Effect of root wrenching in the nursery on the quality of Japanese larch transplants

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Abstract

The influence of root undercutting and wrenching in the nursery on the quality of two-year-old Japanese larch (*Larix kaempferi*) seedlings was investigated. Seedlings were undercut in June and then subjected to a factorial combination of wrenching in July, August and October. All treated stock plus one set of controls (not undercut or wrenched) received additional fertiliser. The effect of these treatments on the phenology of height growth and bud flushing the following spring, end-of-season morphology and root growth potential (RGP) was evaluated. Undercutting (June) had the largest effect on the rate of shoot growth. Wrenching in July reduced the rate of shoot elongation further, wrenching in August had a smaller effect, while wrenching in October had no effect. Treatments had little effect on the date of growth cessation in the year of treatment or date of bud flushing the following spring. Wrenching had little effect on root collar diameter, but improved (reduced) sturdiness (height/diameter), especially if carried out late in the season and/or more than once. Wrenching also increased RGP, decreased height and improved (decreased) the shoot:root ratio, but had a small or non-consistent effect on shoot and root dry weights. Except for final height, the time of wrenching had a small effect on this outcome. The results of this study suggest that larch transplants should be undercut in June and wrenched early if height control is required, but more than one wrenching may be necessary to improve RGP.

Keywords

Root wrenching, undercutting, root growth potential, plant morphology.

Introduction

The Forest Service requirement (Department of Agriculture Food and Forestry 1996) for species diversity in new plantations has encouraged the planting of larch (*Larix* spp.) in Ireland. The number of larch seedlings[3] planted increased from 0.8 million trees in 1995 to 6.75 million in 1999, mostly composed of Japanese larch (*L. kaempferi* (Lamb.) Carr.) and hybrid larch (*L.* x *eurolepis* Henry) (Anon. 2000). Although larch is adaptable to a wide range of site types (Macdonald et al. 1957), plant failure rates during the early establishment phase are at least twice those of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on the same sites in Ireland (Carey 2001). Losses of up to 50% have been reported for larch in Britain (McKay and Howes 1994). The survival and early growth of planted trees depends largely on their readiness to rapidly produce new roots and thereby re-establish intimate contact with the soil after planting (Ritchie 1985). The poor root regeneration capacity of larch after planting may be the main cause of mortality after planting (McKay 1998, McKay and Morgan 2001). The morphological quality of the shoot system also may contribute to this problem.

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

Most bare-root planting stock used for forest establishment in Ireland is produced as transplants. In addition to providing extra growing space, transplanting usually also stimulates root development (Mason 1994a). However, transplanting alone does not appear to be fully effective in stimulating the development of a fibrous root system in larch. The quality of the root system of transplants can also be further improved by using undercutting and wrenching treatments (Duryea 1984). This treatment is more commonly used to improve the quality of stock that has not been transplanted (e.g. 1u1 stock). Undercut and wrenched (non-transplanted) seedlings generally perform better than transplanted stock, mainly owing to the better quality of the root system (McKay and Howes 1994, McKay and Morgan 2001). Undercutting involves horizontally drawing a sharpened, thin blade through the nursery bed, severing roots at a desired depth. Wrenching differs from undercutting by using a thicker blade, angled at 25-30° downwards, and drawn through soil at a depth below the undercutting level. Wrenching loosens and aerates the soil around the root ball and breaks off smaller roots. This action usually stimulates root regeneration (Benson and Shepherd 1977). The severing of the root system causes water stress in the plants, and is best carried out in moist, humid weather conditions. Irrigation should be available after treatment because of the risk of drought stress during dry weather (Duryea 1984, Mason 1994b).

There is little published information available concerning the benefits of using wrenching treatments to improve the quality of transplanted stock in Ireland. In one study, Sitka spruce was wrenched late in the season (September) in an attempt to induce early dormancy in transplanted stock to facilitate early lifting, but the treatment was found to have the opposite effect (O'Reilly and Keane 1996).

The objectives of this study were to examine the effect of root wrenching treatments on:

1. the phenology of shoot growth in the year of wrenching and the date of bud flushing in the following spring and;
2. the morphological characteristics and root growth potential (RGP) of Japanese larch transplants.

Materials and methods

Plant material, nursery and general cultural care

Japanese larch transplants (1+1) (British seed source: 96(3015); exact origin unknown), from the Coillte nursery at Ballintemple, Co Carlow (52° 44' N, 6° 42' W, 100 m elevation) were used in the experiment. The soil is a sandy loam, with a pH 4.8-5.7, 6-10% organic matter and sand, silt and clay fractions of 66%, 19% and 15%, respectively. The seed was broadcast sown in May 1998.

Prior to transplanting, 50 m^3 of waste mushroom compost, 500 kg of 0-16-0, and 250 kg of kieserite (15% Mg) fertilisers/ha were applied to the soil. These amendments were made soon after ploughing and were incorporated in the top 15 cm of soil. The seedlings were transplanted (25 September, 1998) using a *Super Prefer* five-row machine, with rows 25 cm apart, achieving an average seedling density of 18/linear metre. After transplanting, 100 kg/ha of calcium ammonium nitrate (27% N) was applied once per month in April, May, June and July 1999. Sulphate of potash (42% K) was applied in the first week of July at 100 kg/ha. All other aspects of cultural care were similar to those described by Mason (1994a).

