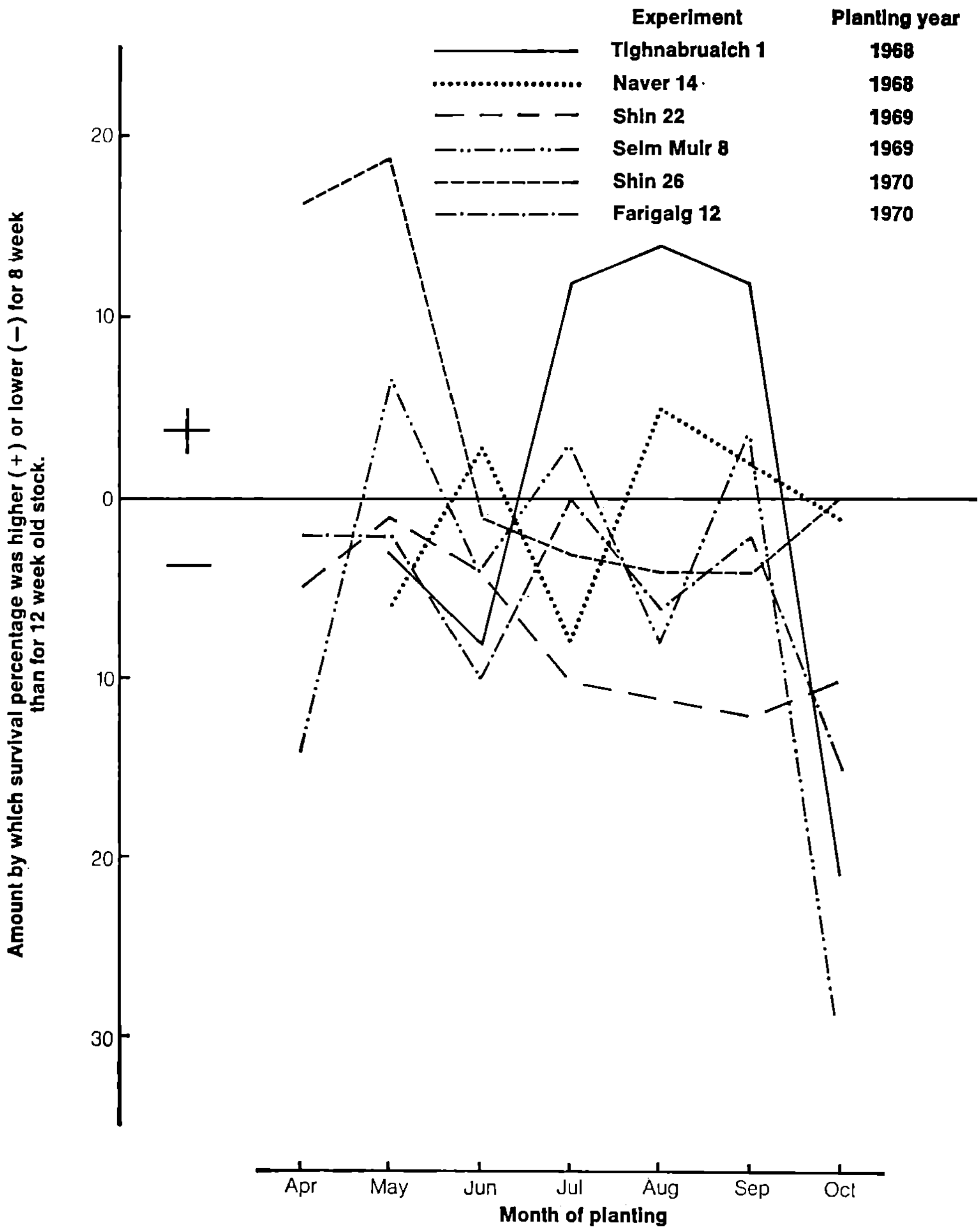

Figure 5. Comparison of survival after the second winter for 8 and 12 week old Lodgepole pine stock planted between April and October.

Plate 1. Eight-week-old Lodgepole pine tubed seedling ready for planting. A3702.

Plate 2. Interior view of polythene house used for tubed seedling production at Inchnacardoch Forest, Fort Augustus, Inverness-shire. Note oil-fired warm air heater at rear and trays of 5-week-old Lodgepole pine seedlings on benches. A4387.

Plate 3. Tray of 440 eight-week-old Lodgepole pine seedlings ready for planting. A3720.

Plate 4. Typical greenhouse experiment at Tulliallan Nursery, Devilla Forest, Fife (in this case testing fertiliser regimes). Each of the 24 trays contains 100 tubes—50 sown with Lodgepole pine (on the left) and 50 with Sitka spruce (on the right). A3774.

Plate 5. Sitka spruce step-planted as an 8-week-old tubed seedling on an upland peat site in June 1969 and photographed 16 months later. Note the planting "step" (cut by hand) in the single mouldboard plough ridge. The scale is 30 cm long. Farigaig Forest, Inverness-shire. A3848.

Plate 6. Effect of planting date on the performance of Lodgepole pine tubed seedling stock after 4 seasons growth on an upland peat site at Shin Forest, Sutherland. Foreground row of trees was planted in September 1969; adjacent two rows behind were planted in June of the same year. A4407.

Plate 7. Single mouldboard plough fitted with a "Logan" sock (above), which produces a continuous step along the peat ridge (below). A4417 and A4415.

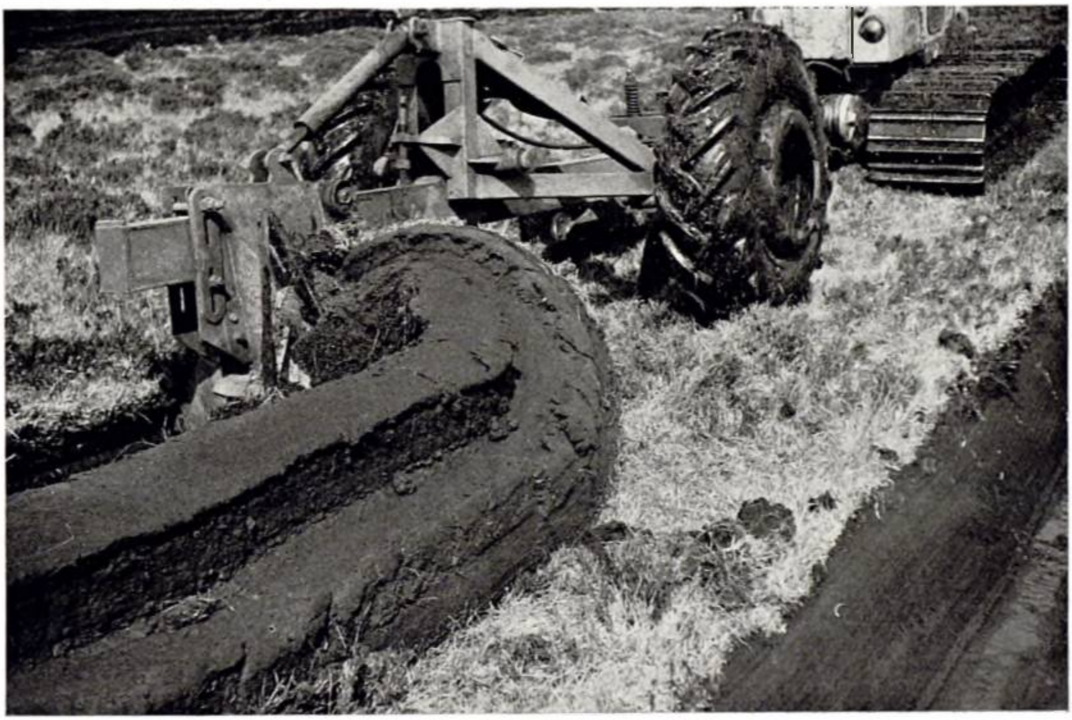

Plate 8. Lodgepole pine tubed seedling stock after four years growth on a poorly-flushed blanket peat at Shin Forest, Sutherland. Planting was done in July 1969. A spacing of 1 m along ridges was used to reduce the area occupied by the trial. A4408.

Plate 9. Sitka spruce step-planted in June 1969 as an 8-week-old tubed seedling on a poorly-flushed blanket peat, and photographed in September 1971 after three years growth. Scale is 50 cm long. Selm Muir, Clydesdale Forest, Midlothian. A3896.

Plate 10. Lodgepole pine (of coastal Washington provenance) step-planted in June 1968 as 8-week-old tubed seedlings on a poor blanket peat, and photographed after five years growth. Stems have remained straight and upright despite vigorous growth. A spacing of 1 m along ridges was used to reduce the area required for the experiment. Tighnabruaich Forest, Argyll. A4394.

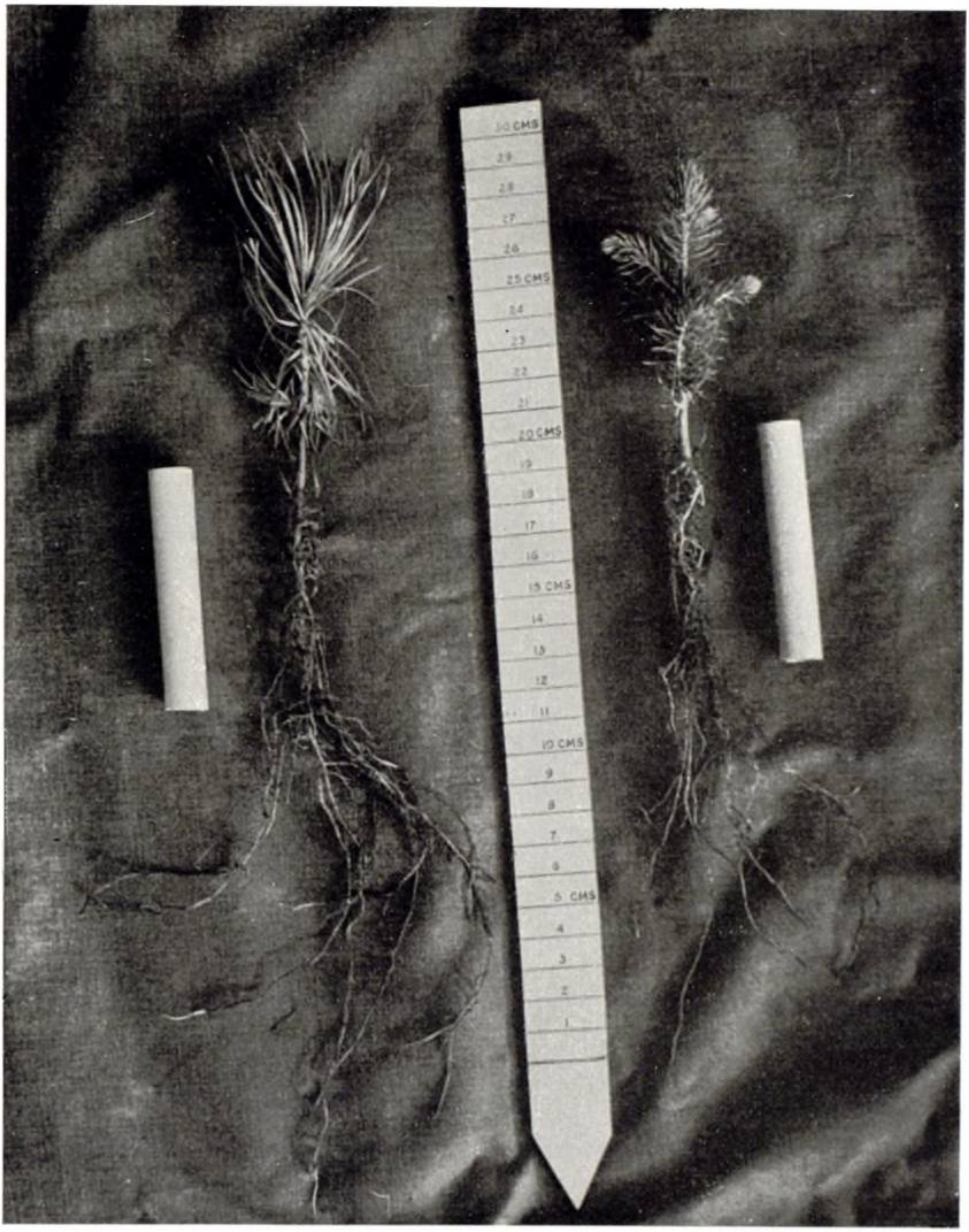

Plate 11. Root systems of Lodgepole pine and Sitka spruce tubed seedlings planted in August 1968 and excavated at the end of the 1969 growing season. Unflushed basin peat at Eddleston, Glentress Forest, Peebles-shire. A3744.

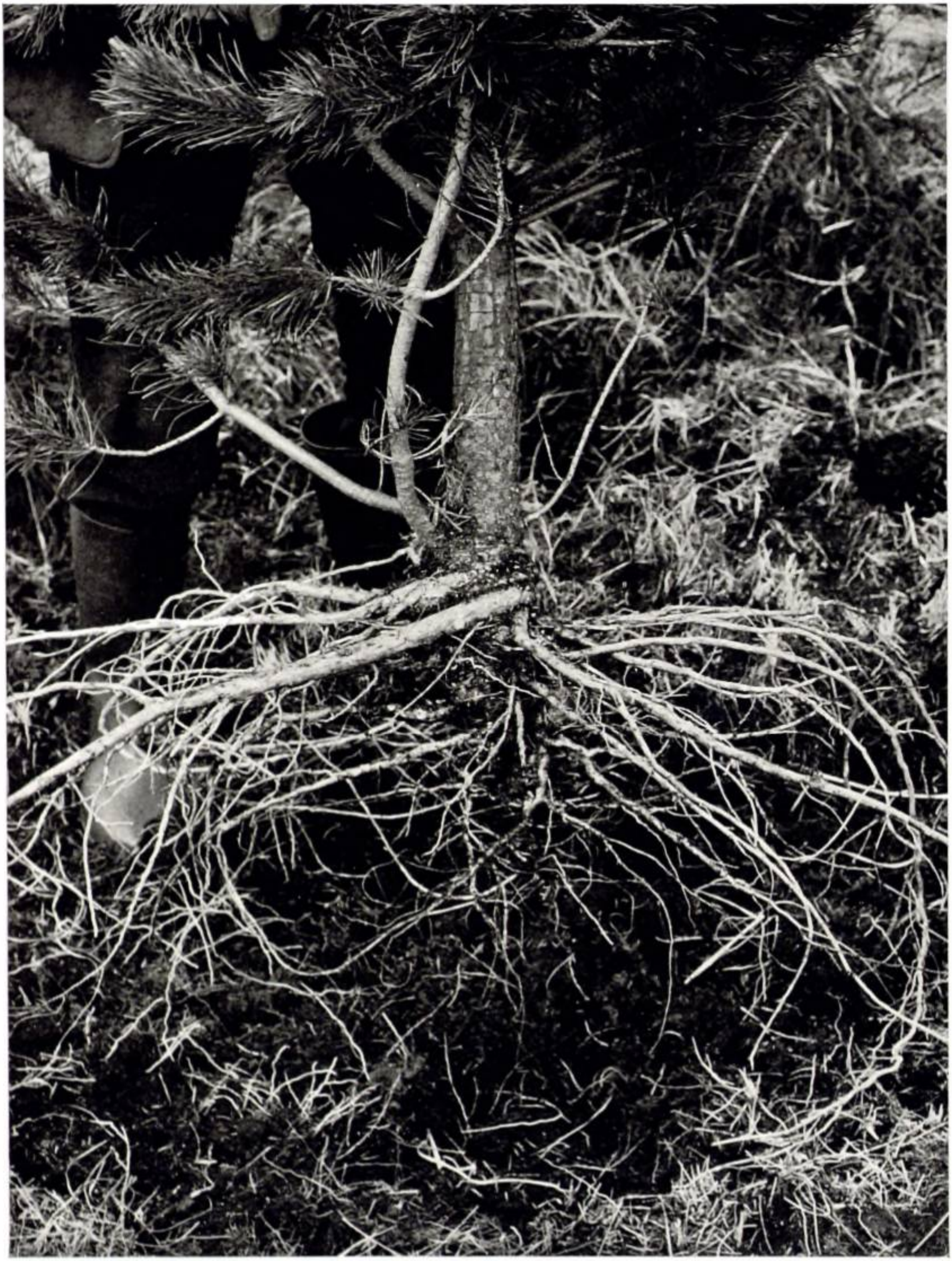

Plate 12. Root system of vigorous Lodgepole pine (of coastal Washington provenance) $6\frac{1}{2}$ years after being planted as an 8-week-old tubed seedling on a poorly-flushed blanket peat site in Naver Forest, Sutherland. Note excellent distribution and depth of root system which penetrated over 30 cm below the original ground surface. A4421.

Plate 13. Base of Lodgepole pine after five years growth, showing remains of tube which has opened up as the root collar diameter has increased. Note relative straightness of stem. Poor blanket peat site at Tighnabruaich Forest, Argyll. A4391.

