Tubed Seedling Research and Development in Britain

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SUMMARY

Based initially on Canadian practice, research on the production and use of tubed seedlings in Britain has been in progress for 3 years (1968–70), and was begun because of their potential advantages as planting stock. Polythene greenhouses are used to produce pine and spruce seedlings grown in small plastic tubes filled with fertilized peat-sand compost, and planting is possible 8 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. Animal browsing is the main adverse factor encountered, but has been less serious than expected. Very high planting rates are possible with a special tool. Seedling use could lead to large savings in peatland afforestation costs, and large-scale trials are planned. In contrast, seedling performance on ploughed mineral soil has been unsatisfactory due to severe frost lifting and poor height growth. Results in reafforestation trials have not been very promising.

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 was 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) but use of container-grown stock appeared to be the most promising means of obtaining a major 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 in diameter) open-ended, side-slit plastic tubes. When only a few weeks old, these tubed seedlings 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 1 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:

(i) 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;
(ii) much increased nursery output leading to reduced supervisory costs and other overheads;
(iii) elimination of transplanting, thus avoiding a seasonal peak in labour requirement;
(iv) simplified selection of nursery sites because large areas of easily worked land would no longer be required;
(v) considerable extension of the planting season, by making possible the safe planting of actively growing trees, thus reducing a seasonal peak in labour requirement;
(vi) increased speed of planting due to ease of planting tubes, giving higher output per man-day and reduced planting costs;
(vii) 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 potential disadvantages, all associated with the small size of the tubed seedlings when planted, were:

(i) greater vulnerability to animal damage;
(ii) unsuitability for weedy sites unless cheap, effective, weed control could be achieved;
(iii) 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*) and Sitka spruce (*Picea sitchensis*) 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 this country 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.

PRODUCTION OF TUBED SEEDLINGS

Research on the production of tubed seedlings has now been in progress for three seasons (1968, 1969, and 1970) at three Forestry Commission nursery research centres—Tulliallan (Fife), Inchnacardoch (Inverness-shire), and Newton (Moray). Both Tulliallan and Inchnacardoch are equipped for the purpose with a large (12 m × 6 m) polythene-covered greenhouse, while at Newton a smaller conventional glasshouse is used. In these houses, day and night temperatures of 20–25 °C and 10–15 °C respectively are maintained by thermostatically controlled warm air heating and fan ventilation. The degree of temperature control which is possible varies with the external air temperature and in consequence both day and night temperatures are somewhat higher in summer than in spring and autumn.

In each season a similar research programme has been carried out at the three centres. A 'standard' technique derived from Ontario seedling production methods (Anon., 1967) was used as a basis for investigating a range of factors which were likely to influence germination and growth of seedlings in tubes. Factors studied have included tube size, soil mixture used for filling tubes, fertilizer regime, seed cover depth, seed grading prior to sowing, use of fungicides, and root growth control. While most experiments have been concerned with raising Lodgepole pine and Sitka spruce seedlings, some work has been done to determine the extent to which methods found suitable for these species required modification for other species, particularly Grand fir (*Abies grandis*). The short duration (usually 12 weeks) of individual experiments has frequently allowed them to be repeated in the second half of the growing season, thus providing rapid confirmation of results. Where appropriate the effect of nursery treatments on growth after planting has been studied in forest trials.

The number of experiments carried out to date is large and in the interests of brevity it is not proposed to describe them here. Details of most have been published in the Forestry Commission's annual Research Report (Low, 1969a; Low and Brown, 1970a).

Current procedure for tubed seedling production

As a result of the greenhouse research programme, the following procedure has been developed for the production of tubed seedling planting stock under British conditions:

Extruded polystyrene tubes 75 mm long × 13 mm internal diameter, with a wall thickness of 0·3 mm and 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 in × 9 in) polystyrene seed trays, each containing 400–40 tubes. A mixture of equal parts by volume of granulated horticultural peat (screened through 0·25 in (6 mm) 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.

Two alternative fertilizer regimes can be used—one based on 'Enmag' (manufactured by Scottish Agricultural Industries Ltd) and the other on Fison's 'FL3P' liquid fertilizer. In the first, Enmag at 1·5 kg/m^3 (1·5 oz/ft^3), fritted trace elements (Frit 253A, distributed by Tennant Trading Ltd., 9 Harp Lane, Great Tower Street, London, E.C. 3) at 0·25 kg/m^3 and ground limestone at 1·5 kg/m^3 are added to the peat-sand mix prior to filling the tubes, and no subsequent fertilizing is required. In the second, fritted trace elements at 0·25 kg/m^3 and ground ***magnesian*** limestone at 1·5 kg/m^3 are added prior to filling the tubes; subsequently Fison's 'FL3P' at a dilution of 3 ml/l (0·5 fl oz/gal) is applied at weekly intervals beginning 3 weeks after sowing, using an application rate of 2·5 l/m^2 (0·5 gal/yd^2) of bench space. The 'Enmag' regime is more convenient to use and gives greater average vigour, while the 'FL3P' regime gives a slightly higher seedling yield and very uniform growth.

