EVALUATING THE QUALITY OF SITKA SPRUCE PLANTING STOCK BEFORE AND AFTER COLD STORAGE

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Abstract. Replanting second rotation conifer forests in Great Britain will require better quality planting stock because of more difficult site conditions compared with the first rotation Case histories revealed that poor cold storage practice was a major cause of planting failure Data from three studies with Sitka spruce are presented to explore the relationship among storage, plant type, physiological quality and forest performance. Plants lifted to cold store from early December to March and outplanted in April showed generally high survival with no difference between undercuts and transplants The onset of this lifting window coincided with a rise in prestorage root growth potential (RGP) and around 300 accumulated chilling hours below 5 °C. However, undercut plants could be lifted up to two weeks earlier than December 1 without apparent loss in quality Alternative tests of physiological status such as mitotic index and membrane leakage gave as good indication of planting stock quality as RGP and were quicker to use

INTRODUCTION

Successful establishment of forest plantations is achieved by using good quality planting stock, together with appropriate site preparation, plant handling, planting, and post-planting maintenance. In Great Britain, there is increasing awareness that replanting of clear-felled conifer forests will require planting stock of higher quality than was used to establish the first rotation. This is because the presence of stumps and harvesting residues makes cultivation more difficult and there are greater pressures on newly planted trees from insects, browsing animals, and weeds (13). As a result the morphological grades applied to conifer planting stock have become more stringent, and now include the requirements for a larger root-collar diameter for a given height (2). Stricter morphological standards have both short- and long-term benefits for the forest performance of conifers (7, 12), but there is only an imperfect relationship between morphology and physiological status. The latter is generally considered a better guide to the forest performance of a batch of planting stock (8, 14).

Recognition of the importance of seedling physiology in influencing plantation success (4, 8) has resulted in the development of a range of tests for monitoring the physiological status of seedlings. These include techniques for assessing nutrient and carbohydrate status, bud dormancy, frost hardiness, shoot water potential, stomatal resistance and root regenerative ability and other parameters. One or more of these tests could be used to complement or even replace the morphological criteria of seedling quality used at present.

Case histories of post-planting failure can offer a guide to problem areas and indicate which tests may be useful. Table 1 gives figures for the number of cases of immediate post-planting failure investigated by Forestry Commission Northern Research Station (NRS) staff from 1985-1989 and the likely causes. The number of plants involved in a single case can be considerable. For instance, one investigation in 1989 covered nearly one million dying trees planted in some 10 forest areas. It is clear that lifting practice, particularly time of lifting and subsequent storage regime, is implicated in most reported cases of planting failure. Therefore, our recent work has considered the ability of conifer planting stock of varying quality to withstand the stresses imposed by lifting and/or cold storage. We have also attempted to relate post planting performance to various measurements of physiological status. The research programme is still continuing, but this paper presents results from 3 cold storage studies with Sitka spruce (*Picea sitchensis*). This is the major conifer species in British forestry and featured in each year of Table 1. These studies illustrate some of the complex problems which will need to be considered before monitoring the physiological status of seedlings can become a reliable operational measure.

Table 1. Cases of conifer post-planting failure in seasons 1985-1989 and attributed causal factors

		Attributed causal factors			
Season	Number [3] of cases	Lifting and/or storage practice	Causes[1] Handling/ Insecticide	Planting, site factors	Species[2]
1985	6	2	4	1	DF, SS
1986	9	7	3	2	SS, NF, SP
1987	8	5	2	2	HL, SS
1988	13	9	4	5	JL, NF, DF SP, CP, SS
1989	11	10	3	1	JL, DF, SS, NF, LP
Total	47	33	16	11	

Notes
[1] Total of causes is more than number of cases since in some cases a single causal factor could not be identified
[2] Species codes are DF—Douglas fir, SS—Sitka spruce, NF—noble fir, SP—Scots pine, HL—hybrid larch, JL—Japanese larch, CP—Corsican pine, LP—lodgepole pine
[3] Case histories are from both private and state forests