Wrenching treatments

Seedlings were subjected to a factorial combination of early-season (E) (23 July), mid-season (M) (19 August), and late-season (L) (5 October) wrenching treatments in 1999 (Table 1). The late season wrenching was carried out approximately two weeks later than scheduled, because of heavy rainfall. The plants were wrenched at 15-20 cm depth (approximate depth of upper and lower sides of blade, respectively). Wrenching is normally carried out after the roots of the plants have already been undercut (Hobbs et al. 1987, Sharpe et al. 1988). For this reason, the roots of the seedlings destined for wrenching were first undercut at 13 cm on 28 June. Because root wrenching reduces the ability of plants to absorb nutrients (Landis 1985), additional fertiliser was applied to the plots that contained wrenched seedlings. However, two sets of controls were used. Seedlings in one set received additional fertiliser while those in the other did not. The seedlings in the control plots were not undercut or wrenched. Calcium ammonium nitrate, at 75 kg/ha (27% N), was applied to all plots containing wrenched seedlings, plus one set of controls. The fertilisers were applied on 28 June, 23 July and 19 August, just before the undercutting/ wrenching treatment. Fertiliser was not applied before the last wrenching (October) because sufficient fertiliser had been applied earlier in season. There were a total of nine treatment combinations (including two controls).

Table 1. *Description of the wrenching treatments applied to Japanese larch transplants in 1999.*

	Wrenching treatments[1]		
Treatment number	*Fertiliser treatment*	*Description*	*Number of wrenchings*
1	No	No wrenching	0
2	Yes	No wrenching	0
3	Yes	Wrenched early (E) in growing season	1
4	Yes	Wrenched in mid (M) growing season	1
5	Yes	Wrenched late (L) in growing season	1
6	Yes	E x M	2
7	Yes	E x L	2
8	Yes	M x L	2
9	Yes	E x M x L	3

[1] All wrenched seedlings were undercut 28 June.

Experiment design

The experiment was laid down as a randomised block design. Each of the nine treatment combinations (Table 1) was replicated once in each of the three blocks. Each bed was approximately 215 m long and was divided into three blocks of equal length. Each block was further sub-divided into nine 5.5 m treatment plots. Plots were separated from each other by a buffer zone (2 m) containing untreated plants. A larger buffer of 5.5 m was allowed at the top and bottom of each bed.

Phenology of shoot growth and date of flushing

The effect of the wrenching treatments on shoot elongation was evaluated using 10 permanent sample trees per plot. These 10 seedlings were in the centre transplant line in each plot. Height measurements commenced on 25 June 1999, just before the date of undercutting. Subsequent measurements were made just before each wrenching and the scheduled (September) wrenching date and in mid October (after all elongation had ceased).

The same sample trees were used to evaluate treatment effects on the date of flushing in the following spring. The number of seedlings per plot that had flushed dwarf-shoot buds was recorded during February and March 2000. The date of flushing of the long-shoot buds of the branches and leader of each plant was not determined. The long-shoot buds usually flush in about April or May (personal observations), but the transplants were scheduled for lifting for field planting before this time.

Morphology

In mid February 2000, 15 plants from near the centre of each plot (excluding the permanent sample trees) were carefully lifted by hand. The soil was gently washed from the roots of the seedlings to minimise root loss. The plants were stored in co-extruded polyurethane plastic bags at 2°C until all measurements were completed (over 10 day period following lifting).

The root collar diameter (RCD), seedling height and height increment in 1999 was recorded for each plant. After this, the shoot was excised from the root at the root collar. The shoot and root of each plant was dried separately at 75°C for 24 h and then weighed. The sturdiness (shoot length (cm):RCD (mm)) and shoot/root ratios (shoot weight (g): root weight (g)) of each plant were calculated from these values.

Root growth potential and number of days to bud break

In a similar manner to that described for the morphology assessment, a further six plants were carefully lifted in mid February from near the centre of each plot and placed in plastic bags. The plants were immediately stored at 2°C at the nursery and then dispatched in early March to University College Dublin (UCD) for testing. Six pots (replications), containing three seedlings each, represented each treatment combination (total of 18 plants/treatment combination). The three seedlings (one from each nursery plot) were placed in 3.5 l pots containing a 3:1 (vol:vol) mixture of peat-perlite. The pots were placed in a heated (17-23°C day/15-17°C night) greenhouse at UCD. The positions of the pots were randomised. The photoperiod was extended to 16 h using high-pressure sodium vapour lights. Relative humidity was maintained above 50% by using time-controlled fine mist nozzles. Just after potting, the medium was watered to field capacity and at 2-3 day intervals thereafter.