The seed used should be of maximum possible viability because only one seed is sown in each tube. In the case of Lodgepole pine and Sitka spruce it has been found beneficial to have the lightest seed (approximately one-fifth by volume) removed by means of a vibrating gravity table. No seed dressing of any sort is required. Depending on species and condition of seed, the rate of germination may be increased by soaking the seed in cold water (3–5 °C) for 24 hours, or by soaking for 24 hours followed by moist storage in a refrigerator at 3–5 °C (pre-chilling) for 3 weeks prior to sowing. The need for pre-chilling is best determined on the basis of seed laboratory test results, but Sitka spruce will normally benefit from such treatment whereas soaking for 24 hours may be adequate for Lodgepole pine. If any degree of seed dormancy is suspected, the seed should be pre-chilled. A satisfactory method is to 'sandwich' the seed between moist blotting paper inside sealed polythene bags, which are placed in the food compartment (not the freezer) of a domestic refrigerator.

Immediately after sowing, the seed is covered with a layer of medium sand —3 mm thick for Lodgepole pine, Sitka spruce, and other small-seeded species, and 6 mm thick for the large seeded Grand fir. Sand with a high proportion of very fine ($<$ 0·2 mm) particles should be avoided as caking may occur and reduce germination. It is preferable that 60–70 per cent of the sand particles should be in the 0·6–0·2 mm size class. The trays of tubes are then stood in shallow water (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 at a steady 25 °C. (The germination room is based on a design by the North West England Electricity Board—see Newton and Gould, 1969). Trays are covered with polythene sheeting to minimize water loss and

Fig. 1. Tray of 400 8-week-old Lodgepole pine tubed seedlings ready for planting.

