The Forestry Authority
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231 Corstorphine Road
Edinburgh
EH12 7AT
http://www.forestry.gov.uk

Overwinter Physiology and the Practical Implications for Handling of Noble Fir Seedlings

INFORMATION NOTE

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PREPARED BY HELEN McKAY[1], CHRISTIAN NIELSON[2] AND COLIN McEVOY[1] OF FOREST RESEARCH

ABSTRACT

Noble fir was intermediate between Sitka spruce and Douglas fir in its root electrolyte leakage, root growth potential and root frost hardiness. However, it differed from most conifer species in having very deeply dormant buds, poor cell wall development around the terminal buds and being very sensitive to desiccation which increased, rather than decreased as expected, during autumn.

INTRODUCTION

1. True firs are minor species in British forestry but noble fir (*Abies procera* Rehd.) is grown in increasing numbers mainly for Christmas trees and its foliage. Its natural distribution is comparatively limited; it originates in the upper elevations (900-1800 m) of the Coast and Cascade mountains of Washington and Oregon from 44 to 48°N. Most of its distribution is within the Cascade Range, particularly on the western slopes and along the crest. Isolated populations are also found on peaks in the Oregon Coast Ranges and in the Willapa Hills of Southwestern Washington (Franklin 1990). Noble fir was introduced to Britain in 1831 and has been grown in a limited scale since the 1850s. Compared to Sitka spruce, noble fir has slightly poorer timber density but better growth rates on many sites (Aldhous and Low, 1974).

2. This paper summarizes information on the physiological changes during 1992-93, 1994-95 and 1995-96 in 1u1 noble fir grown at Wykeham Nursery. The outplanting performance of stock planted without storage at different times of winter 1994-95 and 1995-96 and also stock planted in spring 1995 and 1996 after chill storage is also reported.

METHODS

3. The seed of 1992-93 stock was imported in 1982 from zone 412, i.e. King Country, Washington State, whereas stock in 1994-95 and 1995-96 was raised from seed collected in Farigaig and Queens Forests in Scotland in 1989 from stands of unknown seed origin. Seedlings were raised as 1u1 stock following Mason (1994) at Wykeham Nursery (0° 32' W, 54° 16' N, 215 m altitude).

4. Several characteristics indicative of plant condition were assessed at regular intervals during winter; membrane function of the fine roots of freshly lifted samples, sensitivity to desiccation and frost resistance of the fine roots, root growth potential, bud lignification and bud dormancy. Fine root membrane function and root growth potential of stored stock were measured in April at the end of the cold storage period. Membrane function was assessed by the rate of root electrolyte leakage, REL (McKay 1992). In freshly lifted, undamaged plants, it is a measure of cell activity with actively growing material having higher leakage rates than non-dividing material which has hardened off. Damage to cell membranes by desiccation or frost increases the leakage rate so this can be used to quantify the level of damage caused by these factors. Sensitivity to desiccation was determined by exposing plants at 15°C for 5 h in an air flow of about 2 m s^{-1}; the initial relative humidity of 95% fell to 80% over the experimental period. Frost resistance was determined by cooling fine root sections to one of a series of minimum temperatures and calculating the temperature causing 50% electrolyte leakage. Root growth potential (RGP) was determined by placing plants in a favourable environment and counting the number of new roots > 1 cm long produced in 14 days. Bud lignification was assessed on the terminal 2 cm stem including the bud as the dry weight divided by the fresh weight; it is a measure of the amount of cell wall material in that tissue. Bud dormancy was determined by placing potted plants in a greenhouse with standard favourable conditions and counting the number of days required for the terminal bud of half of the plants to flush.

[1] FCRA, Northern Research Station, Roslin, Scotland
[2] Royal Veterinary & Agricultural University, Horsholm, Denmark

5. The forest sites used in both 1994-95 and 1995-96 were within 5 km of the nursery at North Moor (155 m asl) and Broad Head Farm (230 m asl) respectively. At both sites, the soil is an iron pan over mid-calcareous Jurassic grit with a soft limestone lithology. The North Moor site was ploughed to a depth of 45 cm and ripped to 60 cm. The site at Broad Head Farm was an ex-agricultural field which was cultivated using a single furrow shallow agricultural plough. In both experiments, treatments were planted in a randomized layout. Height and diameter were measured at planting and after year 1. Survival was assessed at the end of the first growing season.

