Root wrenching may influence dormancy development of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings in the nursery

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Summary

The influence of root wrenching on the dormancy and cold hardiness development of Queen Charlotte Island (QCI) provenance of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings was investigated. The root wrenching treatment was carried out in mid September, 1991, with the objective of inducing early dormancy to facilitate early lifting of stock for field planting. Wrenching delayed bud development, lowered root mitotic activity, and reduced cold hardiness levels during dormancy development, compared with the unwrenched seedlings. The rate of root mitotic activity and cold hardiness deacclimation in the spring was also slowed by the wrenching treatment. Although late season root wrenching had the opposite effect to that envisaged, it may be possible to extend the lifting season by two to three weeks using this treatment, as dormancy release was also delayed.

Introduction

Sitka spruce is the most important commercial tree species grown in Ireland. Approximately 41 million Sitka spruce (*Picea sitchensis* (Bong.) Carr.) seedlings[1] were dispatched for field planting in 1993, accounting for over 80% of nursery planting stock production in Ireland. Most of these seedlings were conventional 2+1 transplants.

A variety of cultural practices are used in the nursery to condition Sitka spruce seedlings for eventual field planting. Undercutting is among the most commonly used root cultural treatments. Undercutting is the passing of a sharp blade horizontally through the seedbed at a prescribed depth to sever the roots (mainly the tap root). In other countries, it is common practice to wrench the roots a few weeks later, but this is not normally carried out in Ireland. Wrenching involves the passing of a thicker, broader blade at an angle of 20-30°, to cut the secondary roots down beneath the initial undercut. The seedlings are lifted slightly during this operation, and the soil is aerated. The severing of the root system in this operation

[1] The term seedling is used in the broadest generic sense to include all phases of growth of planting stock in the nursery, including transplants.

causes water stress in the plants, and irrigation should be available if very dry weather follows (Duryea, 1984; Mason, 1994). Although Irish summers are normally cool with adequate precipitation, long periods of warm dry weather do occur, as was the case in 1995. As most Irish nurseries lack irrigation equipment, there has been little interest in using wrenching treatments. Furthermore, the majority of Irish nurseries have relatively heavy soils compared with nurseries in most other countries, and therefore may not be suited to repeated wrenching treatments.

There is, nevertheless, some interest in Ireland in using wrenching treatments late in the season, when temperatures are lower and the risk of prolonged drought is minimal, in order to induce dormancy and to facilitate early lifting. The stress caused by late season wrenching might be expected to cause a moderate water stress response, similar to the method of withholding irrigation water to induce dormancy in seedlings in some nurseries in the USA (Duryea, 1984).

There is no information, however, on the effects, if any, of late season wrenching on the morphology or physiology of Irish grown seedlings. The objective of this work was to assess the feasibility of using late season wrenching as a means of inducing early dormancy in Sitka spruce transplants, and to evaluate its effect on the physiology of the seedlings.

Materials and methods

Plant material

Sitka spruce seeds of QCI provenance (97/d/86-89) were sown in April, 1989 and were lined out in July, 1990 at the Coillte Teo. Ballintemple Nursery, Co. Carlow. The wrenching (W) treatment was applied to several transplant beds in mid September, 1991, as part of an operational field trial. A section of one of these transplant beds at the periphery of the treatment was set aside for the study, together with a similar section of an adjacent unwrenched (UW) control bed.

Sampling, measurements and tests

Bud development, shoot apical mitotic activity and cold hardiness development were observed in seedbeds sampled at two to three week intervals from October, 1991 to mid March, 1992. Shoot tips were excised from 10 seedlings per treatment on each date. The apical bud was dissected from each shoot tip and the number of needle primordia[2] determined, after which the apex was fixed in 10% neutral formalin. In addition, one fine root tip was removed from each seedling from December to March and placed in the fixative. At a later date, the shoot and root

[2] A primordium is defined as an organ or structure, in this instance, a leaf, at its earliest stage of development.

apical meristems were excised, stained and squashed to determine the mitotic index (MI), i.e. the percentage of dividing cells, following the Feulgen method described elsewhere (O'Reilly *et al.*, 1989; Grob, 1990).