PLATE I

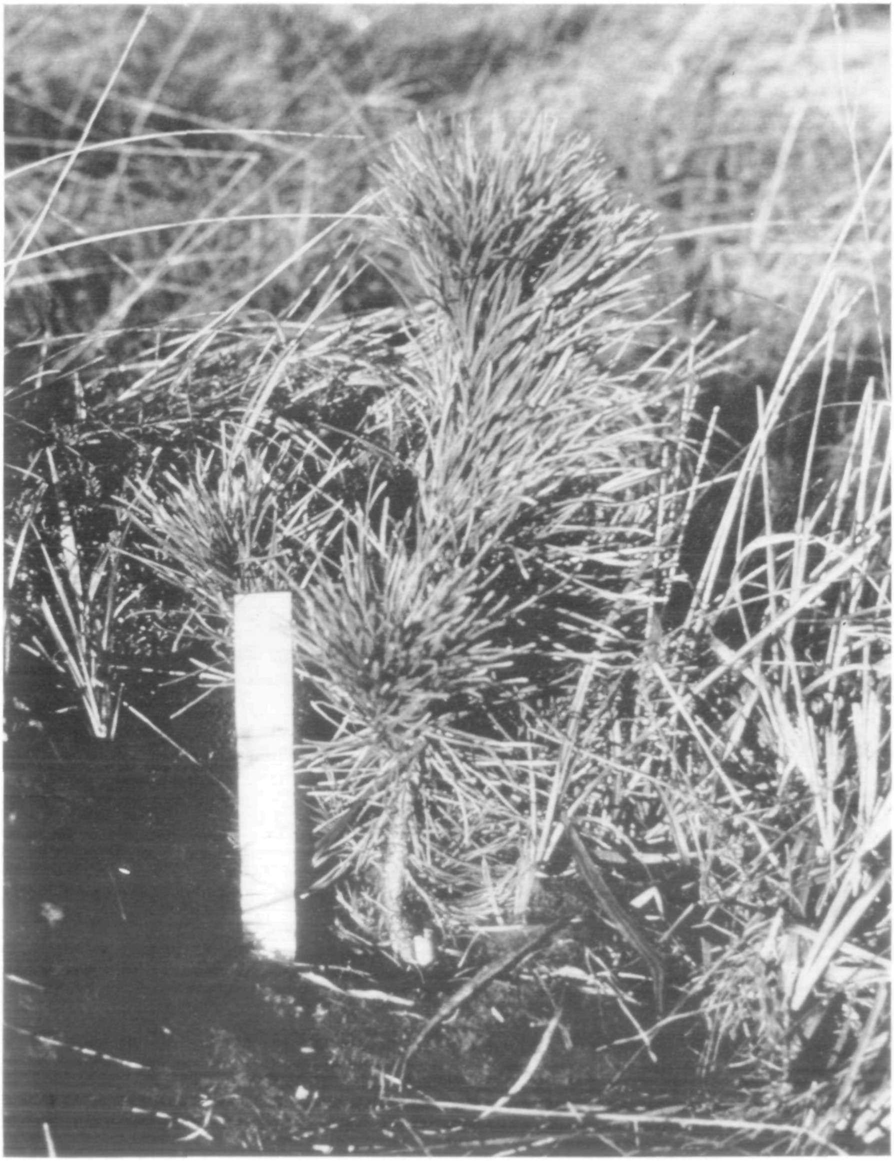

FIG. 2. Lodgepole pine step-planted as an 8-week-old tubed seedling on ploughed deep peat in September 1967 and photographed in November 1969. Naver Forest. (Scale is 15 cm long.)

PLATE II

FIG. 3. Sitka spruce plants step-planted as 8-week-old tubed seedlings on ploughed deep peat in July 1968 and photographed in June 1970. Note vigorous current shoots. Tighnabruaich Forest.

PLATE III

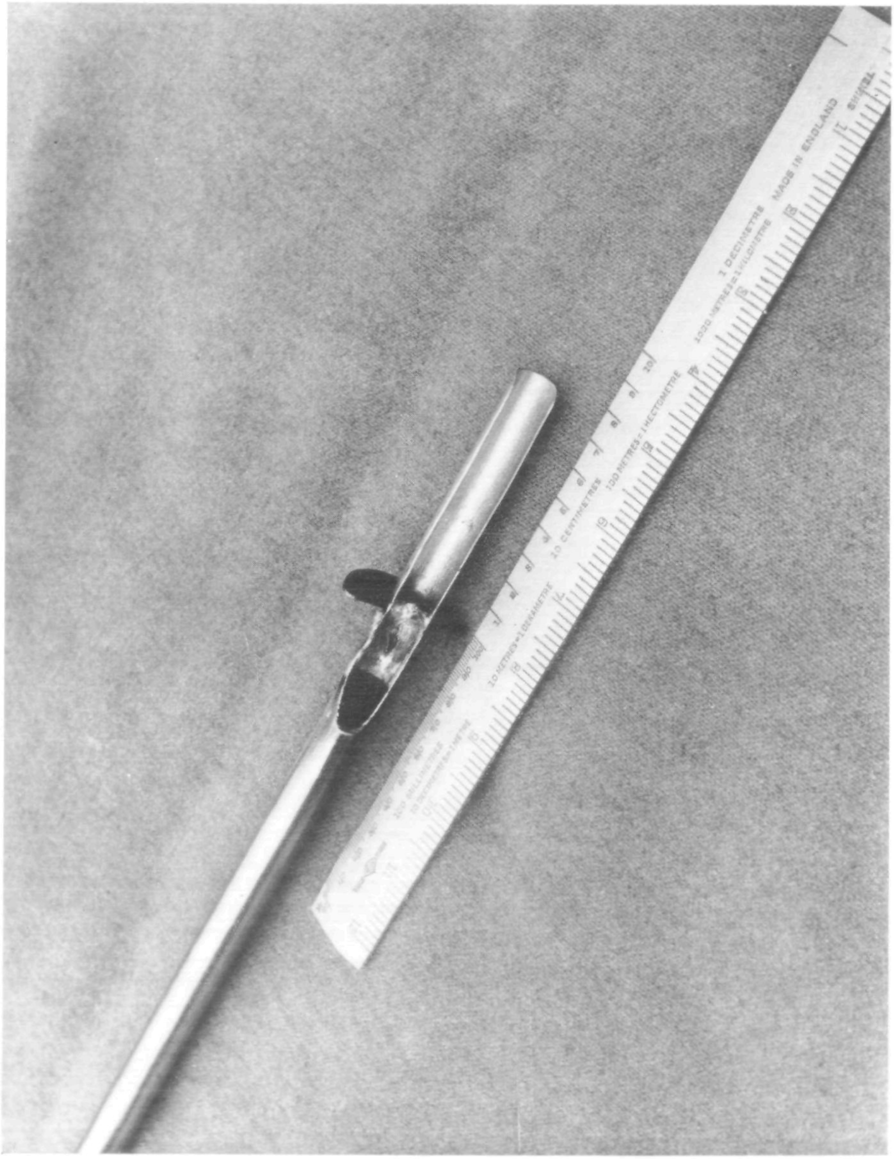

FIG. 4. Prototype tool under development for rapid planting of tubed seedlings.