RESULTS

6. Root electrolyte leakage showed the normal seasonal pattern, decreasing during autumn, remaining at a more or less constant level from mid-November or early December to late March, and increasing in April (figure 1a).

7. Frost resistance of the fine roots improved during autumn and winter to a maximum around January (figure 1d). Thereafter noble fir roots dehardened. This is the normal pattern for most conifers. Frost hardiness did differ from one year to another, reaching a maximum frost hardiness of -9°C in 1992-93, -4.5°C in 1994-95 and -7°C in 1995-96. Provenance differences are discussed in paragraph 21.

8. After desiccation, the fine roots of noble fir had high REL values. During autumn, leakage values after desiccation increased significantly ($P < 0.05$) as lifting was delayed before stabilizing with lifting dates during winter and spring. During November to March, REL values rose from 10-20% at lifting (figure 1a) to 40-60% after desiccation (figure 1b). At all times of year, the RELs of desiccated roots were significantly greater than before desiccation ($P < 0.001$).

9. Root growth potential at lifting in both 1994-95 and 1995-96 was < 15 at all times (figure 1c). RGP tended to be low in autumn and increased as lifting was delayed but there were considerable differences between the two years.

10. Following cold storage in 1994-95, the REL of plants stored in September and early October was > 50% but post storage REL decreased as storage date was delayed and by late October was generally similar to the REL at lifting (figure 1a). Thereafter there were only minor differences between the RELs before and after storage through to the latest lifting date in early March. In the following year, the REL of plants that were put into storage on dates from mid-November to mid-February did not differ significantly ($P < 0.05$) from the REL values at the end of cold-storage in mid-March.

11. After cold storage in 1994-95, RGP of noble fir was consistently low (< 6) for all storage dates (figure 1c). In the following year, storage commencing on all dates between mid-November to mid-February was associated with low RGP with a maximum post storage RGP of 8.

12. In 1994, bud dry matter increased slowly from 19% in September to 24% in October and 27-28% in November (figure 2a). In both 1992-93 and 1994-95, this level of 27-28% was maintained for most of the winter.

13. The number of days required for half of the terminal buds to burst decreased as the plants experienced temperatures below 5°C in the nursery; this decrease was particularly rapid during September (Figure 2b).

14. Survival of noble fir planted directly from mid-October 1994 to late March 1995 fluctuated between 80-95% but earlier planting, i.e. in September, was associated with poor survival (58%) (figure 3). Seedlings planted over the following winter from early October to late March had survivals of 85-99%. Early cold storage, i.e. in September and October 1994, resulted in very poor survival. Survival increased as the date of cold storage was delayed. In the first experiment, lifting to cold storage on dates from mid-November 1994 to mid-February 1995 with early April planting gave survivals of 80-90% but as lifting to cold storage was delayed further, i.e. into March, survival tended to decrease again. In the second experiment lifting to cold storage in November through to mid-March resulted in consistently high survival (97-100%). Height growth ranged from 20-50% of height at planting and was in general not significantly affected by either date of lifting for planting or cold-storage. Diameter growth ranged from about 10-50% initial diameter; date of lifting had no significant effect on the diameter growth of either directly-planted or cold-stored stock.

15. In the first experiment, cold storage was generally detrimental. Survival of stock cold stored in September and October was significantly poorer than stock planted directly on these dates and diameter growth for all dates except mid-November was significantly poorer after cold storage. However in the second experiment, stock planted out in November and December had significantly poorer survival and growth than stock cold stored on these dates planted in April.

DISCUSSION

16. Noble fir resembled the majority of evergreen conifers previously studied in its pattern of REL at lifting, root frost hardiness, and RGP. The absolute values of these parameters were intermediate between Sitka spruce and Douglas fir, and noble fir can be grouped with Scots and Corsican pine.