The plants were monitored at 2-5 day intervals and the dates at which the first flushing of the lateral and terminal bud of each plant occurred were recorded. At the end of the test, after 28 days, the plants were removed from the pots and the roots washed carefully in tap water. The number of new white roots (>1 cm) per plant was recorded (Ritchie 1985).

Meteorological data and irrigation

Since undercutting/ wrenching may induce drought stress in seedlings (Duryea 1984, Mason 1994b), rainfall data for the June to October 1999 period were obtained for a weather station at Oakpark, Co Carlow, approximately 18 km from Ballintemple Nursery.

The summer and autumn of 1999 was much wetter than normal (Table 2). Nevertheless, there was no rainfall for 10 days after wrenching in July, but it rained shortly after treatment on all other occasions. The transplant beds were irrigated during dry periods. About 3 mm h^{-1} of water was applied on 13 (2 h), 22 (4 h), 24 (1 h) 27 (2 h), 30 July (4 h) and 3 August (2 h).

Table 2. *Daily accumulated rainfall (mm) during the June – October period in 1999 for Oakpark, Co. Carlow (18 km from nursery).*

			Month		
Day	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*
1	0.0	30.2	0.0	0.0	n/a
2	1.8	3.0	1.4	0.2	n/a
3	31.8	0.6	9.4	0.0	n/a
4	4.6	0.4	0.0	0.0	n/a
5	8.4	0.0	57.6	0.0	18.4
6	4.0	0.0	9.0	0.0	0.2
7	1.4	0.2	14.8	63.8	0.0
8	0.0	0.0	0.2	0.0	0.4
9	0.0	0.2	1.8	14.8	0.0
10	0.6	0.0	0.0	0.2	0.2
11	0.0	0.0	0.0	57.2	0.8
12	0.0	0.0	0.0	9.4	0.0
13	0.2	3.8	1.8	22.4	0.2
14	2.8	0.6	0.8'	0.6	0.0
15	0.0	0.0	1.0	0.0	1.8
16	0.2	0.0	0.6	25.4	7.8
17	0.0	0.2	12.0	0.0	0.0
18	0.0	9.2	1.4	16.2	0.0
19	0.0	6.6	17.2	23.4	0.0
20	5.6	9.6	0.0	8.6	0.0
21	1.6	0.2	0.0	58.8	3.2
22	0.0	4.0	0.0	0.4	10.8
23	1.8	0.0	5.6	8.8	19.0
24	0.0	0.0	0.4	0.0	11.4
25	0.0	0.0	8.6	48.6	0.0
26	0.0	0.0	2.0	14.8	0.0
27	5.6	0.0	0.0	18.0	0.0
28	1.8	0.0	0.0	12.8	0.2
29	0.6	0.0	0.0	2.0	0.6
30	0.4	0.0	1.4	1.6	2.4
31	—	0.0	0.0	—	9.8
Mean	73.2	68.8	147.0	408.0	87.2
Long term average	53	49	67	71	81

[1] not available.

Data analyses

All data except the root growth potential data were analysed according to a factorial randomised block design, using the GLM procedure in SAS (SAS 1989). Plot means were used in all analyses. The effects of block, fertiliser, and the factorial combinations of early, mid and late season wrenching on the responses were evaluated. The mean for the standard (operational practice) treatment (control without fertiliser) was compared with the means for all other treatment combinations using Dunnett's test. The data also were analysed according to a second model to determine the effect of the number (0, 1, or ≥ 2) of wrenchings on parameter responses, followed by less square means tests. The RGP data were analysed in a similar manner, but there were no block effects for this parameter. The RGP data were transformed to ranks to standardise variation, but this transformation and others did not correct this problem for some parameters. In such cases, the data were analysed using non-parametric tests. However, the results from these tests were similar to those obtained using parametric procedures, so only the results of the latter tests are presented.

