working well do not change to fog just because fog is there. Remember also the basic principles. No quantity of highly developed electronic equipment can replace good propagation practice. It is essential to have good propagation material at the correct time of the year, to use a well-balanced medium and accurate temperature controls, both of the medium and the atmosphere above and, above all, to practice good hygiene standards; diseases or pests will move very rapidly through a fogging area particularly in warm summer conditions when there is considerable air movement. Observe these basic principles and your fog system will work very well. You will be amazed at the speed of throughput and the quality of the resultant product.

LITERATURE CITED

1. Milbocker, D. C. 1980. Ventilated high humidity propagation. *Proc. Inter. Plant. Prop. Soc.* 30:480–481.
2. Warner, Z. P. 1966. Fogging machines versus intermittent mist. *Proc. Inter. Plant. Prop. Soc.* 16:167–169.

PROPAGATING SITKA SPRUCE UNDER INTERMITTENT MIST AND OTHER SYSTEMS

W. L. MASON

Forestry Commission,
Northern Research Station
Roslin, Lothian EH25 9SY

J. C. KEENLEYSIDE

Forestry Commission
Research Division,
Newton Nursery, Elgin,
Morayshire LV30 3XR

Abstract. The reasons for the recent interest in using stem cuttings of tree species to produce rooted cuttings for forest use are reviewed. In Britain, commercial developments are currently confined to Sitka spruce (*Picea sitchensis* Bong. (Carr.)). A prototype facility for rooting conifer cuttings is described. Results indicate that high rooting can be obtained in a wide range of media and under different propagation systems. Correct feeding of the mother plant is shown to be important in obtaining high quality cuttings. Future developments are reviewed.

INTRODUCTION

Plants of tree species used in commercial forestry have traditionally been raised from seed. Only poplars and willows have normally been propagated using stem cuttings and in Britain these are a very small percentage of the number of plants produced. However, in the last 15 years, there has been increasing interest worldwide in the vegetative propagation of a wide range of other tree species (8). This has occurred for 3 reasons. Firstly, tree breeders have begun to identify high yielding genotypes with appreciable gains over unimproved stock. Such genotypes are generally available in very small numbers and thus cannot be grown from seed quickly in commercial quantities. Secondly, the advent of reliable mist propagation systems has made it possible to consider propagating these genotypes economically on a large scale. Thirdly, an improved understanding of problems involved with maturation has resulted in great emphasis upon propagating juvenile material that is relatively easy to root, and grows vigorously in the forest.

In Britain, systematic research into the vegetative propagation of conifers began in the 1970s (4, 12). Species of particular importance were Sitka spruce (*Picea sitchensis*), and hybrid larch (*Larix* × *eurolepis*). Results with Sitka spruce have been very successful, leading to commercial uptake of the technique by the early 1980s. Over one million rooted cuttings of improved Sitka spruce will be planted in forests in 1988 and this could reach five to ten million by 1995 (13). Progress with hybrid larch has been slower, but reliable rooting methods have now been developed (11) and the limiting factor is shortage of tested high quality seed. Small trials have been carried out to examine propagation of a wide range of other commercial conifer species, and most have proved easy to root using the techniques developed for Sitka spruce (12).

Conifers grown from seed are a relatively low value product selling at six to eight UK pence per plant in 1987. At current levels of genetic gain, Sitka spruce cuttings must be produced at no more than two to three times that of standard stock. This means that costly propagation facilities and techniques used in other areas of horticulture may not be justifiable economically.

A comparatively large propagation facility to test techniques at a scale more appropriate to commercial practice has been developed since 1981 at Newton Nursery near Elgin, Scotland, and has proved a valuable testbed for large scale conifer propagation. This paper describes the facility and a number of experiments performed in it.

PROPAGATION FACILITY

The facility consists of one polythene mist house (Table 1), a double skinned polythene house, 24m by 8 m, for rearing stock plants; plus ancillary standing-out beds and potting sheds. Rooting capacity is one crop of about 100,000 cuttings per year. Up to 300 stock plants can be raised indoors and a further 500 outdoors.