PLATE IV

should not require further watering during this period. Continuous light is provided by a warm white fluorescent tube, but this is probably not essential.

After 7 days the trays are transferred to benches in a greenhouse where approximate day and night temperatures of 21 °C and 10 °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, the need being readily determined by examining the soil mixture in the split tubes. Watering should not be done in strong sunshine because of the risk of scalding damage to seedlings, and over-watering should be avoided as it leads to poor root development and may encourage damping-off. As a precautionary measure against fungal attack, a Captan drench at 2·5 l/m² (0·5 gal/yd²) is normally applied 2 and 4 weeks after sowing and if the risk of damping-off is high (e.g. in cool damp weather in spring and autumn) additional applications may be given 1 and 3 weeks after sowing. 'Orthocide Concentrate' at 1·5 g/l (6 g/gal) or 'PP Captan 50' at 2 g/l (10 g/gal) should be used 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 dispatched 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 at least 85 per cent (a value commonly found for seed of the more readily available origins) it is possible to obtain 70–80 per cent germination of both Lodgepole pine and Sitka spruce with a usable seedling yield after 8 weeks of 65–75 per cent of tubes sown. Seedlings of pine and spruce usually begin to appear 5–6 days and 7–8 days respectively after sowing, and germination has largely been completed 2 weeks later. Average seedling heights 8 and 12 weeks after sowing are 25 and 40 mm for pine and 20 and 35 mm for spruce. Because of more favourable growing conditions, germination, yield, and growth rates all tend to be higher during the summer months (June–August) than at the beginning and end of the season. Fig. 1 shows a tray of 440 8-week-old Sitka spruce seedlings ready for transport to the forest.

FOREST TRIALS OF TUBED SEEDLINGS

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. During the following three seasons (1968–70) a further fifty-nine experiments have been planted, mainly at forests in the North, West, and South Scotland Conservancies, but including a few located 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 peats and mineral soils in upland areas, but some attention has been given to their use for regeneration planting, particularly on clear-felled spruce sites.

In almost all cases, simple randomized block experimental designs have been 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 have been Lodgepole pine (almost entirely of Washington Coast origin) and Sitka spruce in afforestation trials, and Sitka spruce, Norway spruce, Western hemlock, Grand fir, and Corsican pine in regeneration trials. Factors being tested in the experiments include date of planting, seedling age at time of planting, tube size, soil mixture in tube, nursery fertilizer regime, method of planting, position of planting, and forest fertilizer regime. Almost all of the planting has been done using a simple steel dibble. Initially the length of the dibble was such as to leave approximately 1 cm of the tube protruding from the soil surface, but since the beginning of 1969 it has been considered desirable to insert tubes completely into the soil.

Results to date from the older (1967–9) experiments are summarized in the following sections. Additional information can be obtained from the Annual Report on Forest Research (Low, 1969b, Low and Brown, 1970b). The most recently planted (1970) experiments are at present too young to provide useful information.

Afforestation trials on peat

The principal localities of the 1967–9 trials on ploughed peatland are Naver Forest (Sutherland), Shin Forest (Sutherland), Selm Muir Forest (Midlothian), and Tighnabruaich Forest (Argyll). Experiments were also planted at Rumster Forest (Caithness) and Towy Forest (South Wales). On each site, application of phosphate fertilizer was considered essential for the satisfactory establishment of a tree crop on the acid, infertile hill or bog peats involved.

Early results for both Lodgepole pine and Sitka spruce have been very promising. On most sites, including some with a relatively high degree of wind exposure, the better treatments tested have given 95 per cent or higher survival at the end of the first winter after planting, and over 90 per cent at the end of the second winter. Height growth has varied with site conditions, but on a number of sites has been remarkably vigorous when related to the small size of the seedlings at time of planting. For example, on an exposed deep peat site at Naver Forest, Lodgepole pine step-planted as 8-week-old seedlings in September 1967 averaged 27 cm (10·5 in) in height at the end of the 1969 growing season, and individual tree heights ranged up to 49 cm (19·5 in). Figs. 2 and 3 show examples of good early growth by Lodgepole pine and Sitka spruce step-planted on ploughed deep peat sites.

