ROOT PRUNING, WRENCHING AND OVERWINTER COLD STORAGE: EFFECTS ON THE MORPHOLOGICAL AND PHYSIOLOGICAL CONDITION OF TRANSPLANT *Picea glauca* [Moench] Voss NURSERY STOCK

by

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Title of Thesis: ROOT PRUNING, WRENCHING AND OVERWINTER COLD STORAGE: EFFECTS ON THE MORPHOLOGICAL, PHYSIOLOGICAL CONDITION OF TRANSPLANT *Picea glauca* (Moench) Voss NURSERY STOCK.

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This thesis has been prepared under my supervision and the candidate has complied with the regulations for the degree.

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ABSTRACT

The objectives of this thesis were to: 1) evaluate the effect of a single early spring root pruning followed by a series of five root wrenching treatments at three week intervals on the morphological condition of rising 2+2 white spruce nursery stock, 2) to determine the effect of wrenching and several overwinter cold storage environments on bud dormancy progression, root regenerating potential and planting stock performance, 3) to assess wrenching as a method of conditioning bare root nursery stock for fall lifting and overwinter cold storage.

Root pruning and wrenching was applied to rising 2+2 white spruce in nursery trials one in 1982 and another in 1983 at the Ontario Ministry of Natural Resources Forest Station, Thunder Bay Ontario. The root pruning and wrenching treatment reduced current height increment, reduced the number of primordia in the winter buds, and in 1983 significantly increased root area index. Root pruning and wrenching increased the overall root regenerating potential of stock during overwinter cold storage. Wrenching and root pruning did not significantly alter bud dormancy progression or patterns of root regeneration during the winter.

Both the control and the root pruned and wrenched stock was overwinter cold stored in 3 storage environments. The progression of bud dormancy and root regeneration potential of this stock was monitored monthly for a seven month period during the winter. Stock that was fall lifted and overwinter stored had the same winter bud dormancy pattern as stock overwintered in the nursery bed but a different pattern of root regenerating potential. Cold storage delayed bud flushing in the spring and prevented frost damage from occuring after spring outplanting. A six week spring warm up conditioning treatment at +2 C in cold storage increased root regenerating potential. The exposure of fall lifted stock to natural photoperiods while overwintering in an unheated polyhouse did not appear to improve planting stock quality over that of the same stock overwintered at -2 C in complete darkness.

Abstract

Control stock and root pruned and wrenched stock, both fall-lifted and overwinter cold-stored, and fresh spring lifted all had excellent survival after spring outplanting. Wrenching reduced the height growth of stock the first season after outplanting. Root pruning and wrenching increased the total mean root elongation of fall-lifted overwinter cold stored stock by more than 300 per cent at the time of spring outplanting.

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INTRODUCTION

The success or failure of forest tree planting operations depends heavily upon the conditioning of nursery stock prior to planting. Both overwinter cold storage and root wrenching are used as operational nursery procedures to ensure that stock is in good physiological condition for outplanting.

Overwinter cold storage may be used to ensure that bud flushing does not occur until after trees are planted. There is also some evidence that cold storage may condition the stomates of white spruce to prevent water loss on dry sites and presumably help to improve planting success (Blake 1983). Planting stock may be conditioned in overwinter cold storage for 3 to 6 weeks before planting by increasing the storage temperature from $-2^{o}C$ to $+2^{o}C$. This greatly increases the root regenerating potential and the initial survival of planting stock without causing premature bud flushing. (Day and Harvey 1983, 1984).

Introduction

Wrenching may improve the outplanting survival of fall lifted overwinter cold stored red pine (*Pinus resinosa* Ait.) nursery stock and fresh lifted stock especially on dry sites (Bunting and McLeod 1984b). Wrenching most commonly reduces top/root ratios by increasing root oven dry weights, reducing top dry weight or both. It sometimes produces a seedling with a more fibrous root system (van Dorsser and Rook 1972 and Tanaka *et al.* 1976). Wrenching has in some instances improved the root regenerating potential of planting stock. This is likely related to changes in both the morphology and physiology of conifer nursery stock after root pruning and wrenching treatments in the nursery bed. Wrenching has been shown to increase the proportion of photosynthate directed to the roots and to increase stomatal resistance (Rook 1970, Stupendick and Shepherd 1980).

Wrenching and spring conditioing in storage at +2 °C will help ensure good survival of overwinter cold stored conifer nursery stock. However, for adequate outplanting survival it is also necessary to maintain a storage environment that minimizes stock quality deterioration while allowing the natural progression of dormancy processes to take place. A good cold storage environment will minimize: freezing damage to plant tissues, respiration and dry weight losses, moulding and desiccation. It must also satisfy bud dormancy chilling requirements and maintain good root regenerating potential. Overwinter cold storage in total darkness at -2^{o}C, as recommended for northern conifers by Mullin and Parker (1976), satisfies many of these conditions. There is some evidence that planting stock quality might be improved by exposing stock in overwinter cold storage to long day photoperiods prior to outplanting (Lavender 1978).

This thesis investigates the hypothesis that wrenching and overwinter cold storage will help prepare and condition white spruce nursery stock for planting operations. The study also looks at the effect overwinter cold storage environment has on bud dormancy processes and root regenerating potential.

The objectives of this thesis are:

1) To evaluate and compare the effects of a root pruning and multiple root wrenching treatment on the morphological and physiological condition of transplant white spruce nursery stock.

2) To assess the effects of three overwinter storage environments on the physiological behavior and morphological condition of root pruned and wrenched white spruce transplants both during storage and after outplanting.

3) To assess root pruning and root wrenching as practical nursery procedures to pre-condition stock for overwinter cold storage and improve planting stock quality.

LITERATURE REVIEW

1 ROOT PRUNING AND WRENCHING OF BAREROOT NURSERY STOCK

1.1 Definition Of Terms

Several terms are used to describe the culture, manipulation and modification of seedling roots. In order to clarify discussion, the terms used in this review will be defined.

Root pruning and wrenching or root culture *in situ* are used to modify and improve the morphological and physiological condition of bare root nursery stock. The term wrenching is defined as

> "the breaking of fine roots of nursery plants without removing them from the soil by heaving the soil with a mechanical implement or by partially lifting and then refirming" -Empire Forestry Association 1953.

Root pruning is defined as

> "the pruning of roots particularly for the purpose of encouraging the development of a compact fibrous root system" - Empire Forestry Association 1953.

The term "undercutting" of roots is often used interchangeably with the term root pruning. "Undercutting" of roots is defined as follows

> "to root prune nursery stock *in situ*" - Empire Forestry Association 1953.

Several types of root cutting or root pruning methods used in nursery beds incorporate the word "pruning". These are horizontal root pruning, vertical root pruning and box pruning. Horizontal root pruning or undercutting is the pruning of roots with a sharpened blade run horizontally through the soil. Vertical root pruning is the pruning or cutting of roots with sharpened blades or coulters run vertically through the soil. Box pruning is vertical root pruning on all four sides and horizontal pruning underneath a seedling.

In this review, the term "root trimming" is used to describe the cutting of roots once nursery stock is removed from the soil and the term "root pruning" is reserved to describe root cutting of trees _in situ_. The terms "horizontal root pruning" and "undercutting" will be treated as synonyms in this review. The term "root culturing" will be used to describe the _in situ_ culturing and manipulation of roots in seedling nurseries. This includes all forms of root pruning and root wrenching. The term "root conditioning" is sometimes used in the literature and may in many cases be considered a synonym to the term root culturing as it is defined in this study.

1.2 Description Of Root Wrenching And Root Pruning Of Bare Root Nursery Stock

Horizontal root pruning and wrenching utilize similar types of equipment. Van Dorsser and Rook (1972) describe the traditional types of mechanical equipment commonly used for wrenching and root pruning in forest tree nurseries. There are many local modifications to the types of equipment used for horizontal root pruning and wrenching operations. All these mechanized operations use a horizontal steel blade and farm tractor. The blade is positioned underneath or behind the tractor and it is adjusted hydraulically to obtain and maintain the desired cutting or wrenching depth. A single root pruning often preceeds a root wrenching program. The pruning operation employs a thin sharpened steel saw blade that is passed through the soil of the nursery bed severing tap roots and deep fibrous roots 8 to 12 cm below the soil surface. A hardened spring steel blade tilted 20^{o} forward from the horizontal and passed through the soil at 12 to 25 cm below the soil surface is used to wrench. Wrenching severs deep roots, lifts seedlings slightly and aerates the soil and the seedbed. The combined action of a single root pruning followed by a series of wrenchings at two to three week intervals during the growing season promotes the proliferation of a fibrous lateral root system and the removal of long tap roots. In New Zealand undercutting and wrenching are commonly conducted with a reciprocating blade that is powered from a tractor Power Take Off (P.T.O.). In North America both fixed and reciprocating blades are used (Shoulders 1963, Cameron and Rook 1969, van Dorsser and Rook 1972, Eis and Long 1972, Tanaka *et al.* and van den Driessche 1983).

The removal of lateral roots using a vertical root pruning process is not as common a practice in nurseries as is wrenching and undercutting. Lateral root pruning

Terminology Table

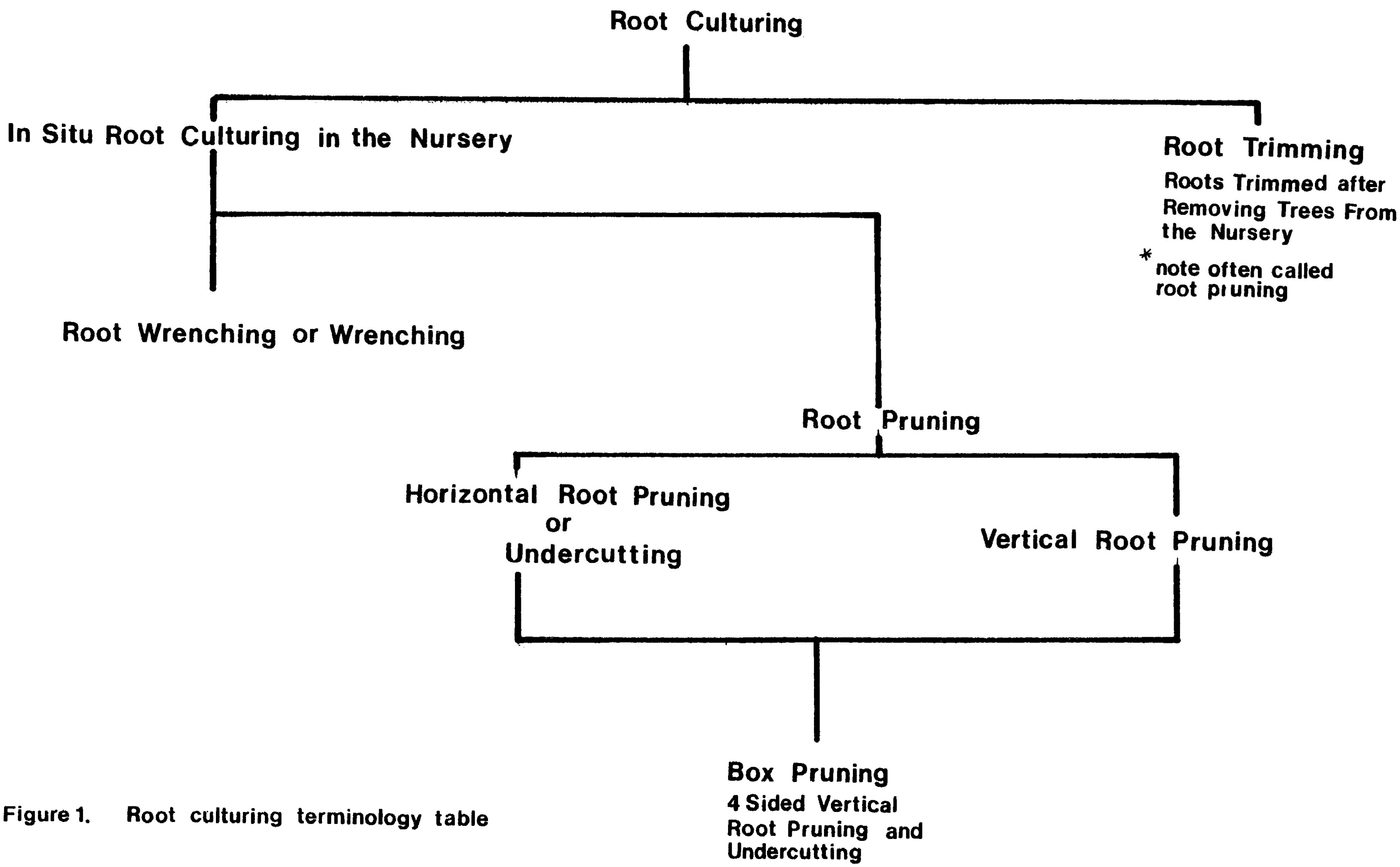

Figure 1. Root culturing terminology table

utilizes sharpened coulters or steel knife blades that are passed vertically through the soil between rows of the nursery bed. These cutting implements are again lifted up and down hydraulically and are mounted beneath or behind a farm tractor (Gingerich and Hertel 1962, Burgar 1965, Eis 1968, van Dorsser and Rook 1972 and Chavasse 1978a).