17. Noble fir was particularly damaged by root desiccation. During 1994-95 and 1995-96, the post-desiccation levels of 50-60% REL suggest that almost all these noble fir seedlings would die. Data from other experiments indicate that noble fir is similar to Douglas fir in its sensitivity to desiccation. However, unlike all other conifers including Douglas fir, noble fir's sensitivity to root desiccation did not decrease during autumn, indeed it increased in all three years between September and October to January depending on the year. This sensitivity to desiccation may partly explain the poor survival of both bare-root and container stock in the Pacific Northwest (Franklin 1990; McDonald and Cosens 1980; Owsten 1980; Halverson and Emmingham 1982) and the negative effect of simulated drought on early height and diameter growth of cell-grown seedlings (Tung and DeYoe 1988). In its native range, noble fir is found only at upper elevations with high precipitation (1960-2410 mm per annum of which about 75% falls between October and March) and relatively cool temperatures (annual mean air temperature of 4.4 to 7.2°C ranging from -4.4 to -1.1°C in January and 13.3 to 16.1°C in July) (Franklin 1990). In a comparison of Sitka spruce of Alaskan seed origin with Queen Charlotte Islands and Oregon origin, Alaska provenance was more sensitive to desiccation McKay (in prep.), suggesting that populations from cool wet regions are poorly adapted to root desiccation.

18. In 1994, early cold storage was detrimental to noble fir stock. This was shown by poor survival and the high post-storage REL. September and October were warm with average to high rainfall (table 1) which is likely to delay root dormancy leading to severe root damage of cold-stored stock. Once REL at lifting had fallen below 20%, cold storage at +2°C until early April gave satisfactory (> 90%) survival. In 1994-95, which was generally wet with no damaging temperatures (table 1), cold storage at all times of year was associated with poorer diameter growth than direct planting. In the following winter, the severe temperatures during November and December had a two-fold effect; changes in root membranes made plants very resistant to cold storage and newly-transplanted stock were damaged with the net result that cold storage in mid-winter gave better performance than direct planting.

19. Our RGP results agree with the observations of Wilcox (1955) who reported that noble fir seedlings were characterised by a small root system with few apices and poor regeneration capacity. Although undercutting and wrenching improve the R:S ratio and increase root system fibrosity in most species, root regeneration in noble fir is slow and does not produce a more fibrous root system (Wilcox 1955).

20. RGP was reduced by cold storage in 1994-1995. A reduction in RGP of stock grown near Olympia, Washington and stored for four weeks beginning in October to January was reported by Winjum (1963). However he also found an increase in RGP following storage in February and March not evident in our experiments.

21. Differences between years in root frost hardiness are thought to be related both to seed source (the Washington provenance used in 1992-93 may be hardier than the Scottish provenance used in later years) and to winter climate at the nursery (severe cold in late December 1995 may account for the greater hardiness of stock from January 1996 onwards which was not evident in the milder winter of 1994-1995; see table 1). Perks and McKay (1997) found significant differences in root frost hardiness among Scots pine seed origins. Differences in desiccation damage may also be related to provenance since the Washington provenance used in 1992-93 was less sensitive than the Scottish provenance used in later years.

22. Dry matter content of the terminal bud is used in Sweden to determine cold storage dates (Ritchie 1984). The pattern, identified over many years, is an increase during autumn reaching a plateau in early winter. Plants are stored when the dry matter content plateaus usually at a value of ~33% for pine and 36% for spruce. The stable level for noble fir in 1992-93 and 1994-95 was 27-28%. Values of 19 and 24% in September were associated with poor survival after cold storage.

23. The time required for noble fir terminal buds to flush decreased exponentially in common with all conifers but it seemed to have a greater chilling requirement than usual for conifers from mid-November onwards. This may be an adaptation to the winters in its natural range and may explain why noble fir in Britain and Denmark flushes several weeks later than most other conifers. In 1994-95, its chilling requirement after November was similar or actually greater than that of beech (Nielsen and McKay in prep) which had the greatest level of dormancy of 15 species studied by Murray et al. (1989).

24. Two factors must be taken into account when extrapolating from this study to the general situation. Firstly, the plants used here were two-years-old and generally < 20 cm in height whereas some British nursery stock is three-years-old. Thus the values for RGP and damage by desiccation may be unrepresentative. Secondly, considerable annual variation was detected in stress resistance. This may be due to differences in seed source, plant size or climate.

CONCLUSIONS & PRACTICAL RECOMMENDATIONS

25. • The root system of noble fir is very sensitive to desiccation and great care must be taken at all times between September and March to reduce root exposure.

• Its root system is also comparatively sensitive to frost. After lifting, plants in bags should be given overhead protection during severe weather and in mild winters, noble fir should not be stored below -2°C.