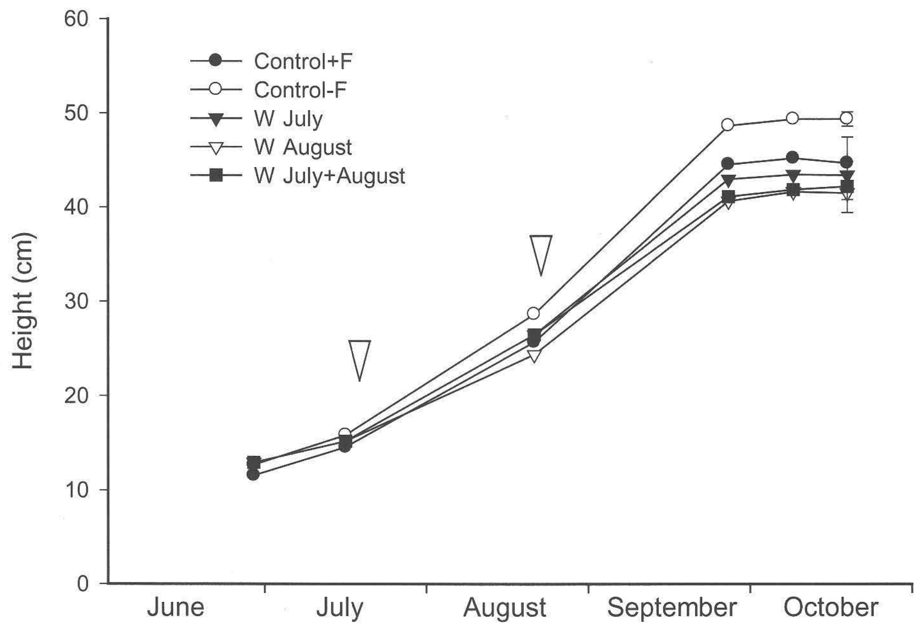

Figure 1. *Height growth of Japanese larch seedlings transplanted in the autumn or spring and then subjected to combinations of early (E) or mid (M) season wrenching or no wrenching (control, C). All seedlings except one set of the controls (C-F; standard treatment) received additional fertiliser. The date of each wrenching is indicated (arrows). Means are based on three replications of each treatment combination, each replicate containing 10 seedlings.*

Results

Shoot elongation and flushing

Early wrenching significantly reduced the height growth that occurred over the period between the first and the second wrenching ($p \leq 0.05$). However, wrenching treatments did not significantly influence height growth after each of the two subsequent wrenchings. Although mid or late season wrenching had no significant effect on height growth, treatment effects were apparent for mid season wrenching due to the effect of undercutting in June. For this reason, only the effect of early (July) and mid (August) season wrenching (and combinations of these treatments) on height growth is shown (Figure 1). The effect of wrenching treatments on end-of-season plant height is described in detail below (based upon a separate sample of plants).

The seasonal pattern of height growth was similar regardless of wrenching treatment (Figure 1). Height growth was slow in June and early July, and then increased rapidly during late July and early August. Height growth was most rapid from late August until mid to late September. Thereafter, height growth was slow and ceased in about early October. The control seedlings (no fertiliser) were the tallest at the end of the growing season.

Root wrenching in the 1999 growing season had no significant effect on the date of lateral bud flushing in the following spring (mean, 8 March).

Morphology

Final plant height was significantly reduced by mid or late season wrenching (Table 3). In addition, the number of wrenchings received (regardless of application date) significantly affected plant height. Mean height ranged from 39–46 cm for wrenched seedlings, smaller than the 49 cm for both controls (Figure 2). Compared with the standard treatment (control minus fertiliser), a single wrenching reduced height increment by about 7%, while more than one wrenching reduced it by about 15%.

Table 3. *Significance of effect of fertiliser and wrenching treatments on morphological characteristics and root growth potential in Japanese larch transplants. Abbreviations: Root collar diameter (RCD); shoot (SDW) and root (RDW) dry weights; root growth potential (RGP), not significant (ns).*

Source of variation	*Height*	*RCD*	*Sturdiness*	*SDW*	*RDW*	*SDW/ RDW*	*RGP*
Fertiliser	ns	ns	ns	ns	ns	ns	ns
Early season wrenching (E)	ns	ns	0.0043	ns	ns	0.0004	ns
Mid-season (M) wrenching	0.0029	ns	0.0036	ns	0.0248	0.0013	0.0417
Late season (L) wrenching	0.0062	ns	ns	ns	ns	0.0129	ns
E x M	ns	ns	ns	ns	ns	ns	ns
E x L	ns	ns	0.0279	ns	ns	ns	ns
M x L	ns	ns	ns	ns	ns	ns	ns
E x M x L	ns	ns	ns	ns	ns	ns	ns
Number of wrenchings	0.0029	ns	<0.0001	ns	ns	<0.0001	0.0162