The desirability of some initial shelter for the seedlings, particularly on exposed areas, has been convincingly demonstrated in some of the earlier experiments. Step-planting was found to give considerably improved survival and growth, and has been adopted as normal practice for tubed seedling work on peat. Hand preparation of conventional planting steps is a time-consuming operation and studies are in hand to determine the simplest effective form of 'stepping' for tubed seedling establishment.

TABLE I. *Tubed seedling survival after the first winter in a trial at Selm Muir Forest*

8-week-old seedlings planted during 1969 and assessed in April 1970

Month of planting	Survival per cent	
	Lodgepole pine	Sitka spruce
April	87	40*
May	96	95
June	92	94
July	97	95
August	75	89
September	76	81
October	41	61

* Seedlings badly injured by late frosts soon after planting.

To determine the effective planting season, actively growing tubed seedlings were planted out at monthly intervals from mid April to mid October. Early results from one experiment are shown in Table I. Taking into consideration all the experiments involved, survival has been highest for planting between May and July, somewhat lower for April and August, and progressively poorer for September and October. Height growth has so far followed a more or less similar pattern with the best results for planting between May and July, and a marked reduction for late-season planting. Results for April planting have been variable and often poor because frequently seedlings either suffered frost damage or developed terminal buds and stopped growing soon after planting. In an effort to avoid this the most recent (1970) experiments include dormant seedlings planted in March and April, but results for these are not yet available.

Canadian experience and the results of preliminary trials indicated that seedlings would probably be sufficiently well developed for 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 have been compared in many of the experiments. Results to date have not been very consistent but for the most part average differences in survival and height growth have been small. There is, however, some indication that the older seedlings have given slightly better survival for early planting (April–May) particularly in the case of Sitka spruce.

Root excavations in various experiments 13–15 months after planting showed that both Lodgepole pine and Sitka spruce were developing vigorous well-balanced root systems, with main roots up to 18 cm (7 in) long extending downwards from the tube base. Roots emerging from the slit in the tube were uncommon, presumably because of pressure on the slit from the surrounding peat. There was little sign of any tendency for roots to remain in the vicinity of the tube and the root systems appeared satisfactory from the viewpoint of subsequent growth and stability. However, slight loosening of the most vigorous Lodgepole pine plants by wind has recently been observed in the oldest trials, and it is not yet possible to say whether use of tubed seedlings can reduce the incidence of basal bowing of this species.

Because of the relatively inert nature of the polystyrene plastic, it was originally feared that there would be some risk of vigorous trees becoming strangled by pressure of the tube around the expanding root collar region. However, there have been no reports of such trouble in older plantings in Canada. Early evidence from British trials suggests that trees will have little difficulty in forcing open the slit tube, which appears to lose a good deal of its strength within a year of planting.

Because of the small size of tubed seedlings the effects of any animal browsing soon after planting are inevitably more serious than in the case of much larger transplant stock. Fortunately serious browsing damage has so far been less than anticipated, although in some cases both survival and growth (but particularly the latter) have been greatly reduced by repeated browsing. Some damage has occurred in almost all experiments but has frequently been patchy and limited in extent. Damaged seedlings have shown considerable powers of recovery but height growth is retarded and the period of vulnerability is extended. Most of the damage has been caused by roe deer, hares, or blackgame. In one experiment at Shin Forest, red grouse appeared to be responsible for pulling many tubes out of the peat and pecking them open, probably to obtain sand particles for digestive purposes.

The small initial size of tubed seedlings also makes them more susceptible than transplants to suppression by competing vegetation. Fortunately weed growth is usually not very vigorous on the poorer peats and has not proved to be a serious danger in most of the experiments. However, in some cases vigorous growth of grasses has been stimulated by the phosphate fertilizer applied, and has provided a clear demonstration of the difficulty of finding small seedlings in dense vegetation and of keeping them reasonably free from suppression.

Except where planting has been done very early or very late in the growing season, climatic damage to seedlings has not been serious. On the more severely exposed sites some winter killing of foliage and shoot tips (particularly of Sitka spruce) has occurred even with step planting. However, as in the case of browsing damage, recovery has usually been good. Slight frost-lifting of tubes has sometimes occurred on patches of relatively amorphous peat during the first winter after planting, but the effect on survival and growth has been small.

Afforestation trials on mineral soils

Between 1967 and 1968 afforestation trials on various ploughed mineral soil types were planted at Glen Garry Forest (Inverness-shire), Farigaig Forest (Inverness-shire), Tighnabruaich Forest (Argyll), Selm Muir Forest (Midlothian), and Towy Forest (South Wales). The soils included surface water gleys with and without appreciable peat layers, a humus iron podsol, an ironpan soil, and a podzolic brown earth. As in the case of the peatland trials, application of phosphate fertilizer 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 tine 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 trials, early results on these mineral soils have been far from encouraging. The most serious adverse factor has been the high incidence of frost-lifting of tubes during the first and, to a lesser extent, the second winters after planting. All experiments have been affected in this way and in most of them a very high proportion (often over 75 per cent) of the tubes have been lifted at least partly out of the soil during the first winter. Often tubes have been 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 lift was seldom observed, as was also the case in the peatland trials.