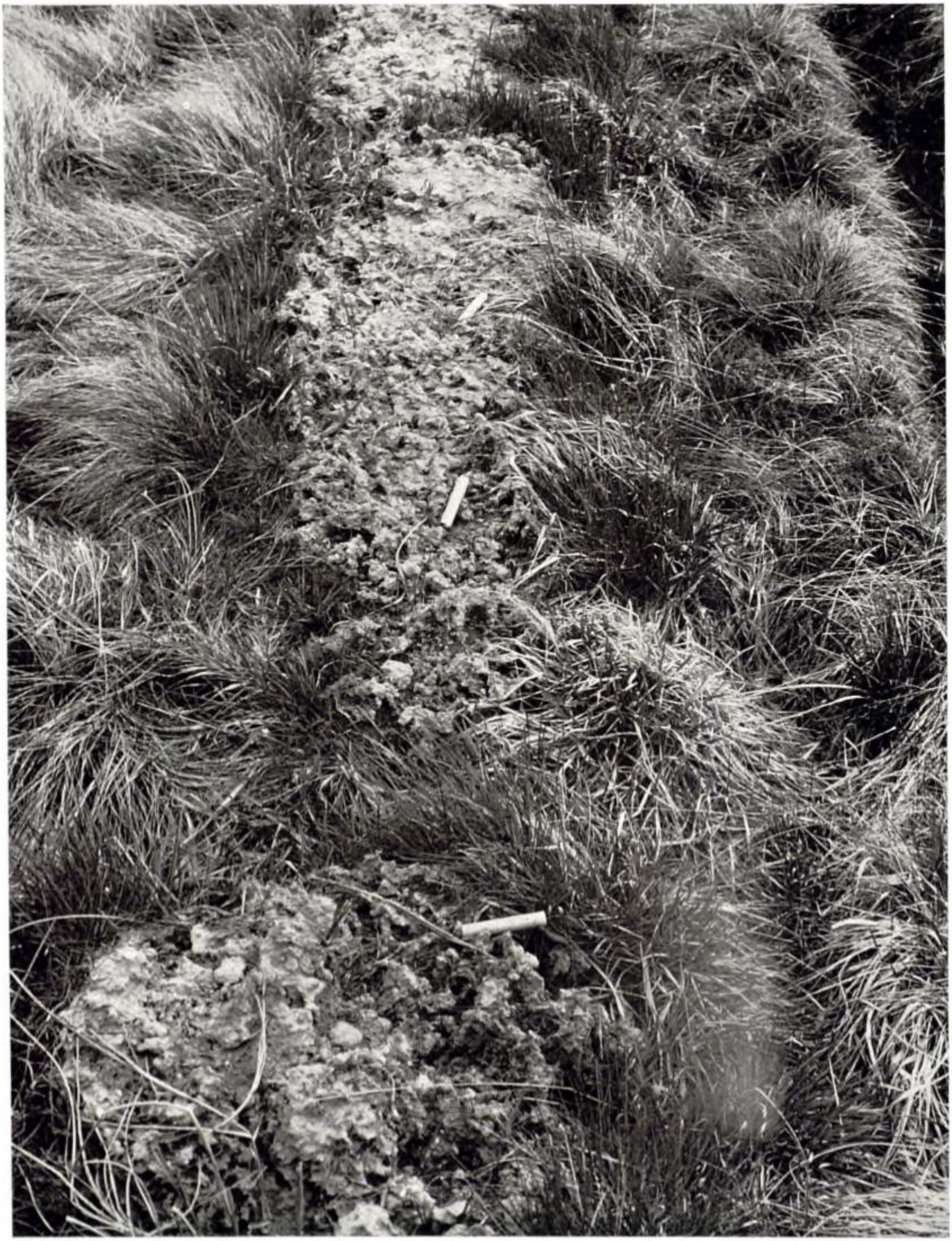

Plate 14. Tubed seedlings frost-lifted during the first winter after mid-summer planting in plough ridge on a gley soil. Selm Muir, Clydesdale Forest, West Lothian. A3762.

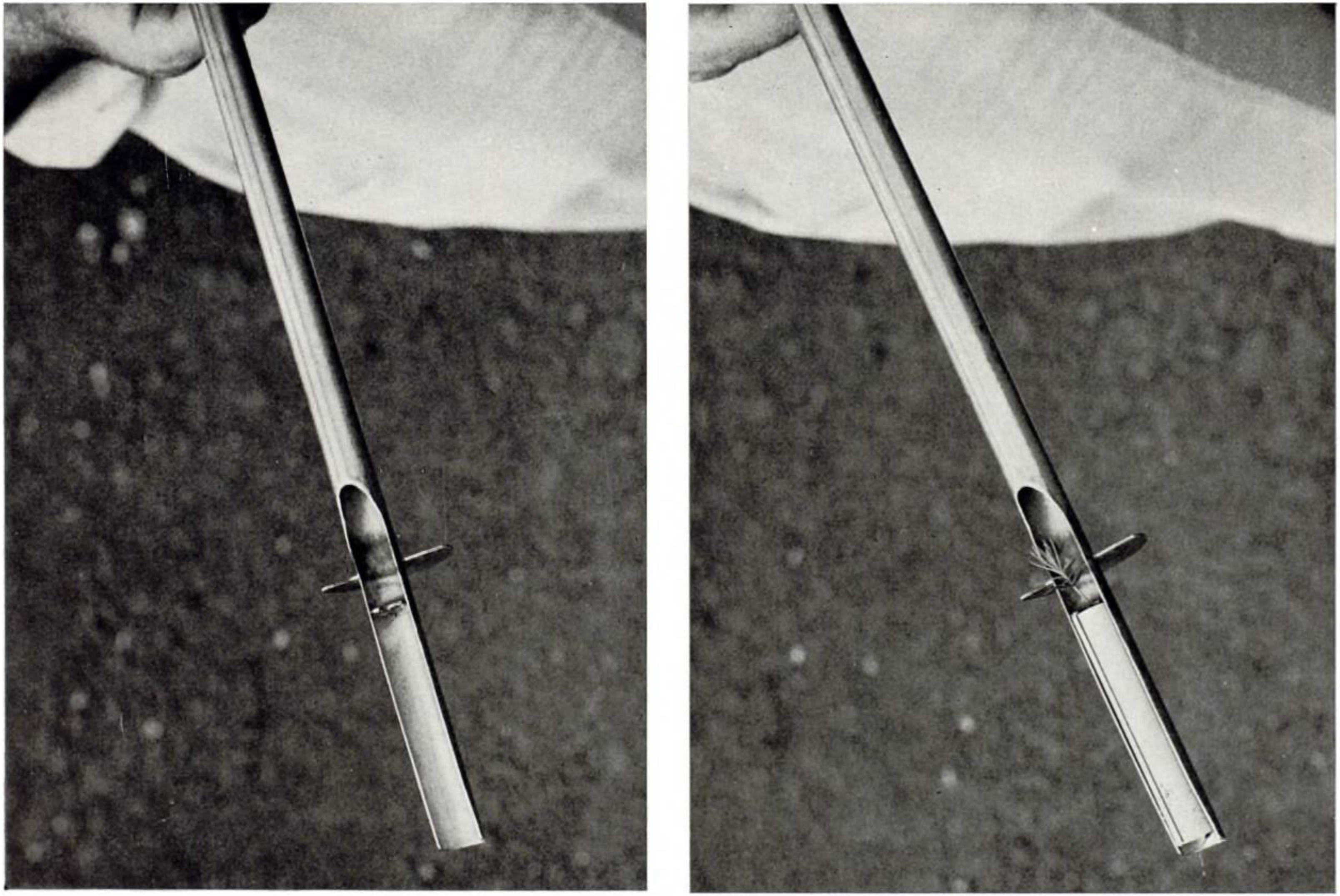

Plate 15. Special tool for planting tubed seedlings in peat, shown unloaded (left) and with seedling in position (right). Note cut-away portion of tube, internal "stop" and external depth gauge. A4401 and A4402.

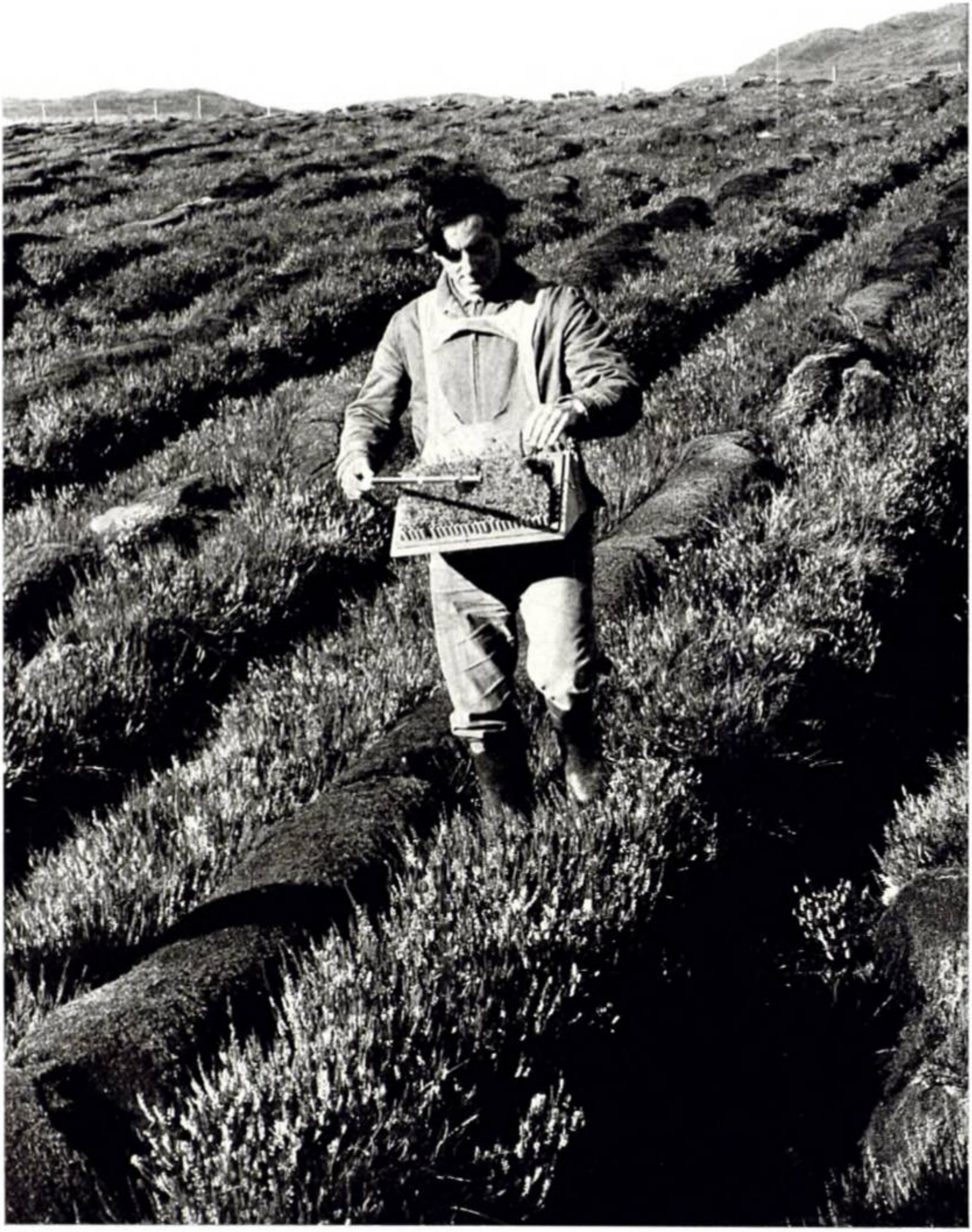

Plate 16. Planting tubed seedlings on ploughed peatland using the special tool and tray-carrying harness. The ridges have been stepped by hand prior to planting. Note that the worker loads the tool while walking from one planting spot (step) to the next A4343.

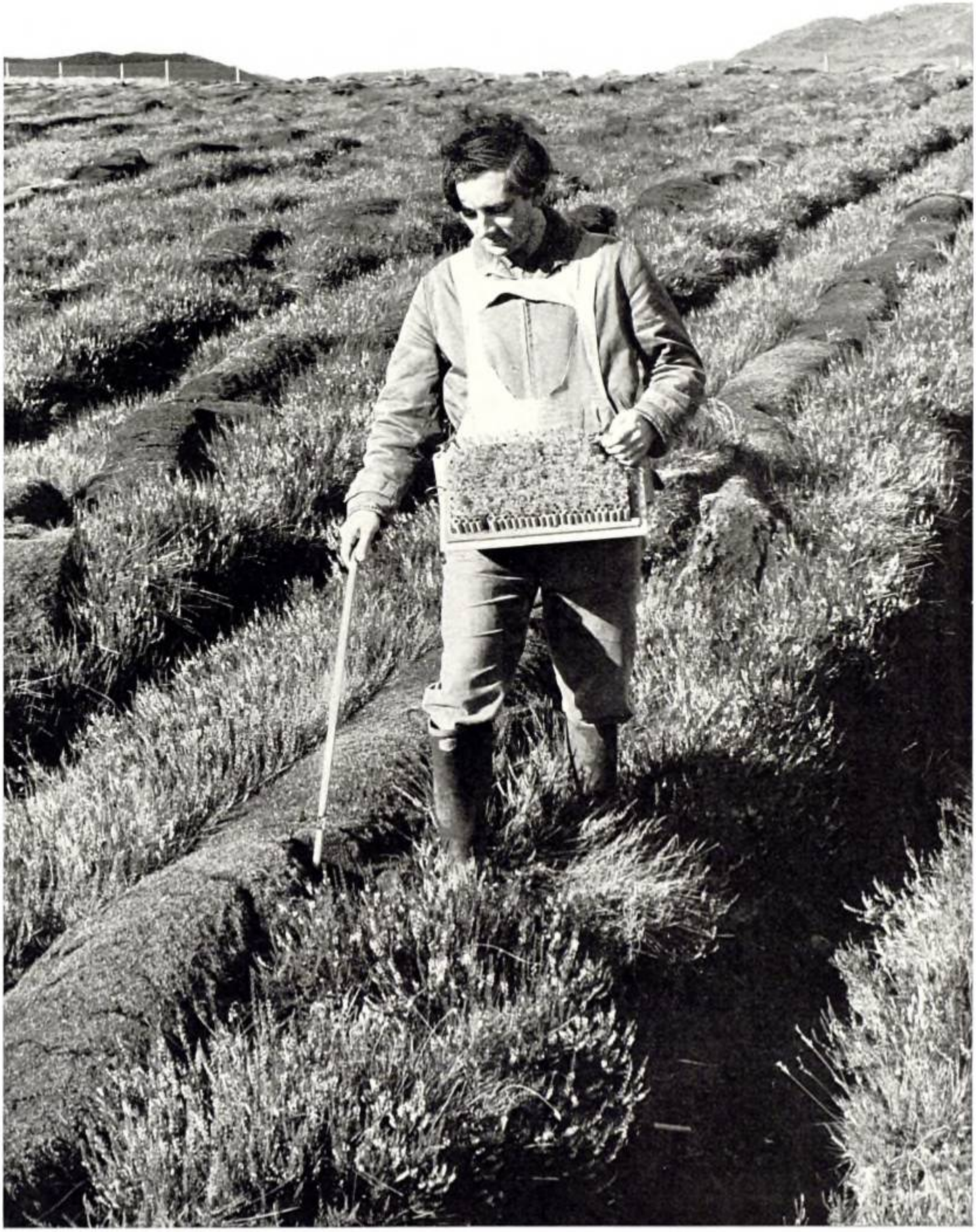

Plate 17. As the worker pushes one seedling into the peat he selects another in preparation for re-loading. A4339.