The mains water supply at Newton is both relatively soft and maintains comparatively high pressure although this can fluctuate in dry seasons. Thus neither acidification of the water nor a break-tank was necessary. Good misting was achieved by dividing the system into a set of six banks and activating them in sequence. The present nozzles have improved misting cover and their nondrip valves are also an advantage. The locally designed mist control unit works well during the rooting phase. It is less satisfactory during weaning when some water must be supplied at regular intervals irrespective of ambient conditions. The photocell-based unit is more appropriate at this stage since it is not so sensitive to ambient humidity.

Our major mistake has been the failure to level the site initially, since moist air tends to flow from the top of the house to the bottom and crops at the top can dry out more. However we normally expect at least 85 to 90 per cent rooting in Sitka spruce and 75 to 85 per cent in hybrid larch. Five to 10 per cent of these are not used due to poor roots or other defects.

PROPAGATION METHODS

Seed of the desired genotypes is germinated in a greenhouse and the resulting seedlings are grown on for 2 years to produce stock plants 50 to 100cm tall (see Mason, 1984 for details). Cuttings are collected from these plants in late February to March prior to flushing. They are normally 8 to 10cm long and are inserted without a rooting hormone, stripping of basal needles, or wounding, for rooting under mist. Base heat is generally not used. A wide range of media can be used provided they have a minimum of 15 per cent porosity. Cuttings flush shortly after insertion, making 2 to 5cm of growth during the rooting phase. Callusing is seen by 8 to 10 weeks, and root development from 10 to 12 weeks. Cuttings are weaned by 20 weeks and are lifted and lined out in the open nursery. They are grown on for a further 18 months to a height of 30 to 40cm. Cuttings can then be taken from the first cycle material and rooted in their turn. Normal multiplication factors over two propagation cycles are between 250 and 500 times, making it possible to produce around one million plants from an initial batch of 2,500 seedlings. More than two propagation cycles are not yet advised, largely because of fears of a reduction in the genetic base through differential loss of juvenility. However, recent work shows no decline in rootability over 5 cycles (5), findings which are supported by work in Germany on Norway spruce (14).

EXPERIMENTAL DETAILS

Experiment 1. First cycle cuttings of Sitka spruce were inserted in 24 different media. These were made by using the mixtures and proportions shown in Table 2. Components of the media were a medium-grade sphagnum moss peat (P), a coarse lime-free grit of 2 to 3mm average particle size (G), a fine lime-free sand (average size 0.05mm) (S) and a fine (<8 to 9mm) composted pine bark. The experiment was a split-plot design with the 24 media main plots replicated 5 times. The main plot size was 40 cuttings at 4cm spacing in a seed tray (40cm × 27cm × 7cm). Main plots were split for assessment at 14 and 20 weeks after insertion. Aeration of the

Table 1. Newton misthouse specifications.

Dimensions:	36m × 6 m.
Water supply:	Mains (pH 7.4 but negligible $CaCO_3$; conductivity 100 μS/cm).
Mains pressure:	5–6 kg/cm^2.
Bed heating:	Electric cable (300 W) in one small section (5 m^2) for experimental purposes (60 w/m^2). Maintains 3–5°C above unheated bed.
Mist control:	(a) Own design based upon a relative humidity sensor sited in middle of house; (b) MacPenny* Solarmist based upon a photocell.
Mist system:	6 banks of 8 Brumiflore* blue tip nozzles. Each bank consists of 2 sets of 4 nozzles. The nozzles are mounted at 1.2m apart and 1.5m above the bed.
Pipework:	Mist nozzles are mounted on copper pipe 12mm diameter. Remainder is alkathene.
Mist activation:	Banks are operated in sequence through a central control.
Misting frequency:	Aiming to maintain 95% RH during rooting, declining to 50–60% during weaning. Frequency varies according to ambient conditions, but on warm days in May might be 5 second burst every 2–3 min. Mist switched off at night.
Propagation beds:	32m × 2.5m wide. Beds are 30cm deep with bottom layer of sand/gravel and 8–10cm of rooting medium.
Rooting medium:	Originally 80% lime-free grit (2–3mm) and 20% sphagnum moss peat. Now 50% composted pine bark: 50% sphagnum moss peat plus a further 20–30% added lime-free grit (2–3mm).
Shading:	50% Lobrene* shading from early May–July. Sides are pegged out like a flysheet to reduce heat transfer.
Ventilation:	(a) fan (440 W) used throughout growing season. Set at 25°C; (b) skirts of Lobrene* 1m high along sides. Used to harden cuttings immediately prior to transfer outside.
House orientation:	Long axis runs approximately north-south. There is also a 2.5m fall from the south end to the north.