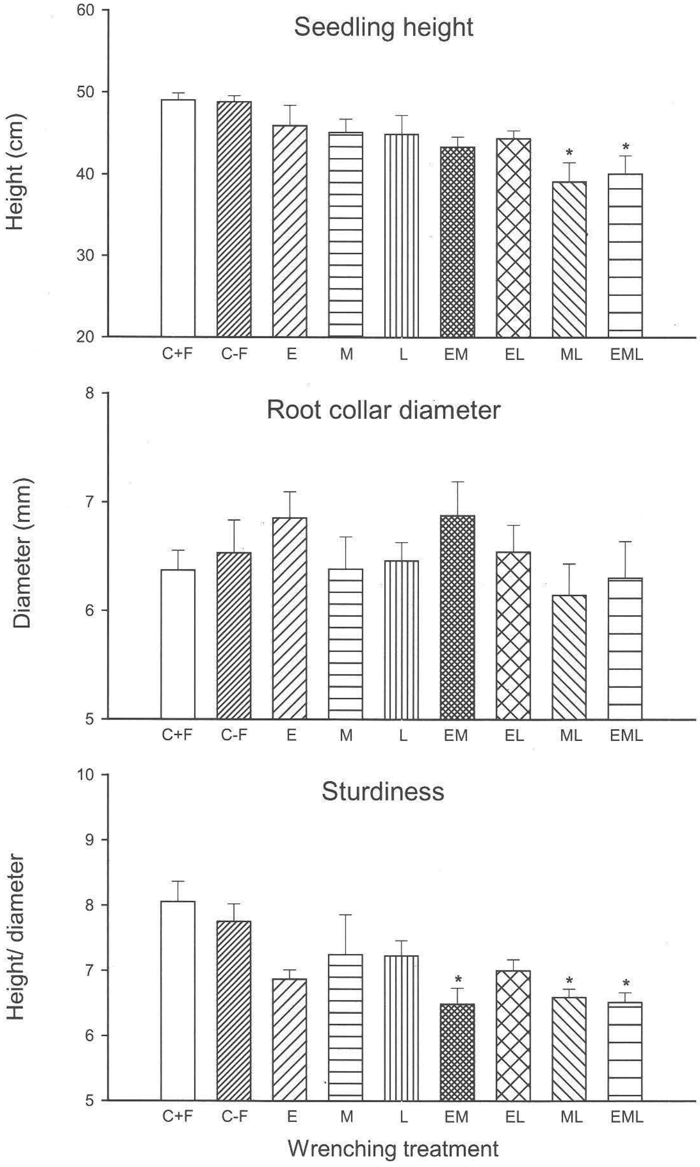

Figure 2. *Mean total height, root collar diameter and sturdiness of Japanese larch seedlings lined-out in autumn or spring and then subjected to combinations of early (E), mid (M), and late (L) season wrenching or no wrenching (control, C). All seedlings except one set of controls (C-F) received additional fertiliser. Means significantly (p<0.05) different from the standard (operational practice) treatment (C-F) are indicated (*). Means are based on three replications of each treatment combination, each replicate containing 15 seedlings. Vertical lines are standard errors.*

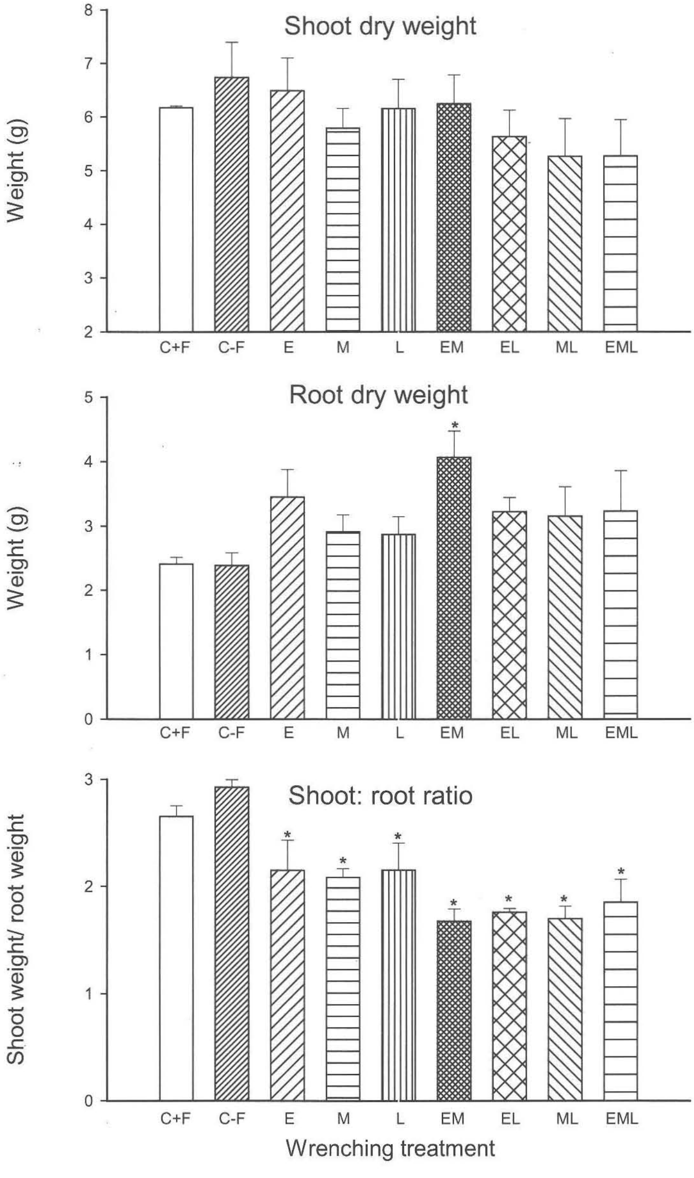

Figure 3. *Mean shoot and root dry weights and shoot to root ration of Japanese larch seedlings lined-out in autumn or spring and then subjected to combinations of early (E), mid (M), and late (L) season wrenching or no wrenching (control, C). All seedlings except one set of controls (C-F) received additional fertiliser. Means significantly ($p<0.05$) different from the standard (operational) treatment (C-F) are indicated (*). Means are based on three replications of each treatment combination, each replicate containing 15 seedlings. Vertical lines are standard errors.*

The date of wrenching or the number of wrenchings applied did not significantly affect root collar diameter of the seedlings (Table 2). The mean RCD ranged from 6.1–6.9 mm (Figure 2).