• Satisfactory survival of directly planted stock seemed possible from mid-October to late March.

• Stock should not be cold stored until the REL has fallen below 20%; in undercut and wrenched stock from Wykeham this was generally mid-November at the earliest. Providing plants are put into storage in good physiological condition, storage of up to five months was possible with satisfactory survival (i.e. > 85%). In mild winters, cold storage during the recommended period may give slightly poorer performance than directly-planted stock but in extremely cold conditions cold storage may give slightly better performance.

• Noble fir has a low RGP and should always be planted on cultivated, weed-free sites.

Table 1 Temperature (°C) and precipitation (mm) for Fylingdales Meteorological Station (54° 22' N, 00° 40' W, 262 m above sea level).

	Year	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Mean air temperature Precipitation	1992-93	11.1 131	5.6 100	4.8 101	2.0 77	2.6 NA	3.3 39	4.1 20	6.8 118
Mean air temperature Precipitation	1994-95	10.0 115	8.1 65	7.6 74	3.8 98	1.8 120	3.7 85	2.8 66	6.4 123
Mean air temperature Precipitation	1995-96	11.5 130	11.0 24	6.1 113	1.3 191	2.6 71	1.0 99	1.9 48	6.3 29
Minimum air temperature Days with ≥ 0.2 mm rain	1994-95	2.8 21	-0.9 19	0.3 18	-4.3 25	-4.3 25	-2.0 21	-5.2 19	-2.5 11
Minimum air temperature Days with ≥ 0.2 mm rain	1995-96	0.5 19	0.7 10	-2.8 18	-9.2 24	-4.0 23	-4.5 20	-3.8 19	-3.6 12

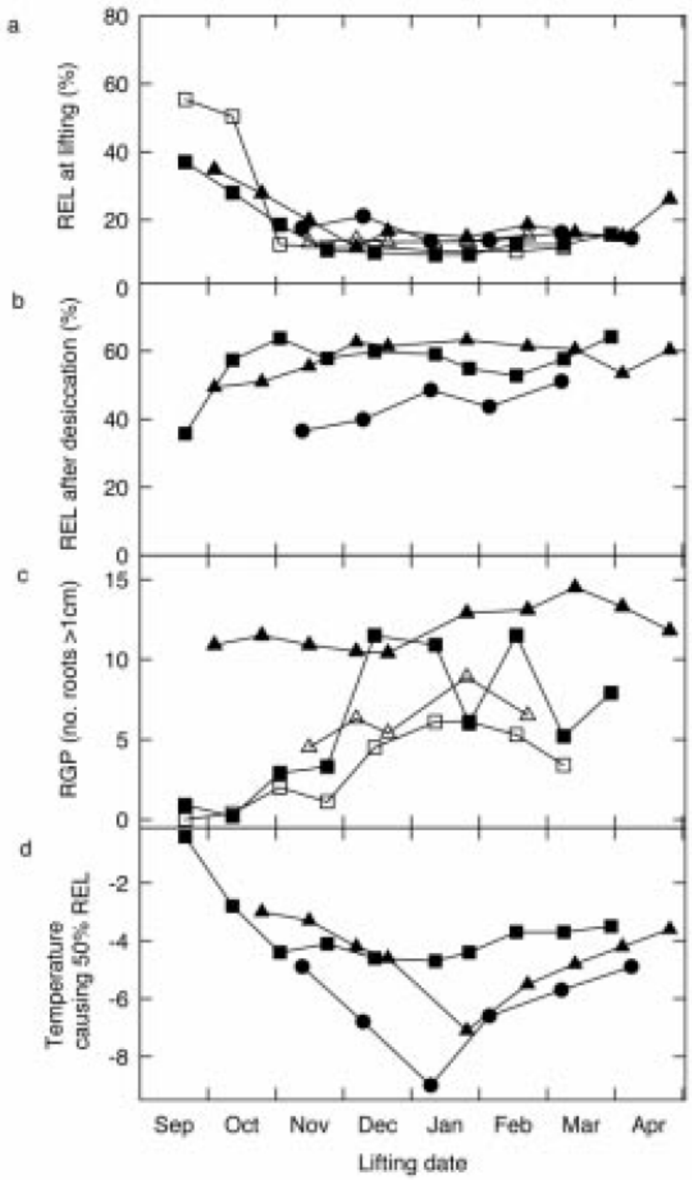

Figure 1

Root electrolyte leakage (%) at lifting (a) and after desiccation (b), root growth potential (number of new roots > 1 cm length) (c), and the temperature (°C) causing 50% REL (d) in 1992-93 (●), 1994-95 (■), and 1995-96 (▲). Open symbols represent values after cold storage.