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-lift. Seedlings tended to check after planting and were slow to resume normal growth except where above-average moisture conditions resulted from the presence of peat in the plough ridge. Growth has been further hampered by the recurrent frost-lifting and in general has not been satisfactory, with average heights usually less than 10 cm (4 in) after two full seasons' growth.

Experimental comparisons of 75, 100, and 125 mm (3, 4, and 5 in)-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 have tended to obscure 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.

In view of the poor results described above it was decided at the end of 1969 that future experimental work on mineral soils would be restricted to peaty gley soils with a peat layer sufficiently thick to form at least half the thickness of plough ridges. It seems likely that such sites will give early results similar to those obtained on deep peat.

Regeneration trials

Tubed seedlings were developed in Canada for replanting felled woodland and in order to obtain some information on their suitability for this purpose in Britain a few small experiments have been planted on selected sites. The first was located at Kielder Forest (Northumberland) in 1968 and in 1969 others followed at Kielder Forest, Glenbranter Forest (Argyll), Allerston Forest (Yorkshire), and Thetford Forest (East Anglia). As yet these experiments are too young to provide more than a very general indication of seedling performance. Early results have been variable and frequently disappointing.

On the peaty gley sites at Kielder and Glenbranter, where tubed seedlings were planted after removal of a previous spruce crop, it appears that poor aeration due to waterlogging of the peat layer is an important factor restricting both survival and growth. Some tubed seedlings of Sitka spruce, Western hemlock (*Tsuga heterophylla*), and Grand fir are growing well, but most survivors are not vigorous and often look less healthy than adjacent natural Sitka spruce seedlings. Some frost-lifting has occurred, particularly in the wetter areas.

The same three species were used on an ironpan soil at Allerston, where there has so far been little difference in initial growth and survival between seedlings planted beneath a Japanese larch overwood (300 stems/hectare) and in an adjacent clear-felled area. Seedling performance has been somewhat better where screefing rather than Paraquat was used for pre-planting weed control because dense re-growth of grass after the latter treatment smothered many seedlings. Little or no frost-lift has been observed.

At Thetford damage by pheasants and finches, followed by winter frost-lift, 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 carried out in connection with other research work. Considerable bird damage also occurred in a second experiment planted beneath a light Scots pine overwood, but the presence of the overwood appeared to prevent frost-lift. Heavy weed growth has proved to be a considerable problem on these sites.

Planting method and tools

When planting tubed seedlings with a simple dibble, the planter normally uses both hands—one to hold the dibble and the other to insert the tube into the hole. Keeping him continually supplied with seedlings so as to allow fast, rhythmic planting is difficult because he has to bend down when inserting the tubes and it is therefore not practicable for him to carry a tray of seedlings in a carrier attached to his body. It is possible for him to carry a tray in one hand using a special frame or basket but this is cumbersome and breaks his rhythm as it has to be laid down beside each planting spot to free one hand for tube insertion. Alternatively, he 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 the dibble holes into which the tubes are then inserted by the other who carrys a tray of plants in one hand. The latter two methods appear to be widely employed in Canada (Anon., 1967; Carman, 1967; Mackinnon, 1968) and have been used successfully in Britain. On previously stepped peat ridges an average planting rate of up to 2,000 seedlings per man-day (including the man carrying the plants) appears possible but this requires close co-ordination between the men involved.

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 planter 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 very limited, but it seems to have achieved only limited success because of difficulty in placing tubes sufficiently firmly in the soil and in preventing soil from clogging the moving parts.

Forestry Commission Work Study staff are now developing a new type of tool designed to allow rapid single-handed planting of tubed seedlings on peatland sites in Britain (Fig. 4). 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 in dibble planting) are thus combined into one movement. When the tool is withdrawn the tube is held by suction in the moist peat in the plough ridge. As in the case of the Ontario 'planting stick', the planter does not have to bend down when planting and so can carry a tray of tubes strapped in front of him. Time trials have indicated that a planting rate well in excess of 3,000 seedlings per man-day should be attainable on previously stepped plough ridges. Experiments are in progress to determine whether use of the new tool has any adverse effects on root or shoot growth as compared with dibble planting. Early indications suggest that there will be little difference between the two methods. As already noted, to obtain maximum benefit from the high planting rate which is possible with tubed seedlings, a cheap, rapid method of stepping plough ridges is required. This should preferably be done as part of the ploughing operation and possible methods are now being investigated.