To determine cold hardiness levels, 10 whole seedlings per treatment were subjected to freezing treatments overnight in a programmable freezer. The freezer cooled at a rate of 5°C/h, held the target freeze temperature for three hours, and warmed at a rate of 10°C/h to 5°C. The seedlings were held at 5°C until the time of removal. The roots of the plants were protected from freezing by placing them in styrofoam containers and covering with loose perlite. During each test period, two target freeze temperatures (5°C apart) between -5°C and -20°C were selected in the range expected to cause lethal damage to the shoots (Cannell *et al.*, 1990). The freezing tests were run on two consecutive nights. After removal from the freezer, the seedlings were trenched outside together with 10 unfrozen controls of each treatment. The severity of needle damage was assessed four to six weeks later. Damage to each plant was assessed subjectively using the following index: 0, no damage; 1, less than 50% of the needles damaged; 2, greater than 50% but less than 100% of the needles damaged; 3, all needles dead (after Cannell *et al.*, 1990). For presentation purposes, the levels of damage per treatment were converted to percentages assuming that the scores represented 0%, 33%, 66% and 100% damage respectively. As the unfrozen control plants showed no damage (as expected), mean values did not have to be adjusted.

Root collar diameter, seedling height, current (1991) height increment and length of main root (mostly sinker root from tap root) were recorded for each of 60 seedlings per treatment in those sampled between February and March.

Data analysis

Differences between treatments for morphological data and numbers of needle primordia were compared using the t-test. Due to the high frequencies of zeros on some dates and the heterogeneous variance of most MI data, differences between treatments were compared using the Mann Whitney U test. For the controlled freeze tests, the frequencies of the damage scores per treatment were compared using the Chi-squared test.

Results and observations

Morphology

As expected, wrenching of Sitka spruce in September had no significant effect on seedling morphology, presumable because all growth had ceased by the time of wrenching. The seedlings had a root collar diameter of 6.7 (0.14 SE) mm and a height of 36 (0.8 SE) cm, and had a current leader length of 17 (0.7 SE) cm and a main root (primarily extension of sinker root from the tap root) length of 21 (0.8 SE) cm.

Physiology and development

Dormancy development was slower in the wrenched than in the unwrenched seedlings, as shown by the pattern of needle primordium initiation, shoot and root apical mitotic activity, and cold hardiness development.

In early October, the W seedlings had 107 needle primordia (28% of the final number) in their buds, significantly fewer ($p<0.001$) than the 202 primordia in those from the UW treatment (60% of final number) (Figure 1). A similar trend was noted for the mid October samples. Nevertheless, all primordium initiation was complete by late October in both treatments, and differences between treatments in the final number were small.

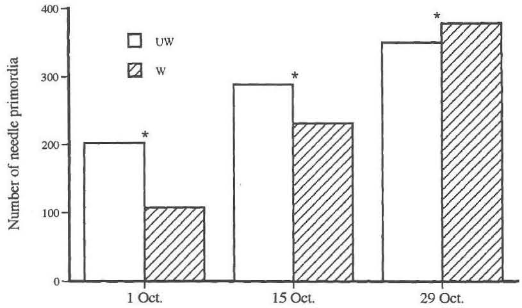

Figure 1. Number of needle primordia versus date in unwrenched (UW) and wrenched (W) Sitka spruce seedlings. Numbers were significantly different on all dates (*) at $p<0.05$.

The trend for primordium initiation is consistent with that for shoot apical mitotic index (Figure 2). The W seedlings were still undergoing rapid primordium initiation, i.e. lower percentage of the final number present, and therefore had significantly higher shoot MI[3] in early and mid October, whereas most production was complete in the UW seedlings. In late October and November, shoot MI was low, with the UW plants tending to have slightly higher rates of activity (significant in mid November only). The shoot apices were inactive (zero MI) from early December onwards, and activity resumed in early March (UW) to mid March (W).

Root MI was significantly lower in the W than the UW seedlings in early December (Figure 3). Root MI was at or near zero from late December to late January in both treatments. In early February, root MI resumed, with MI rates being much higher in the UW seedlings from then until early March. MI was higher, however, in the W than the UW seedlings in mid March.

[3] Note that the percentage of cells in division or mitosis in the shoots rarely exceeds 5% even in the most active non-dormant period. Therefore, MI rates greater than 0.5-1% are indicative of high rates of activity. Slightly higher values occur in root apices.