According to Chavasse (1978a, 1978b and 1980) box pruning is used to produce Radiata pine (Pinus radiata D. Don) that are more wind firm than trees that are wrenched. Box pruning that uses a four sided lateral root pruning process across and between the rows in the nursery bed prevents the intermeshing of adjacent tree roots but it is not easily mechanized and is therefore only experimental (Burdett and Simpsom 1984).

1.3 The Effects Of Root Pruning And Wrenching On The Morphological Quality Of Nursery Stock

Root pruning and wrenching have been shown to affect shoot elongation, size and type of root system and, in some instances, stem diameter. These morphological attributes are manipulated by adjusting the timing, frequency and depth of undercutting and wrenching and by adjusting fertilizer and irrigation programs (van Dorsser and Rook 1972).

Both root pruning and wrenching reduce height growth and shoot dry weight, but only if these treatments are applied just before or during periods of shoot elongation. The shoot elongation of wrenched radiata pine was reduced by 50 per cent or more in extensive trials in New Zealand (Rook 1971 and van Dorsser and Rook 1972). Similar shoot elongation reductions have been observed in 2+0 radiata pine in Australia (Benson and Shepherd 1976). Wrenching and root pruning also significantly reduced the shoot growth of Douglas-fir (*Pseudotsuga menziessii* (Mirb.) Franco) (Tanaka *et al.* 1976 and van den Driessche 1983) and horizontal root pruning reduced the shoot elongation of rising 3+0 white spruce (Mullin 1966). As was expected horizontal root pruning and wrenching red pine late in the summer after shoot elongation was complete had no effect on the current year's height increment (Bunting and McLeod 1984b).

Root culturing of bare root nursery stock causes a prolific growth and development of fibrous roots thereby increasing the absorptive capacity of the root system (Cameron and Rook 1969, Rook 1969, Benson and Shepherd 1977, Koon and O'Dell 1977, Bacon and Hawkins 1979 and van den Driessche 1983). As well as increasing root system fibrosity, wrenching of Douglas-fir seedlings was shown to increase root oven dry weights by both Tanaka *et al.* (1976) and by van den Driessche (1983). Rook (1969) and Bacon and Bachelard (1979) feel that a decline in shoot growth after wrenching is associated with the development of a strong "sink effect" in the roots resulting in a greater proportion of current photosynthate being allocated to the roots and a resultant proliferation of new roots.

Root cultured nursery stock is characterised by reductions in top/root ratios. This may be a result of reduced top oven dry weights, increases in root dry weight or both. Rook (1971) found that root wrenching 2+0 radiata pine in New Zealand decreased the top/root ratios by 50 per cent. Very similar reductions in top/root ratios were reported for wrenched radiata pine in Australia (Benson and Shepherd 1977). Vertical root pruning combined with horizontal root pruning of 2+0 Austrian pine (*Pinus nigra* Arnold) reduced top/root ratios from 8.65 to 6.26 a reduction of 28 per cent (Gingerich and Hertel 1962). Wrenching 2+0 Douglas-fir seedlings in the Pacific Northwest has also been shown to significantly reduce top/root ratios (Tanaka et al. 1976, Duryea and Lavender 1982 and van den Driessche 1983). It was suggested by Rook (1969 and 1971) and Bacon and Hawkins (1977) that the reduced top/root ratios of root cultured nursery stock is the key morphological attribute linked to improved survival and growth after outplanting on droughty sites.

Response to root culturing has resulted in either no change or a reduction in stem diameter. In one trial Mullin (1966) showed that a single root pruning had no significant effect upon radial stem growth of 3+0 white spruce. In another instance concurrent wrenching trials of two species resulted in unaltered stem diameters for Douglas-fir and significantly reduced stem diameters for loblolly pine (Pinus taeda L.) (Tanaka et al. 1976). Duryea and Lavender (1982) also found that stem diameter of 2+0 Douglas-fir was not altered by wrenching. Koon and O'Dell (1977) found wrenching the same stock type reduced stem diameters by up to 29 per cent. These differences in the effects of root culturing on diameter growth may be due to variation in the interal moisture content of seedlings or different root culturing programs. Root culturing has been shown to reduce per cent moisture contents and increase internal negative water potentials (Chavasse 1980 and Duryea and Lavender 1982). A reduction in the internal moisture content of trees will cause radial shrinkage of stems that is quickly recovered after rehydration (Kramer and Kozlowski 1979).

The morphological effects of root culturing have been found to vary with the seedling's phase of growth at the time when treatments are applied (van Dorsser and Rook 1972, Eis and Long 1973 and Duryea and Lavender 1982). The response of nursery stock to any given root culturing treatment will also vary with the degree and regularity of inter-tree spacing in the nursery bed (Chavasse 1978a, 1978b and 1980 and van den Driessche 1982). Nursery stock in lower density nursery beds responds more favourably to wrenching than stock grown at higher densities.

Root cultured nursery stock shows some morphological variation but is often characterized by the following morphological features: 1)a short sturdy top, 2) a large fibrous root mass, 3) reduced shoot dry weights, 4)unaltered or increased root dry weights and 5)greatly decreased top/root oven dry weight ratios.

1.4 The Effects Of Root Culturing On The Physiololgical Condition Of Nursery Stock

The effects of root culturing upon the physiological condition of nursery stock are not as clearly understood or defined as they are for seedling morphology. The physiological responses of nursery stock that have been reported after wrenching and root pruning treatments are not always consistent. This is particularily true for a number of studies that have measured stomatal resistances after root culturing treatments. Root cultured stock usually shows an increase in stomatal resistance and internal negative water potential immediately following a root culturing treatment (Cameron and Rook 1969, Stupendick and Shepherd 1980 and Duryea and Lavender 1982). These responses of seedlings immediately after root culturing resemble drought response (Hsiao 1974) and may be associated with the temporary severing of roots and increased soil aeration that occurs after wrenching and root pruning (Chavasse 1978a, Denison 1980 and Stupendick and Shepherd 1980). Stupendick and Shepherd (1980) state that multiple root wrenching programs with radiata pine may have a conditioning effect that increases stomatal resistances and that this effect is often maintained until after outplanting. This conditioning of the stomates, they feel, helps reduce water loss after planting and allows these seedlings to maintain a more favourable internal water balance and to exhibit improved survival rates after planting. In contrast Rook (1969) concluded that repeated wrenching of Radiata pine 2+0 seedlings does not condition stomates to resist opening after planting and is of no particular physiological importance to the survival of these seedlings after outplanting. Whether stomates are conditioned to maintain higher stomatal resistances after planting is unclear , but wrenched trees do maintain a more favourable internal water regime than unwrenched trees , especially on dry sites (Tanaka et al. 1976, Bacon and Hawkins 1979 and van den Driessche 1983). This more favourable water balance may depend more on the well balanced morphological condition of root cultured nursery stock that is characterized by small tops and large fibrous root systems than it is on stomatal conditioning (Rook 1969 and Bacon and Bachelard 1977).

The Root Regenerating Potential (RRP) of nursery stock has been reported to be greatly increased in many root culturing trials (Cameron and Rook 1969, Rook 1971, van Dorsser and Rook 1972, Tanaka et al. 1976, Bacon and Bachelard 1977, Stupendick and Shepherd 1979 and Denison 1980). Bacon and Bachelard (1977) showed that wrenching Caribbean pine (Pinus caribeae Mor. var. hondurensis B.G.) increased RPP by 10 times over that of unwrenched stock. Sutton (1967) and Ritchie and Dunlap (1980) found that the trimming of roots also stimulates root development. Tanaka et al. (1976) and Bacon and Hawkins (1977) reported that wrenching 1+0 loblolly and Caribbean pine, respectively increased lateral root production. The increase in lateral root production helps create a larger framework from which many new roots can be regenerated. The greatly enhanced RRP of root cultured nursery stock supposedly allows these seedlings to tap very quickly available soil moisture and soil nutrients during their initial establishment after outplanting (Stone and Schubert 1959, Rook 1971, van Dorsser and Rook 1972, Bacon and Hawkins 1977, Koon and O'Dell 1977, Denison 1980 and Stupendick and Shepherd 1980).

Some of the physiological mechanisms that may be involved in increased RRP following root pruning and wrenching have been investigated. Ritchie and Dunlap (1980) suggest that the removal of root caps during root culturing may reduce the production and concentration of abscissic acid (ABA) a root growth inhibitor. The resultant effect would be to strenghten the root growth promotor/inhibitor ratio. Root culturing also causes an increase in the movement of ^{14}C into the root systems. Rook (1971) showed that root wrenching caused a three-fold increase in the percentage of ^{14}C transported to the roots of radiata pine. The increase in transport continued for 2 1/2 months after undercutting the roots of radiata pine seedlings. Root culturing caribbean pine in Australia had the same effect on ^{14}C translocation (Bacon and Bachelard

1978). Rook (1971) also demonstrated that root cultured 2+0 Radiata pine seedlings contained higher concentrations of stored carbohydrates than unwrenched seedlings. The root cultured seedlings were also shown to have a greater proportion of this carbohydrate in the roots than the untreated stock. Possibly disturbances to the root system result in an increase in the percentage of current photosynthate that is directed to the roots with a simultaneous reduction in shoot growth and an increase in root growth. According to a theory suggested by Bacon and Bachelard (1978) well conditioned root cultured nursery stock may have a higher photosynthetic rate than unconditioned stock. In some cases this is may be due to lower negative water potentials in root cultured stock. Bacon and Hawkins (1978) hypothesised that when root culturing modifies these two factors, photosynthate translocation and rate of photosynthesis, the combined effect causes a greater amount of photosynthate to be transported to the roots in both absolute and relative terms (Bacon and Bachelard 1978). This may further help to improve the RRP of root cultured stock.

Root pruning and wrenching may not only increase drought avoidance, but also alter dormancy status, cold hardiness and growth patterns. It is not understood exactly how dormancy status is altered but according to

Young and Hanover (1978) and Ritchie and Dunlop (1980) a temporary moisture stress, such as that which may occur immediately following root culturing, will change the process of dormancy induction and deepening. It has been clearly demonstrated that cold hardiness and tolerance to cool and cold storage conditions are greatly improved by root pruning and wrenching (van Dorsser and Rook 1972, Denison 1980, van den Driessche 1983 and Bunting and McLeod 1983a). These two factors may be related to changes in dormancy status, but are most likely related to reduced relative water contents and increased levels of stored carbohydrates in root cultured stock (Rook 1971, van Dorsser and Rook 1972, and Tanaka *et al.* 1976). It is also apparent that root culturing may alter the timing of shoot elongation. Tanaka *et al.* found that early spring wrenching of loblolly pine delayed the flushing of shoots. This results in seedlings of superior planting stock quality. Early cessation of shoot elongation by wrenching is important in the production of morphologically balanced high quality radiata pine seedlings (Cameron and Rook 1967, Rook 1971, van Dorsser and Rook 1972 and Chavasse 1980). The timing of root culturing treatments relative to the growth phase of seedlings is another important consideration when manipulating dormancy, cold hardiness and shoot growth.

The term conditioning or hardening is often used to describe the effect root culturing has on nursery stock. It is a general term that does not address itself to any specific morphological or physiological seedling attribute. It does, however, describe the process that occurs when a specific type of stress, such as moisture stress, is applied to seedlings. Conditioning or hardening produces a seedling that is generally more resistant to stresses than a non- conditioned or unhardened seedling (Sutton 1979a). The conditioning of root cultured nursery stock may improve the physiological quality of outplanted stock by reducing internal moisture stress. This effect could be related to reduced top/root ratios (van den Driessche 1983), larger more absorptive root systems (Rook 1969) and greater RRP (Bacon and Bachelard 1978). The conditioning of stomates may, in some cases, temporarily reduce transpiration and reduce negative water potentials (Denison 1980 and Stupendick and Shepherd 1980). In contrast to this, higher photosynthetic and transpiration rates may be expected following wrenching and root pruning due to a more favourable internal water balance that is maintained because of a greater absorptive capacity of the enlarged root system. All these factors enhance the vigour and early growth potential of conditioned *in situ* root cultured nursery stock and may improve outplanting performance.

1.5 The Outplanting Performance Of Root Pruned And Wrenched Nursery Stock

The outplanting survival of root cultured stock has, in most cases, been shown to be markedly improved especially on dry sites. Van Dorsser (1967) and Benson and Shepherd (1977) found that the survival of radiata pine was greatly improved by root pruning and wrenching. Bacon and Hawkins (1977) showed that as wrenching of 1+0 Caribbean pine increased from one to three treatments, outplanting survival increased from 37 to 67 per cent. In other wrenching trials with 2+0 Douglas-fir Koon and O°Dell (1977) discovered that an increase in the frequency coupled with a shallower depth of root wrenching improved survival after outplanting. These same outplanting trials that tested the effect of root culturing on the survival of radiata pine, Caribbean pine and Douglas-fir substantiate the importance of a reduction in top/root ratio as a means of improving survival (van Dorsser and Rook 1972). As the intensity and frequency of wrenching increases there tends to be a corresponding increase in the survival rate of outplanted stock especially under droughty conditions.