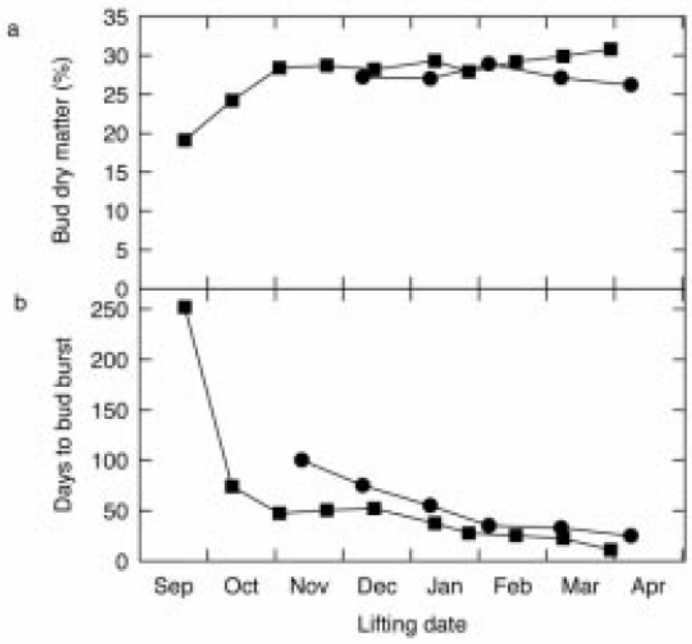

Figure 2

Terminal bud dry matter content (a) and the number of days till 50% terminal bud burst (b).

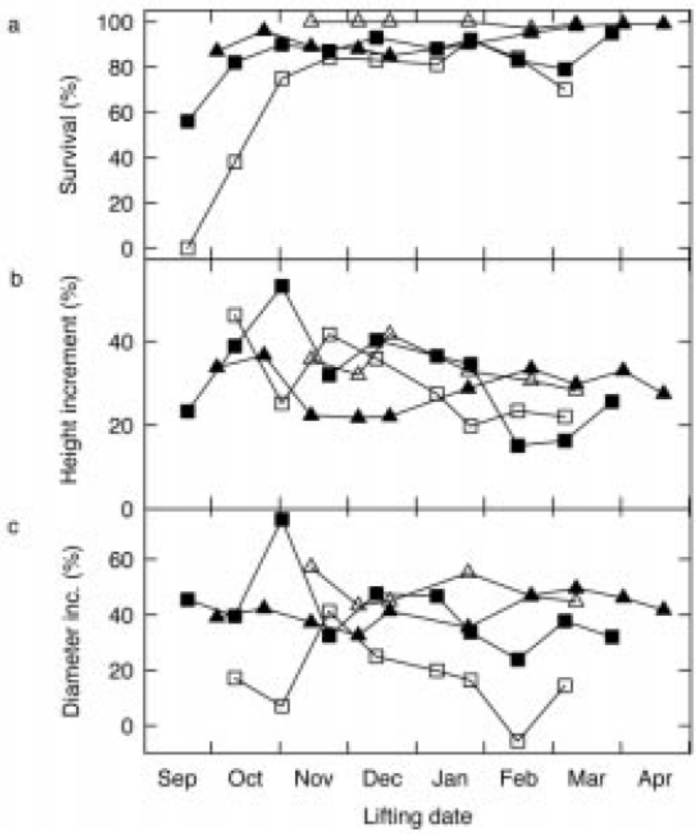

Figure 3

Survival (%) after one growing season (a) , height (b) and diameter (c) growth as percentages of initial dimensions of stock lifted in 1994-95 (■) and 1995-96 (▲) and planted directly (■) or cold-stored (□).

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Enquiries relating to this publication should be addressed to:

Dr Helen McKay
Forestry Commission Research Agency
Northern Research Station
Roslin
Midlothian
EH25 9SY

Tel: 0131 445 2176
Fax: 0131 445 5124

E-mail: h.mckay@forestry.gov.uk

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