MATERIALS AND METHODS

Experiment 1. Two-year-old planting stock of Sitka spruce of Queen Charlotte Islands (QCI) origin was raised at Wykeham nursery, North Yorkshire, during 1984-85 as either 1+1 transplants or 1u1 undercut plants. Nursery regimes followed those described by Aldhous (1) for 1+1 and by Sharpe (11) for 1u1 plants. At fortnightly intervals from October 15, 1985 to December 15, 1985 and on January 15 and March 15, 1986, 100 randomly chosen plants of each treatment were lifted, put into a sealed black-and-white coextruded polythene bag and placed in a direct-cooled cold store (1 °C). On April 2, 1986, a further 100 plants were lifted and kept in temporary cool storage to provide a direct lifted contrast. On April 11, 1986, all treatments were removed from cold or temporary store, and 10 plants per treatment were placed in a root observation box (see 13, Plate 1) in an unheated greenhouse under natural day length. After 21 days the number of new white root tips more than 1 cm long was counted to give an estimate of Root Growth Potential (RGP) (10). A further 50 plants per treatment were planted in Wykeham forest on cultivated ground; a randomised block design was used with 5 replicates of each treatment and 10 plant plots. Plant survival was assessed at the end of 1986. Air temperature on the nursery was recorded daily from September 1, 1985, using max-min thermometers.

Experiment 2. Two-year-old transplants or undercuts of QCI origin Sitka spruce were raised at Wykeham nursery during 1985-86 (see Experiment 1). Plants were lifted to cold store at fortnightly intervals from October 1, 1986 to January 15, 1987 and again on April 1, 1987 (direct lifted). Trees were removed from storage for planting and RGP testing on April 6, 1987. RGP tests and experimental design and assessments in the forests followed the procedures used in Experiment 1. In addition, mitotic index of shoots calculated as the number of actively dividing cells as a percentage of the total of mitotic cells viewed (3) was assessed on 10 samples per lifting date during October-December 1986 to indicate when plants entered dormancy. Air temperature on the nursery was monitored as in Experiment 1 and chilling hours below 5 °C were accumulated hourly from September 1986 (Biophenometer TA5I, Omnidata Systems Inc, Utah, USA). Chilling hours below 5 °C may be an reliable indicator of a plant's dormancy status (8).

Experiment 3. Two-year-old transplants or undercut planting stock of Sitka spruce (QCI origin) were again raised at Wykeham nursery during 1987-88 (see Experiment 1). At fortnightly intervals from October 1, 1988 to January 1, 1989 and on February 1 and March 1, 80 randomly chosen plants of each treatment were lifted and cold stored as in Experiment 1. On each of the 9 lifting dates, a further 40 plants of each treatment were lifted for measurement of RGP (14 day test in a growth room at 20 °C with 16 h photoperiod) and other parameters. The terminal bud from 20 plants in each treatment was fixed immediately for later determination of mitotic index.

Chronic cold tolerance of fine roots was also assessed (McKay and Mason, in prep.). The degree of damage was assessed by electrolyte leakage using a temperature compensated conductivity meter (8), with values in the text expressed as the post-storage figure divided by the pre-storage ones. On April 1, 1989, all plants were removed from cold store and planted in Wykeham forest using a similar design to Experiment 1, except 20 plant plots were used and survival was assessed at the end of June. In addition, a further 30 plants were checked for RGP after storage. At time of writing, data analysis has not been completed so only preliminary results are reported here.

RESULTS

Experiment 1. For the first 4 dates of lifting only, there were highly significant differences in survival between the 2 plant types (Table 2) with undercuts showing better survival than transplants. RGP at time of planting was significantly lower in transplants than in undercuts for all dates of lifting.

Table 2. Experiment 1. Sitka spruce plant type and cold storage Relationship between forest survival, RGP, and monthly mean temperature for 1+1 and 1u1 stock lifted to cold store on different dates during 1985/86

	Date of lifting								
Plant type and assessment	15 Oct	1 Nov	15 Nov	1 Dec	15 Dec	15 Jan	15 Mar	1 Apr	5% LSD
1+1 Survival[1]	0	0.6	4.4	7 8	10 0	9 4	10.0	10.0	) 1 03
1u1 Survival	9.0	9 2	10 0	10.0	9 8	10 0	10 0	10.0	
1+1 [2] RGP	0	0	3.4	4.2	4.6	20 0	15.8	20.8	) 12.6
1u1 [3] RGP	17.9	28 5	29.6	30.9	57 0	33.0	57.4	47.4	
	Oct	Nov	Dec	Jan	Feb	Mar			
Temperature, °C	10 5	3.0	4.7	2.1	-0 8	3.8			

[1] Survival is average number of plants per pot (maximum=10).
[2] 1+1=transplants, [3] 1u1=undercuts.