The survival of white spruce and eastern white pine

(*Pinus strobus* L.) and red pine was improved in outplanting trials by root pruning in the nursery (Mullin 1966 and Mullin and Hutchison 1979). Mullin (1966) also determined that root pruning white spruce in the spring and summer during the grand phase of growth improved survival but that fall pruning did not. The same trial showed that horizontal root pruning at either 5 or 10 cm had no effect on outplanting survival.

The effect of root culturing on post planting height growth is not always positive. The number of needle primordia initiated in the buds of tree species such as Douglas-fir and white spruce with largely predeterminant growth patterns may be reduced by moisture stress and competition by the root system for photosynthates after root culturing (van den Driessche 1983 and Simpson 1983). This may explain why terminal shoot elongation for both Douglas-fir (van den Driessche 1983) and white spruce (Mullin 1966) was reduced the first year after outplanting. This trend became less significant subsequent years after outplanting and reversed itself after three years (Mullin 1966). Reduced needle primordia initiation may be of particular significance if wrenching takes place at the time of needle primordia initiation, usually mid-summer to early fall in Canada (Owens and Molder 1976). Trees with largely indeterminant growth patterns do not consistently demonstrate a reduction in shoot elongation after outplanting. Benson and Shepherd (1977) found that a series of 5 wrenchings of 1+0 radiata pine only slightly reduced over-all height after two years in the field, and that two wrenching treatments increased shoot growth. In contrast to these results, van Dorsser (1969) and van Dorsser and Rook (1972) showed that wrenched 1+0 radiata pine seedlings had up to 4 times the total height of unwrenched seedlings one growing season after outplanting. It is likely that any reductions in the height of root cultured stock following planting are quickly compensated for by the superior morphological and physiological quality and faster growth rates that soon develop after field planting.

2 OVERWINTER COLD STORAGE OF BAREROOT NURSERY STOCK

2.1 Definition

Overwinter cold storage may be defined as the storing of dormant, cold tolerant, hardened nursery stock at a temperature close to 0 ^{o}C from the time of fall lifting until spring planting. In Ontario this is usually assumed to be -2+/-1 ^{o}C for conifer nursery stock that is fall lifted and overwinter cold stored in a forest tree nursery cold storage unit.

2.2 Introduction

Fall-lifted overwinter cold stored stock has numerous advantages over spring-lifted or fresh-lifted stock. At many forest tree nurseries fall lifting and overwinter cold storage operations help to reduce heavy workloads during the busy spring lifting season and ensures an adequate, reliable and steady supply of stock for spring planting in the field planting (Brown 1971 and Hocking and Nyland 1971). This is of particular importance in cases of poor weather that interrupts busy spring lifting schedules. Nursery stock left to overwinter in the nursery bed may, during some winters be subject to severe temperature fluctuations, snow scald and desiccating winds. Thus stock overwintered in the highly controlled environment of a cold storage unit may be in better condition for planting than spring lifted stock that overwintered in the nusery bed (Hocking and Nyland 1971).

Stock quality deterioration often occurs when stock is fall lifted and overwinter cold stored. This has been attributed in part to pathological deterioration caused by molds and other fungi (Hocking and Nyland 1971, Navratil et al. 1975, Navratil et al. 1976), respiration and associated dry weight losses (Hellmers 1962, Hocking and Nyland 1971, van den Driessche 1979, McCracken 1979 and 1980 and Navratil 1982), desiccation (Navratil et al.1975) and a build-up of ethylene gas in storage containers (Barnett 1983). Storage at -2^{o} C rather than above freezing may help reduce molding and rates of respiration (Navratil 1976 and van den Driessche 1977).

Readiness for overwinter cold storage in terms of lifting date, dormancy status and cold hardiness are known to be major factors in determining the quality of nursery stock when it is shipped for spring planting (Stone and Schubert 1959, Stone et al.1962, Hocking and Nyland 1971, Hermann et al. 1972, Bunting 1975, Mullin and Parker 1976, Askren and Hermann 1979, Rietveld et al. 1982, Day and Harvey 1983 and 1984 and Burdett and Simpson 1984). The dormancy status of the shoots and the potential for root activity at the time nursery stock is removed from overwinter storage for spring planting has been recognized as a critical factor in outplanting performance (Stone and Jenkinson 1971, Webb 1976, Ritchie and Dunlap 1980, Day and Harvey 1983 and 1984, Burdett and Simpson 1984 and Day *et al.* 1984).

2.3 Phases of Dormancy and Overwinter Cold Stored Nursery Stock

Dormancy and cold hardiness are two closely related but different aspects of nursery stock physiology (Irving and Lamphear 1967 and Glerum 1976) that largely determine the physiological readiness of nursery stock to be placed into overwinter cold storage (Burdett and Simpson 1984). An understanding by nurserymen of some of the fundamentals of the dormancy processes and associated cold hardiness is helpful when attempting to successfully overwinter cold store nursery stock. A review of these topics by Samish (1954), Romberger (1963), Smith and Kefford (1964), Vegis (1964), Wareing (1969), Perry (1971), Weiser (1970), Glerum (1976) and Levitt (1980) may be useful for developing a basic understanding of these processes. However, with reference to these current concepts of dormancy, readiness for fall lifting and overwinter cold storage has not been accurately defined for forest tree nursery stock in Canada. The dormancy processes as described by Smith and Kefford (1964) and then modified by Nienstaedt (1966) gives the general progression of dormancy as it pertains to the bud dormancy phases of overwinter cold stored white spruce nursery stock in interior Canada. These two references have been used extensively to develop the sequence of dormancy processes outlined in Table 1.

Table 1. The dormancy phases of white spruce nursery stock for southern interior Canada.

	DATE	PHASE OF DORMANCY
	1) Mid-July until Early September	Dormancy development transitional state
	2) Early September until early November	Dormant steady state
	3) Early November until mid-December	Dormancy release transitional state
INCREASING COLD HARDINESS	4) Mid-December until April	Non-dormant steady state
	5) April until Early June	Spring burst transitional state
DECREASING COLD HARDINESS	6) Early June until mid-July	Spring steady state

A brief description of shoot bud dormancy that is outlined in Table 1 is presented as follows.

1) Dormancy development transitional state

Shortening photoperiods initiate the cessation of shoot extension and the onset of dormancy (Glerum 1982). Buds have been set and visually appear dormant. This is a period of needle leaf initiation and rapid meristematic activity in the bud apices (Nienstaedt 1967, Owens and Molder 1976). Flushing and free growth may occur under very favourable growing conditions. This is a period of low frost tolerance.

2) Dormant steady state

Shortening photoperiods and cool nights cause stock to become increasingly cold hardy (Weiser 1970). Nursery stock will not flush under favourable growing conditions. Stock will successfully withstand cold storage at -2° C by the end of this period. This is the most critical stage of dormancy with respect to fall lifting and overwinter cold storage.

3) Dormancy release transitional state

The bud chilling requirements are met after about 8 weeks at temperatures near 0°C. Bud flushing will occur under favourable growing conditions presumablely because promotor/inhibitor ratios of plant growth regulators (phytohormones) controlling shoot growth increase (Lavender and Hermann 1970, Wareing and Saunders 1971, Lenton et al. 1972, Bachelard and Wightman 1975, Campbell and Sugan 1975, van den Driessche 1975, Hanover 1980 and Lavender 1981). Nursery stock will reach its maximum cold hardiness by the end of this dormancy phase (Glerum 1982). Nursery stock is in good physiological condition to withstand overwinter cold storage.

4) Non-dormant steady state

Nursery stock will remain in an imposed state of dormancy for many months if temperatures remain near or below 0°C. Buds will flush readily if stock is in a good growth environment. It is unlikely that the resting buds of trees in this dormancy phase are inert (Perry 1971 and Campbell and Sugano 1975). Physiological processes may occur that result in a gradual decline in cold hardiness and resistance to cold storage environments (Holbo *et al.* 1981). This may be related to sugar depletion through respiration with a resultant dehardening of nursery stock (Ritchie 1983).

5) Spring burst transitional state

The exposure of nursery stock to increasing temperatures initiates the progression of nursery stock from the non-dormant steady state into this phase of dormancy (Owens *et al.* 1977 and Lavender 1981). As the time stock is exposed to temperatures well above 0^{o} C increases it becomes increasingly less cold tolerant and more susceptible to the environmental stresses of spring outplanting especially with the onset of bud flushing. Bud scale initiation begins during this dormancy phase (Owens and Molder 1976).

6) Spring steady state

This is a period of rapid shoot extension and height growth. Stock is very easily damaged by frost and transplanting. Nursery stock is in very tender physiological condition and may be damaged by any type of storage. This is a period of bud scale initiation and development (Owens and Molder 1976). The amount of shoot extension at this time is largely determined by the response of stock to the current environment and by the number of stem units that were initiated the previous summer in the winter buds (Cannell *et al* 1976).

2.4 Pulses of root growth

It is not known if the roots of northern conifers become truly dormant in the fall as do winter buds. According to Webb (1976) northern hardwoods do not exhibit a period of innate dormancy. Root systems do go through periods of very high and very low RRP (Lyr and Hoffmann 1967). Many current investigations support the hypothesis that the initiation and the growth of tree roots is largely controlled by endogenous substances in the shoot and the dormancy status of the buds (Richardson 1958, Farmer 1975, Webb 1976, Webb and Dumbroff 1978 and Ritchie and Dunlap 1980). The pulses of root growth that have been observed in nusery stock are also influenced by soil moisture, soil temperature and a great many other environmental and physiological factors (Larson 1970, Day and MacGillivray 1975 and Ritchie and Dunlap 1980). According to Ritchie (1982) there is a growing body of evidence that indicates the supply of currently produced photosynthate moved from the shoot to the root is an important factor controlling RRP.

Observations and measurements of root growth periodicity may in some instances be confused. This is because two distinctly different physiological processes;

1) root initiation and 2) root elongation, are not recognized for their differences (Thompson and Timmis 1978 and Ritchie and Dunlap 1980).

2.5 Readiness for overwinter cold storage

The cold hardiness and dormancy condition of nursery stock when fall lifted are factors that are critical in determining when stock may be safely placed into an overwinter cold storage environment (Stone and Schubert 1959, Hocking and Nyland 1971, Stone and Jenkinson 1971, Mullin and Parker 1976 and Burdett and Simpson 1984). Nursery cultural practices such as root wrenching and the withdrawal of nitrogen fertilizer and irrigation water applications are commonly used to condition bare root stock storage (van den Driessche 1969, Blake _et al._ 1979 and van den Driessche 1983). The following is a list of some of the techniques nurserymen may find useful in assisting them to decide when stock is ready for fall lifting and overwinter cold storage: 1) lifting windows, 2) negative degree hardening days, 3) DC and AC impedance techniques, 4) the oscilloscope technique, 5) differential thermal analysis (DTA), and 6) the mitotic index in shoot apical meristems.

The definition of periods of days in the fall or "lifting windows" thought to be suitable for lifting stock for overwinter cold storage has not always proven reliable largely because of climatic variation (Holbo et al. 1979 and Burdett and Simpson 1984). Variability in the time nursery stock is ready for lifting is also related to cultural practices and provenance (Sutton 1982b).

Negative Degree Hardening Days (DHD) have been used as a criterion for determining readiness for lifting and overwinter cold storage. Negative DHD are determined by the cumulative daily difference below 10 ^{o}C for soil temperatures at the 15 cm depth. Mullin and Laupert (1981) have used DHD to determine the readiness of eastern white pine nursery stock for fall lifting. Bunting and McLeod (1984) suggest that for best outplanting results red pine in Southern Ontario should receive 475 DHD before lifting in the fall. This system accounts for the accumulation of the effects produced by cold weather that stimulates the physiological processes such as cold hardening and dormancy progression in the fall. Changes in these physiological processes are, in some largely unknown way, related to readiness for overwinter cold storage. Sutton (1982b) feels that the DHD readiness for cold storage relationship is subject to variation between provenances, site region, nurseries and year to year weather patterns. Navratil (1982) suggested calibrating this technique for seedlot and nursery to improve its potential as a measure of readiness for overwinter cold storage.

Readiness for cold storage is related to the electrical properties of plant tissues. Currently the following three techniques are being developed for use in nursery operations. 1) The oscilloscope technique (Askren and Hermann 1979), 2) the frequency ratio method or M E D C dormancy meter (Rietveld et al. 1982), and 3) the A C electrical impedance ratio method (van den Dreissche and Chung 1979 and Glerum 1980). These electrical techniques are still inadequate for general operational use at many tree nurseries (Askren and Hermann 1979, Holbo et al. 1981, Navratil 1982, Rietveld et al. 1982 and Burdett and Simpson 1984). Day et al. (1984) are recommending the A C electrical impedance technique for operational use in southern Ontario nurseries and the oscilloscope technique for northern Ontario nurseries. According to Day et al. (1984) these electrical techniques appear to adequately determine readiness for cold storage in regions with a northerly continental climate and a rapid drop in temperature in the fall of the year. This may explain why these electrical techniques have not been recommended for operational use at nurseries near the Pacific Coast and areas south of the Great Lakes.