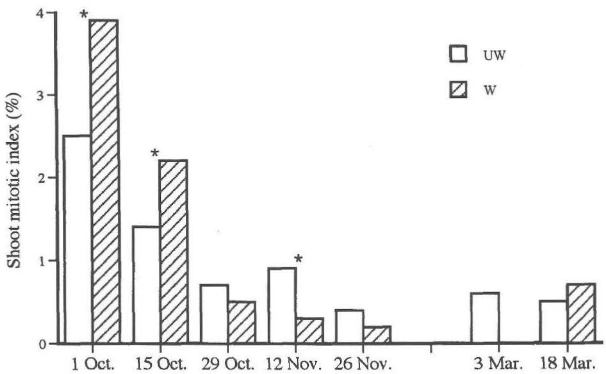

Figure 2. Shoot mitotic index (%) versus date in unwrenched (UW) and wrenched (W) Sitka spruce seedlings. Indices were significantly different at p<0.05 on dates indicated (*). The shoot mitotic index is zero between 26 Nov. and 3 Mar.

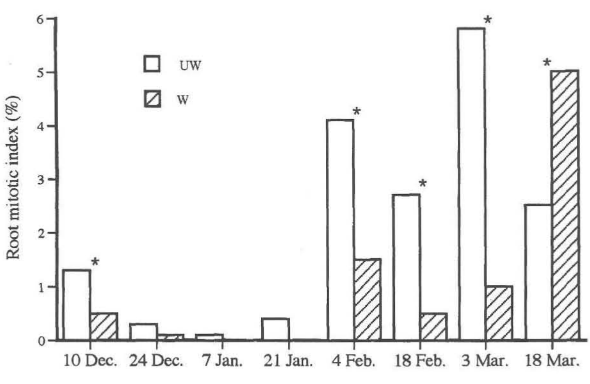

Figure 3. Root mitotic index (%) versus date in unwrenched (UW) and wrenched (W) Sitka spruce seedlings. Indices were significantly different at p<0.05 on dates indicated (*). Missing bars indicate zero.

The pattern of cold hardiness development and deacclimation was generally consistent with that noted for bud development and shoot and root MI. Figure 4 shows the differences in damage at selected temperatures for a number of dates between October and March 1991/92. However, as baseline data on cold hardiness was not available, it was difficult to bracket the temperatures likely to cause damage to obtain LT_{50} levels. For this reason, the magnitude of the damage levels on each date are not necessarily important, rather, it is the relative differences between

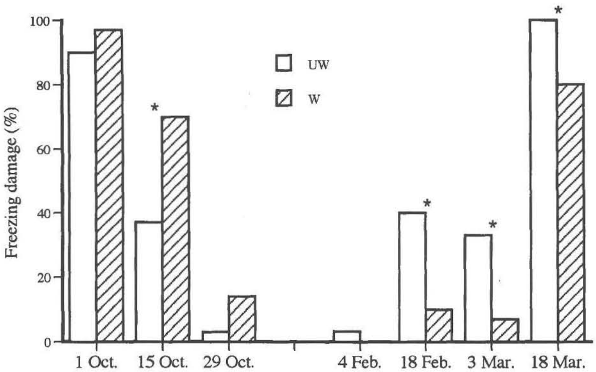

Figure 4. Levels of freezing damage (%) versus date in unwrenched (UW) and wrenched (W) Sitka spruce seedlings. Levels were significantly different at $p<0.05$ on dates indicated (*). Missing bars indicate zero. October tests were at -10°C, while all other tests were at -20°C. Note that the absolute levels of damage at a given temperature are not important, rather it is the relative differences between treatments that are important.

treatments that are important. The seedlings were hardy at temperatures of -20°C (lower limit of freezer) from late December to late January/early February.

As shown in Figure 4, the W seedlings were less cold hardy than the UW seedlings in October and early December, while the reverse was true for the February to March period. These differences in cold hardiness were not significant on all dates.

The time of flushing of the seedlings used as unfrozen controls in the cold hardiness damage evaluation also differed. The UW seedlings began to flush on the 21st of March, and most had fully flushed by late March. In contrast, the W seedlings did not begin to flush until approximately three weeks later, in mid April.

Discussion

The results of this study clearly show that root wrenching can influence the dormancy and cold hardiness development of Sitka spruce seedlings of QCI provenance grown in Ireland. Dormancy and cold hardiness development in the autumn/early winter period and subsequent dormancy release were delayed, compared with the untreated controls. The dormancy and cold hardiness status influence the ability of seedlings to withstand the stresses of lifting, handling and storage (Burr, 1990), and therefore have implications for nursery and field operations.

Late season (September) root wrenching of Sitka spruce seedlings of QCI provenance slowed bud development, reduced root mitotic index, and lowered shoot cold hardiness levels during dormancy development, compared with the untreated seedlings. Wrenching at this time of year does not appear to be a viable treatment for inducing early dormancy to facilitate early lifting of seedlings. Wrenching seedlings earlier in the season, e.g. July/August, however, might be effective, but only in nurseries with irrigation equipment, as previously suggested. Similarly, a single wrenching of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings in early August also delayed dormancy development in one US study (Stein, 1985). In contrast, repeated root wrenching increased the cold hardiness of Sitka spruce of QCI origin in one study in Britain (McKay and Mason, 1991).