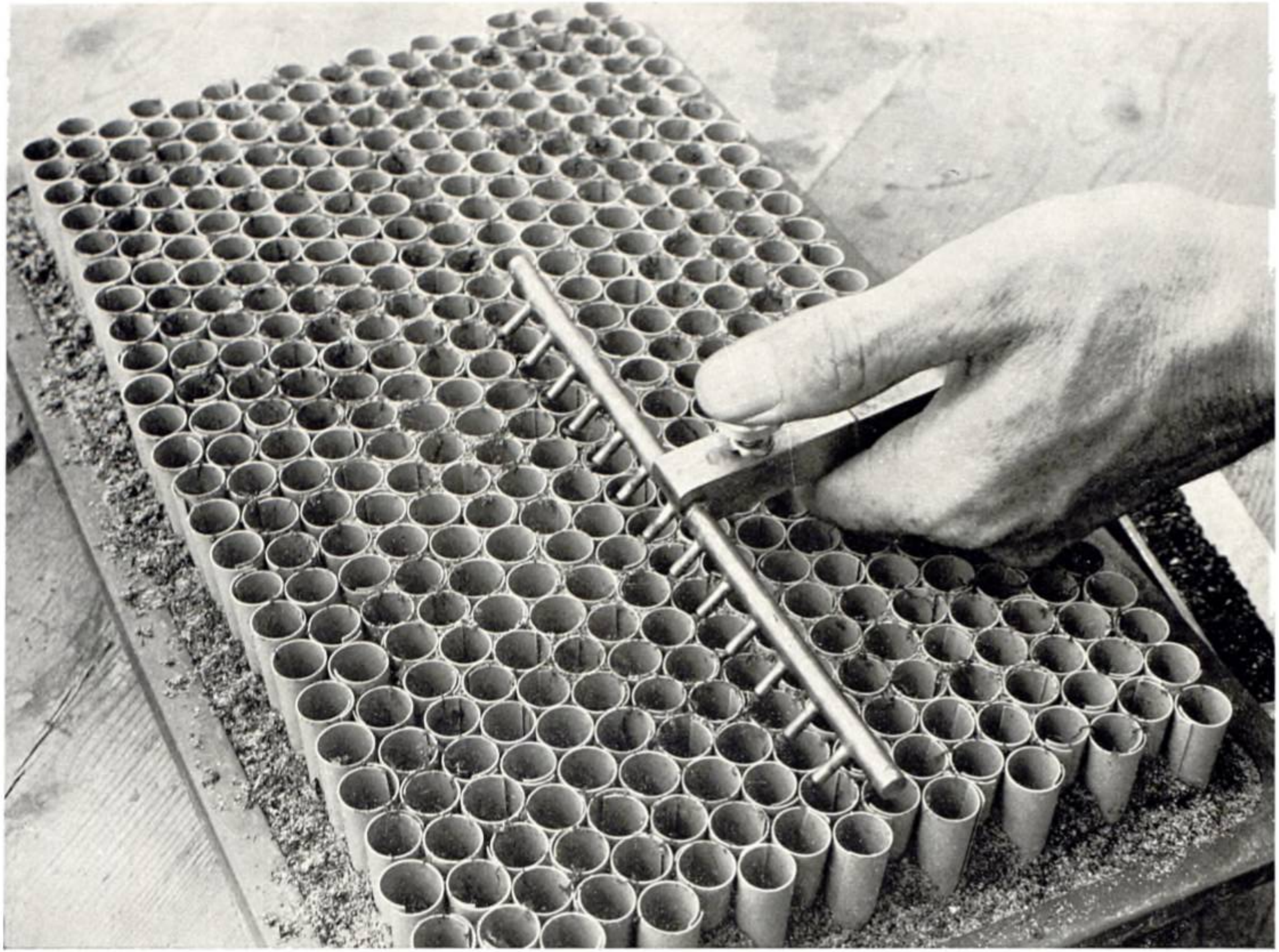

Plate 18. Sowing seed in tubes with the aid of a hand-operated vacuum sowing head. When the head is placed in a shallow trough of seed, one seed is held by suction on each nozzle. Operation of the thumb valve releases the vacuum and allows seed to fall into tubes. A3840.

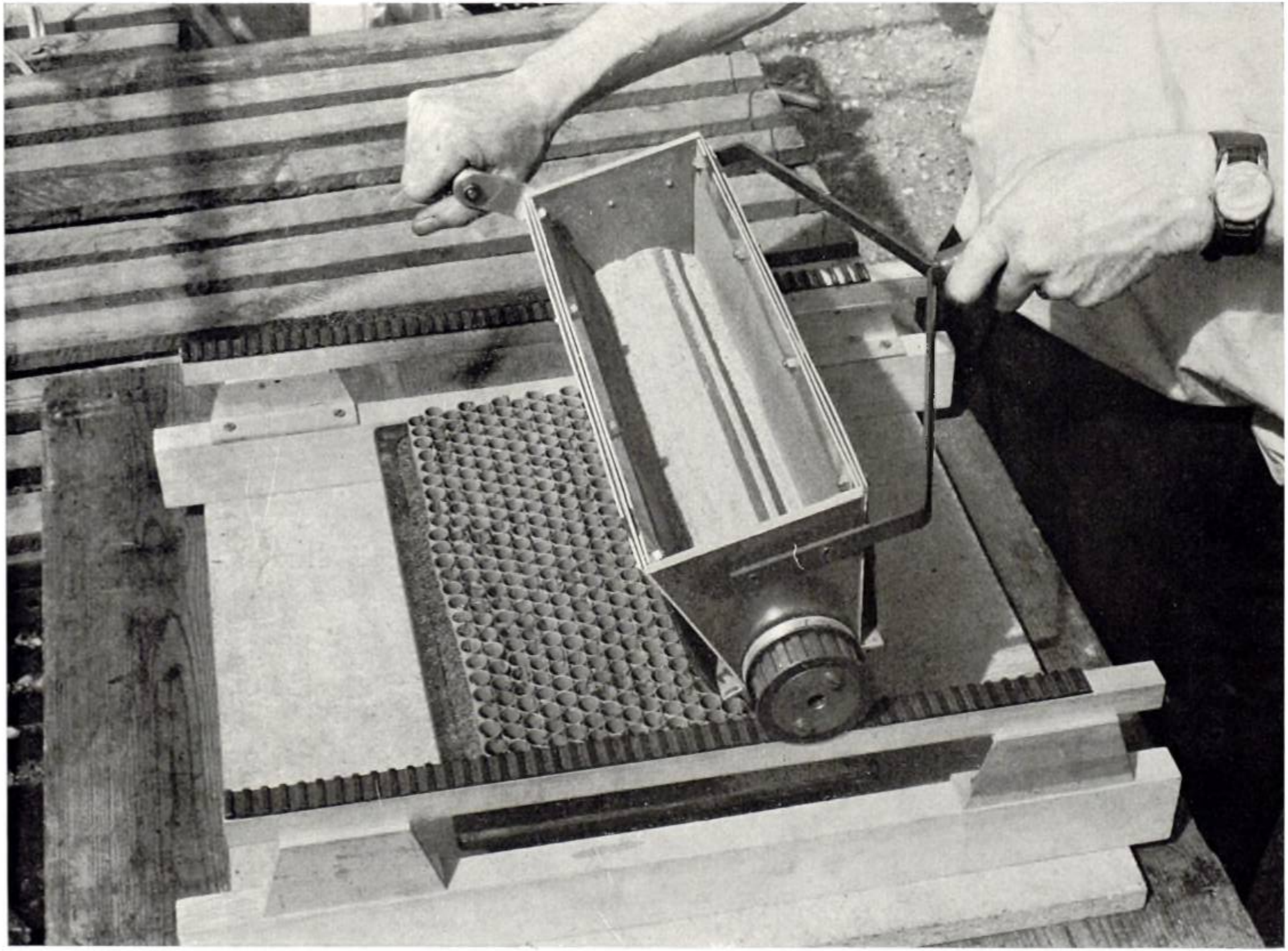

Plate 19. Sand hopper used to cover seed with a 3 mm sand layer. A3842.

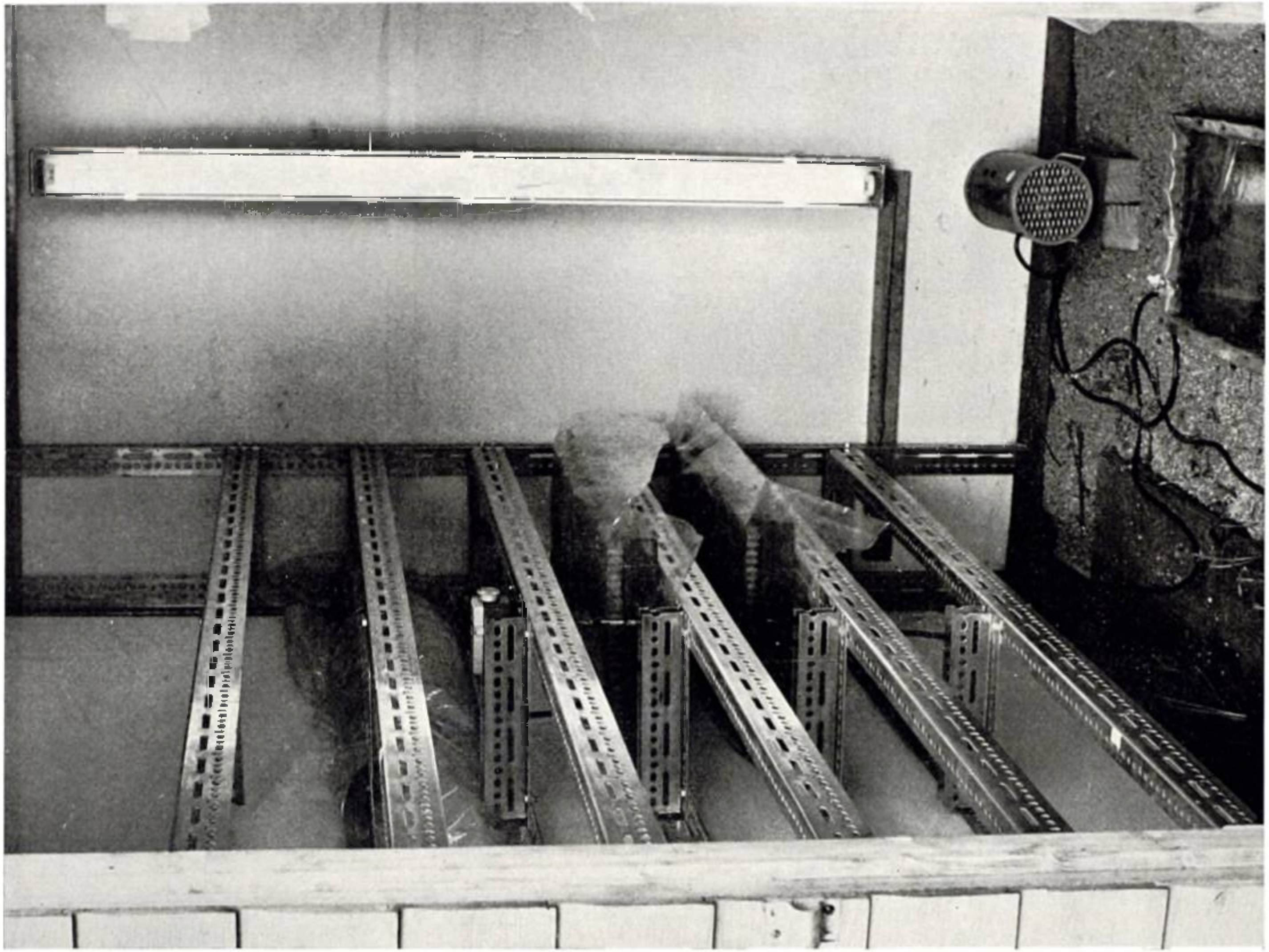

Plate 20. Insulated germination room used to promote rapid germination in tubes. Note heater, light and racking for trays which are covered with polythene to minimise water loss. A3746.

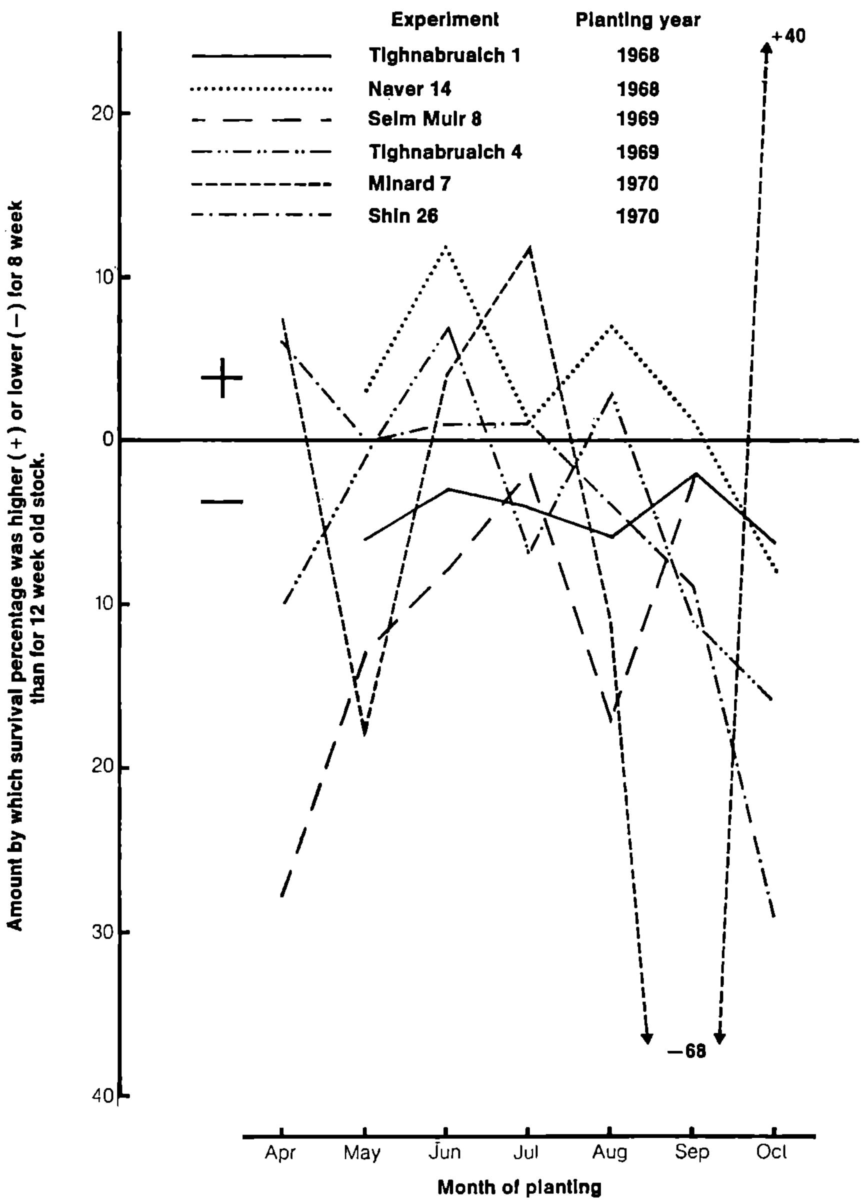

Figure 6. Comparison of survival after the second winter for 8 week and 12 week old Sitka spruce stock planted between April and October.

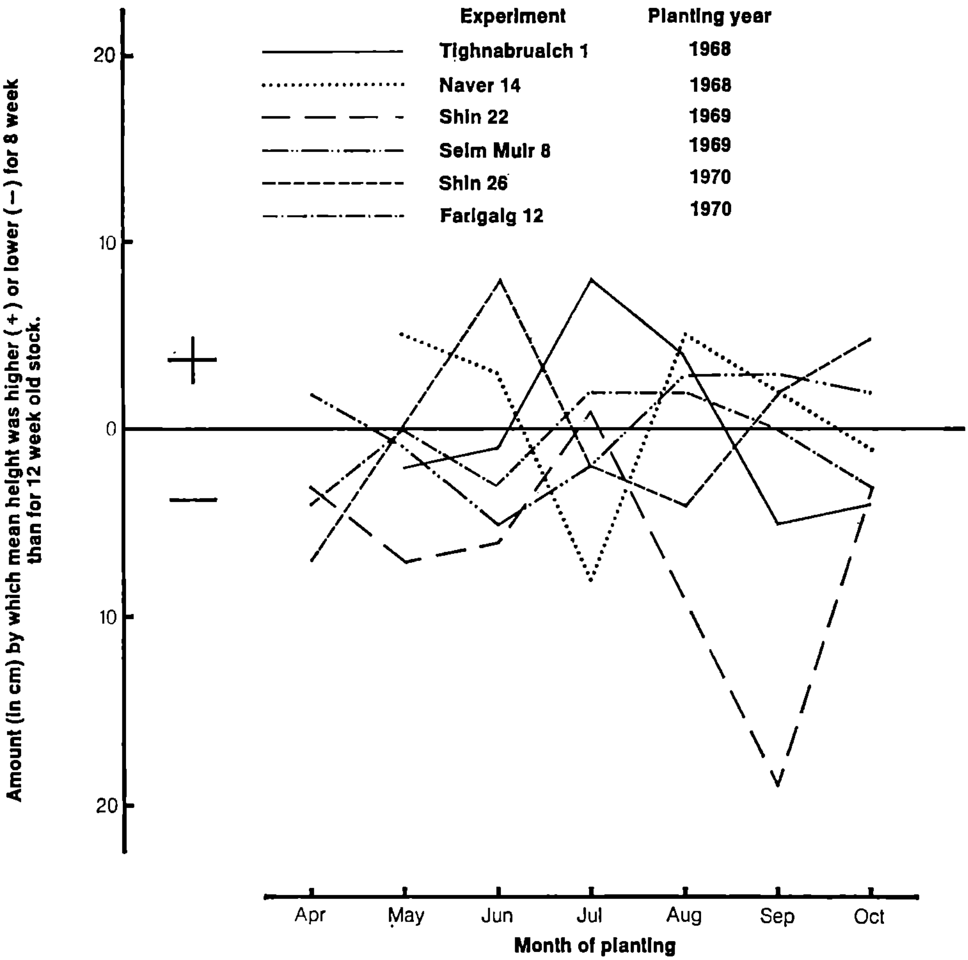

Figure 7. Comparison of mean heights after 4 seasons for 8 and 12 week old Lodgepole pine stock planted between April and October.