GENERAL DISCUSSION AND CONCLUSIONS

Over the past 3 years an intensive programme of greenhouse research has been carried out with the object of determining the most satisfactory method of producing Lodgepole pine and Sitka spruce seedlings in tubes under British conditions. To a large extent this aim has now been achieved with the development of the production procedure described earlier on pages 29–31, which has been used successfully during 1970 for raising many thousands of pine and spruce seedlings for use in forest trials.

The procedure also appears satisfactory for other common conifer species used in Britain, although minor modifications may be required to cope with large-seeded or slow-germinating species. Canadian practice in 1967 was used as a 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 fertilizer regime used.

As stated earlier, it is now possible to obtain with reasonable consistency 70–80 per cent germination of Lodgepole pine and Sitka spruce, and a usable 8-week-old seedling yield of 65–75 per cent of tubes sown. Such a germination percentage compares very favourably with results from normal nursery sowings, but there is some room for improvement because the laboratory-assessed viability of the more readily available seed origins of these species is usually 85–95 per cent (as a rule somewhat higher for Lodgepole pine than for Sitka spruce). Further studies on seed grading and seed pre-treatment should result in improved germination of seeds sown and in a higher yield of usable seedlings. However, with only one seed sown in each tube it is unlikely that the proportion of tubes with usable seedlings can be raised much above 85 per cent. Sowing two seeds per tube has been considered as a possible means of increasing the proportion of tubes of seedlings, and is 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 would delay establishment after planting. With seed of high viability, such as that of 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 for raising seedlings of species such as Douglas fir (*Pseudotsuga menziesii*), Western hemlock, and Grand fir, the seed of which is often of relatively low viability and tends to germinate unevenly.

Canadian experience has shown that reasonably efficient large-scale production of tubed seedlings is possible with the various stages of the operation carried out almost entirely by hand (see, for example, Carman, 1967 and Kococinski, 1968). The provision of specially designed hand-operated tools has enabled teams of experienced workers (usually women) to pack tubes in 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. However, the uniform tube size and repetitive nature of the work suggest that a high degree of mechanization should be possible in these early stages of the seedling production cycle. A prototype machine for this purpose is being developed in Canada (MacKinnon, 1969) with a projected daily out-turn of 500,000 tubes loaded, seeded, and sanded. Because of the potential advantages, the development of mechanical tube-handling procedures is now being considered by Forestry Commission staff.

Turning now to the forest use of tubed seedlings, it is inevitable that many of the conclusions which can be drawn at present will be tentative. Because the earliest trials in Britain were planted near the end of the 1967 growing season, little more than 3 years' experience is currently available for assessing seedling performance. In addition, although the experiments sample a relatively wide geographic area, planting has until recently been on a very limited scale at any one forest.

Nevertheless, the results to date from the peatland trials have for the most part been very encouraging. They suggest that in the absence of serious animal damage tubed seedlings could well be suitable for use in the afforestation of upland peat sites where early weed growth is not normally a problem. With the aid of early shelter provided by step planting, both Lodgepole pine and Sitka spruce seedlings have proved capable of high survival and vigorous early growth despite their small size when planted on the low-fertility, often exposed peat sites used for the trials. The effective planting season is likely to be from mid April to the end of August, possibly extending into September in mild areas. For most of this period 8-week-old seedlings appear to give as satisfactory results as older stock, but for spring planting there may be some advantage in using 10–12-week-old seedlings, particularly when Sitka spruce is being planted.

From the experiments it has emerged that the most important factor likely to restrict use of tubed seedlings on peatland is the incidence of browsing damage by hares, deer, and blackgame. However, when considering the risk of serious animal damage, it is necessary to bear in mind that animal curiosity may well lead to a higher incidence of damage within the relatively small experiments, which are surrounded by large areas planted with transplant stock, than would be the case if tubed seedlings were planted over large areas. Guidance on this point will soon be available from relatively large trial blocks 3–4 ha (8–10 ac) in area, planted during 1970. For the present, it seems best to assume that successful use of tubed seedlings on peatland will frequently require a higher intensity of animal pest control than is necessary when using transplants.