The sturdiness (height/root collar diameter) of seedlings was significantly affected by early or mid season and the combination of early with late season wrenching (Table 3). The number of wrenchings received by the seedlings also significantly affected sturdiness. Low values indicate sturdier, better-balanced plants. For autumn lined out stock, mean sturdiness ranged from 6.5–7.2 for wrenched plants, compared with 8.1 (+fertiliser) and 7.8 (-fertiliser) for the controls (Figure 2). The mean sturdiness values were 7.9, 7.1 and 6.7 for seedlings that received 0, 1 or ≥ 2 wrenchings, respectively

The date of wrenching or number of wrenchings had no significant effect on shoot dry weight (SDW) (Table 3). The mean SDW ranged from 5.3–6.7 g (Figure 3). Early wrenching significantly influenced root dry weight (RDW), but the number of wrenchings used had no significant effect (Table 3). The mean RDW ranged from 2.9 to 3.5 g for wrenched seedlings compared with 2.4 g for both controls (Figure 3).

The shoot: root (S:R) ratio was significantly affected by early, mid or late season wrenching (Table 3). The S:R ratio was also significantly influenced by the number of wrenchings applied. A low S:R ratio indicates a better balance between the shoot and the root mass. The S:R ranged from 1.7–2.2 for wrenched plants, smaller than the 2.7 (+ fertiliser) and 2.9 (-fertiliser) for the controls (Figure 3).

Root growth potential

RGP was significantly increased by mid season wrenching only (Table 3). However, the number of wrenchings applied had a large effect on RGP. Seedlings wrenched two or three times had significantly higher RGP than those that received a single wrenching ($p \leq 0.05$) or no wrenching ($p \leq 0.01$). However, the RGP of seedlings wrenched once did not differ from the RGP of the controls. The mean RGP of seedlings wrenched two or more times ranged from 87–92, compared with 74–77 for those wrenched once, and 73 (- fertiliser) and 75 (+ fertiliser) for the controls (Figure 4).

Discussion

The results showed that root undercutting/ wrenching improved the quality of Japanese larch transplants (Figures 1-3). These treatments improved sturdiness and RGP, decreased height and the shoot: root ratio, but the effect on shoot and root dry weights was small and non consistent. Wrenching had no effect on the date of height growth cessation and date of bud break the following spring. Therefore, root wrenching may be a viable cultural practice for operational use for larch in Irish nurseries. There is no published information of this kind for transplanted stock of larch, although there is considerable information available from other countries on the use of wrenching for non-transplanted (often called "undercut") stock (Rook 1969 & 1971, Benson and Shepherd 1977, Duryea 1984, Mason 1986).

Fertiliser was applied to all plots except one set of controls. Undercutting and wrenching may induce nutrient deficiency so extra nutrients are usually supplied to treated seedlings (Sharpe et al. 1988, Mason 1994b). The shoot elongation data indicated that the control seedlings that received no fertiliser were taller at the end of the season than the controls that received no additional fertiliser, whereas the end-of-season morphology data showed no difference between these treatments. Since the morphology data were based upon larger sample sizes than the shoot elongation data (used to study phenology of growth only), the former are probably more accurate than the latter. The effect on growth was small, perhaps because there was an adequate store of nutrients already in the soil. However, the nutrient status of the seedlings was not determined in this study. The intention of the study was to examine the effect of wrenching treatments on seedling growth responses under non-limiting nutrient conditions. Further research is needed to determine the nutrient requirements of wrenched Japanese larch transplants.

Bud flushing, phenology of shoot growth and final height

Wrenching treatments had no effect on the date of growth cessation (leader growth ceased in early October) or the date of flushing of buds in the following spring, but affected the rate of height growth. In contrast, a single late (September) wrenching delayed bud flushing the following spring in Sitka spruce sampled from Ballintemple Nursery (O'Reilly and Keane 1996). Most shoot growth in mature larch trees is predetermined (i.e. from a bud), although some additional free (or neoform) growth usually occurs in the same growing season (Owens and Molder 1979). Therefore, shoot elongation ceases much earlier in mature trees (probably June or July), but growth ceases much later in seedlings because they undergo considerable free growth (Colombo et al. 2001).

Undercutting in June followed by wrenching in mid July reduced the rate of height growth of seedlings in this study, but undercutting followed by wrenching later in season had a small or negligible effect on height growth. However, the height growth of stock that was wrenched late was reduced due to the effect of the undercutting in June. Undercutting/wrenching reduced height growth probably because the uptake of moisture and nutrients were restricted (Rook 1969& 1971). Rook (1971) also reported that the initial undercutting treatment had a greater effect on height growth than the subsequent wrenching. Undercutting/wrenching reduces height growth probably because photosynthate is re-allocated from the shoot to the root (Rook 1971, Mason 1994b). Although treatments had no effect on date of height growth cessation in this study, wrenching induced slightly earlier bud set in slash pine (*Pinus elliottii*) seedlings growing in Florida, suggesting that height growth also ceased earlier (Kainer et al. 1991). Wrenching delayed bud set in Douglas fir seedlings during drought conditions in NW America (Duryea and Lavender 1982). The generally mild, moist climate that prevails in Ireland probably induced much less moisture stress in the seedlings in this study than occurred in the countries in which the other studies were carried out. Furthermore, the 1999 growing season was wetter than normal, although there was no rain for 10 days (Table 1) after wrenching in July. Irrigation was used to minimise the effect of drought stress during dry periods.