The development of dormancy and cold hardiness is a complex physiological process occurring over a large proportion of the annual cycle of development. Progression through the various stages of the dormancy cycle requires energy, particularly in the early phases (Lavender, 1984). Wrenching treatments presumably delay dormancy development through their effect on the plant's energy and growth regulator balance. In one study using Douglas fir grown at nurseries in Oregon and Washington in Northwest USA, wrenching during the period June to early August delayed bud set in seedlings subjected to simulated drought after wrenching, and resulted in seedlings having fewer active roots than the unwrenched seedlings (Duryea and Lavender, 1982), perhaps suggesting that the development of dormancy and cold hardiness was also delayed. In contrast, in another study with Douglas fir on Vancouver Island, BC, there was evidence that wrenching, carried out on eight occasions between early August and mid September, hastened the development of dormancy, although no differences in cold hardiness levels could be detected (Van den Driessche, 1983). The results of those studies are difficult to compare with this study because of differences in species, the timing and severity of treatments, and other factors.

Interestingly, in this study, dormancy release and cold deacclimation were also delayed by wrenching. This result, however, is perhaps not surprising as seedlings that enter dormancy late might also be expected to begin the release process late, as dormancy development in one stage may be influenced by the previous stage (Lavender, 1984). In particular, root MI was lower in February and early March in the W seedlings compared with the UW seedlings, but was higher in the W seedlings in late March. Root growth (Lavender, 1984), and consequently root MI is often quite cyclical compared with shoot MI (see also McKay and Mason, 1991), and the higher root MI rates of the UW seedlings early in spring probably reflected the normal pre-budburst increase in root activity (Ritchie and Dunlap, 1980; Cannell *et al.*, 1990). The W seedlings flushed approximately three weeks later than the UW seedlings. The increase in root activity that occurred in late

March in the W seedlings (Figure 3) probably reflected the delay in reaching the normal pre-budburst peak in root MI. Although wrenching did not have the desired effect of inducing early dormancy, the fact that dormancy release was delayed may be an advantage in extending the planting season, as also suggested for Douglas fir and loblolly pine (*Pinus taeda* L.) seedlings growing in the USA (Tanaka *et al.*, 1976).

As mentioned above, the use of root wrenching as a means of stimulating early dormancy in Sitka spruce was the principle focus of this study. In addition to the possibility of hastening dormancy and cold hardiness acclimation, wrenching, usually applied after the initial undercutting, is used in New Zealand (Rook, 1971; van Dorsser and Rook, 1972), the USA (Tanaka *et al.*, 1976; Duryea and Lavender, 1982; Duryea, 1984), Canada (van den Driessche, 1983) and the UK (Sharpe *et al.*, 1988; Mason, 1994), with the additional objectives of slowing or stopping shoot growth, increasing root fibrosity, decreasing the shoot:root ratio, and encouraging root development in the upper soil layer. Wrenching may also influence physiological responses of the seedlings, such as root growth potential (Bacon and Bachelard, 1978), water relations (Rook, 1969) and carbohydrate metabolism (Rook, 1971). The effect of wrenching on field performances is generally positive for most species (Rook, 1971; van Dorsser and Rook, 1972; Tanaka *et al.*, 1976; van den Driessche, 1983; Deans *et al.*, 1989; Mason *et al.*, 1989; Kainer and Duryea, 1990), but this is not always the case (Duryea and Lavender, 1982; Duryea, 1984). It is likely that the vast differences in soil conditions, treatment timing, species and provenance, climate, etc. make comparison of study results difficult. Further studies of the effects of root wrenching on the morphology, physiology and field performance of Irish grown seedlings are needed before implementing this procedure operationally.

In addition to information on the effects of root wrenching on dormancy development of seedlings, this study provides some preliminary baseline information on the annual cycle of dormancy development in Sitka spruce of QCI origin. The UW seedlings were adequately dormant to permit 'hot' lifting during the late November to early December period, while the W seedlings reached this stage approximately two to three weeks later. The seedlings remained sufficiently stress-resistant for lifting until late February (UW) or early March (W). Additional data from a parallel study (unpublished data on file) also suggest that, for unwrenched stock in the same nursery, Washington provenances of Sitka spruce enter dormancy almost four weeks later than QCI provenances.

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