Experiment 2. For the first 3 dates of lifting, there were significant differences in survival between the Sitka spruce plant types, with the undercuts being superior to the transplants (Table 3). From the November 15 lift onwards survival was high throughout with no significant differences occurring. RGP values were consistently higher in the undercuts than the transplants when averaged across all lifting dates (P<0.001). RGP values were noticeably higher in the undercuts at the beginning of the experiment. Apart from a mild spell in early October, chilling hours accumulated progressively throughout the winter months. Mitotic index values were high in October and declined progressively until January when no bud activity was apparent. Values for undercuts tended to be lower than for transplants (standard errors are typically 10% of the means).

Table 3. Experiment 2. Sitka spruce plant type and cold storage Relationship between forest survival, RGP, mitotic index (MI), mean monthly temperature and chilling hours of 1+1 and 1u1 stock lifted to cold store on different dates during 1986/87

	Date of lifting									
Plant type and assessment	1 Oct	15 Oct	1 Nov	15 Nov	1 Dec	15 Dec	1 Jan	15 Jan	1 Apr	5% LSD
1+1 Survival[1]	0	0 6	8 6	9.4	9 6	10 0	10 0	9 8	10 0	) 0.9
1u1 Survival	8 2	9 2	9.6	10 0	10.0	9 8	9 8	10 0	10.0	
1+1 [2] RGP	0	0	21.8	31 9	51 7	30.8	38 5	50 6	47.9	
1u1 [3] RGP	17 7	7.5	38 5	42.1	61 1	35.7	48.0	62 6	58.6	
1+1 MI	12.4	10 0	11.7	10.2	6 5	1 2	0 0	—	—	
1u1 MI	9 7	6.3	8.4	8 7	4 3	1.9	0 0	—	—	
Chilling hours 5 °C	33	33	1-4	170	324	500	809	1133	—	—
	Oct	Nov	Dec	Jan	Feb	Mar				
Temperature, °C	9.3	6 2	4.2	1.4	3.0	2.5				

[1] Survival data are average number of plants per plot (maximum = 10)
[2] 1+1 = transplants,
[3] 1u1 = undercut seedings

Experiment 3. Survival at the end of June showed significant differences among plant types for the first 3 dates of lifting with undercuts outperforming transplants (Table 4). RGP values before storage (i.e. fresh lifted) show few significant differences among treatments except in January and March when the undercut plants had higher values. However, RGP after storage revealed differences among plant types with undercuts being consistently higher than transplants. Post-storage RGP values were generally lower than pre-storage ones. Plants stored on or before November 15 had much greater root membrane leakage after storage than was found for plants stored later in the season. Assessment of mitotic index showed that activity in shoot tips declined from October to December, remained negligible until after March 1 and then increased rapidly in the spring. Frost hardiness testing (data not presented) revealed shoots of both plant types to be hardy to -10 °C by late October and to -25 °C by late November.

Table 4. Experiment 3. Numbers surviving at end of June, 1989, monthly mean temperature, RGP before and after cold storage, mitotic index and membrane leakage for 1+1 and 1u1 plants of Sitka spruce lifted to cold store on different dates during 1988/89

Plant type and assessment		Date of lifting: 1 Oct	15 Oct	1 Nov	15 Nov	1 Dec	15 Dec	1 Jan	1 Feb	1 Mar	1 Apr	5% LSD
Survival	1+1	3 0	1 4	9 0	19 4	19 0	16 2	19 6	17 2	20 0	17 8	3 7
Numbers[1]	1u1	12 8	9 8	19 4	19 8	19 8	19 6	19 6	20 0	20 0	19 6	
RGP	1+1	13 8	5 9	5 5	9 1	19 9	9 9	18 3	44 4	19 8	5 6	8 5
before	1u1	15 9	7 5	6 1	10 4	15 4	11 2	31 8	40 0	49 9	12 6	
RGP	1+1	0	0	0 1	4 3	3 3	4 9	5 0	7 2	3 8	—	4 7
after	1u1	2 4	2 1	3 2	9 2	8 9	10 5	8 4	13 6	20 6	—	
Membrane	1+1	D	D	10 2	2 6	1 2	1 4	1 9	1 2	1 3	—	N/A
leakage	1u1	1 8	4 9	1 9	N/A	1 3	0 9	1 4	1 1	1 3	—	
Mitotic	1+1	2 2	2 5	1 8	1 3	0 3	0 1	0	0	0	2 7	N/A
index %	1u1	3 0	1 9	1 5	1 1	0 1	0 1	0	0	0	2 8	
Temperature,		Oct	Nov	Dec	Jan	Feb	Mar					
°C		9 1	5 1	6 5	5 1	4 6	5 8					