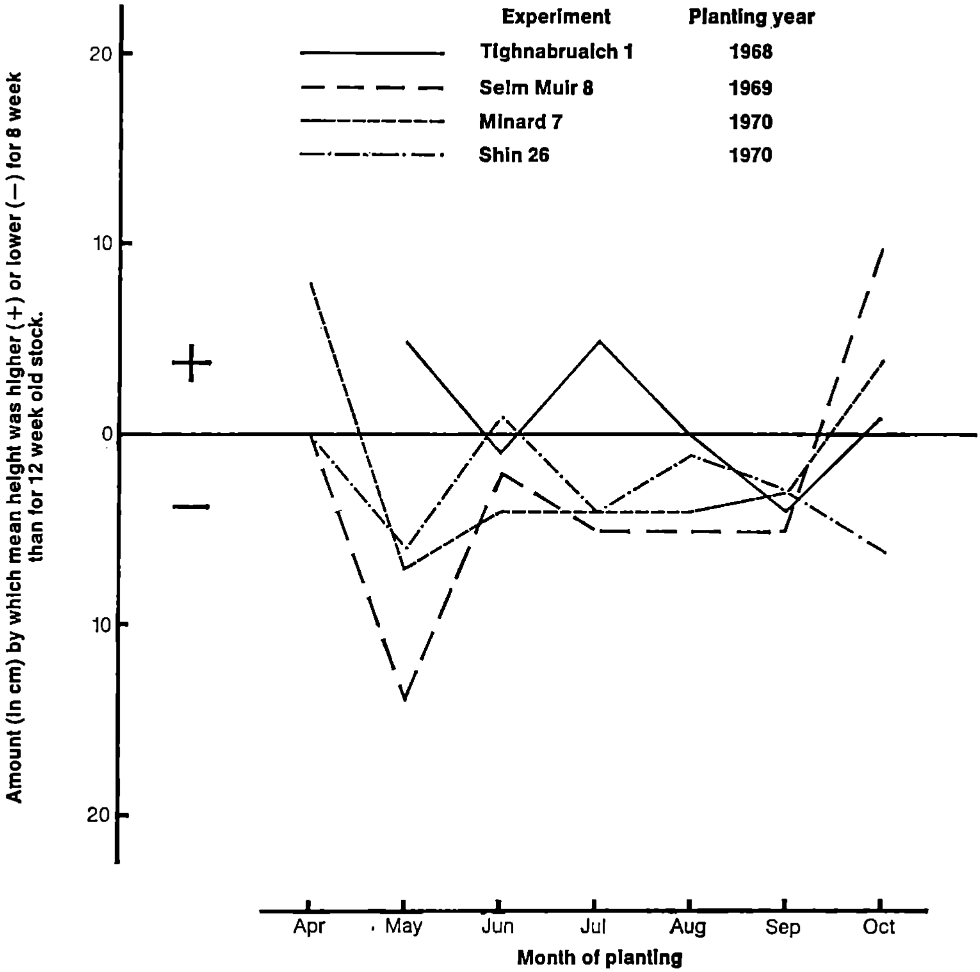

Figure 8. Comparison of mean heights after 4 seasons for 8 and 12 week old Sitka spruce stock planted between April and October.

In most experiments, the difference in survival after the second winter varied considerably from month to month, particularly with Sitka spruce (see Figure 6). There was no obvious reason for this irregular variation. On balance, survival of Lodgepole pine was similar for both ages of stock, except for October planting, where the older seedlings quite clearly gave a better result. As regards Sitka spruce, overall survival appeared to be some 8% better for twelve weeks than for 8 week old stock, with no obvious seasonal trends.

At the end of the fourth season after planting, there were no consistent differences for either Lodgepole pine or Sitka spruce between the mean height of trees planted as 8-week and 12-week-old seedlings. Month to month variation was less pronounced than for survival differences, and there were no noticeable trends.

Considering results for both survival and height of Lodgepole pine, there is no evidence to suggest that use of seedlings older than 8 weeks would lead to improved performance. With Sitka spruce, on the other hand, a slight improvement in survival (but not in height growth) could be expected from the use of 12-week rather than 8-week-old stock. However, it is doubtful if the benefit to be gained would justify the cost of increasing by 50% the length of the production period. Furthermore, recent experience has suggested that with satisfactory greenhouse conditions, a production period of 10 weeks should be more than adequate for Sitka spruce seedlings.

Early Shelter Requirement and Type of Step

When afforestation trials were begun, it seemed highly probable that the small size of tubed seedling stock would necessitate some form of early shelter for successful establishment on the relatively exposed upland sites involved. Evidence to support this was soon available from one of the earliest trials, planted in early September 1967 on a blanket bog site in Naver Forest. Survival following the second winter after planting was 97% for trees planted in hand-cut "steps" on single mouldboard (SMB) plough ridges, but only 17% for trees planted centrally on top of appreciably lower double mouldboard (DMB) ridges. Much better survival for planting in the ridge top position was recorded in experiments planted entirely on DMB ploughing at Naver during 1968, but subsequent height growth was considerably poorer than on comparable sites with stepped SMB ploughing.

From 1969 onwards, step planting on SMB ploughing was adopted as standard practice for tubed seedlings on peat, using conventional steps cut by hand at approximately half ridge height (see Plate 5). However, at the same time it was decided to investigate alternative types of "step" which might be cheaper to prepare or provide more protection than the relatively costly conventional steps, or which might be suitable for mechanical production if a tubed seedling planting machine were developed in the future. Two experiments in 1969 (at Shin and Selm Muir Forests) compared the following types of step, planted with eight week old Lodgepole pine and Sitka spruce seedlings in July and September:

- C—Conventional spade stepping with step level at half ridge height;
- H—Horizontal channel 15–20 cm wide × 10 cm deep cut through ridge top;
- D—Diagonal channel 15–20 cm wide × 10 cm deep cut from top to base of ridge;
- S—Slot 5 cm wide × 15 cm deep cut through ridge top.

Results from Shin for survival and height growth of both species indicated only minor (and non-significant) differences between the four step types. At Selm Muir, heavy losses caused by frost lifting, smothering

Table 7

SURVIVAL AND MEAN HEIGHT OF LODGEPOLE PINE AND SITKA SPRUCE PLANTED IN VARIOUS TYPES OF HAND-CUT STEPS AND ON TOP OF THE PLOUGH RIDGE IN TWO 1970 EXPERIMENTS

Type of planting step	Month of planting	Survival % after 2nd winter			Mean height (cm) after 4th season		
		Shin		Farigaig	Shin		Farigaig
		Lodgepole pine	Sitka spruce	Lodgepole pine	Lodgepole pine	Sitka spruce	Lodgepole pine
C—Step at half ridge height	June	93	97	97	75	47	35
	September	89	90	85	50	23	26
L—Low step 7–8 cm above ridge base	June	95	91	96	72	42	38
	September	82	78	94	42	17	27
H—Horizontal channel cut through ridge top	June	95	98	94	81	45	36
	September	88	93	77	55	21	25
D—Diagonal channel cut from ridge top to base	June	93	97	99	79	38	33
	September	90	87	89	54	20	25
O—No step	June	88	98	89	67	40	24
	September	63	73	74	46	20	14
Mean	June	93	96	95	75	42	33
	September	83	84	84	49	20	23

of seedlings by weathered peat, and animal browsing made it difficult to compare treatments. There was howevr some indication that conventional and diagonal steps had given the best results, and that seedlings planted in the narrow slots were most prone to smothering by weathered peat.

A modified range of step types was tested in four experiments planted during 1970 at Shin, Farigaig, Selm Muir and Minard Forests on various peat types. Step types C, H and D remained as used in 1969 apart from the channel depth of the latter two being increased to 15 cm. The slot treatment S was replaced by low conventional stepping, with the step level 7–8 cm above the ridge base (treatment L). (The object of the latter was to allow the base of the tube after planting to reach the vegetation "sandwich" layer below the plough ridge.) Planting directly into the ridge top (treatment O) was also included in order to confirm the need for stepping. Seedlings were planted in both June and September. See Table 7.

On the relatively amorphous peat at Selm Muir, high early losses (caused by the same factors as in the 1969 experiment) prevented satisfactory treatment comparisons, and animal browsing during the second season severely damaged the Minard trials. Results from the other two experiments are summarised in Table 7. This shows that at Farigaig (planted with Lodgepole pine only) survival and growth were quite clearly poorer for the ridge top planting position than for any of the planting steps, particularly with September planting; differences between the step types were small. At Shin, however, the situation was less clear-cut; considered overall, ridge top planting was the poorest treatment, but gave very high survival for June-planted Sitka spruce. In addition the low step gave poorer growth of Lodgepole pine and the diagonal channel poorer growth of Sitka spruce than the other step types. At both forests, seedling performance with ridge top planting was better than expected, probably as a result of the unusually mild 1970–71 and 1971–72 winters in the north of Scotland.

Cutting of steps by hand is a relatively costly operation and would be impracticable for large scale planting programmes because of the labour requirement. In consequence, work was begun in North Scotland Conservancy on the development of plough modifications which could produce a continuous step along the ridge at the time of ploughing. An existing design of sock-mounted step cutter which had originated in Northern Ireland (the "Stinson" sock) was tested but proved unsatisfactory for tubed seedling purposes. The cutter (in the form of an inverted "L" attached to the plough sock) was too easily damaged and the cut peat often did not fall clear of the step. A new design was then produced by the Conservancy workshops (the "Logan" sock). A robust attachment on the sock (Plate 7) cuts the step and leaves the cut peat pressed against the base of the furrow wall. The stepped ridge produced can be somewhat ragged in appearance but normally gives an acceptable planting position. A possible future development involves redesigning the entire plough body (rather than modifying the sock alone) so as to leave the unwanted peat from the step undisturbed at the bottom of the furrow. Such a change would give more consistent step production and more reliable performance on the shallower peats where the plough may strike patches of mineral soil.

Experiments were planted on exposed sites in June 1972 (at Farigaig) and in June 1973 (at Farigaig and Shin) to compare the effectiveness of plough and hand stepping on east and west facing sides of SMB plough ridges. Initial results from the 1972 experiment suggest that the effectiveness of the discrete hand-cut steps may be more or less unaffected by aspect, and that the continuous plough stepping is likely to be as effective when on the east side of the ridge. However, survival was decidedly lower with plough stepping on the west side of the ridge, i.e. facing the prevailing wind direction. A similar impression of reduced effectiveness of plough stepping when on the windward side of ridges was gained from inspection of the large-scale user trials in North Scotland. No useful information can be drawn at present from the 1973 experiments.

Planted seedlings in a continuous slot running along the top of the peat ridge has been suggested by North Scotland staff as an alternative to step planting. A metal "horn" mounted on the plough sock can be used to produce such a slot which subsequently opens up as the ridge dries out. Apart from the fact that the slot may take up to a year to open satisfactorily, it is very doubtful if planting in slots would give as satisfactory results as step planting. In particular, there is a risk either that the tubes will be left loose by the slot continuing to open up after planting, or that seedlings when small will be smothered by weathered peat falling into the slot. Some reduction in rate of planting also seems likely.

Height Growth After Planting

Despite their small size when planted in the forest, tubed seedlings are capable of vigorous early growth on peatland sites. Examples of the results obtained are shown in Plates 5, 8, 9 and 10.

The pattern of early height growth in various tubed seedling forest experiments is demonstrated for Lodgepole pine and Sitka spruce in Figures 9 and 10 respectively. These show *mean* height at the end of the growing season plotted against the number of seasons which have elapsed since planting (N.B. the growing season during which planting took place is counted as the first, although almost half of it may have passed prior to planting). The month and year of planting are shown for each curve. For comparison purposes, the extrapolated *top* height/age curves for Lodgepole pine of General Yield Class (GYC) 8 and for Sitka spruce of GYC 12 (see Hamilton and Christie, 1971) have been included in the Figures. These Yield Classes were selected as being representative of the site types on which the tubed seedling experiments had been planted.

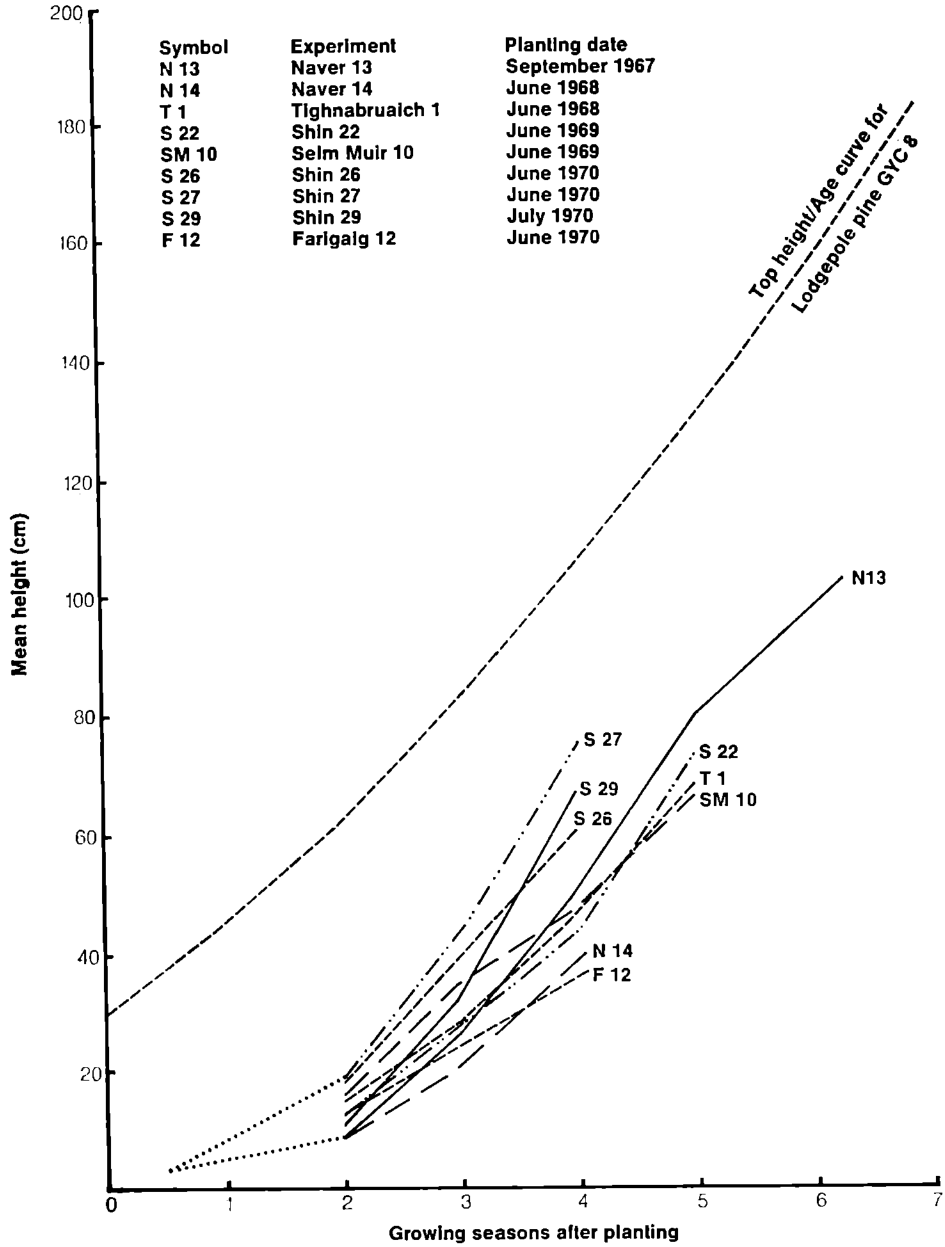

Figure 9. Height growth of Lodgepole pine (coastal Washington and Oregon provinces) planted 8 weeks old tubed seedlings.