*Commercial names are quoted for information only and do not represent an endorsement by the Forestry Commission

media was calculated as percentage macropore space (16). Cuttings were inserted on 27 February 1984.

Experiment 2. Second cycle cuttings of Sitka spruce were collected from first cycle material that had received four different top-dressing regimes after lining-out in the nursery. All treatments received a basal dressing of PK (0-24-24) at 500 kg/ha prior to lining out. The regimes were an unfertilised control (SC), a high nitrogen regime (SN: 168,14,42 units of NPK from March–September), a balanced regime with moderate levels of NPK (SB1: 135,135,180 units of NPK), and another balanced regime applied at twice the rate (SB2: 270,270,360 units of NPK). First cycle cuttings (F) were also included: these were collected from stock plants grown under standard regimes. A randomised block design was used with five treatments replicated five times. Each plot consisted of 45 cuttings inserted at 4cm spacing in an 20:80 sphagnum moss peat; grit (2 to

3mm) medium. Cuttings were collected and inserted on 21 March 1986 and assessed after 18 weeks.

Table 2. Experiment 1. Composition of rooting media.

Mixtures		Proportions (% by volume)
Peat/grit		
Peat/sand		80:20
Peat/bark	×	60:40
Bark/grit		40:60
Bark/sand		20:80
Sand/grit		

Experiment 3. First cycle cuttings of Sitka spruce were inserted in five different media both in the Newton mist houses (N) and in 3 contrasting propagation houses at Banff and Buchan Nurseries at Portsoy, Scotland. These houses were (W) a white polythene house with a propagation bed heated to 18°C, a white polythene house (L) with cuttings sealed in a white polythene cloche and (C) a clear polythene house with cuttings in a white polythene cloche. All treatments in the Banff and Buchan houses were hand watered daily. The five different media were combinations of sphagnum moss peat and a coarse lime-free grit (2 to 3 mm). Three replicates of each of the medium treatments were placed in each of the houses. Cuttings were inserted at 4cm spacing in similar seed trays as used in Experiment 1 with 45 cuttings per tray. Cuttings were collected and inserted on 1 March 1983 and assessed after 20 weeks.

ANALYSIS

Each cutting was assessed after lifting for the presence or absence of roots to give rooting percentage. Root volume was assessed as a root score of 1 to 10 (low to high) using photographic standards. A root of 4 or 5 is roughly equivalent to the root volume found on a good one-year seedling. Both rooting percentage and root score were analysed by standard analysis of variance procedures with percentages being subject to an arcsin transformation.

RESULTS

Experiment 1. The major effect in this experiment was that of the various media mixtures. Significant differences were found among the mixtures, particularly at the 14 week harvest (see Table 3). The effect of differing proportions was much less than that of the various mixtures. At 14 weeks, the differences were largely due to the superior performance of the peat-bark combination which was significantly ($p<0.05$) better than all except bark-grit for rooting percentage and all except bark-grit and peat-sand for root score. At

20 weeks, peat-bark was still the best treatment, but only rooting percentage in peat-sand and sand-grit was significantly poorer. Rooting percentages were high overall and the major improvement from the peat-bark was in speed of rooting. Examination of the percentage macropore space results revealed that good rooting performance was closely linked to adequate aeration and drainage since all mixtures with bark showed much higher values. A minimum value of 15 to 20 per cent macropore space seems desirable.