In contrast to the peatland results, seedling performance on ploughed mineral soils has generally been unsatisfactory. The recurrent frost-lift and poor height growth in the trials have already demonstrated convincingly that there is little future for tubed seedlings (of the type under test) on such sites. The only possible exception is on peaty gley soils where the peat layer is deep enough to form a large part of the plough ridge. Modification of the tube shape has been suggested as a means of reducing frost-lift, but Canadian work suggests that this would not be successful (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. A considerably larger type of container plant seems likely to be required for successful container-planting on such sites, and this is under investigation (Brown, 1970).

In the small number of regeneration trials, results to date have not been very promising. Both growth and survival have been variable and additional trials will be required in order to allow definition of the possible place of tubed seedlings in regeneration work in Britain. It may be that use of a larger type of plant may have to be considered as in the case of ploughed mineral soils. At first sight this situation may seem surprising in view of the current annual use of millions of tubed seedlings in the restocking of felled woodland in Canada (MacKinnon, 1969) and a recent report of successful trials in the U.S. state of Minnesota (Alm and Schantz-Hansen, 1970). However, it appears that Canadian foresters will accept as satisfactory a survival level well below what would be considered acceptable in Britain, and frost-lift, low survival, and poor growth have all proved to be problems in Canadian work.

Continuation of assessments in existing peatland trials for at least a further two seasons will be required in order to confirm that trees originating as tubed seedlings are comparable with trees from transplant stock in growth and stability. In addition, information is required from the recently planted large blocks of seedling stock in order to clarify the risk of serious browsing damage. Nevertheless, on the basis of the results to date large-scale user trials of tubed seedlings are now being planned for selected upland peat sites. Potentially suitable peatland sites (including peaty gleys with a peat depth exceeding 30 cm as well as deep peats) could well form up to half of the land available for afforestation in the foreseeable future. On such land, assuming successful development of planting and stepping methods, it has been estimated that large-scale use of tubed seedlings would lead to a saving in establishment costs of up to £12 per hectare (£5 per acre). This saving would arise partly from the lower cost of producing tubed seedling stock and partly from a considerable reduction in planting costs. 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. Valuable benefits are therefore likely to follow from successful development of tubed seedling techniques for peatland afforestation, and on present evidence the probability of such success appears to be high.

LITERATURE REFERENCES

Alm, A. A., and Schantz-Hansen, R. (1970): Planting pine tubelings in Minnesota. *J. For.* **68** (6), 353–7.

Anon. (1963): *Tree planting practices for arid zones.* F.A.O. Forestry Development Paper No. **16**.

Anon. (1967): *Provisional instructions for growing and planting seedlings in tubes.* Research and Timber Branches, Ontario Dep. Lands and Forests (restricted circulation).

Brown, R. M. (1970): Forest use of roll ('Nisula') transplants. *Rep. For. Res., Lond.* for 1970, 49–50.

Carman, R. D. (1967): An industrial application of the container planting technique. *Pulp Pap. Can.* **68,** WR 181–2, 184–6, 188.

Davies, E. J. M. (1968): Scarce resource. *Scott. For.* **22** (4); 291–9.

Day, R. J., and Cameron, D. A. (1968): The effect of frost heaving on different tube shapes for tubed seedlings. Extr. from *Rep. For. Res. Glendon Hall Fac. For. Univ. Toronto 1967/68*, 5.

Kococinski, G. H. (1968): Growing tubed seedlings in the Kenora District. *For. Chron.* **44** (1), 18–20.

Low, A. J. (1969a): Tubed seedlings. *Rep. For. Res., Lond. for 1969*, 36–9.

—— (1969b): Forest use of tubed planting stock. Ibid., 60–2.

—— and Brown, R. M. (1970a): Tubed seedlings. *Rep. For. Res. Lond. for 1970*, 42–6.

—— —— (1970b): Forest use of tubed planting stock. *Rep. For. Res., Lond.* for 1970, 47–9.

MacKinnon, G. E. (1968): Planting nursery stock and tubed seedlings on Crown lands in Ontario. *Pulp Pap. Can.* **69** (21), 95–8.

—— (1969): Expérience de régénération artificielle nouveau genre. *Forêt Conservation* **35** (8), 12–13.

Newton, P., and Gould, C. W. (1969): Germination room can bring controlled growing a step nearer. *Commercial Grower*, No. **3809,** 17–18.

Walters, J. (1961): The planting gun and bullet. A new tree-planting technique. *For. Chron.* **37** (2), 94–5.

—— (1963): An improved planting gun and bullet: a new tree-planting technique. *U.S. Dep. Agric. Tree Planters' Notes*, **57,** 1–3.

Williamson, V. H. H. (1964): *Preparation and planting of tubed seedlings*. Res. Rep. Ontario Dep. Land and Forests, No. 52.