Similar to the results of this study, undercutting and wrenching treatments reduced height growth in Douglas fir seedlings (Duryea and Lavender 1982; Hobbs et al. 1987). Van den Driessche (1983) also found that early (May/June) wrenching reduced height growth in Douglas fir seedlings, but wrenching later in the season (July/August) had no effect on this parameter. Undercutting and wrenching significantly reduced height growth of Monterey pine (Rook 1971, Benson and Shepherd 1977), Caribbean pine (*Pinus caribaea* Mor. var. *hondurensis* B. & G.) (Bacon and Bachelard 1978) and slash pine (Kainer and Duryea 1990) seedlings. The time of wrenching application had a relatively small effect on shoot growth in this study, but this may be more important in other species than in larch (Aldhous 1972).

Root collar diameter, sturdiness, shoot and root dry weights, and shoot:root ratio
Wrenching had no significant effect on root collar diameter of the seedlings in this study. Wrenching might be expected to increase root collar diameter if photosynthate is reallocated from the shoot to the cambium and the roots at the expense of the shoots (Ritchie and Dunlap 1980). In contrast, the height:RCD ratio (sturdiness) was affected greatly by wrenching, probably mainly caused by the decrease in height since diameter growth was affected little by the treatments. Wrenched seedlings, especially those treated late in the season and/or more than once, were sturdier than the unwrenched controls. In other similar studies, undercutting and wrenching of Monterey pine reduced height growth relative to RCD, thus improving sturdiness (van Dorsser 1981, Rook 1971). However, wrenching reduced root collar diameter in loblolly pine (*Pinus taeda* L.) seedlings (Tanaka et al. 1976). A similar response was reported for Douglas fir in one study (Duryea and Lavender 1982), but it had virtually no effect in another (Tanaka et al. 1976). Sturdy (low sturdiness values) plants are generally considered to be of better quality (Thompson 1985). However, it is difficult to compare results because of differences among studies in the number of wrenchings used, depth of wrenching, weather conditions after wrenching, nursery soil type, and study location etc.

Early wrenching significantly reduced the shoot dry weight of seedlings. This result is not surprising since this treatment also influenced plant height. However, treatment effects on plant height were not always reflected in shoot dry weight differences, perhaps because most height differences were relatively small and much of this extra shoot tissue was probably non-woody. Shoot dry weight of Douglas fir seedlings was virtually unaffected by root wrenching in one study (Tanaka et al. 1976), but was reduced in another (Duryea and Lavender 1982). Wrenching was found to have reduced the shoot dry weight of slash pine seedlings (Kainer and Duryea 1990).

Wrenching early slightly increased the root dry weight of seedlings in this study. Similar to the effect on the shoots, wrenching probably increased fine (non-woody) root mass, without having a large effect on total root dry weight. In Monterey pine, wrenching had little effect on root volume (weight not determined), but it increased the number of fine roots (Rook 1971). While wrenching may stimulate root growth, an increase in root mass may not be detected since roots are also excised during the undercutting/wrenching operation. For example, wrenching reduced taproot dry weight in Douglas fir (Duryea and Lavender 1982). Wrenching did not affect root dry weight in slash pine seedlings (Kainer and Duryea 1990), increased it in Douglas fir in some studies (van den Driessche 1983, Tanaka et al. 1976), but had no effect in another study (Duryea and Lavender 1982).

Wrenching improved (reduced) the shoot: root ratio of larch seedlings in this study, although the effect on the parameter components of ratio was less clear. Seedlings that have low shoot: root ratio are likely to perform better in the field than those having a high ratio (Aldhous 1994, Tanaka et al. 1976). Nevertheless, the shoot: root ratio of seedlings, regardless of the wrenching treatment used, did not exceed the recommended maximum value of 3.0 (Aldhous 1994). Similar to the findings of this study, wrenching reduced the shoot:root ratio in Douglas fir (van den Driessche 1982, Duryea and Lavender 1982, Tanaka et al. 1976) and in Monterey pine (Rook 1971) seedlings. Wrenching also reduced the S:R ratio in Caribbean pine seedlings (Bacon and Bachelard 1978). The reduction in the S:R ratio may be a response of the plant to drought stress induced by wrenching (Bacon and Bachelard 1978).