Table 3. Experiment 1. Effect of media mixtures on rooting of Sitka spruce cuttings.

14 weeks						
	Peat/grit	Peat/sand	Peat/bark	Bark/grit	Bark/sand	Sand/grit
Rooting %	78	75	95	94	84	77
Root score	2.4	2.6	2.8	2.5	2.4	2.3
Variance-ratio test: rooting percentage ($p<0.001$), root score ($p<0.001$)						
20 weeks						
	Peat/grit	Peat/sand	Peat/bark	Bark/grit	Bark/sand	Sand/grit
Rooting %	95	92	100	98	96	92
Root score	6.7	6.8	7.1	6.9	6.5	6.7
Variance-ratio test: rooting percentage ($p<0.05$), root score (ns)						
Macropore space (%)						
	Peat/grit	Peat/sand	Peat/bark	Bark/grit	Bark/sand	Sand/grit
%	12.5	6.5	26.3	25.5	25.0	12.5

Experiment 2. The results (Table 4) showed that fertiliser regime had an important influence upon the subsequent rooting performance of second cycle cuttings. Thus SB1 (moderate nutrition using NPK) showed significantly higher rooting percentages than SN and SB2 (high nitrogen and high NPK). When second cycle cuttings were compared with first cycle material (F) only SB1 did not show significantly lower rooting percentage and root score.

Table 4. Experiment 2. Effect of nursery fertilisation on rooting of Sitka spruce cuttings. (See text for explanation of codes.)

	Rooting performance				
Treatment	F	SC	SN	SB1	SB2
Rooting %	99.2	95.2	90.2	98.4	90.8
Root score	4.9	4.2	4.2	4.4	4.2
Variance-ratio test: rooting percentage ($p<0.01$), root score ($p<0.05$)					

Experiment 3. Rooting percentage was very high at Newton and nearly as high at Banff and Buchan. Analysis of the results showed different trends between regimes for rooting percentage as opposed to root score (see Table 5). There were highly significant differences among media ($p<0.001$) and there was a significant

media house interaction ($p<0.05$). A quadratic regression was fitted to the data from each house to see which medium gave the best results. For the Newton house (N) there was no difference among the various media. The regression was significant for the Banff and Buchan houses ($p<0.01$) and suggested maximum rooting percentage between 75 per cent grit 25 per cent peat, and 50 per cent grit 50 per cent peat. The only significant differences for root score were between the media ($p<0.001$) with 50 per cent grit 50 per cent peat giving the best result. Fitting a quadratic regression indicated a maximum mean score at around 45 per cent grit 55 per cent peat.

Table 5. Experiment 3. Effect of propagation regime and medium on rooting of Sitka spruce cuttings. (For details of regime codes see text.)

Location	Regime	G100		G75 P25		G50 P50		G25 P75		P100	
		%	RS	%	RS	%	RS	%	RS	%	RS
Newton	N	99	4.6	100	5.2	100	5.7	100	5.2	99	5.0
Banff and Buchan	W	97	4.8	99	5.6	99	6.1	98	5.8	85	5.3
	L	81	3.4	97	4.0	93	4.2	92	3.8	69	3.4
	C	76	3.6	95	5.3	93	5.6	94	5.5	68	5.8

Medium is grit (G) and peat (P) in percentage proportions by volume.

DISCUSSION

Good rooting performance with Sitka spruce cuttings can be obtained in a wide range of propagation media. However, the major effect of the mixtures noted in Experiment 1 suggests that not all products will be equally suited for use in rooting media. For example, an additive model was fitted ($p<0.01$) to the data from Experiment 1 to predict the rooting percentage if each component were used on its own. This gave theoretical rooting percentages after 20 weeks of 96, 94, 89 and 100 per cent for cuttings inserted in pure peat, pure grit, pure sand and pure bark, respectively. Thus, fine sand would seem to be undesirable for use in a propagation medium.