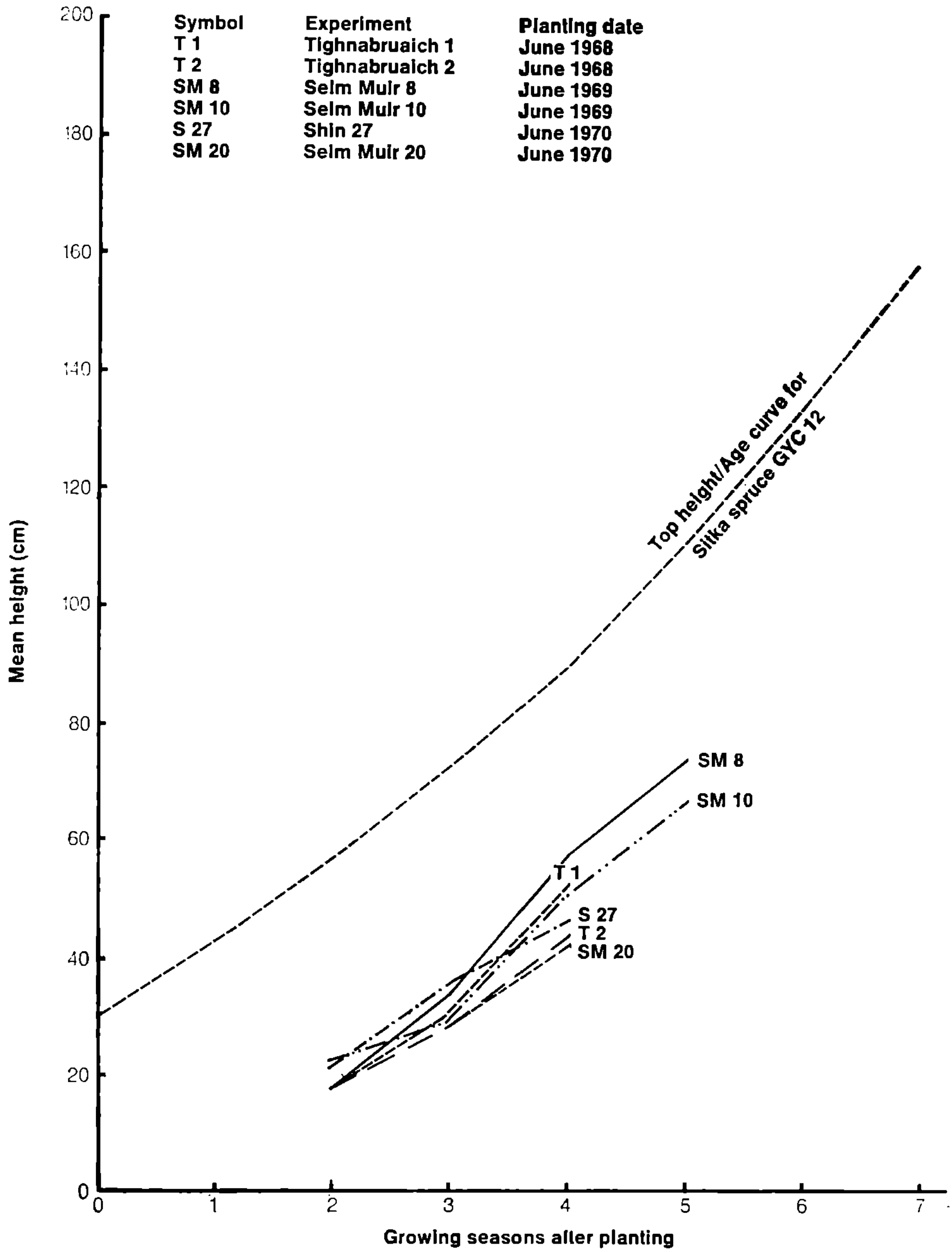

Figure 10. Height growth of Sitka spruce (Queen Charlotte Islands provenance) planted as 8 week old tubed seedlings.

From a detailed study of the available data, it seems probable that the basic height growth pattern of trees planted as tubed seedlings will be very similar to that shown by transplant stock after planting in the forest. In the older tubed seedling experiments current leader growth is comparable with that in adjacent areas planted with transplant stock, and there is no evidence of any change in the pattern five or six seasons after planting. However, on any particular site the growth curves for tubed seedling and transplant stock planted in the same year will differ in absolute terms because of the much smaller initial size of the seedlings. For both species the difference between the more or less parallel height curves is likely to be equivalent to less than two seasons' and frequently little more than one season's growth, i.e. at any one time mean height of trees planted as tubed seedlings is likely to be similar to that of transplant stock planted one to two years later. (*Note:* Comparison of the tubed seedling stock and GYC curves in Figures 9 and 10 exaggerates the difference because the curves for tubed seedling stock relate to *mean* height while the GYC curves are based on notional *top* height data.) Table 8 gives the mean heights after four growing seasons in four experiments planted in 1970 to provide large scale comparisons of tubed seedling and transplant stock. In each experiment an area of 3 to 4 ha was planted in June or July with 8 week old tubed seedlings and adjacent areas of similar size on each side were planted in spring of the same year with 2 or 3 year old transplant stock of the same provenance type.

Table 8

HEIGHT GROWTH COMPARISON OF TUBED SEEDLING AND TRANSPLANT STOCK AFTER FOUR SEASONS' GROWTH

Location	Species	Provenance	Mean height (cm) after four growing seasons	
			Tubed seedlings	Transplants
Shin 32	Lodgepole pine	South coastal	48	81
Farigaig 17	Lodgepole pine	Skeena	30	44
Selm Muir 20	Sitka spruce	Queen Charlotte Islands, B.C.	43	62
Whitelee 1	Sitka spruce	Queen Charlotte Islands, B.C.	36	45

Note: Growth of both seedling and transplant stock has been retarded at Farigaig and Whitelee by browsing damage and at Selm Muir by frost damage.

At one point it was suggested that plots of trees originating as tubed seedlings contained a wider range of individual tree heights than would have been expected for transplant plots of similar mean heights. However, comparison of data obtained both from tubed seedling trials and from other forest experiments (e.g. provenance trials) on similar sites showed that this was not the case. Both types of planting stock gave similar height class frequency distributions when compared at similar stages of development after planting. Figure 11 shows frequency distributions derived from one of the large scale tubed seedling/transplant comparison experiments described above. It can be seen that in each year the range in tree heights is less for tubed seedling than for transplant stock. However, to allow for the differences in mean height (see Table 8), it is necessary to compare tubed seedling heights at the end of 1973 with transplant heights at the end of 1972. When this is done it is then apparent that there is little basic difference between the distribution patterns for the two types of stock.

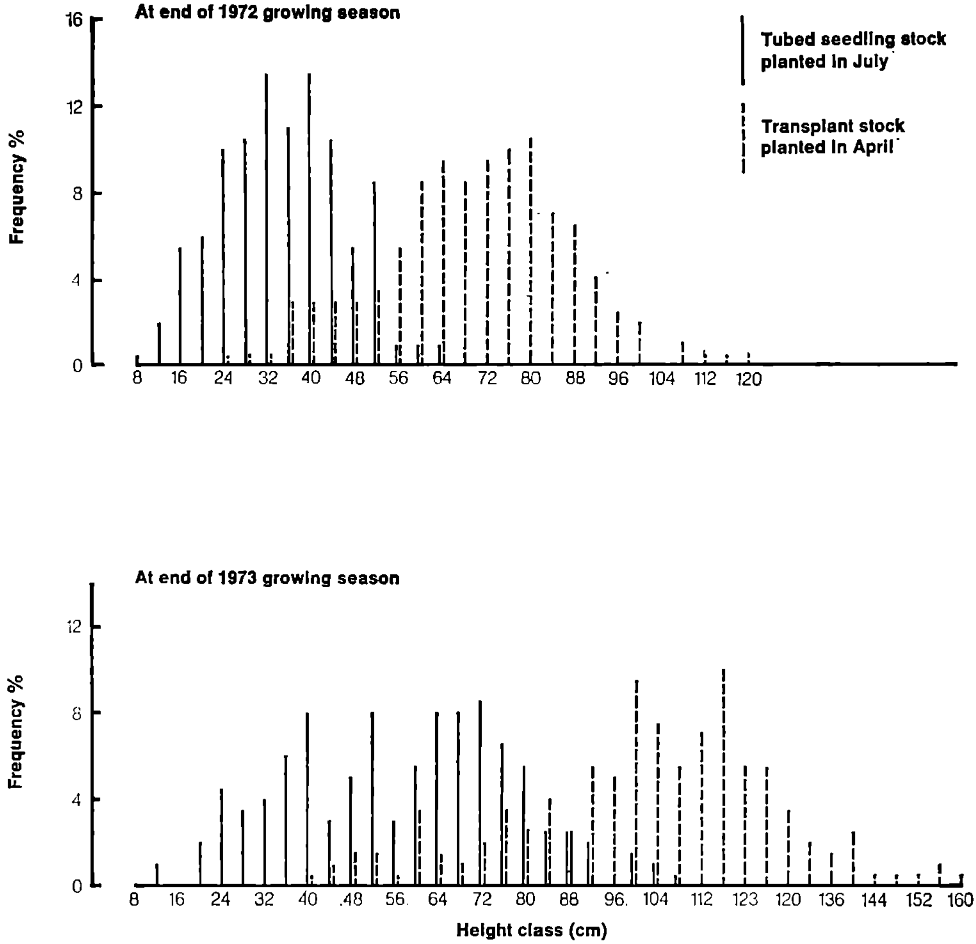

Figure 11. Height class frequency distributions for tubed seedling and transplant stock after 3 and 4 seasons growth. Shin experiment 32, planted in 1970 with Lodgepole pine.

Root Development and Stability

After intervals ranging from one to seven seasons after planting, the root systems of sample trees were excavated for examination in a range of experiments covering the various forest locations involved in the research programme. Sample trees were generally selected at random within experimental treatment plots. In most cases, it was found that the size and vigour of the root system was related to the above-ground performance of the tree. Trees of both Lodgepole pine and Sitka spruce with satisfactory shoot growth were generally developing well-balanced root systems, with several vigorous roots growing downwards and outwards from the base of the tube (see Plates 11 and 12). After only two seasons' growth, it was frequently found that roots well over 20 cm in length extended into and often through the "sandwich layer" beneath the plough ridge. The extent of penetration into the underlying peat was difficult to determine because root tips usually broke off during excavation. The development of vigorous roots from the tube slit was not uncommon, particularly in the case of Sitka spruce. There was little sign of any tendency for roots to remain in the vicinity of the tube once they had emerged from it, and the root systems appeared adequate in relation to subsequent tree growth.

Trees with non-vigorous shoot growth tended to have poorly developed root systems. Planting late in the season, already mentioned as giving poor height growth, usually gave rise to trees with much less vigorous root systems after two seasons than those planted earlier in the season. The difference is probably due to the roots of the late-planted trees having had insufficient time to penetrate adequately into the surrounding peat before the onset of winter.

Because of the relatively inert nature of the polystyrene plastic, it was originally feared that there would be a risk of vigorous trees being strangled by pressure of the tube round the expanding root collar region. However, the young trees appear to have little difficulty in forcing open the slit tube (Plate 13), which loses a good deal of its strength within a year or so of planting. Inside the tube the roots become tightly bunched with some spiralling but there was little sign of incipient strangulation of one main root by another, even after seven seasons' growth.

In comparison with transplant stock, tubed seedlings undoubtedly give more balanced early root and shoot growth, particularly in the case of Lodgepole pine. Because of their vigorous top-heavy shoot growth, coastal Washington and Oregon provenances of Lodgepole pine planted as transplants are prone to loosening by wind action and to subsequent development of basal stem curvature. Use of tubed seedling stock is likely to alleviate (although not eliminate) this problem (see Plate 10). Until very recently, there was little sign of appreciable wind loosening in the older tubed seedling experiments, despite the exposed nature of some of the sites and the vigorous growth of the Lodgepole pine in them. However, near the end of the 1972–73 winter, a heavy fall of wet snow accompanied by gale force winds led to a considerable number of trees becoming loosened to varying degrees in several of the older (1967–69) experiments in North Scotland. The degree of loosening was rated as considerably less than would have been expected for transplant stock of equivalent size and vigour, and most trees appeared to re-stabilise themselves during the 1973 growing season. Little serious loosening occurred during the 1973–74 winter, although heavy snowfalls accompanied by strong winds were again recorded.

Tube Length

From an early stage in the research work, it appeared that a tube length of 7·5 cm (as used in Canada) was likely to be adequate for satisfactory production and planting of tubed seedlings on peat sites. However, as part of an investigation concerned primarily with planting on mineral soils, seedlings raised and planted in tubes 7·5, 10 and 12·5 cm long were compared in two 1970 peatland trials at Tighnabruaich Forest and Selm Muir, Clydesdale Forest. For both June and September planting early survival and growth of Lodgepole pine and Sitka spruce did not differ consistently between the three tube lengths and the differences seldom approached significance. It was concluded that there was little to be gained in the way of improved seedling performance by increasing the tube length used.

Fertiliser Treatment at the Time of Planting

As far as growth of conventional transplant stock is concerned, Forestry Commission studies had shown little effective difference between "spot" and broadcast application of fertiliser at time of planting. ("Spot" application implies placing fertiliser in a limited area round each tree.) Since tubed seedlings have initially much smaller root systems, it was thought that spot application might enable the trees to obtain greater benefit from the applied fertiliser. It was also considered that more rapid early growth might be obtained by using fertiliser applying phosphorus (P) and potassium (K) rather than P alone on the poor peats involved.

In experiments planted with eight-week-old tubed seedlings in July 1970 at Shin Forest and Selm Muir, Clydesdale Forest, fertilisers were either applied within a 30 cm radius of each tree or broadcast uniformly over the whole area. The fertilisers used were unground Gafsa rock phosphate (13% P) applied at 60 g/plant (spot) or 375 kg/ha (broadcast); and a commercially available mixture of unground phosphate rock and crude muriate of potash (9% P, 16·5% K) applied at 90 g/plant (spot) or 565 kg/ha (broadcast). Table 9 summarises results obtained on the hill peat site at Shin, where there were no significant differences in early survival of either species. At the end of the fourth growing season mean heights were clearly (and highly significantly) better and foliage colour much greener with PK fertiliser than with P alone. Differences between spot and broadcast application were not significant, although the former gave somewhat better results in most cases. On the poorly-flushed blanket bog site at Selm Muir, early survival of Lodgepole pine only was slightly but highly significantly lower with spot than with broadcast application; other survival differences were small and not significant. Subsequently treatment differences were largely obscured by browsing damage which led to premature closure of the experiment. However, there was some indication that differences in height growth were following a similar pattern to that at Shin.

On the limited evidence available, there is little reason to sugest the use of spot rather than broadcast fertiliser application when tubed seedlings are planted. The use of fertiliser supplying both P and K rather than P alone seems likely to be worthwhile on the poorer peats, where in fact such treatment is increasingly being recommended for transplant stock.

Table 9

SURVIVAL AND HEIGHT GROWTH IN EXPERIMENT AT SHIN FOREST COMPARING SPOT AND BROADCAST APPLICATION OF P AND PK FERTILISERS

Fertiliser application	Survival % after 2nd winter				Mean height (cm) after 4th season			
	LP		SS		LP		SS	
	P	PK	P	PK	P	PK	P	PK
Spot	97	97	96	97	65	72	28	38
Broadcast	99	95	96	93	58	69	28	36

Climatic Damage

In the early stages after planting, tubed seedling stock has generally suffered less climatic damage to shoots and foliage than was expected, except where planting was done very early or very late in the growing season. On the more severely exposed sites, some winter killing of foliage and shoot tips (particularly of Sitka spruce) can be expected even with good step planting. In the autumns of 1971 and 1972, severe early frosts killed or damaged the leading shoots of Sitka spruce trees in various experiments, but damage was almost as bad in adjacent areas planted with Sitka spruce transplants. As in the case of browsing damage, recovery from climatic shoot damage has usually been good although inevitably height growth has been affected.

Some frost lifting of tubes during the first winter has sometimes occurred on the more amorphous peat types (which are usually associated with a high proportion of *Molinia* in the vegetation). On the more fibrous peat types signs of frost lifting were rare.

Animal Damage

Because of the small initial size of tubed seedlings, the effects of any animal browsing soon after planting are inevitably more serious than in the case of much larger transplants. Damaged seedlings have shown considerable powers of recovery, but height growth is retarded and the period of vulnerability is extended. Some damage has occurred in most of the experiments planted, but has frequently been patchy and limited in extent. In experiments located in North Scotland forests, animal damage has so far been slight, particularly in the northern part of the Conservancy which contains a large area of peatland potentially suitable for tubed seedling use. Damage has been most common and most severe in experiments at forests in West and South Scotland (mainly Tighnabruaich and Selm Muir), where both survival and growth have often been reduced to such an extent by repeated browsing that premature closure of experiments has been necessary.

In most experiments which have suffered from browsing damage, Lodgepole pine has been more severely affected than Sitka spruce, particularly where adjacent Conservancy transplant plantations have consisted mainly or entirely of Sitka spruce. There have, however, been a number of instances of a relatively high level of damage to Sitka spruce seedlings (e.g. at Tighnabruaich) which usually have softer and therefore more palatable shoots than Sitka spruce transplants. Although no clear pattern has emerged, high damage levels on both species have tended to be associated with relatively high local populations of browsing animals and with the more grassy vegetation types.