Differential thermal analysis DTA is a technique that measures the differential exothermic processes that occur when extracellular and intracellular water freezes (Sakia 1978). This technique may be usefull for determining the fitness of stock for overwinter cold storage but it is still in the experimental phases of development (Wallner *et al.* 1982).

Carlson *et al.* (1980) showed that the dormancy status of Douglas-fir container grown seedlings in the fall was related to the number of cell divisions or mitotic index of the terminal buds. The mitotic index may have potential as an indicator of readiness for fall lifting and overwinter cold storage.

2.6 The Effect of Overwinter Cold Storage Environment on Bud Dormancy Status

Temperature and possibly photoperiod are factors that influence the dormancy status of nursery stock while stock is in overwinter cold storage.

Bareroot nursery stock is normally kept in complete darkness during cold storage. Lavender (1978) studied the effect of illuminating overwinter cold stored Douglas-fir at 1000 lux for 16 hours. The illuminated stock broke bud more quickly after outplanting. A study by Hermann (1972) with the same species confirms this effect of photoperiod on the spring rate of bud flushing with overwinter cold stored nursery stock. Illuminating nursery stock for, a period of time using a long day photoperiod may improve the readiness of stock to grow after outplanting. Because bareroot nursery stock is stored in cardboard cartons that do not transmit light a photoperiod treatment is not practical using conventional storage techniques.

Nursery stock is stored overwinter at temperatures from +5 ^{o}C to -2 ^{o}C. In Ontario white ash was successfully overwinter stored at +5 ^{o}C (Webb 1976). In Ontario white spruce is best stored at -2 ^{o}C (Mullin and Parker 1976) while interior Douglas-fir in British Columbia may be stored at +2 ^{o}C or -2 ^{o}C (van den Driessche 1976). These temperatures closely correspond with temperatures that satisfy the bud dormancy chilling requirements of individual northern tree species. The bud chilling requirements of white ash, Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and *Taxus* spp. were satisfied at temperatures of +5 °C (Webb 1976), +2 (van den Driessche 1976) to +4 °C (Campbell and Sugano 1975), +5 °C (Nelson and Lavender 1975) and -2 to +4 °C (Lathrop and Meckleburg 1971) respectively. The steady non-fluctuating temperatures supplied to nursery stock while in overwinter cold storage will adequately satisfy bud chilling requirements before spring shipping. Overwinter cold storage also retards spring bud flushing and is used to successfully extend the outplanting period (Brown 1971 and Hocking and Nyland 1971). White spruce is subject to shoot damage from late spring radiation frosts (Nienstaedt and King 1970). A cold storage induced delay in spring flushing may reduce frost damage after outplanting.

2.7 The Effect Of Overwinter Cold Storage Environment On Root Regeneration Potential

Lifting date, storage duration and storage temperature have all been related to the RRP of overwinter cold stored nursery stock (Ritchie and Dunlap 1980).

Studies with Douglas-fir in British Columbia showed that November lifted stock had a much higher RRP while in storage than stock lifted early in the fall (Burdett and Simpson 1984). Stone and Jenkinson (1971) found that Ponderosa pine (Pinus ponderosa Laws.) in California maintained the best levels of RRP during overwinter storage when lifted late in the fall after receiving 300 to 1200 hours of air temperatures below 10 °C. They also found that when stock was lifted during a period of high RRP it maintained higher RRP during the storage period than stock that was lifted during a period of low RRP. In Canada however, there are no studies that clearly relate RRP levels at time of lifting to the RRP maintained during the winter in storage (Burdett and Simpson 1984).

Changes in the physiological condition of nursery stock while in overwinter cold storage may result in an increase, decrease or no change in RRP. Ritchie (1983) showed that as respiration caused carbohydrates to become depleted during a six month cold storage period at -1 °C, the RRP of Douglas-fir increased. He also found that there was no significant difference between the RRP of nursery stock stored at +1 °C or -1 °C. In the same study, both the RRP and the non-structural carbohydrate concentration in leaves, stems and roots declined rapidly after a 6 month cold storage period. Ritchie (1983) did not find a good relationship between carbohydrate concentration and the RRP of overwinter cold stored nursery stock. Webb (1976) found that the RRP for white ash that was overwinter stored at +5 °C increased from November until April and was maintained at a plateau during the spring planting season.

A number of studies have attempted to relate the bud dormancy status of nursery stock in cold storage to RRP Webb (1976 and 1977) showed that the RRP of some northern deciduous species is negatively correlated to the degree of bud dormancy. Further evidence for this was demonstrated by Richardson (1958) and Farmer (1975). Possibly, as the chilling requirements of overwinter cold stored deciduous nursery stock are met, RRP increases. There is evidence of a similar bud dormancy and RRP relationship with coniferous nursery stock (Ritchie and Dunlap 1980).

METHODS

1 CONDITIONING IN THE NURSERY BED : ROOT PRUNING AND WRENCHING TREATMENTS

1.1 Description Of The Conditioning Treatments

The conditioning treatments were tested twice during two years on different fields of rising 2+2 white spruce nursery stock at the Ontario Ministry of Natural Resources Forest Station, Thunder Bay Ontario. Two nursery beds in 1982 and one nursery bed in 1983 were given a single early spring root pruning followed by multiple summer wrenching. In this thesis the summation of these treatments is often referred to as only wrenching rather than root pruning and wrenching. Two adjacent nursery beds in 1982 and 1 adjacent nursery bed in 1983 were used as untreated controls.

The trees were horizontally root pruned once during the first week of May, just after the frost left the ground. The root pruning equipment consisted of a belly mounted, horizontal, sharpened, non-reciprocating rigid steel blade. The blade was passed beneath the trees cutting the roots 8 to 10 cm below the soil surface. Both the root pruned and the adjacent control nursery beds were then irrigated.

Wrenching began 21 days after root pruning and was repeated at triweekly intervals until the middle of August for a total of 5 wrenchings. The method of wrenching was similar but not identical to that described by van Dorsser and Rook (1972). Wrenching was applied using a tractor mounted non-reciprocating hardened steel blade tilted 20° forward. The wrenching blade was passed 12 cm below the soil surface.

With the exception of the root pruning and wrenching treatments, the nursery beds selected for these trials were treated identically to each other and received the standard cultural treatments practiced at this nursery.

1.2 Monitoring The Effects Of Conditioning On Nursery Stock Morphology In Permanent Sample Plots

Ten randomly selected 1.0 by 1.23 m permanent sample plots were established. Each contained 25 randomly selected individually labelled trees. Five plots were located in the treated nursery beds and five were in the control nursery beds. A position near the Root Collar Diameter (RCD) of each individually labelled tree was marked with white latex paint to ensure accurate remeasurement through-out the summer. The height increment of the leader shoot and the RCD of each tree were measured at four intervals, once before growth began in the spring, twice during the summer and once in the early fall. These data were used to establish differences in seasonal growth patterns between the treated and the control nursery stock.

The experimental design was a nested or hierarchal classification (Sokal and Rohlf 1981 and Steel and Torrie 1960). There were 25 subsamples (trees) x 5 experimental units (plots) x 2 treatments (wrenched and unwrenched). Data were analysed by Analysis of Variance (ANOVA).

1.3 Year End Destructive Sampling

Destructive measurements were taken on both the treated and the control beds at the end of the 1982 and 1983 growing seasons. Ten randomly selected 1.0 by 1.23 m plots or replications were placed in one treated nursery bed and another ten in an adjacent control nursery bed. The experimental design was a randomized complete block design (Steele and Torrie 1960). There were 2 treatments (wrenched and unwrenched) x 10 replications. Data were analysed by ANOVA.

At the time of fall lifting in late October ten whole tree samples were selected at random within each sampling plot. These trees were carefully excavated so as to minimize damage to the roots. The lifted trees were then taken to the nursery packing barn where the roots were trimmed to 23 cm, according to standard nursery practice. The morphological condition of the nursery stock was assessed by measuring the Root Area Index (RAI) with a rhizometer (Morrison and Armson 1968). The total, top and root Oven Dry Weights (ODW) were determined. Two methods of evaluating seedling quality , the Seedling Index (SI) (Armson and Sadrieka 1979) and the Mean and Standard Deviation (MSD) Method (Day 1980) were applied to the trees.

1.4 Needle Leaf And Stem Unit Primordia In Winter Buds

The effects of wrenching on the production of needle leaf and stem unit primordia in the terminal buds of rising 2+2 white spruce was assessed using only the 1982 treated and untreated stock. In the fall of 1982 after needle leaf primordia initiation was assumed to be complete 85 random destructive samples were taken from both the wrenched and the control beds. Each sample consisted of the distal 4 cm of the leader shoot and contained a terminal bud. All samples were immediately fixed in a solution of formalin acetic acid and alcohol (FAA) and stored in plastic bottles. The terminal buds were then dissected and studied using a dissecting microscope and the wet mount technique. The arrangement of the primordia exposed on the primordial shoot formed a well defined phyllotaxis of 13:21. To estimate the number of primordia in total on the terminal bud apex the number of primordia in 2 of the 13 type parastichies in each bud were counted and averaged. This average n was used to calculate the mean total number of primordia. The results were analysed using a t test to compare sample means.

2 OVERWINTER COLD STORAGE

2.1 Fall Lifting And Desciption Of The Storage Facilities

The nursery stock from only the 1982 root culturing trial was fall lifted for overwinter cold storage trials.

The dormancy status of the nursery stock was monitored beginning in mid September using the oscilloscope technique as described by Askren (1978) and Rietveld *et al.* (1982). This was used to assess the readiness of stock for fall lifting and overwinter cold storage. Past experience using the oscilloscope technique at this nursery was also used to interpret oscilloscope wave traces and their significance to readiness for overwinter cold storage. On October 24, 1982 the nursery stock was considered in good physiological condition for lifting and overwinter cold storage. Samples of several thousand trees in the treated and the control beds were fall lifted using an Egedal shaker tree lifter powered by a farm tractor. Trees were moved to the nursery packing and grading barn where the roots were trimmed to 23 cm. Only those trees that were to be outplanted in the spring of 1983 after a winter cold storage treatment were visually culled. Those trees that were used for monitoring the stock during the storage period were not culled. Culling would have necessitated lifting twice as many trees and this would not have been possible for trees that were overwinter stored outside in the nursery bed and lifted during the winter. The culled and unculled trees were then prepared for placement into two of the three overwinter cold storage treatments.

Samples of the root cultured and control stock were overwinter cold stored in three environmental regimes as follows.

1) Field — left to overwinter in the nursery bed.

2) MNR Cooler — fall lifted and overwinter cold stored in the nursery cold storage unit.

3) Polyhouse — fall lifted and overwinter stored in an unheated polyhouse.

Nursery bed lifting boxes were constructed to ease whole tree sampling of nursery stock overwintering in the Field. The boxes were designed so that each would hold at least 30 trees. The sides were constructed of 20 mm pine boards and the bottom was made of heavy gauge galvanized steel. Twelve of these boxes were constructed and 6 were placed in each of the root cultured and control nursery beds. The boxes were placed underneath a section of nursery bed so that there was a minimum of root disturbance. This was accomplished by digging a trench adjacent to the nursery beds equal to the width and depth of the boxes and then sliding the boxes into place through the sandy nursery soil with the use of a sledge hammer. Crowbars were then angled underneath each nursery box to help facilitate lifting from the frozen ground later in the winter. Climatic data related to this storage environment were obtained from the Thunder Bay Weather Station, 5 km east of the nursery.

Nursery stock for overwintering in the MNR Cooler was packed in polyethylene bags and waxed kraft cartons and closed. This is the standard method of packing trees for overwinter cold storage at this nursery. These trees were then overwintered at $-2\,^{o}C$ and given a spring warm up conditioning treatment at $+2\,^{o}C$ for six weeks before spring planting.

Nursery stock to be placed in the Polyhouse was packed as above except that moist sphagnum moss was placed around the roots, the stock was packed vertically not horizontally in the cartons, and both the polyethylene bags and cartons were left open. This was done to allow the shoots to be exposed to the natural photoperiod. These cartons of trees were then placed on the earth floor of the Polyhouse. A single layer of opaque polyethylene was loosely placed over the trees to help reduce both moisture loss and exposure to bright sun. The Polyhouse was 10 m long and 2 m in height at the center. It was constructed of aluminium hoops and covered with a layer of clear and a layer of opaque 4 mil polyethylene. No attempt was made to separate the two layers of plastic. A two probe remote thermograph was placed just outside the Polyhouse. The probes were run inside the Polyhouse through a small incision in the double plastic covering. One probe was placed in the center of the root mass of a carton of nursery stock and the other was placed within the mass of exposed shoots. Weekly chart recordings provided the temperatures that roots and shoots were exposed to during the storage period. One end of the Polyhouse was sealed and the other end closed so that it could be entered periodically for inspection and to obtain whole tree samples during the winter.