The positive relationship noted in Table 2 between percentage macropore space and rooting performance suggests that this measurement could be used to identify media prone to waterlogging because of poor drainage. Media of less than 15 per cent macropore space would be rejected. However, as noted by Loach (9), such measurements are an imperfect guide to the suitability of a medium for use with other species in different houses or at different times of year.

Experiment 3 emphasises the influence of the propagation system upon the choice of medium. At Newton, under open mist, all the five media tested were equally satisfactory for rooting although subsequent root development was better in media with approximately 50 per cent peat. However, under the various regimes at

Banff and Buchan, media with at least 25 per cent peat were desirable for rooting, particularly in the absence of base heat. This was because cuttings in pure grit tended to dry out, while cuttings in pure peat performed poorly presumably because of poor aeration, particularly following watering. The high rooting percentages in the better L and C treatments are interesting since they do not fully agree with Grange and Loach's (2) suggestion that conifers do not root well under enclosed polythene. This discrepancy may reglect climatic variations between Littlehampton in northern England where their studies were carried out and the more northerly position of our work on the Morayshire coast. For instance, interpreting data from max-min thermometers placed among the cuttings in our experiment suggests that average air temperatures at Newton and at Banff and Buchan were some 5°C lower than in the Littlehampton work.

There is no single "ideal" medium for propagating Sitka spruce. Providing the medium gives adequate support, drainage, and aeration, the propagator has a wide range of mixtures at his disposal and his choice is as likely to be dictated by cost as by cultural factors. Although we have noted that different media produce variations in root morphology, especially in the fineness of the root systems [see also Copes, (1)], these differences have never influenced subsequent performance of the cuttings when lined out into the nursery.

Experiment 2 shows how the nutrient regime given to a stock or mother plant before cutting collection can influence subsequent rooting performance. Thus cuttings given a high nitrogen (SN) or high general fertiliser regime (SB2) show poorer rooting than those given a lower balanced regime (SB1). More importantly, first cycle cuttings performed better than most second cycle cuttings apart from treatment SB1. Were it not for the latter, there would be a danger of ascribing these results to a difference in maturation state rather than to feeding regime. Similar effects of fertiliser regimes have been reported by Kleinschmit (6) for Norway spruce. Leakey (7) has also reported how adjusting fertiliser regimes improved rooting in cuttings from basal shoots of obeche (*Triplochiton scleroxylon*). Our results might be attributed to differences in nitrogen: carbohydrate ratios since these are considered to affect rooting (e.g. Hartmann and Kester, 1983, p. 259). Unfortunately, detailed foliar and carbohydrate analysis does not reflect striking treatment differences, particularly between second cycle cuttings.

CONCLUSIONS AND FUTURE DEVELOPMENT

These experiments were essentially empirical and aspects of climate during rooting and physiological processes in the cutting were mostly unrecorded. However, the high rooting percentages obtained in different years are encouraging, particularly in view of current commercial expansion in the vegetative propagation of genetically improved Sitka spruce. It is clear that cuttings can be rooted under a range of systems and in a variety of media. In addition, correct nutrition and manipulation of the mother plants to maintain cutting quality appear as important as the propagation system used. Results since 1982 indicate that Sitka spruce rooted cuttings can be produced in the type of facility described in Table 1 at approximately twice the cost of conventional transplants.