The principal form of damage has been the browsing of shoots by blue and brown hares (*Lepus timidus* and *L. capensis*), roe deer (*Capreolus capreolus*), or black grouse (*Lyrurus tetrix*), although the red grouse (*Lagopus lagopus*), sheep and rabbits (*Oryctolagus cuniculus*) have also been involved on occasion. There have also been instances of seedlings being pulled from the peat and left lying more or less intact, occasionally by hares, but usually by grouse, which had pecked the tubes open, probably to obtain grit particles for digestive purposes.

From the experimental results, there is little doubt that the most important factor likely to restrict the use of tubed seedlings on peatland is the incidence of browsing damage by hares, deer and black grouse. However, when considering the risk of serious damage to tubed seedling plantations it is necessary to bear in mind that animal curiosity may well have led to a higher incidence of damage within the relatively small experiments, which are surrounded by large areas planted with transplant stock, than will be the case if tubed seedlings are planted over large areas. Valuable guidance on this point is now available from the four relatively large experiments planted in 1970, which provide direct comparison between tubed seedlings and transplants, each in blocks of 3–4 ha. The evidence from these does not suggest that tubed seedlings are necessarily browsed preferentially by animals. In two of the trials (at Shin, planted with Lodgepole pine and at Selm Muir, planted with Sitka spruce) there has been little serious damage on either tubed seedlings or transplants up to the beginning of the fourth growing season. At the other two (at Farigaig, planted with Lodgepole pine and at Whitelee, planted with Sitka spruce) browsing damage appears to have been related to the conspicuity of the plants at the time damage occurred. In both experiments the transplant blocks suffered considerable damage within a year of planting while the tubed seedlings were scarcely affected; subsequently the situation was more or less reversed at the end of the second growing season and during the second winter when damage increased considerably in the tubed seedling areas. Since then the level of damage has fallen off for both types of stock.

General confirmation of the results obtained in the four large experiments was obtained in spring of 1973 from an inspection of the large-scale tubed seedling trials planting during 1971 and 1972 by North Conservancy Staff. Out of 20 large blocks planted, only two have suffered very serious browsing damage—in one case by red deer and sheep, and in the other by hares. In the remainder the damage to date was negligible or of minor importance, despite signs of deer, hares or black grouse in the vicinity of most. It was generally considered that the level of damage might well increase as the trees grew taller and hence more conspicuous but that they were then unlikely to suffer more damage than transplant stock of similar size.

Until further evidence is available, it seems best to assume that successful use of tubed seedlings on peatland will at times require a higher intensity of animal pest control than would normally be considered necessary when using transplant stock.

Weed Competition and Control

A further consequence of their small initial size is that tubed seedlings are more susceptible than transplants to suppression by competing vegetation. Fortunately, weed growth is not very vigorous on the poorer upland peats where tubed seedlings have shown considerable potential and weeding has seldom been necessary in the season of planting in any of the experiments. However, during the second season and particularly on the more fertile peats, growth of grass species (especially *Molinia* and *Holcus*) stimulated by the phosphate fertiliser applied has often proved more troublesome than was originally anticipated. This has necessitated some hand weeding in most of the experiments, and on the more grassy sites one or two weedings in the second season and a further weeding in the third season have often been required to prevent excessive plant losses (particularly in the less successful experimental treatments under trial). The occurrence of browsing damage has often led to a need for more prolonged weeding than would otherwise have been the case.

By their nature, small scale experiments comparing a range of treatments usually require closer attention to be paid to weed control than would be the case with large-scale planting. It appeared likely that most experiments on hill peat and some blanket bog sites would have required little or no weeding if the poorer experimental treatments had been excluded. Support for this viewpoint has come from the large tubed seedling/transplant experiments, now at the end of their fourth growing season. Two have required no weeding and a third only very limited weeding to control vigorous *Calluna*. In the fourth experiment, which suffered most from animal browsing, one weeding was required in the second and third seasons to control grass growth in the tubed seedling block but not in the transplant block. Experience to date in the large scale user trials in North Scotland also suggests that relatively little weeding will be required in tubed seedling plantations on the poorer peats.

In a situation where weeding is necessary, the size of the seedlings makes them difficult to find during any weeding operation. Hand weeding is labour-intensive, time-consuming and expensive. During 1970 an attempt was made in some of the Selm Muir experiments to use paraquat as an alternative method of weed control, but even with careful treatment it proved very difficult to prevent accidental transfer of the chemical on to the small seedlings, with consequent damage to foliage and shoots. The use of paraquat cannot therefore be recommended for weeding tubed seedlings.

In 1971 a small trial was carried out at Selm Muir in an attempt to find a safe alternative to paraquat for grass control on peatland. Atrazine in both wettable and granular formulations and chlorthiamid ("Prefix") proved ineffective, but dalapon solution applied by knapsack sprayer showed considerable promise.

The use of dalapon was further tested in a new experiment at Selm Muir in 1972. As in the case of the 1971 trial, the experiment was located in an area planted during the previous season with Sitka spruce tubed seedlings and having *Molinia coerulea* and to a lesser extent *Deschampsia flexuosa* as important constituents of the ground vegetation at the time of treatment. Dalapon was used at a rate equivalent to 13 kg of chemical product (74% w/w active ingredient) per treated hectare, diluted in 350 litres of water for high volume application by knapsack sprayer and in 110 litres of water for low volume application by mistblower. Two application times were compared: the first immediately prior to flushing of the young trees in spring; and the second delayed until at least 50% of the grass cover showed fresh growth, by which time the trees would have begun to flush. Treatments were applied in strips extending from the top of the ploughed ridge to the furrow edge on the same side as the planting steps.

By late summer of 1972, a very high proportion of the grasses in the treated strips had been killed by dalapon treatment prior to flushing of the trees, with low volume application slightly more effective than high volume; there was little sign of damage to the trees. Delayed application had given somewhat less effective grass control and, not unexpectedly, had caused severe shoot damage to many trees. At the end of the growing season, there was little difference in tree survival and mean shoot growth between the control plots (both hand weeded and unweeded) and the pre-flushing dalapon treatment. Delayed treatment caused a moderate reduction in survival, particularly with low volume application and reduced shoot growth to half of that in the control plots. Grass control by the treatments persisted through the 1973 growing season, with only limited re-growth of *Molinia* in the plots treated prior to tree flushing, and almost none in the delayed treatment plots.

Although further evidence on the subject is required, it appears that use of dalapon applied prior to flushing of the trees provides a possible means of controlling growth of grasses in tubed seedling plantations on peatland more cheaply than by hand. Nevertheless, a substantial cost would still be involved and it seems best to avoid if possible the need for any weeding operations. This can be done by not using tubed seedlings on sites where grass growth is likely to be at all vigorous, e.g. on flushed basin peats and some of the richer blanket bog types. Planting on ploughing more than a few months old should preferably be avoided as should sites where fertiliser has been applied some time before planting and particularly if application has been prior to ploughing. Cutting of planting steps at too low a level may also cause problems due to grass growing through the base of the step as well as from beside the ridge.

Forest Extension Trials of Nursery Treatments

As noted earlier, forest extension trials were used to compare the effects after planting of selected nursery treatments which have been tested in greenhouse experiments. Results obtained are summarised below:

(1) Growing medium in tubes: Two experiments, planted in June and August 1968 at Naver and Tighnabruaich Forests, compared eight week old Lodgepole pine and Sitka spruce seedlings raised in four soil media (see p. 3): screened horticultural Sphagnum peat; 1 : 1 mixture of peat and medium sand; John Innes seed compost mixture; and "Levington" peat potting compost.

In both experiments there were no consistent differences in early survival between the soil media, and at Tighnabruaich all four resulted in similar height growth. At Naver, height growth was significantly better with John Innes mixture than with the other three soil mixes. However, the difference between the John Innes mixture and the next best treatment (peat-sand or peat) was only 4–5 cm after four seasons' growth—insufficient to justify changing from the cheap, easily prepared standard peat-sand mixture.

(2) Root control by copper paint: A small experiment planted at Tighnabruaich Forest in September 1968 compared 13 week old Lodgepole pine and Sitka spruce seedlings raised in trays with and without copper paint on their bases as a root growth control measure (see p. 10). Relatively high losses due to planting late in the season and to browsing damage limited the value of the comparison, but the results suggested that nursery root control by copper paint had little important effect on survival, height growth, and root growth after planting.

The effect of using copper paint was further studied in two 1969 experiments (at Shin and Selm Muir) in which 8-and 12-week seedlings raised with and without copper paint on the trays under three fertiliser regimes were planted in July. In these experiments, neither survival after two seasons nor mean height after three seasons was significantly affected by copper paint treatment during seedling production. However, at Selm Muir height data showed that there was a significant interaction between copper paint treatment and fertiliser regime. It appears that where "Enmag" fertiliser had been used in production of the seedlings, growth after planting tended to be better for copper treated than for untreated seedlings; where the reverse was true for regimes based on potassic superphosphate and "FL3P" or on "FL3P" alone.

Recent Canadian work on the subject (Hocking, 1972 and Scarratt, 1972a) has been mentioned earlier (p. 12), and in the light of this it was decided not to use copper paint treatment as part of the standard production technique.

(3) Greenhouse fertiliser regime: Seedlings raised using three contrasting greenhouse fertiliser regimes were planted in July 1969 in the Shin and Selm Muir experiments described above in relation to the effect of copper root control. Details of the regimes are given on p. 10. At both locations there were no significant differences between the fertiliser regimes as regards survival after two seasons or height growth after three. The significant interaction at Selm Muir between fertiliser regimes and root control by copper paint has already been noted and discussed above.

Another set of contrasting greenhouse fertiliser regimes was compared in three experiments planted in July 1970 at Shin, Farigaig and Selm Muir Forests. The eight week old seedlings were raised using regimes based on "Enmag", on "FL3P", and on "Nitroform" + superphosphate + potassium sulphate, all with and without addition of trace element frit (see p. 6 for details). Results for the Shin and Farigaig experiments are summarised in Table 10. Any treatment differences at Selm Muir were obscured by browsing and frost damage.

Table 10

INFLUENCE OF GREENHOUSE FERTILISER REGIME ON SURVIVAL AND GROWTH OF 8-WEEK-OLD TUBED SEEDLING STOCK PLANTED IN JULY 1970 AT SHIN AND FARIGAIG FORESTS

Species	Fertiliser treatment	Survival % after 2nd winter				Mean height (cm after 4th season			
		Shin		Farigaig		Shin		Farigaig	
		Frit	No Frit	Frit	No Frit	Frit	No Frit	Frit	No Frit
Lodgepole pine	"Enmag"	96	93	83	95	68	60	35	32
	"FL3P"	93	94	90	92	68	58	34	33
	"Nitroform" + superphosphate + potassium sulphate	96	91	91	89	59	68	41	34
	Mean	95	94	88	91	65	62	37	33
Sitka spruce	"Enmag"	97	98	—	—	36	32	—	—
	"FL3P"	93	97	—	—	39	35	—	—
	"Nitroform" + superphosphate + potassium sulphate	96	92	—	—	39	33	—	—
	Mean	96	95	—	—	38	33	—	—

Note: Lower survival of Lodgepole pine in the Enmag/frit treatment at Farigaig was due to deer browsing damage in two plots.

There was no evidence that survival after planting was influenced by the basic greenhouse fertiliser treatment or by the use of trace element frit. However, height growth of Lodgepole pine at Farigaig and Sitka spruce at Shin was slightly but significantly improved by inclusion of frit in the soil mix and there was a similar trend for Lodgepole pine at Shin. There were no significant height growth differences attributable to the basic fertiliser treatments, all three of which gave satisfactory results.

AFFORESTATION EXPERIMENTS ON MINERAL SOILS

Between 1967 and 1970 afforestation experiments with tubed seedlings were planted on various ploughed mineral soil types at Glen Garry Forest (Inverness-shire), Farigaig Forest, Tighnabruaich Forest, Selm Muir Forest, Lleyn Forest and Tywi Forest. The soils included surface water gleys with and without appreciable peat layers, a humus iron podsol, an ironpan soil, and a podsolic brown earth. As in the case of the peatland trials, application of phosphate fertiliser at normal rates was considered necessary for satisfactory establishment of a tree crop on all the sites used.

Seedlings were planted into the side of the plough ridge in order to provide some early shelter. Planting was often less easy than on peat because loose soil particles tended to block the hole when the dibble was withdrawn. After planting, seedlings were sometimes buried by loose soil falling or being washed down on top of them, but this was seldom serious.

In contrast to the promising seedling performance in most peatland soils, results on these mineral soils were generally unsatisfactory. The most serious adverse factor was the high incidence of frost lifting of tubes during the first and, to a lesser extent, the second winters after planting (see Plate 14). All experiments were affected in this way and in many of them over 75% of the tubes were lifted at least partly out of the soil during the first winter. Often tubes were lifted completely out of the planting hole and left lying on the soil surface with seedlings intact but dead or dying inside them. The presence of an appreciable peat layer at the base of the plough ridge was usually associated with reduced frost-lifting if the tube bases had reached the peat when inserted into the ridge. Where the tubes were largely or wholly in peat, serious frost lifting was much less frequent, particularly if the peat was fibrous in nature.

Initially, survival was often high, even when planting was done in summer drought periods, but fell off considerably after the first and second winters mainly as a result of deaths following frost-lifting. Seedlings tended to check badly after planting and were slow to resume normal growth except where above-average moisture conditions resulted from the presence of peat in the plough ridges. Growth was further hampered by the recurrent frost-lifting and in general has not been adequate, with average height usually less than 10 cm after two full seasons' growth.

Experimental comparisons of 7·5, 10, and 12·5 cm long tubes have shown that the longer tubes did little to reduce frost-lift or improve survival and growth. In other experiments frost-lift and poor growth tended to obscure the differences between treatments. In most cases the pattern of treatment response appeared to be basically similar to that found on peat sites but because of the generally poor growth, treatment differences were small and unimportant in practical terms.

Experimental work on mineral soil sites was ended after 1970. From the poor results obtained it was concluded that tubed seedlings were unsuitable for use on such sites except where the peat layer was deep enough to give plough ridges consisting wholly or largely of fibrous (not amorphous) peat and the risk of vigorous grass growth was low. In such cases, results seemed likely to approach those obtained on deep peat.

REGENERATION EXPERIMENTS

Tubed seedlings were developed in Canada for replanting felled woodland. In order to assess their suitability for this purpose in Britain nine experiments were planted between 1968 and 1971 in the Kielder Forest District (Northumberland), Glenbranter and Glenfinart Forests (Argyll), the Allerston Forest complex on the North Yorkshire moors, close to Pickering (now comprising Cropton, Langdale, Wykeham and Dalby Forests), and Thetford Forest (East Anglia).

At Kielder (four experiments), Glenbranter (one experiment) and Glenfinart (one experiment), tubed seedlings were planted on peaty gley sites after removal of previous spruce crops. Survival and early growth were very variable and often very poor, largely obscuring any treatment differences. Results for Sitka spruce were better than those for Western hemlock and Grand fir where the latter were included in experiments, but were generally unsatisfactory because of low survival (seldom exceeding 60% at two years and often much lower). After three seasons' growth, mean heights of 30–36 cm were recorded in the best plots of the Argyllshire experiments, but both there and elsewhere many survivors looked less vigorous and less healthy than adjacent naturally-seeded Sitka spruce seedlings. Considering the experiments as a whole, the main factors leading to poor tubed seedling performance were frost lifting of tubes in wet areas, intermittent water logging and poor aeration of the peat layer, vole browsing, and stem girdling by weevils after the effects of an initial insecticide drench had worn off.

On an ironpan soil at Allerston, tubed seedling survival was almost nil after two years. Planting beneath a Japanese larch (*Larix kaempferi* (Lambert) Carr.) overwood gave no better results than planting in an adjacent clear-felled area. Losses were attributed to smothering by grass, birds pulling out tubes, and frosting of shoots (but not frost lifting).

At Thetford, bird damage soon after planting followed by winter frost lifting of tubes resulted in poor survival of Corsican pine seedlings on a brown earth site which had previously carried a Scots pine crop and from which the vegetation had been removed by bulldozing. Considerable bird damage also occurred in an adjacent experiment planted beneath a light Scots pine overwood, but the presence of the overwood appeared to prevent frost lift. Heavy weed growth further reduced survival to an unacceptable level.

From the results of these experiments, it became obvious that tubed seedling stock was not suitable for replanting the various site types involved.