2.2 The Physiological Condition Of Conditioned Nursery Stock In Overwinter Cold Storage

The physiological condition of wrenched and unwrenched nursery stock in each of the three overwinter storage regimes was monitored monthly from November 1982 until April 1983. RRP and bud flushing tests were used as monitoring techniques. Both tests were conducted in a walk-in controlled environment chamber with a computerized control unit. This chamber was maintained at a 24 ^{o}C, 20 hour day and a 18 ^{o}C, 4 hour night. The illuminance during the day ranged from 2,500 lux at dawn and dusk to 54,000 lux at mid-day. Light was supplied by a mixture of incandescent and cool white fluorescent lamps. The relative humidity ranged from 60 per cent at 15.00 hr.to 80 per cent at 24.00 hr.

The experiment for the bud flushing tests was designed as a 2 x 3 x 6 factorial superimposed on a randomized complete block design. There were 2 nursery bed conditioning treatments (wrenched and unwrenched) X 3 overwinter cold storage regimes (MNR Cooler, Polyhouse and Field) X 6 test dates (November, December, January, February, March and April) X 4 replications. The experimental design for the RRP tests was a 2 X 3 X 7 factorial superimposed on a randomized block design with subsamples. The treatments for the RRP tests were the same as those for the bud flushing tests except there was an additional test date, May. This additional RRP test was borrowed from another experiment that was designed to evaluate the physiological condition of nursery stock at the time of spring outplanting (see Section 3, The Outplanting Trial). There were 4 replications in the RRP tests.

To assess the RRP 20 transplants of wrenched and unwrenched trees were taken from each of the overwinter storage regimes at monthly intervals. The trees from the Field were initialy held for 24 hours at +10 ^{o}C to allow the soil to thaw from around the roots. The roots of the Field trees were then trimmed to 23 cm. Trees from all three storage regimes were then placed into a Root Mist Chamber (RMC) for a 30 day RRP test.

The trees were held in the RMC by racks that kept the roots suspended in the moist air in the dark interior of the RMC and left the shoots exposed to the interior of the controlled environment chamber. The trees were grown aeroponically by delivering a 30 second mist of fine water droplets tempered to 22 ^{o}C to the roots every 30 minutes. The air temperature in the interior of the RMC ranged from

17 to 20 ^{o}C. After a 30 day RRP test period, the trees were removed from the RMC and the total Root Elongation (RE) and total Root Number (RN) of new white root tips was evaluated.

The RE for each tree was evaluated by estimating and accumulating the elongation of new white root tips. To aid in the estimation of the elongation of new white root tips four root lenght classes were established as follows.

Class	Root Elongation (cm)
1	≤ 0.50
2	0.51 to 1.0
3	1.10 to 5.0
4	> 5.00

Class 1 was arbitrarily assigned an average value of 0.25 cm. The means for Classes 2, 3 and 4 were estimated by measuring 100 roots in each of these Classes. The values assigned to each Class are given as follows:

Class	Assigned RE Values (cm)
1	0.25
2	0.75
3	2.80
4	6.50

These values were used when determining total RE.

The RN for each tree was evaluated by counting the number of new white root tips in RE Classes 2, 3 and 4. New white root tips in RE Class 1 were counted if there were less than 85 and were arbitrarily assigned a value of 85 if there were more than 85.

Once the RN for RE Classes 1 to 4 was determined the following relationship was used to estimate the total RE for the root system of a tree.

$$\sum_{\text{Class 1 to 4}} (\text{RN} \times \text{assigned RE value (cm)}) = \text{total RE}$$

The total RN for the root system of a tree was estimated as follows.

$$\sum_{\text{Class 1 to 4}} \text{RN} = \text{total RN}$$

The experimental design allowed for analyses by ANOVA but because Rankit plots (Sokal and Rohlf 1981) showed the data to be non normally distributed the results were more effectively analysed by subjective means and graphical representation.

The mean RN of Class 1 was used to represent very short roots and the mean RNs of Classes 2 through 4 were used to represent longer white roots. This was done to isolate periods of short root development and long root development during the seven month RRP test period. The percentage of roots in each of these 2 classes as a percentage of total RN was calculated and transformed using the $(\arcsin)^{1/2}$ method. As the transformed data were normally distributed, it was analysed using ANOVA and Student Newman Keuls' Tests (SNK) (Steel and Torrie 1960).

Bud flushing tests were conducted to assess bud dormancy status at monthly intervals from November 1982 until April 1983. Stem portions from 20 trees were taken from wrenched and unwrenched stock in the three overwinter cold storage regimes. Each stem sample consisted of the leader shoot and contained the terminal bud, the top whorl of lateral branches and 10 cm of stem below the top whorl. All lateral and terminal buds on the whorl of branches and stem portion above this were counted and recorded for each stem sample on day 0 of the bud flushing test. The stem portions were placed in 500 ml beakers filled with water and then placed beside the RRP test trees in the controlled environment chamber. The percentage of flushed lateral and terminal buds was evaluated every seven days for four weeks. The 28 day bud flushing test values were transformed using the $(\text{arcsin})^{1/2}$ method (Steel and Torrie 1960). Buds were considered flushed when the bud scales were broken apart by the emerging shoot.

The 28 day bud flushing tests were analysed by ANOVA using the Lakehead University VAX Computer and Fortran programs and a Texas Instrument programmable calculator. When ANOVA showed that there were significant differences between treatment means, (SNK) (Steel and Torrie 1960) were applied. The remaining bud flushing test results from day 0, 7, 14 and 21 are presented graphically.

The RRP and bud flushing data from the tests described above were graphically compared in order to establish possible RRP and bud dormancy relationships.

3 THE OUTPLANTING TRIAL

An outplanting trial was set out in the spring of 1983 to assess the effects of nursery bed conditioning (root culturing) and overwinter cold storage environment on performance after outplanting.

A 30 day RRP test was used to assess the physiological quality of the nursery stock at the time it was outplanted. The methods used were the same as those outlined previously for monitoring the physiological condition of stock during overwinter cold storage. However, as the RRP data from this test fitted a normal distribution, it was analysed by ANOVA using the Lakehead University VAX computer and Fortran programs especially designed for RRP analyses in Ontario (Day *et al.* 1984).

The planting site was located on the Abitibi Price Block 3 forest tract near Raith Ontario. This is in the B11 - Upper English River Section of the boreal forest according to Rowe (1972). The site is covered by a deep water worked glacial till. It is gently rolling and well drained. The top 1 m of the soil profile was characterized by a sandy loam texture and many unsorted stones up to 15 cm in diameter.

The planting site had been clear cut of white spruce, black spruce and jack pine several years prior to planting. The planting site was occupied by a few residual birch and pine and a dense mat of perennial grasses at the time of planting. The area was site prepared the fall prior to planting by a TTS Disc Trencher. The Trencher is a row scarifier which operates on the same principal as the agricultural disc harrow. It cuts into the soil, turning up two equidistant furrows (Myles 1978, Smith 1979, Murray 1980).

A complete set of climatic records for the summer after outplanting was available from a temporary weather station on the site.

The nursery stock was planted during the last week of May using the L slit hand planting method. A total of 960 trees were planted at a 2 m spacing. The experimental design was a 2 x 3 factorial superimposed on a randomized complete block design. There were 2 conditioning treatments (wrenched and unwrenched) X 3 overwinter cold storage environments (MNR Cooler, Polyhouse and Field) X 4 replications.

Plant Moisture Stress (PMS) measurements using the pressure chamber (Cleary 1967) were taken in the early afternoon on 10 trees from each replication (40 trees per treatment) 21 days after outplanting. These values were used to test if the stock was in PMS Moderate, PMS High, PMS Excessive or PMS Lethal Classes according to Day and Walsh (1980). These values were also used to test the hypothesis that wrenching reduces internal - water potentials after outplanting.

The following non destructive measurements were taken in the fall: survival, the number of frost damaged terminal shoots on the leaders, the seasons height increment and RCD.

Destructive measurements were made in the fall using a sample of trees from the outplanting trial. 10 trees per treatment from each of the 4 replications were carefully removed from the ground. These samples were used to evaluate the total, top and root ODW.

All data from the morphological evaluation of the outplanting trial were analysed by ANOVA. When ANOVA indicated that there were significant differences between treatment means, SNK tests were applied.

RESULTS

1 THE MORPHOLOGICAL CONDITION OF CONDITIONED NURSERY STOCK

1.1 The Permanent Sample Plots

Figures 2 and 3 show the current season's height increment and RCD growth curves of the wrenched and unwrenched rising 2+2 white spruce in the permanent sample plots.

The wrenching treatment significantly reduced the height increment (Table 2) of the treated nursery stock by late July after one root pruning and four root wrenchings. The height increment of both the control and treated seedlings was completed by late July. Sylleptic growth was observed in trees in the control nursery beds in August but was not observed in the treated nurserybeds.

Stem diameter growth, unlike height growth, continued

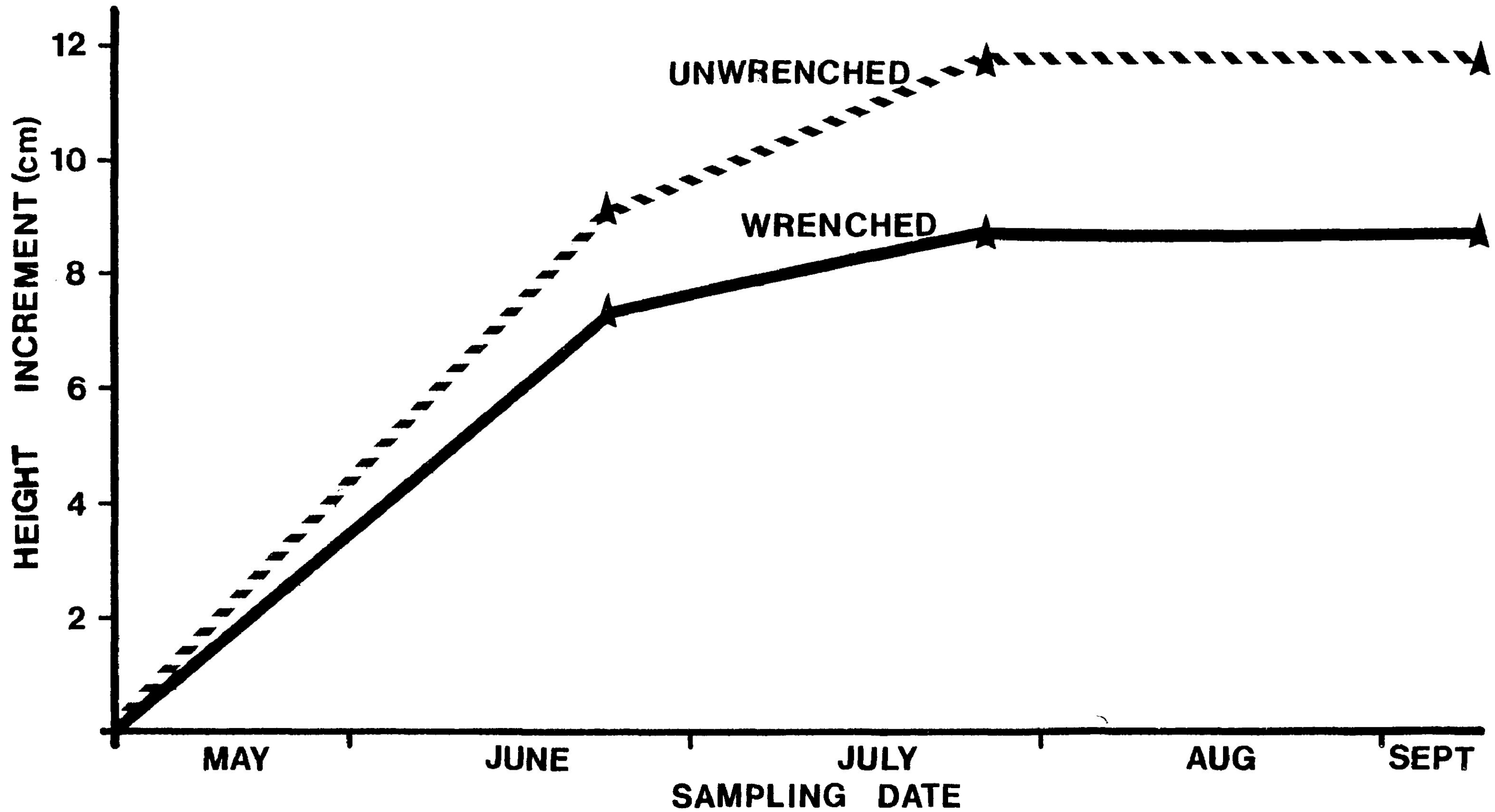

Figure 2. Height increment of wrenched and unwrenched stock in permanent nursery bed sampling plots in 1982