Could fogging systems replace mist for propagating forest conifers, now they are now more competitive in price? Shinn (15) has already described successful use of fogging with Western hemlock (*Tsuga heterophylla*) although rooting percentages are not high. We think that fogging will be of increasing interest for two reasons. Firstly, John and Mason (5) report that successful weaning of micropropagated spruce requires stable, high humidity environments. Humidity under open mist fluctuates too much for satisfactory weaning whereas fogging systems should provide conditions much closer to needed requirements. With Sitka spruce, commercial systems integrating micropropagation with stem cuttings may be operational by the end of the 20th century. Secondly, despite the high rooting being obtained with stem cuttings under open mist, nutrient status of the material is impaired during rooting and use of fogging might maintain the nutrient status better and possibly enhance the speed of rooting. However, the good results being obtained under open mist at the present time and the fact that nurserymen are propagating a relatively low-cost product, suggest that it would be premature for commercial growers to try fogging on a large scale with Sitka spruce until further results are to hand.

Acknowledgements. The experiments described in this paper owe much to the initial inspiration of Paul Biggin. Charles Blackwood, Allan Green, Graham Menzies, Mike Hollingsworth, and Jim Davidson all assisted in various ways. Robin Currie and staff at Banff and Buchan Nurseries were of considerable help with Experiment 3. Ian White provided statistical advice and analysis and Allan John commented on the draft.

LITERATURE CITED

1. Copes, D. L. 1977. Influence of rooting media on root structure and rooting percentage of Douglas-fir cuttings. *Silvae Genetica* 26(2–3): 102–106.
2. Grange, R. I. and K. Loach. 1984. Comparative rooting of eighty-one species of leafy cuttings in open and polyethylene-enclosed mist systems. *Jour. Hort. Sci.* 59(1): 15–22.
3. Hartmann, H. T. and D. E. Kester. 1983. *Plant Propagation: Principles and Practices* 4th ed. Prentice-Hall. Englewood Cliffs, N.J.
4. John, A. and P. Biggin, 1981. Developing physiologically-based methods for rooting forest trees. In: *Vegetative Propagation of Trees in the 1980's*, p. 15. K. A. Longman, ed. CFI Occasional Paper 15, Commonwealth Forestry Institute, Oxford.
5. John, A. and W. L. Mason. 1987. Vegetative propagation of Sitka spruce. *Proc. Royal Soc. Edinburgh* 93B: 197–203.

6. Kleinschmit, J. 1973. Investigation on the effect of fertilizing the initial plants on root formation in spruce cuttings. *Allgemeine Forst- und Jagd-Zeitung* 144(3): 55–60.

7. Leakey, R. B. B. 1983. Stockplant factors affecting root initiation in cuttings of *Triplochiton scleroxylon* K. Schum., an indigenous hardwood of West Africa. *Jour. Hort. Sci.* 58(2): 277–290.

8. Libby, W. J. and R. M. Rauter. 1984. Advantages of clonal forestry. *Forest. Chron.* 60(3): 145–149.

9. Loach, K. 1985. Rooting of cuttings in relation to the propagation medium. *Proc. Inter. Plant Prop. Soc.* 35: 472–485.

10. Mason, W. L. 1984. Vegetative propagation of conifers using stem cuttings. I. Sitka spruce. *Forestry Commission Research Information Note* 90/84/SILN. 7pp.

11. Mason, W. L. 1985. Vegetative propagation of hybrid larch. *Rep. For. Res. Edinburgh 1985*, p. 14.

12. Mason, W. L. and J. G. S. Gill. 1986. Vegetative propagation of conifers as a means of intensifying wood production in Britain. *Forestry* 59(2): 155–172.

13. Mason, W. L. and W. C. G. Harper. 1987. Forest use of improved Sitka spruce cuttings. *Forestry Commission Research Information Note* 119/87/SILN. 4pp.

14. St. Clair, J. B., J. Kleinschmit and J. Svolba. 1985. Juvenility and serial vegetative propagation of Norway spruce clones. *Silvae Genetica* 34(1): 42–48.

15. Shinn, C. W. 1983. Rooting conifer cuttings with a fog system. *Proc. Inter. Plant Prop. Soc.* 33: 110–111.

16. Tinus, R. W. and S. E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. *General Technical Report RM60*, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.