Chapter 4

PLANTING TOOLS AND PLANTING METHOD FOR PEATLAND

Dibble Planting

Prior to 1971, almost all tubed seedlings used (in both peat and mineral soil trials) were planted with the aid of appropriately-sized steel dibbles. When planting with such a tool the worker normally has both hands occupied—one manipulating the dibble and the other inserting the tube into the hole. Keeping him continuously supplied with seedlings so as to allow fast rhythmic planting is difficult because the need to bend down when inserting the tubes makes it impracticable for him to carry a tray of seedlings in a carrier attached to his body. A tray can be carried in one hand, using a special frame or basket, but this is cumbersome and breaks the planting rhythm as it has to be laid down beside each planting spot to free one hand for tube insertion. Alternatively, the planter can be supplied with a few seedlings at a time by another man whose sole function is to carry trays and supply seedlings to two or more planters. A third possibility is for planting to be done by two men working together—one making dibble holes into which the tubes are then inserted by the other who carries a tray of tubes in one hand. The latter two methods appear to have been widely employed for a time in Canada (Anon., 1967; Carman, 1967; Mackinnon, 1968) and were used successfully on a small scale in British trials. On previously stepped peat ridges an average planting rate of up to 2,000 seedlings per man-day (including the man carrying the plants) appeared possible, but this required close co-ordination between the men involved.

Ontario Planting Stick

In Ontario, a special "planting stick" was devised in an attempt to obtain an efficient one-man planting operation (Anon., 1967). By means of a retractable dibble and a remotely operated clip for holding a tubed seedling, this tool allowed the operator to insert the seedling without bending down and so made it possible for him to carry a tray of seedlings in a frame supported by shoulder and waist straps. Published information on its performance is scarce, but it seems to have achieved only limited success because of difficulty in placing tubes firmly in the soil and in preventing soil from clogging the moving parts.

Special Planting Tool

The need for a more efficient planting tool than the simple dibble led in 1969 to the investigation of possible alternative concepts by staff of the Forestry Commission's Work Study Branch. By 1971 this work had resulted in the development of a new tool which allowed rapid single-handed planting of tubed seedlings on ploughed peatland sites (Plates 15 and 16). Using this tool, a tube can be forced into the peat without requiring a hole to be made beforehand. The separate actions of making a hole and inserting the tube (as required by dibble planting) are thus combined into one movement. When the tool is withdrawn the tube is held by suction in the moist peat of the plough ridge. As in the case of the Ontario "planting stick", the worker does not have to bend down when planting and in consequence can carry a tray of tubes held in front of him by a special harness (see Plate 16).

The tool is made from a 1 m length of stainless steel tubing with an outside diameter of 15 mm and wall thickness of approximately 0·75 mm. At one end, half of the circumference (but not more) is cut away for a length of 12 cm and any rough edges filed smooth. An internal "stop" (made from half of a suitable sized washer) is welded 8·3 cm from the end of the tube. An external depth gauge is welded round the outside of the tube 9·5 cm from the end. (The difference between the external and internal gauge locations ensures that the tube is left after planting with its top edge slightly below the peat surface.) The other end of the tube is bent to form a handle. Prior to use, minor adjustments are made to the diameter of the cut-away end to ensure that tubes are held with sufficient pressure to prevent their dropping out before the tool is inserted into the peat.

When planting the worker walks alongside the previously stepped plough ridge carrying the tool in one hand (usually the right but left-handed operation is relatively easy for many right-handed persons). During loading, the tool is held more or less horizontally in front of the tray. A tube is picked from the tray by the other hand and slid into the tool channel with slight downward pressure until it rests against the internal stop with the seedling shoot projecting beyond the stop. The loaded tool is pushed vertically into the peat and is then withdrawn, leaving the tube inserted in the peat. While the tool is being pushed in, the free hand is selecting the next tube seedling to be planted. Tube selection and loading of the tool are done while the worker is moving from one planting spot to the next and if all movements are carried out as part of a steady rhythm, planting can be done at a slow but steady walking pace. (A more detailed description of the working method is given in Chapter 6, pp. 42–45.)

The rate of planting achieved varies with the walking conditions and with the type and condition of the peat in the ridge. Time studies at forests in the north of Scotland have shown that average output per man (including allowances for associated work and rest) can range from 740 seedlings per hour, with easy walking and peat well suited to the technique, to 415 seedlings per hour, with difficult walking and barely suitable peat. Table 11 (p. 44) gives a guide to the expected output for various combinations of site conditions.

Experimental Comparison of Planting Tools and Methods

When tubed seedlings are planted with the special tool, some peat from the plough ridge tends to be forced into the base of the tube, and may form a shallow "plug". It seemed possible that this might impede root emergence or drainage from the tube and so retard growth. To examine this possibility, and to provide a link between results obtained with dibble planting and those with the special tool, three experiments were planted in 1970 at Shin, Farigaig and Selm Muir Forests. Four planting treatments were compared:

(a) Inserting tubes into dibble holes 7·5 cm deep (i.e. the same length as the tubes).
(b) Inserting tubes into dibble holes 10 cm deep (leaving an air space 2·5 cm long beneath the tube).
(c) Inserting tubes into holes 7·5 cm deep, made with an auger.
(d) Forcing tubes directly into peat by means of the special planting tool.

The purpose of treatment (b) was to provide an air space and hence improve drainage and aeration at the base of the tube. Treatment (c), which would be impracticable for normal use, provided planting holes surrounded by uncompressed peat, thus contrasting with the other three treatments. Eight week old seedlings were planted in May and August, with both Lodgepole pine and Sitka spruce being used at Shin and Selm Muir, and only Lodgepole pine aι Farigaig.

Survival after the second winter and mean height after three seasons did not differ significantly between the planting treatments in any of the experiments. Excavation of the root systems of sample trees early in the third season revealed no consistent rooting differences associated with planting method. Where planting had been done with the special tool, there were often signs of peat having been forced into the tube at time of planting but little evidence that this had adversely affected root development. The only major difference in root development observed was between May and August planting by all four methods, with the later date having given distinctly less virogous rooting (as well as less vigorous shoot growth).

All planting in the large scale trials in the North Conservancy has been done using the special tool, and a check on root development was made in spring 1973 during a survey of the areas planted in 1971 and 1972. For most of the trees examined, both vigour and spread of roots (which have grown mainly from the tube base) were regarded as satisfactory. Where tubes had been inserted deeply, roots had sometimes grown over the upper edge of the tube—a finding which adds further weight to the desirability of inserting the tube with its upper edge below peat level. Some degree of peat "plugging" at the tube base was fairly common but an adequate number of roots had usually succeeded in passing between the "plug" and the tube wall (although very rarely through the "plug"). "Plugging" was most noticeable (and likely to have most effect on rooting) where the ridges consisted of firm amorphous peat or had some mineral soil present, i.e. on sites which on other grounds would be regarded as only marginally suitable for use of tubed seedlings.

Chapter 5

GENERAL DISCUSSION AND CONCLUSIONS

Between 1968 and 1971, an intensive programme of greenhouse research was carried out with the object of determining the most satisfactory method of producing Lodgepole pine and Sitka spruce seedlings in tubes under British conditions. This aim was achieved with the development of the production procedure described in Chapter 6 (pp. 42–45), which has been used successfully over the past three years to raise hundreds of thousands of pine and spruce seedlings for use in forest trials. It also appears reasonably satisfactory for several other conifer species used in British forestry, although minor modifications may be required to cope with large-seeded or slow-germinating species. However, since successful forest use of tubed seedlings is confined to the poorer peatland sites (see below), Lodgepole pine and Sitka spruce are likely to be the only species raised in large numbers using this technique.

Canadian practice in 1967 was used as basis for the research programme and, as might be expected, the procedure which has evolved is broadly similar to those used for producing tubed seedlings in Ontario and Alberta. There are, however, numerous differences in detail, notably in connection with the soil mixture and fertiliser regime used.

The production of tubed seedlings on an 8-week cycle is a highly intensive method of raising forest planting stock. Close day-to-day supervision is essential, in particular to ensure adequate but not excessive watering of seedlings, proper functioning of the heating and ventilation equipment, and very early detection of any pathological problems. Neglect is likely to have much more rapid and disastrous effects than would be the case in the production of conventional forest planting stock in an outdoor nursery. The technique in fact compares closely with the raising of many horticultural glasshouse crops.

For efficient seedling production it is essential to use seed of the maximum possible viability and germinative energy. Selection should be based on recent laboratory test data. Using seed with a viability of 85 %, it has proved possible to obtain with reasonable consistency 80% germination of both Lodgepole pine and Sitka spruce, and a usable seedling out-turn after eight weeks of 75 % of tubes sown. These results compare very favourably with results from normal outdoor nursery sowings, but leave some room for improvement. Where seed of very high viability (over 90 %) has been available, usable yields exceeding 90 % have often been obtained in small scale sowings. For large scale sowings, however, it is unlikely that the yield will ever exceed 90 % of tubes sown with one seed per tube unless a very effective seed grading procedure can be developed.

Sowing two seeds per tube has been considered as a possible means of increasing the proportion of tubes with seedlings, and has been done for this purpose in Alberta (Carman, 1967). On average, it could be expected to halve the number of unproductive tubes, but many tubes would contain two seedlings and singling would be required to prevent undesirable competition in the tube which might delay establishment after planting. With seed of high viability (normally the case with Lodgepole pine and Sitka spruce), it was felt that singling would be a more time-consuming operation than the replacement of unproductive tubes at an early stage in the production cycle. However, double sowing might well be worth while if it were necessary for some reason to use seed lots of relatively low viability.

Up to the present the various preparatory operations involved in the production of tubed seedlings for British trials have been carried out by hand (see Plates 17 and 18), and this has proved adequate for the numbers involved (about 700,000 seedlings during 1973). Canadian experience has shown that manual operation can give reasonably efficient large scale production of seedlings (see e.g. Carman, 1967 and Kococinski, 1968). The provision of specially designed hand-operated tools enabled teams of experienced workers (usually women) to pack tubes into trays, fill them with soil, sow seed and apply sand cover at an average rate of up to 8,000 tubes per person per day. Nevertheless, the uniform tube size and repetitive nature of the work suggest that a high degree of mechanisation should be possible (and is also desirable) in these early stages of the seedling production cycle. A prototype machine for this purpose was designed in Ontario (Mackinnon, 1969) with a projected daily out-turn of 500,000 tubes loaded, seeded, and sanded. There appears to be no published information on the subsequent performance of this machine, but it is believed to have achieved only limited success because of problems associated with packing the tubes into trays. Some thought has been given by Forestry Commission staff to the development of mechanical tube handling procedures, but it is felt that the scale of production is not yet large enough to justify the development costs involved.

Forest testing of tubed seedling stock in Britain began towards the end of the 1967 growing season, and in consequence more than 6 years' experience is now available for assessing seedling performance. Most of the large number of experiments planted date from the 1970 growing season or earlier and between them they sample a wide range of site conditions. Initially the scale of planting at any one forest was very limited because of the relatively small area (less than 1 ha) required for most experiments. Since 1971, however, substantial peatland areas at selected forests in North Scotland have been planted with tube seedlings as part of large scale "user" trials in the Conservancy. A total of over 1·3 million seedlings has been used in these trials between 1971 and 1973.

The experiments on peatland have shown that in the absence of serious animal damage tubed seedlings (raised in 7·5 × 1·3 cm tubes) are potentially suitable for use in the afforestation of many upland peat sites, where early weed growth is not normally a problem. Despite their small size when planted, both Lodgepole pine and Sitka spruce seedlings are capable of high survival and vigorous early growth on low fertility, exposed peat sites if early shelter is provided by step planting. In most localities the effective planting season is from mid April to late August, with the optimum period from May to July inclusive. However, on areas prone to late spring frost or to severe weather conditions, April planting of actively growing stock is unwise, particularly if Sitka spruce is being used. Throughout the planting season, 8 week old Lodgepole pine seedlings have given as satisfactory results as older seedlings. Eight week old Sitka spruce seedlings are also likely to give acceptable results in most cases, but somewhat older (probably 10 week old) stock will give slightly improved survival (although not height growth) and should probably be used on the more testing sites. Planting of over-wintered dormant seedlings of both species in March and April is a possible means of extending the planting season, but survival has been surprisingly variable. There are also practical problems in raising and over-wintering large numbers of seedlings for this purpose.

Available evidence indicates that the basic height growth pattern of trees planted as tubed seedlings is similar to that shown by transplant stock after planting in the forest. On any particular site, however, the growth curves for tubed seedlings and transplants planted in the same year can be expected to differ in absolute terms because of the much smaller initial size of the seedlings. For both Lodgepole pine and Sitka spruce the difference is likely to be equivalent to less than two seasons' growth (and frequently little more than one season's growth). Within young plantations of similar mean height, the range of individual tree heights is likely to be similar irrespective of whether the crop originated as tubed seedlings or as transplants. Monitoring of growth in experiments will continue, but on present evidence there is no reason to expect any adverse change in the performance of established trees planted as tube seedlings.

Root development of tubed seedling stock after planting has generally appeared adequate in relation to subsequent tree growth, with little sign of being adversely affected by the presence of the tube. In comparison with transplant stock there is little doubt that root and shoot growth are usually better balanced, particularly in the case of Lodgepole pine. All evidence to date suggests that for Lodgepole pine of coastal Washington and Oregon provenances planting of tubed seedlings rather than transplants will give trees which are less prone to wind loosening and subsequent development of basal stem curvature. The experiments are not yet old enough to demonstrate clearly the extent to which this will be true. However, the recent occurrence of some wind loosening of Lodgepole pine in several of the older experiments in North Scotland has shown that planting tubed seedlings can be expected to alleviate rather than eliminate the problem.

The most important factor likely to restrict use of tubed seedlings on peat land is the incidence of browsing damage by hares, deer and black grouse. The effects of browsing soon after planting are inevitably more serious than in the case of much larger transplants, and severe damage has been recorded on a number of occasions. Nevertheless, in general the problem has been much less serious than was originally anticipated, particularly in the north of Scotland. It is noteworthy that out of 20 large blocks planted by North Conservancy staff in 1971 and 1972, only 2 had suffered serious browsing damage by spring of 1973. Data from several large experiments and from the North Conservancy trials suggest that when planted in large blocks tubed seedlings may well suffer little more damage than transplants. However, until further evidence is available, it seems wise to assume that successful use of tubed seedlings on peatland sites will at times require more intensive animal control than would normally be considered necessary when using transplant stock.

A less important factor which may affect tubed seedling performance is weed growth. Their small initial size make seedlings not only more susceptible than transplants to suppression by competing vegetation but also more difficult to find during any weeding operations. Fortunately weed growth is not very vigorous on the poorer upland peats and weed control measures will frequently be unnecessary. The cost of weeding operations suggest that tubed seedlings should not be used when grass growth (mainly *Molinia coerulea*) is likely to be vigorous, e.g. on flushed basin peats and some of the richer blanket bog types. (Such sites may also be unsuitable because the relatively amorphous peat present can lead to frost lifting of tubes.) However, it is almost inevitable that weed control will be required on some sites planted with seedlings, and application of dalapon immediately prior to flushing of the trees in the season after planting may provide a possible alternative to hand cutting for control of grasses.

In contrast to the peatland results, seedling performance has generally been unsatisfactory in afforestation trials on ploughed mineral soils. Recurrent frost-lifting and poor height growth have demonstrated convincingly that there is little future for tubed seedlings (of the size and type under test) on such sites. The only exception appears to be on peaty gley soils where the peat layer is deep enough to give plough ridges consisting wholly or largely of fibrous (not amorphous) peat and the risk of vigorous grass growth is low. Modification of the tube shape has been suggested as a means of reducing frost lift, but some Canadian work on this achieved little success (Day and Cameron, 1968). Furthermore, even if the incidence of frost lift could be reduced by this or other means, the problem of poor height growth would remain. For successful container planting on such sites, a much larger container will be required and several types are currently being studied (Low and Brown, 1972; Brown and Low, 1973).

Unsatisfactory results were also obtained in the regeneration trials, which have demonstrated that tubed seedlings are unsuitable for replanting various types of felled woodland sites in Britain. At first sight, this situation may seem surprising since tubed seedlings were developed in Canada for planting on cutover forest areas, and, until recently, were being used in very large numbers for this purpose in Ontario (Mackinnon, 1969). However it appears that Canadian foresters were accepting as satisfactory survival levels well below what would be considered acceptable in Britain. Frost lift, low survival and poor growth have all proved to be problems in Canadian work. It has recently been concluded that the plastic tubes which have been used in Ontario (0·5 in. (1·3 cm) diameter) and Alberta (0·75 in. (1·9 cm) diameter) are too small for raising the size of seedlings now thought necessary for satisfactory results (Cayford, 1972). There appears to be general agreement throughout Canada that a container with a diameter of at least 1 inch (or equivalent rectangular cross section) and a length of 3 inches or more is required, preferably removed prior to planting, and various types are being tested (Cayford, 1972; Waldron, 1972; Scarratt, 1972b). A similar conclusion has been reached in Britain where encouraging early results have been obtained on a clear-felled peaty gley site in the Kielder District using Sitka spruce seedlings raised in Japanese Paperpots (F408 type—see Low and Brown, 1972).