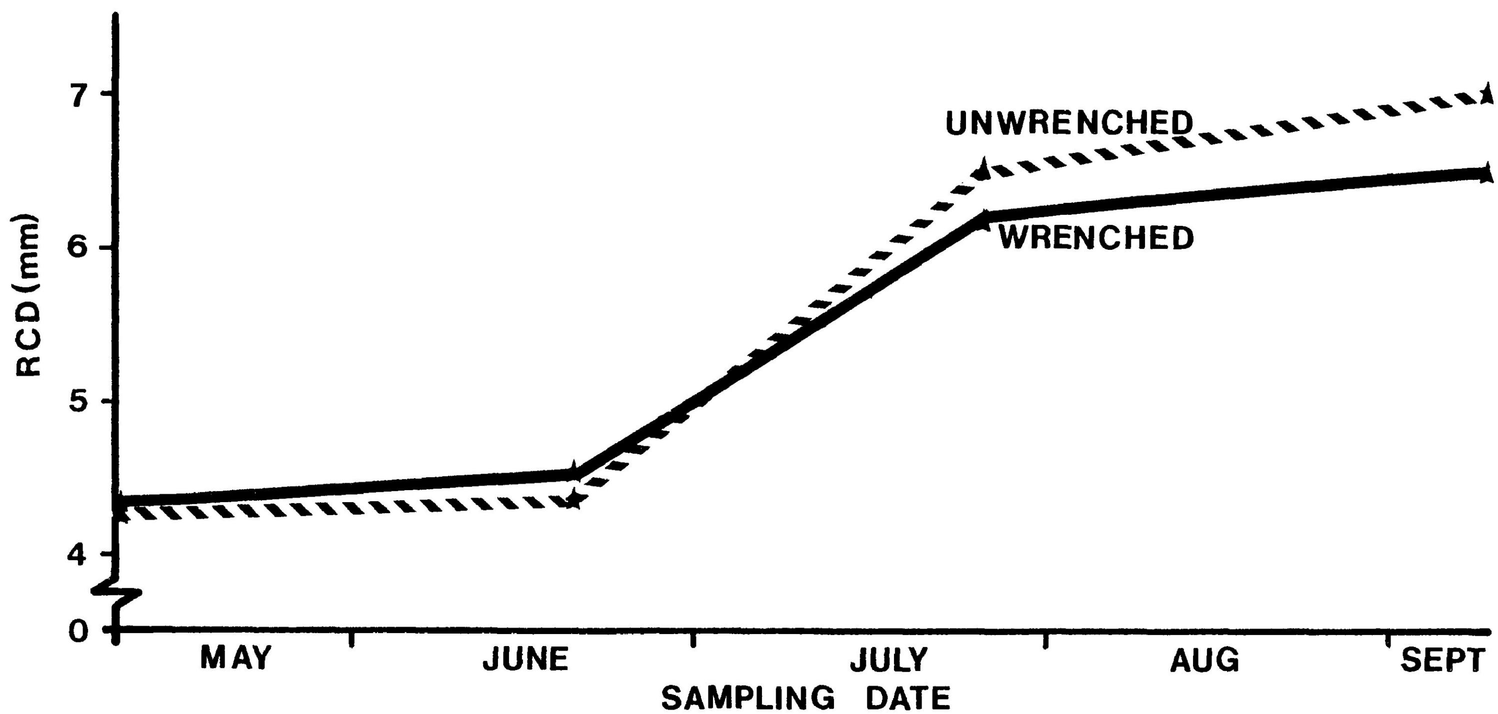

Figure 3. Root collar diameter growth of wrenched and unwrenched stock in nursery bed permanent sample plots in 1982.

Table 2. The height increment and RCD of wrenched and unwrenched rising 2+2 white spruce while growing in permanent sample plots in the nursery bed.

SEEDLING ATTRIBUTE	UNWRENCHED	WRENCHED	SIGNIFICANCE[1]
Early Spring			
Ht. Increment (cm)	0.00	0.00	NS
RCD (mm)	4.15	4.20	NS
June 23			
Ht. Increment (cm)	9.09	7.32	NS
RCD (mm)	4.53	4.68	NS
July 26			
Ht. Increment (cm)	11.64	8.74	*
RCD (mm)	5.98	5.64	NS
September 8			
Ht. Increment (cm)	11.64	8.74	*
RCD (mm)	6.99	6.48	NS

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1. * Significantly different at p=0.05.

into the late summer. In mid June there was no difference between the RCD of the wrenched and unwrenched stock but by mid September the wrenched stock had a reduction in RCD of 8 per cent; however this difference was not significant.

1.2 Year End Destructive Sampling

The morphological evaluation of the wrenching trials at the end of the 1982 and 1983 growing seasons are given in Table 3. The wrenching treatments in 1982 and 1983 significantly reduced total height of the stock by 22 and 14 per cent respectively (Figure 4). Wrenching significantly reduced RCD by 13 per cent in 1982 and by 10 per cent in 1983 (Figure 4). RAI was unchanged by wrenching in 1982 (Figure 4) but was significantly increased by 35 per cent in 1983.

Figure 5 shows the ODW of wrenched and unwrenched stock in 1982 and 1983. The total ODW of the wrenched stock was significantly reduced by 20 per cent from that of the unwrenched stock in 1982, but it was only slightly reduced in 1983. The significant reduction in total ODW of the wrenched stock in 1982 was due to significant

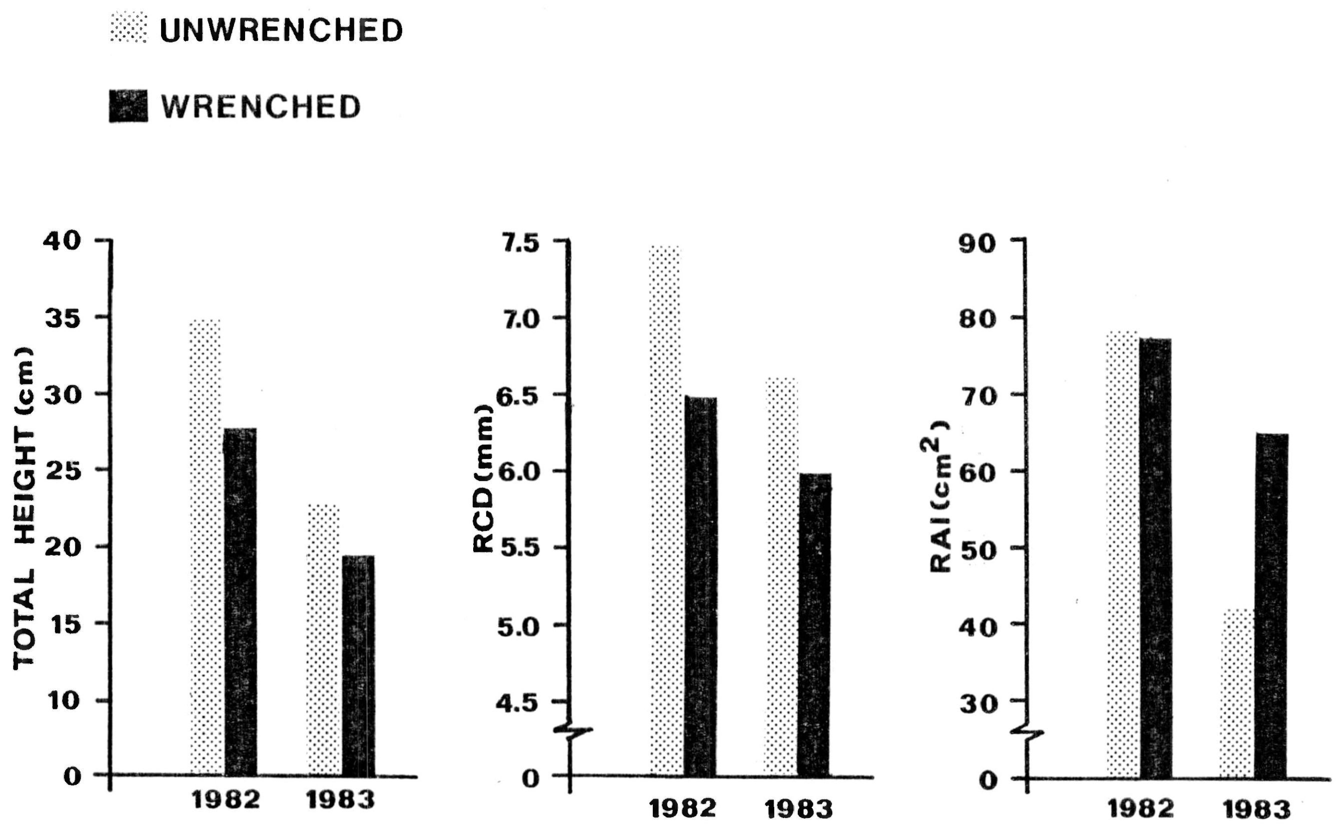

Figure 4. Total height, root collar diameter and root area index of wrenched and unwrenched stock from destructive nursery bed sampling plots, fall 1982 and 1983.

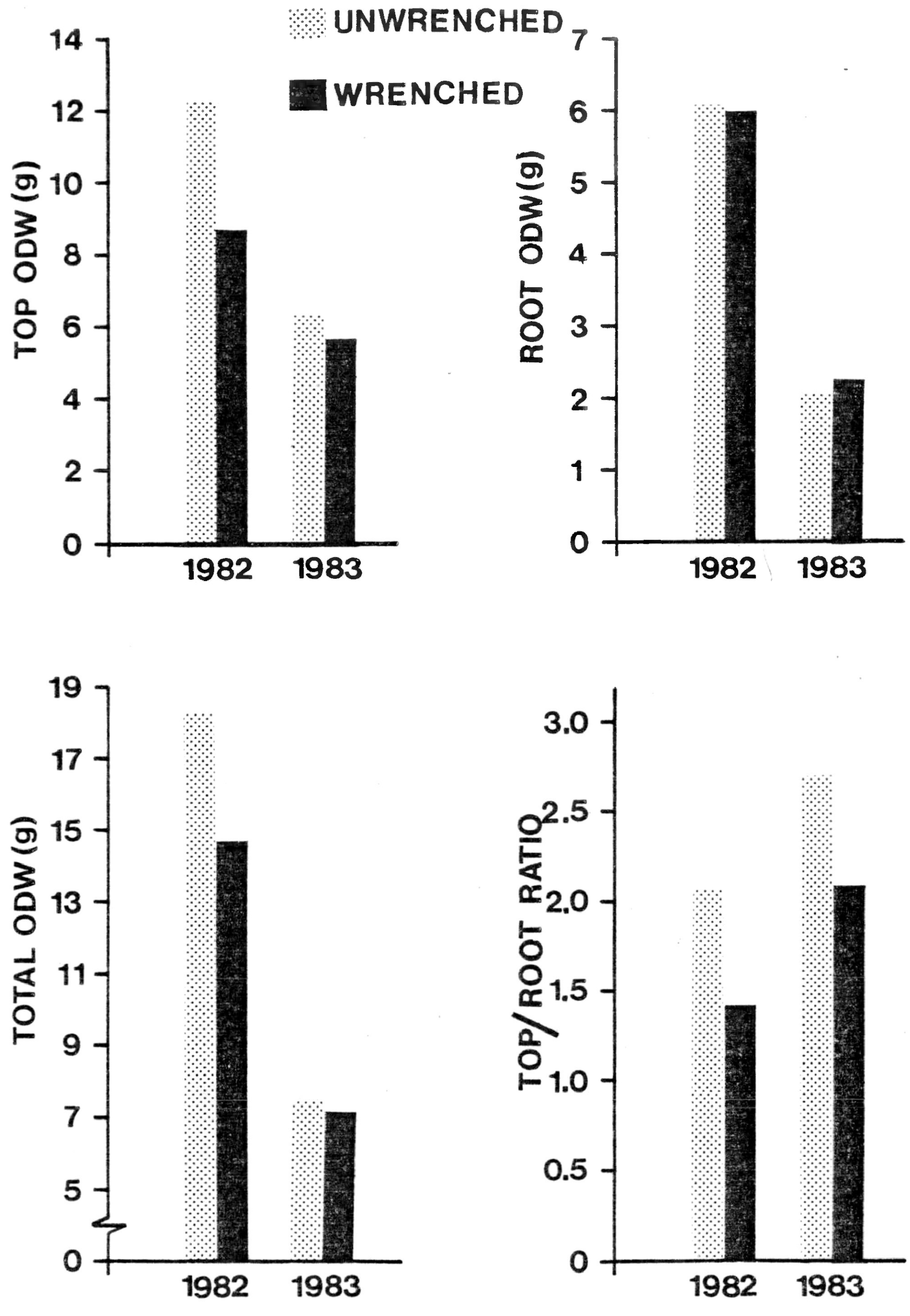

Figure 5. Total, top and root oven dry weight and top/root ratio of wrenched and unwrenched stock from destructive nursery bed sampling plots, fall 1982 and 1983.

reductions in the top ODW that year. Wrenching had very little effect on root ODW in 1982 or 1983. The top ODW of wrenched stock was 12 per cent less than that of unwrenched stock in 1983, but this was not signicant.

The morphological balance of the stock was altered by wrenching as shown by the significant reduction in the top/root ratio of the wrenched stock from that of the unwrenched stock for both the 1982 and 1983 trials (Table 3 and Figure 5). This was a result of lower top ODW while root ODW was not affected by wrenching.

The SI was significantly reduced by wrenching both seasons (Table 4). The lower SI value of the wrenched stock can be traced to reductions in the height/RAI ratio and reductions in RCD.