[1] D = dead, N/A = no data available

1+1 = transplants, 1u1 = undercut seedlings

Survival is average number of plants per plot (maximum = 20)

DISCUSSION

The results from these experiments indicate that undercut Sitka spruce of QCI origin can be safely lifted to cold store from mid-November onwards, and transplants from early December, without reducing post-planting survival. The results with transplants agree with recent general lifting recommendations for this species in Britain (13). The variation we found among plant types shows that these lifting seasons could be lengthened if physiological status could be monitored easily. The difference among plant types is consistent, even though temperature records show appreciable differences among seasons (Tables 2 and 4).

In Experiment 3, fresh lift RGP was highest between December and March, supporting the view that there is a positive relationship between high RGP and storability (10). From the chilling hours data of Table 3 and other unpublished data we suggest that the earliest recommended storage dates coincide with the accumulation of around 300 hours below 5 °C. From the mitotic index (MI) values, we believe plants can be lifted safely to store before activity in the shoot tip has ceased (e.g. December data of Tables 3, 4). The difference in MI among seasons probably results from the use of different observers.

A knowledge of RGP cycles and/or accumulated chilling hours and their relationship with plant dormancy status can help to devise safer lifting and cold storage schedules for a particular nursery. These schedules could be used to predict or manipulate planting stock quality (9).

However, there are problems with this approach since the relationship between chilling hours and RGP is not consistent among plant types within species. Thus, 1u1 Sitka spruce can be safely lifted earlier than 1 + 1 transplants and this difference is evident in the post storage RGP values but not in the values recorded before storage.

Jenkinson (5) reported that the length of lifting seasons for different seed sources of Douglas fir could vary from between two to four months over the period November to March. There would clearly be major logistical problems in attempting to establish definitive storage schedules linking chilling hours, RGP, and survival for all 10 to 15 conifer species commonly grown in large British forest nurseries if seed source and aspects of growing regimes (e.g. undercutting, nitrogen top-dressing) are to be taken into account. The RGP test is also likely to take too long (14 days) for a commercial nursery. Test results are variable and a poor prediction of forest performance (6).

If physiological tests are to be of operational use in defining cold storage schedules, they must firstly indicate that plants are adequately cold-hardened to withstand cold storage and, secondly, reveal any serious damage when plants are removed from the store for dispatch. In both situations, speed of determination and repeatability of measurement are of considerable managerial and financial importance.

It is unlikely that there is any single test available which can be used for both purposes. Shoot MI appears to be useful for identifying the start of the lifting season in early winter since low mitotic activity is linked with the onset of true dormancy and peak storability (Table 4).

After one week's training, at least 40 samples can be processed per day to give an indication of the level of activity in the terminal bud. However, this method is possibly a conservative indicator of storability since plants can be lifted before MI has approached zero, and therefore it may be necessary to define safe threshold levels. Work is also needed to determine how useful the technique could be in determining the end of the lifting season in spring as plants begin growth.

Testing for membrane leakage of shoots after storage when compared against prestorage standards also seems to be a fast, repeatable measurement that could be used to check batches of doubtful plants. Results could be obtained within a maximum of 24 to 48 hours.

Further work is required testing both techniques on a wider range of species before their potential can be properly assessed, but both have the theoretical advantages of being cheaper and faster to apply than RGP while monitoring plant status directly, unlike accumulated chilling or other temperature records.

CONCLUSIONS

It is essential that storage practice be founded upon a sound physiological basis, using appropriate tests to determine when plants should go into store, to monitor their health while in store, and to check their quality after store. Such tests could become equivalent to the ''sell-by'' date labelling used in supermarkets. Ensuring that plants are in the best physiological state when they leave the cold store will not eliminate planting failure, but it may help to make plantation performance more predictable and assist in more cost-effective establishment operations.

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