The planting tool and technique devised for tubed seedlings on ploughed peatland permit remarkably high rates of planting. On the easier peat sites, a planting rate of 4,500–5,000 seedlings per man-day can readily be achieved on previously stepped ridges. This compares with a planting output of about 2,000 bare-rooted transplants per man-day on similar sites and requires less expenditure of effort. The uniform size of the tube and the simplicity of the actual planting action on peat suggest that tubed seedlings would be well suited to planting by machine. However, the high rates of hand planting possible, combined with various technical problems, make it unlikely that any form of mechanised planting developed in the foreseeable future could compete satisfactorily with hand methods.

Provision of a step in the plough ridge at time of ploughing is essential for realisation of the full economic benefits of planting tubed seedlings. Cutting of steps by hand would be impracticable for large planting programmes as well as being a relatively costly operation. (However, it is worth noting that because of the low cost of planting tubed seedlings, the combined cost of planting and hand stepping (as separate operations) may well be similar to the cost of planting bare-rooted stock.) Some further development work is still necessary to provide a thoroughly reliable step-cutting plough, but there is little doubt that this aim can be achieved.

Extensive peatland sites potentially suitable for tubed seedling use (including peaty gleys with a peat depth exceeding 35 cm, as well as deep peat) form a substantial proportion (probably over 20%) of land likely to be available for upland afforestation in the north and south of Scotland. On such land it has been estimated that large-scale use of tubed seedlings could lead to a saving in establishment costs of up to £12 per hectare. This saving would arise partly from the lower cost of producing tubed seedling stock and partly from a substantial reduction in planting cost. In addition there would be important management advantages—notably a high degree of flexibility in programming nursery output and in carrying out large planting programmes with limited labour availability. The potential gains are substantial, but obtaining them in full will entail use of tubed seedlings on a considerable scale (several million per annum) for peatland afforestation in Britain.

Chapter 6

RECOMMENDATIONS FOR PRODUCTION AND PLANTING OF TUBED SEEDLINGS

Procedure for Tubed Seedling Production

From the results of the greenhouse research programme, the following procedure was developed for the production of tubed seedling planting stock under British conditions:

Extruded grey polystyrene tubes 7·5 cm long × 1·3 cm internal diameter, with a wall thickness of 0·3 mm slit up one side (supplied to special order by Telcon Plastics Ltd., Farnborough Works, Green Street Green, Orpington, Kent) are packed in "honeycomb" formation in standard size 14·5 in. × 9 in. (36 cm × 23 cm) polystyrene seed trays, each holding approximately 440 tubes. A mixture of equal parts by volume of finely milled granulated horticultural sphagnum peat (pH 3·5–4·0, screened through 6 mm (0·25 in.) mesh) and lime-free medium sand is used for filling the tubes and is added until approximately 1 cm at the top of the tubes remains empty after light compaction (e.g. with a dense stiff-bristled brush). Care should be taken to avoid air spaces remaining within the tubes.

Two alternative fertiliser regimes can be used—one based on "Enmag" (manufactured by Scottish Agricultural Industries Ltd.) and the other on Fison's "FL3P" liquid fertiliser. In the first, "Enmag" at 1·5 kg/m^3, fritted trace elements (Frit 253A, distributed by Tennant Trading Ltd., 9 Harp Lane, Great Tower Street, London EC3) at 0·25 kg/m^3 and ground limestone at 3·0 kg/m^3 are added to the peat-sand mix prior to filling the tubes, and no subsequent fertilising is required. In the second, fritted trace elements at 0·25 kg/m^3 and ground *magnesian* limestone at 3·0 kg/m^3 are incorporated prior to filling the tubes; subsequently "FL3P" at a dilution of 3 ml/litre is applied at weekly intervals beginning 3 weeks after sowing, using an application rate of 2·5 litres/m^2 of bench space. The "Enmag" regime is more convenient to use and may give greater average vigour, while the "FL3P" regime gives a slightly higher seedling yield and very uniform growth. (*Note:* Limited recent experience has suggested that Fison's "FL5P" (containing 10% N, 4·4% P, and 4·2% K) can be used as an alternative to "FL3P" and may give slightly better growth.)

The seed used should be of maximum possible viability, with high germinative energy, and selection should be based on recent laboratory test data. In the case of Lodgepole pine and Sitka spruce it is desirable to have the lightest seed (approximately 1/8th of total weight) removed by means of a vibrating gravity table. Before sowing, seed should be pre-chilled in a refrigerator or cold store to ensure rapid even germination. The pre-chilling procedure (for Lodgepole pine and Sitka spruce) is as follows: soak the seed in cold tap water (3–5°C) for 48 hours; drain off the water and remove excess moisture from the seed with paper towelling; then store the moist seed in a sealed polythene bag at 3–5°C for 3 weeks, preferably opening the bag once a week to allow in fresh air. Seed lots which show some degree of dormancy will benefit most from pre-chilling, but it has been found in practice that all lots of Lodgepole pine and Sitka spruce seed used to date, whether dormant or non-dormant, have shown some improvement in rate of germination after such treatment. If for any reason (such as shortage of time) pre-chilling is not possible then at the very least the seed should be soaked in cold water for 48 hours prior to sowing. No seed dressing of any sort should be used.

One seed is sown in each tube and covered with a layer of medium/fine lime-free sand—3 mm thick for Lodgepole pine, Sitka spruce and any other small seeded species, and up to 6 mm thick if any larger seeded species are involved. Sand with a high proportion of very fine (less than 0·2 mm) particles should be avoided as caking may occur and reduce or delay germination. 60–70% of the sand particles should preferably be in the 0·6–0·2 mm class. The trays of tubes are then stood in shallow water (about 30 mm deep) until the peat-sand mixture is thoroughly moist before being placed for 7 days on racks in an insulated germination room maintained thermostatically at a steady 25°C. (If such a facility is not available, trays can be taken directly to a greenhouse, but germination will be slower and less even; as a result a longer production period may be necessary.) The trays are covered with polythene sheeting to minimise water loss and should not need further watering during this period. Continuous lighting is provided by a warm white fluorescent tube, but this is probably not essential. Plate 19 shows a germination room based on a design by the North West England Electricity Board—see Newton and Gould, 1967.

After 7 days the trays are transferred to benches in a greenhouse where approximate day and night temperatures of 21°C and 15°C are maintained by thermostatically controlled heating and ventilation. Adequate forced-draught ventilation is essential during sunny weather in summer. Using a fine spray, watering should be done as required—probably once every 2–3 days in early spring, increasing to once or even twice daily in warm sunny summer weather.

The need for watering is readily determined by examining the soil mixture in the split tubes. Water should not be applied in strong sunshine because of the risk of scalding damage to seedlings. Both under- and over-watering should be avoided—the former because it may lead to seedling loss due to desiccation, and also encourages excessive root emergence from the tube bases; and the latter because it leads to poor root development and excessive loss of nutrients by leaching, and may encourage damping-off. A useful "rule of thumb" is to apply approxmately 2·5 litres of water per m² of bench area at each watering.

As a precautionary measure against fungal attack, a captan drench at 2·5 litres/m² can be applied 2 and 4 weeks after sowing if the risk of damping-off is high (e.g. in cool, damp weather in spring) but the treatment should be used with discretion. "Orthocide Concentrate" at 1·5 g/litre or "PP Captan 50" at 2 g/litre are suitable for this purpose.

Prior to planting (and usually 6 weeks after sowing) trays of seedlings are placed out of doors to harden-off for 2 weeks. During this period netting protection is desirable to prevent damage by birds and mammals, and hessian or other screening may be necessary early and late in the growing season in order to reduce the risk of frost damage. Before trays of tubes are despatched for planting it is desirable to bring them up to full stocking by removing and replacing all tubes without seedlings or with weak, under-sized seedlings. To ensure efficient use of greenhouse space this is best done as early as possible in the production period. With an 8 week production period, sorting of Lodgepole pine and Sitka spruce could be done as early as 3 weeks after sowing, because seedlings germinating after that time are unlikely to be large enough for planting at 8 weeks.

By following the above procedure and using seed with a viability of 85% (a value frequently found for seed of the more readily available origins) it is possible to obtain 80% germination of both Lodgepole pine and Sitka spruce with a usable seedling yeild after 8 weeks of 75% of tubes sown. If the seed used is of higher viability (more than 90%), then higher yields are possible and values exceeding 90% have frequently been obtained (see e.g. Table 4, p. 9) in both greenhouse experiments and stock sowings for forest trials.

Seedlings of pine and spruce usually begin to appear 5–6 days and 7–8 days respectively after sowing, and germination has been largely completed 2 weeks later. For lots sown in early spring, average seedling heights 8 and 12 weeks after sowing will be about 2·5 and 4·0 cm for pine and 2·0 and 3·5 cm for spruce. Because of more favourable growing conditions during the summer months (June–August), germination, yield and growth rates all tend to be higher than at the beginning or end of the growing season.

(Plate 3 (central inset) shows a tray of 440 eight week old Sitka spruce seedlings ready for transport to the forest.)

Use of Tubed Seedlings for Peatland Afforestation

Tubed seedlings of Lodgepole pine and Sitka spruce can be used successfully for afforestation planting on a range of upland peat sites (including some peaty gley soils with a peat depth exceeding 35 cm, as well as deep peats). As a general rule, use of tubed seedlings should be restricted as far as possible to the poorer peat types, where there is little risk of vigorous growth of *Molinia* or other grass species. Suitable sites normally fall within the various unflushed or poorly flushed blanket or basin bog categories, with fibrous or pseudo-fibrous peat. The principal ground vegetation species associated with these are *Calluna*, *Trichophorum*, *Eriophorum* and *Sphagnum* in varying proportions; *Molinia*, if present, should be sparse and non-vigorous. Well-flushed bogs should be avoided because of the vigorous *Molinia* growth which follows ploughing and because the amorphous peat may cause frost lifting of tubes.

Spaced furrow ploughing with a relatively deep-going single mouldboard turfing plough produces the most satisfactory planting ridge for establishment and early growth of tubed seedlings. It is not yet clear whether or not the deep double mouldboard turfing plough currently being developed by Forestry Commission staff will produce ridges suitable for tubed seedling planting. Shallow double mouldboard ploughing is not satisfactory. Use of a single mouldboard plough suitably modified to produce a continuous step along the ridge (see p. 25) will provide adequate early shelter with little or no increase in ploughing cost. If such a plough is not available, planting steps should be cut by hand at appropriate intervals along the ridges prior to the actual planting operation. Whether produced by plough or by hand, the step base should preferably be approximately 20 cm above ground level (in practice, about half ridge height in many cases). For large planting programmes hand stepping is likely to be impracticable because of the labour requirement, as well as being a relatively costly operation. (Nevertheless, because of the low cost of planting tubed seedlings, the combined cost of hand stepping and planting may well be similar to the cost of planting bare-rooted stock.)

For most locations the effective planting season is from mid April to late August, with the optimum period from May to July inclusive. However, April planting of actively growing seedlings should be avoided in areas prone to late spring frosts or to severe weather conditions, particularly if Sitka spruce is being used. Eight-week-old seedlings will generally give satisfactory results, but with Sitka spruce on the more testing sites 10 week old seedlings will give slightly better survival. Planting of over-wintered dormant seedlings in March and April is a possible means of extending the planting season, but results are less reliable. There are also practical difficulties involved in raising and over-wintering large numbers of seedlings for such early plantings.

Trays of seedlings can be sent from the nursery to the forest in a suitably racked covered vehicle at any time during the 2 week hardening off period. They must be in good condition when despatched and must be watered as necessary to prevent drying out during any subsequent storage period prior to planting. Netting protection against bird and mammal damage may also be required. Prior to the planting operation, a tracked cross-country vehicle can be used for distributing the trays within the planting area to minimise time spent by planters walking to collect them. (The *average* distance walked for this purpose should preferably not exceed 25 metres.)

Planting is done with a specially devised tool (see Plate 15) made from a 1 m length of stainless steel tubing with an outside diameter of 15 mm and a wall thickness of approximately 0·75 mm. At one end, half of the circumference (not more) is cut away for a length of 12 cm and any rough edges filed smooth. An internal "stop" (made from half of a suitably sized washer) is welded 8·3 cm from the end of the tube. An external depth gauge is welded round the outside of the tube 9·5 cm from the end. (The difference between the gauge locations ensures that after planting the top edge of the tube is slightly below the peat surface.) The other end of the tube is bent to form a handle. Prior to use, the cut-away end is adjusted with pliers to ensure that tubes are held with sufficient pressure to prevent their dropping out before the tool is inserted into the peat.

When planting, each worker requires a harness to support a tray of seedlings held in front of him (see Plate 16). This leaves both hands free to load and use the planting tool. The detailed working method is as follows:

The wokrer walks alongside the previously stepped plough ridge carrying the tool in one hand (usually the right but left-handed operation is relatively easy for many right-handed persons). During loading the tool is held more or less horizontally in front of the tray. A tube is picked from the tray by the other hand and slid into the tool channel with slight downward pressure until it rests against the internal stop with the seedling shoot projecting beyond the stop. The loaded tool is pushed vertically into the peat and is then withdrawn, leaving the tube inserted in the peat with its top edge slightly below the peat surface. While the tube is being pushed in, the free hand is selecting the next seedling to be planted. It is important that tube selection and loading of the tool are done while the worker is moving from one planting spot to the next and that all movements are carried out as part of a steady rhythm. With relatively little practice, planting can be done at a slow but steady walking pace. Where cross-drains have been ploughed prior to planting, workers should progress backwards and forwards between two successive drains. This avoids not only the break in continuity inherent in crossing such drains but also the risk of stumbling or falling in the process and consequent spillage of seedlings. The rate of planting achieved varies with the walking conditions and with the type and condition of peat in the ridges. In North Scotland, average output per man (including allowances for associated work and rest) has ranged from 740 seedlings per hour, with easy walking and peat well-suited to the technique, to 415 seedlings per hour with difficult walking and barely suitable peat. Table 11 gives a guide to the expected output for various combinations of site conditions.

Table 11

HOURLY PLANTING RATE FOR TUBED SEEDLINGS IN RELATION TO SITE CONDITIONS (INCLUDING ALLOWANCES FOR ASSOCIATED WORK AND REST)

Walking conditions	Peat conditions		
	Good	Intermediate	Poor
Easy	740	655	585
Intermediate	585	530	485
Difficult	485	450	415

Notes: 1. *Walking conditions*—

Easy: Little danger of stumbling or tripping; ground reasonably firm; possible to walk easily on either side of ridge.

Intermediate: Impediments to walking necessitate care at times; walking may be very difficult on one side of ridge.

Difficult: Care necessary to avoid falls; little room to walk alongside ridge; ground may be very wet.

2. *Peat conditions*—

Good: Peat fibrous or pseudo-fibrous, firm and moist (but not waterlogged); tubes penetrate easily and remain in peat.

Intermediate: Peat fibrous to amorphous, occasionally hard with patches of mineral soil and stones; tubes usually penetrate easily and remain in peat, but may occasionally break or fail to remain.

Poor: Sphagnum peat or very friable amorphous peat giving easy penetration but very poor retention of tubes; also peat with tough dried-out surface layer which makes penetration difficult and leads to broken tubes.

3. *Allowances included*—

An allowance of 22% has been made for necessary work other than actual planting (collecting trays from nearby supply point, crossing from one furrow to the next, etc.); rest time was also included as 20% of time spent on planting and other necessary work.

Fertiliser treatment at time of planting tubed seedlings can be carried out in the same way and at the same rates as for transplants. Spot and broadcast methods of application appear to give similar results. On the poorer peats, the use of fertiliser supplying both P and K (rock phosphate-muriate of potash mixture at 565 kg/ha) rather than P alone (rock phosphate at 375 kg/ha) should give a worthwhile growth response. If necessary for management reasons, fertiliser can be applied slightly in advance of planting but a lengthy period between fertilising and planting is undesirable because of the possible effect on weed growth.

Unacceptable losses and delay in establishment are likely if serious browsing damage occurs. Exclusion of red deer and sheep is essential, and control of hares and roe deer may be necessary. In the trials, serious damage has been much less frequent than anticipated. However, there is obviously little point in planting tubed seedlings on sites where the occurrence of *severe* browsing damage by hares, deer or black grouse is highly probable and cannot be prevented.

Control of weed growth will usually be unnecessary if planting of seedlings is confined to the poorer upland peats, as described above. However, it is inevitable that on some sites control of grass growth will be required (e.g. where *Molinia* responds to ploughing and fertilising more vigorously than expected). In such cases dalapon treatment (at 10 kg/ha active ingredient) provides an alternative to costly hand weeding. The chemical should be applied as a medium volume spray in water immediately prior to flushing of the trees in the season after planting (or in subsequent seasons if required).

When used in appropriate circumstances, tubed seedlings give high survival and vigorous early growth. The basic height growth pattern is similar to that of transplant stock planted on similar sites, but differs in absolute terms because of the much smaller initial size of the seedlings. For both Lodgepole pine and Sitka spruce, the difference is likely to be equivalent to between one and two seasons' growth. Root development is generally satisfactory, and in the case of Lodgepole pine provenances from coastal Washington and Oregon use of tubed seedling stock is likely to give improved early stability.

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