The MSD quality index also indicated that wrenching induced morphological changes (Table 4). The MSD index showed that both the wrenched and unwrenched stock was larger than average stock grown at northern Ontario nurseries in 1982 and that the wrenched and unwrenched stock was near average size in 1983. The MSD quality index showed that the wrenched stock was of better morphological quality than the unwrenched stock both years. Wrenching caused an increase in stock quality from medium to high

Table 3. The morphological attributes of wrenched and unwrenched 2+2 white spruce from the 1982 and 1983 trials at the time of fall lifting.

SEEDLING ATTRIBUTE	UNWRENCHED	WRENCHED	SIGNIFICANCE[1]
October 20, 1982			
Total height (cm)	35.00	28.09	**
RCD (mm)	7.45	6.51	**
RAI (cm^2)	78.70	77.57	NS
Total ODW (g)	18.36	14.63	**
Top ODW (g)	12.32	8.66	**
Root ODW (g)	6.04	5.97	NS
Top/Root	2.04	1.45	**
October 24, 1983			
Total height (cm)	22.64	19.51	**
RCD (mm)	6.69	6.0	*
RAI (cm^2)	42.27	65.15	**
Total ODW (g)	7.44	7.03	NS
Top ODW (g)	5.36	4.74	NS
Root ODW (g)	2.08	2.29	NS
Top/Root	2.67	2.08	**
Height Inc.[2] (cm)	11.07	7.58	**

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1. NS Not Significantly different; * Significantly different at p=0.05; ** Significantly different at p=0.01.

2. Height Increment data for the 1982 trial is given in Table 2

Table 4. Morphological stock quality indices of wrenched and unwrenched 2+2 white spruce nursery stock at the time of fall lifting.

		UNWRENCHED		WRENCHED	
		1982	1983	1982	1983
Seedling Index (SI) (Armson and Sadrieka 1979)		2.3456	2.5996	3.3908	5.2355
Mean and Standard Deviation Method (MSD) 9 Digit Code	Ht[1]	hAl	hCn	mBn	hDl
	RCD	hAn	hBl	hBl	lBl
	RAI	hAl	mCl	hAl	hBn
Stock Type		CAA (5)	CBC (1)	BBA (8)	DBB (6)
Morphological Grade		Medium	Medium	High	High

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1. Ht = Height; RCD = Root Collar Diameter; RAI = Root Area Index

morphological grades in both 1982 and 1983.

1.3 Needle Leaf And Stem Unit Primordia In The Winter Buds

The wrenched seedlings had 16.5 per cent fewer needle leaf primordia on the terminal bud apices of the leader shoots than the unwrenched stock in 1982. The results of a t test showed that this was significantly different. The same wrenching treatment that caused this reduction in bud primordia reduced the shoot extension of outplanted stock the next year by 21 per cent.

2 THE PHYSIOLOGICAL CONDITION OF CONDITIONED NURSERY STOCK IN OVER WINTER COLD STORAGE

2.1 RRP

The RRP data during the winter months generally exhibited a bimodal distribution and was leptokurtic. The results from Rankit plots showed that many of the data from the RRP tests during the winter were not normally distributed. The analyses by ANOVA was completed but because many of the data were not normally distributed it was decided to use a subjective rather than a parametric approach to the analysis. This lack of normality is characteristic of RRP data for white spruce (Day and Harvey 1983).

Wrenching did have an effect on the level of RE and RN (Figures 6 and 7) on specific dates, but the patterns of RE and RN for both wrenched and unwrenched stock were generally similar during the seven month RRP evaluation. Wrenching appeared to increase the level of both RN and RE especially in January and May.

Figures 6 and 7 show the overall patterns of RE and RN during the seven month RRP test period. The patterns of RE and RN for the wrenched and unwrenched stock were generally similar. RRP peaked in January and was low in March. RE remained low from March through May while RN exhibited a second peak in April and May.

Figures 8 and 9 show the effects of storage on the pooled wrenched and unwrenched data for RE and RN. Stock from the Polyhouse and the MNR Cooler showed similar patterns of RRP throughout the seven month test period.

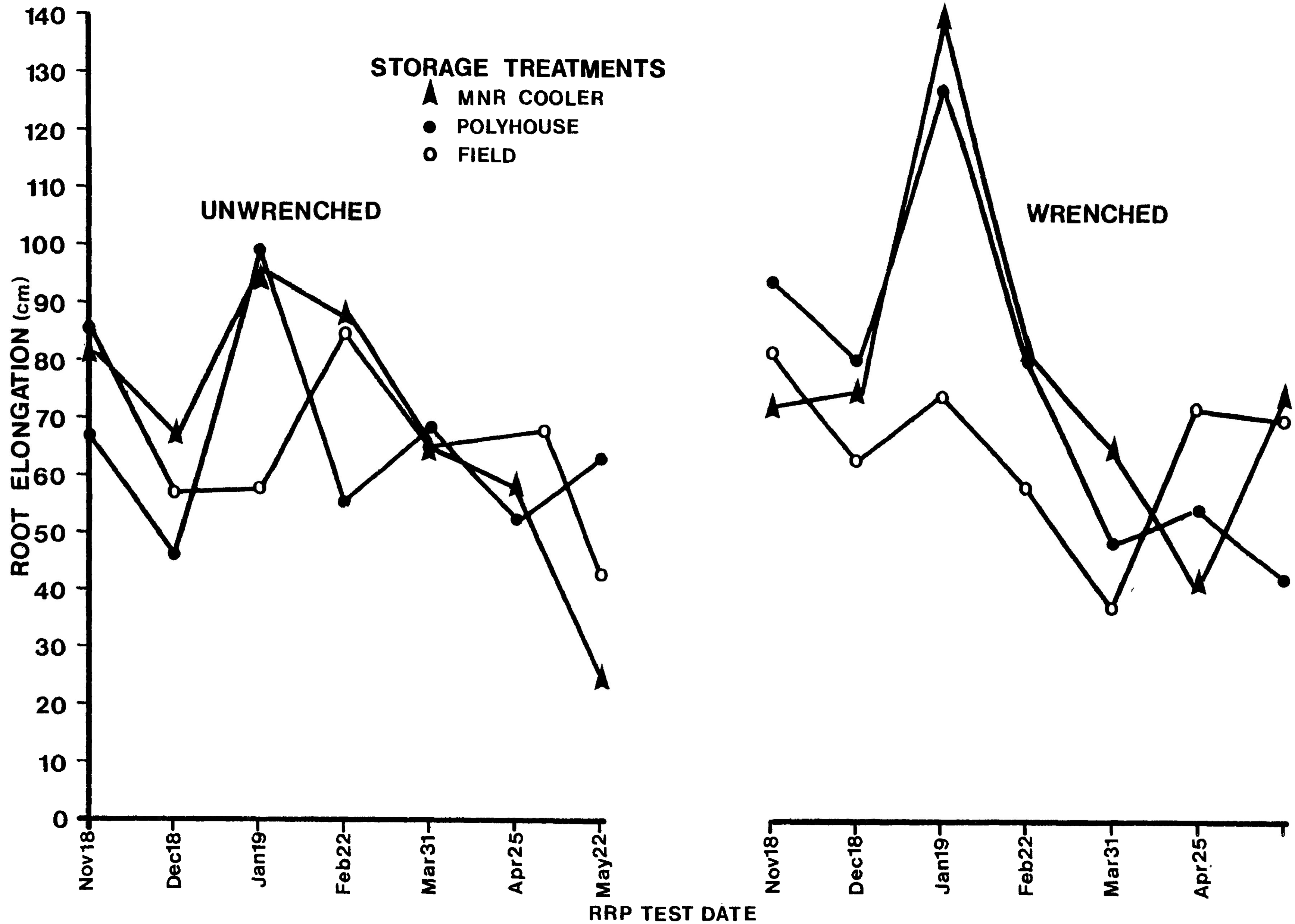

Figure 6. Total root elongation of wrenched and unwrenched stock from the 3 storage treatments after a 28 day RRP evaluation taken at monthly intervals.

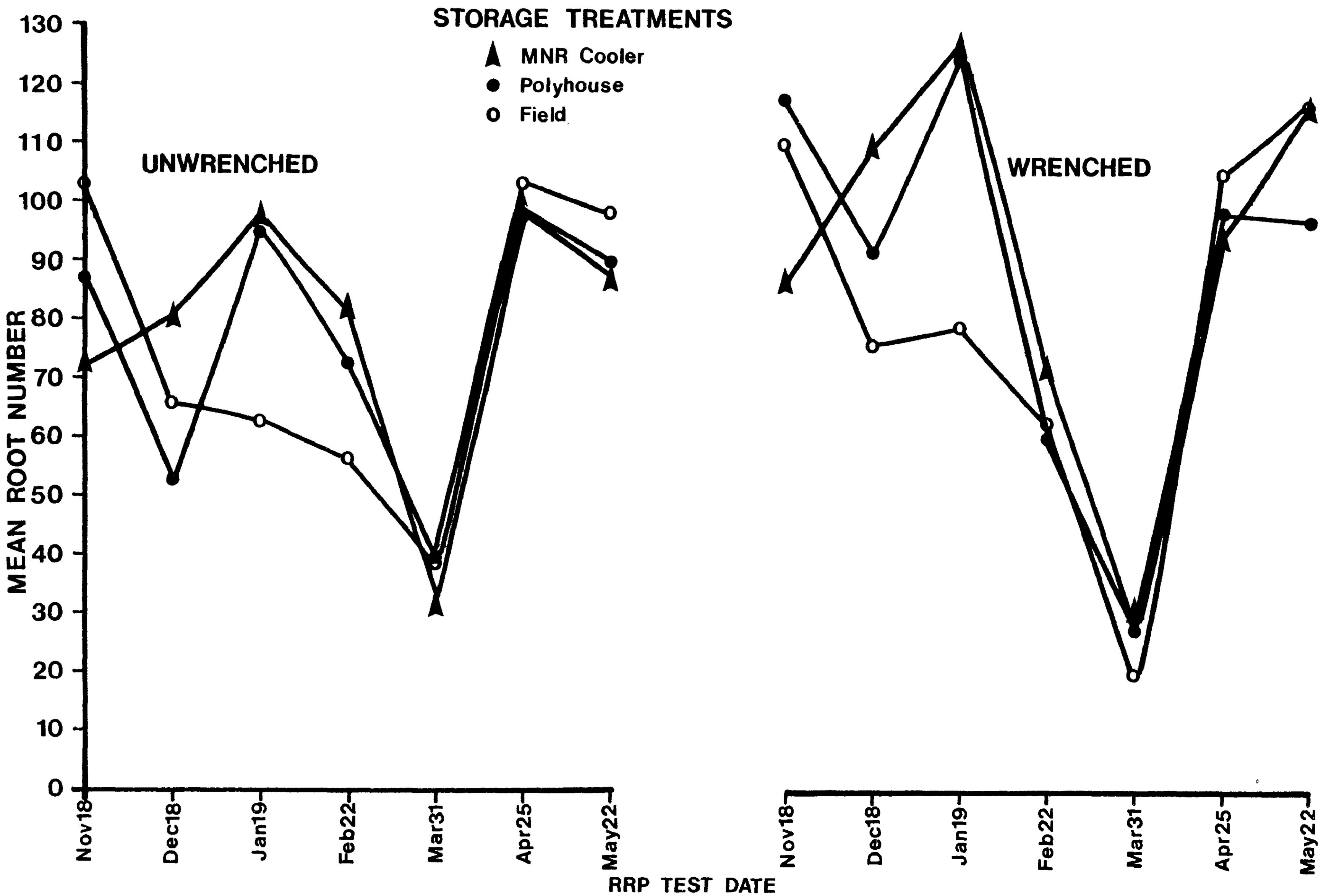

Figure 7. Total root number of wrenched and unwrenched stock from the 3 storage treatments after a 28 day RRP evaluation taken at monthly intervals.