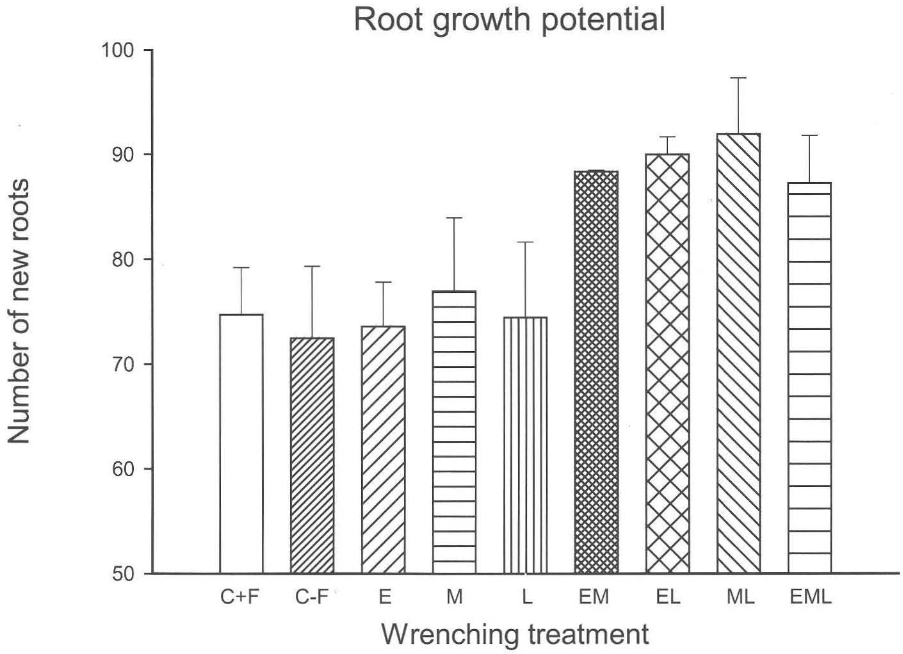

Figure 4. *Root growth potential of autumn lined-out Japanese larch seedlings subjected to combinations of early (E), mid (M) and late (L) season wrenching or no wrenching (control, C). All seedlings except one set of controls (C-F) received additional fertiliser. Vertical lines are standard errors.*

Root growth potential

Seedlings wrenched two or three times had significantly higher root growth potential than those that received one wrenching or no wrenching (Figure 4). This increase probably resulted from an increase in root fibrosity (mainly fine, non-woody roots) due to wrenching (Rook 1971, van den Driessche 1983, Tanaka et al. 1976), although this was not detected in the root dry weight values (Figure 3). RGP tends to be strongly associated with root fibrosity (Deans et al. 1990). Undercutting and wrenching sever many roots and disturb the intimate contact between the roots and the soil, thus leading to moisture stress and a reduction in nutrient availability (Mason 1994b). In response to this, root activity is stimulated and there is usually an increase in the amount of photosynthate allocated to the roots (Rook 1971). Wrenched and undercut seedlings ('undercut' non-transplanted stock) of Sitka spruce and Douglas fir had higher RGP than (unwrenched) transplants in one British study (McKay and Mason 1991).

Root regeneration after undercutting/wrenching is dependent on soil temperature, with rates of regeneration being faster at higher temperatures (Mason 1994b). For this reason, these operations are usually carried out in the warmer months of June to September. In addition, root growth varies seasonally and is influenced by shoot growth (Kramer and Kozlowski 1979), perhaps suggesting that the response of the seedlings to wrenching might vary seasonally. However, the date of wrenching did not have a large impact on RGP in larch in this study.

Operational implications

The relatively heavy nature of nursery soils in Ireland may preclude the widespread use of wrenching, although the method may be more useful for larch than other species since it appears to respond well to treatment over a wide range of wrenching dates. However, further research is needed to assess the effect of undercutting alone (without subsequent wrenching) and its timing on plant quality. Furthermore, the effect of year-to-year variation in climate (especially since 1999 was much wetter than normal), the time and number of wrenching treatments applied, soil type and nursery location on plant quality need to be evaluated. In addition, field trials are required to confirm that the superior quality of wrenched seedlings is reflected in better field performance. Nevertheless, the results of many studies have shown that wrenching improved post-planting survival and/or growth of several conifer species (van den Driessche 1983, Sharpe et al. 1990), including larch (McKay and Howes 1994), especially for cold stored stock (McKay and Morgan 2001).

Conclusions and recommendations

Undercutting (carried out in June only) followed by early wrenching reduced the rate of shoot elongation, with mid season wrenching having a smaller effect on growth. Undercutting followed by late season wrenching had little effect on height growth. However, the rate of height growth was reduced in stock that was wrenched late because of undercutting earlier in season. Wrenching treatments had little effect on the date of growth cessation in the current season or bud flushing the following spring. Undercutting and wrenching improved sturdiness, shoot: root ratio and root growth potential, but had little effect on shoot and root dry weights. Except for final height, the time of wrenching had no consistent effect on this outcome. The results of this study suggest that larch transplants should be undercut and wrenched early in season if height control is required, but more than one wrenching may be necessary to improve RGP.

Acknowledgements

The authors would like to thank Pat Doody, Pat Long, and Michael Doyle for their assistance/support in carrying out this research. Coillte provided financial assistance for this work.

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