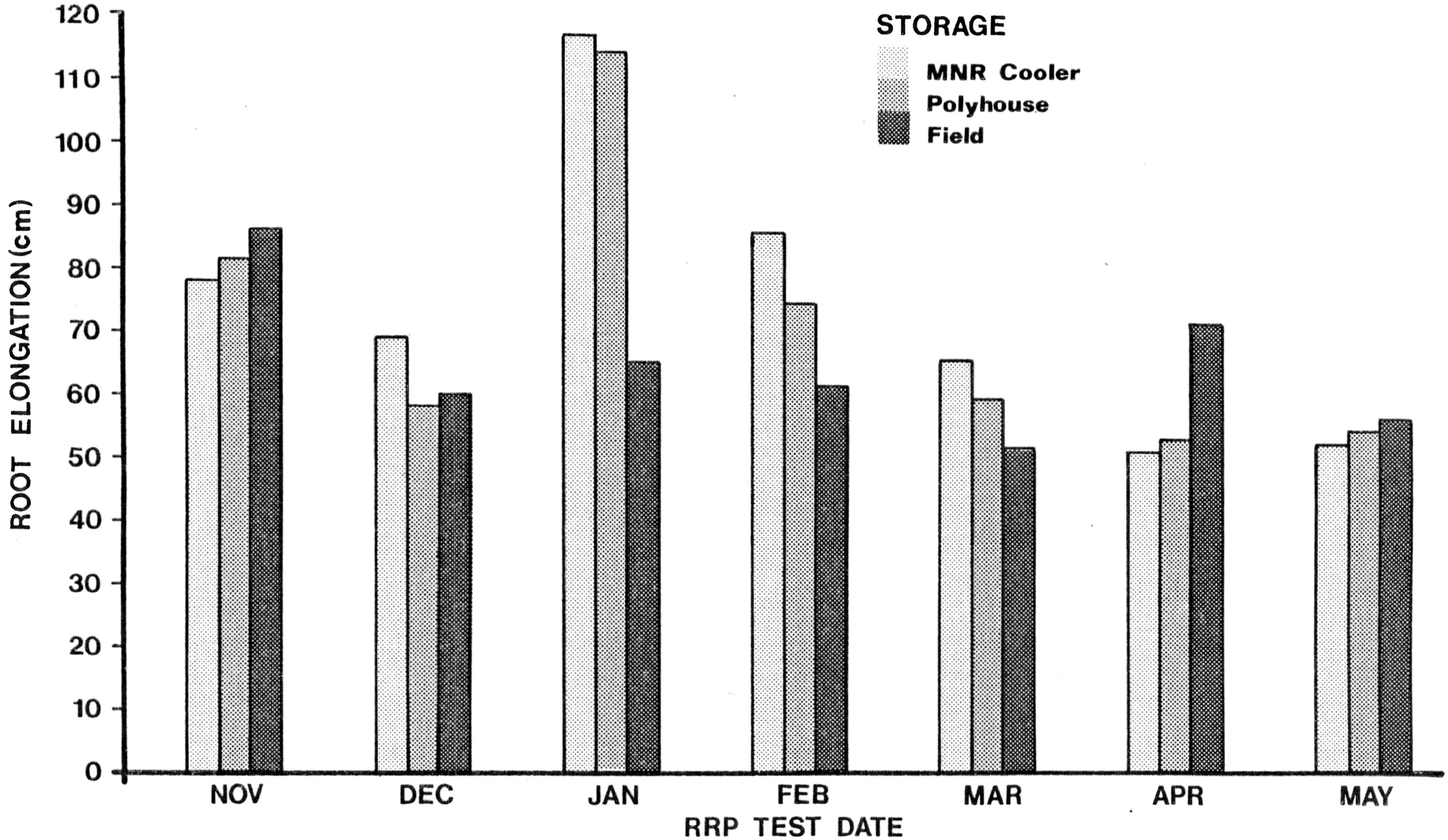

Figure 8. Total root elongation of stock from the 3 storage treatments after a 28 day RRP test on 7 dates using the pooled results from wrenched and unwrenched stock.

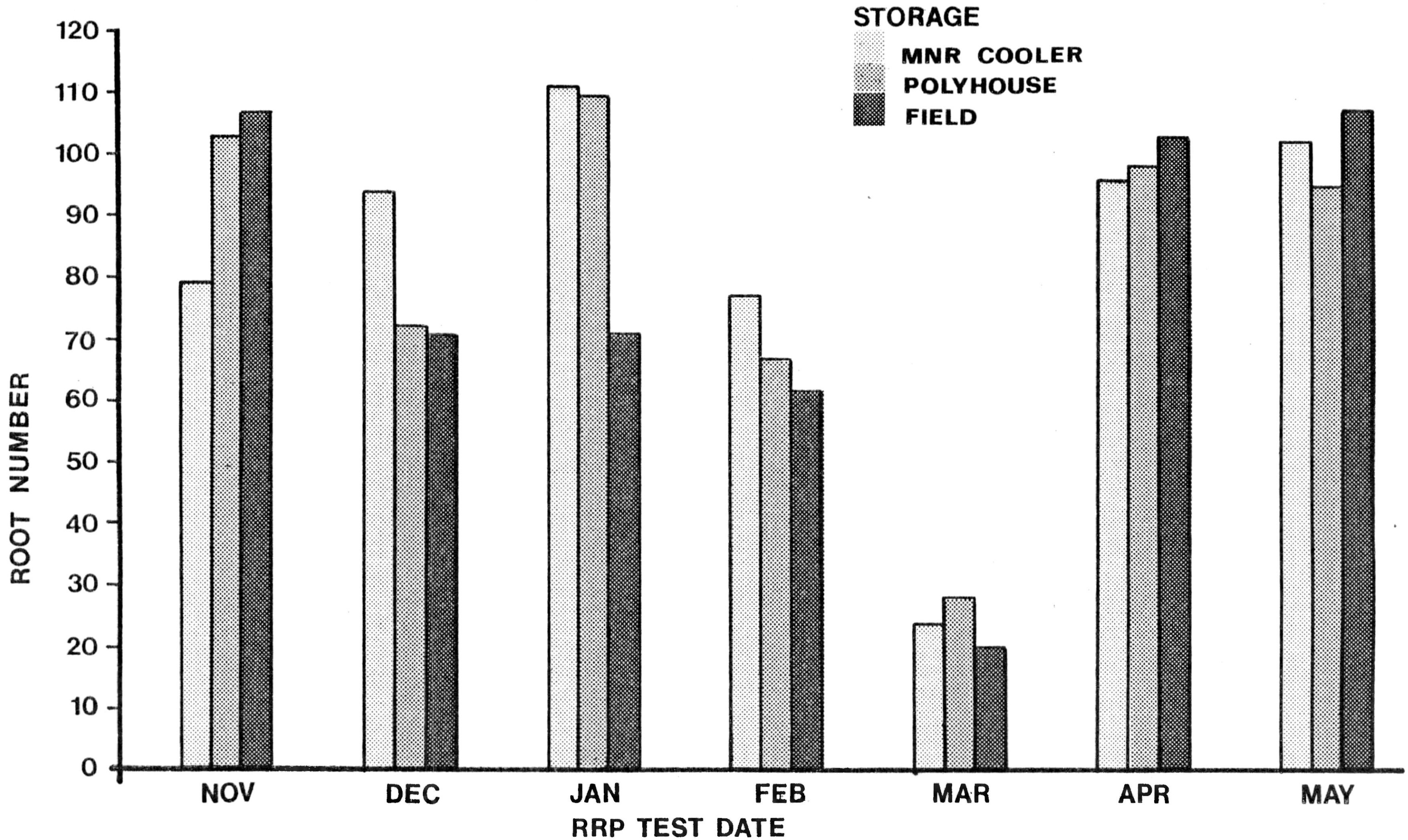

Figure 9. Total root number of stock from the 3 storage treatments after a 28 day RRP test on 7 dates using the pooled results from wrenched and unwrenched stock.

The Field stock differed from the other two storage treatments in that it did not have a January peak in RRP.

The percentage of very short and longer white roots as a percentage of total RN is given in Figure 10. The results shown in Figure 10 do not display the Polyhouse RE and RN data because the data for the MNR Cooler were quite similar and are used to represent both these treatments. The results of ANOVA showed that the percentage of roots in these classes was not significantly changed by wrenching or storage treatments. The results of ANOVA also showed that dates were related to significant differences in these percentages (Table 5). During the November to February period RN was made up of 60 per cent short roots and 40 per cent longer roots for both the MNR Cooler and the Field stock. In March, RN was made up of 17 and 37 per cent short roots and 83 and 63 per cent longer roots for the MNR Cooler and the Field stock respectively. In April this trend was completely reversed from that in March so that the RN of stock from both the MNR Cooler and Field was made up of 90 per cent short roots. April was a period of rising temperatures (Appendix 1a, 2a, 3a and 4a) in all three cold storage units.

The RRP of both the wrenched and unwrenched nursery

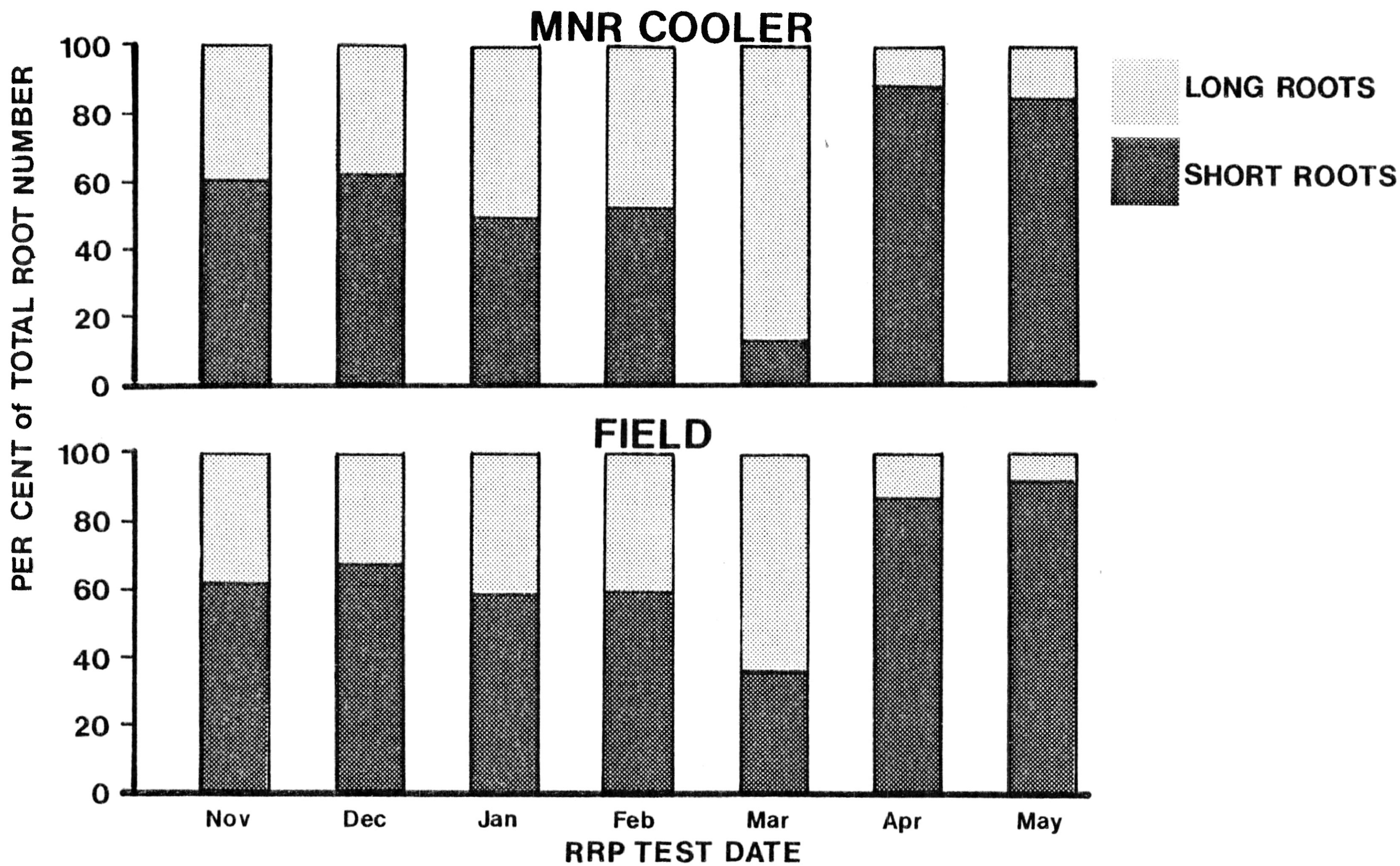

Figure 10. Short (≥0.5cm) and long (<0.5cm) roots as a percentage of total root number of stock from 2 storage treatments after a 28 day RRP test on 7 dates using the pooled results from wrenched and unwrenched stock.

Table 5. Short and long roots as a percentage of total root number. Root number was evaluated at 7 dates after 30 day RRP tests using stock from 3 overwinter storage regimes.

RRP TEST DATE	% OF SHORT ROOTS (<0.5 cm)	% OF LONG ROOTS (>0.5 cm)
November 15	62.5 c[1]	37.5 b
December 15	66.2 c	33.8 b
January 16	55.8 bc	44.2 b
February 22	54.3 bc	45.7 b
March 31	20.0 a	80.0 d
April 25	86.5 d	13.5 a
May 25	83.3 d	16.7 a

----

1. Treatments within a column that were not significantly different at p=0.05 are assigned the same letter.

stock while in the overwinter cold storage environments is summarized as follows:

1) Late Fall — This is a period of moderate RRP. Total RN is made up of more short roots than long roots.

2) Early Winter — This is a period of maximum RRP . Total RN is made up of equal nunbers of short and long roots.

3) Late Winter — This is a period of minimal RRP. Total RN is made up mostly by long roots. There are relatively few short roots.

4) Early Spring — This is a period of moderate RRP. RN is high and RE is low. Total RN is made up of mostly short roots.

2.2 Bud Dormancy

Fiqure 11 shows the percentage of buds that flushed after a 28 day period when wrenched and unwrenched stock from the three overwinter cold storage environments were placed into a good growth environment. The patterns for the percentage of buds flushed after a 28 day period were similar for wrenched and unwrenched stock from all three storage treatments. The Field stock had consistently

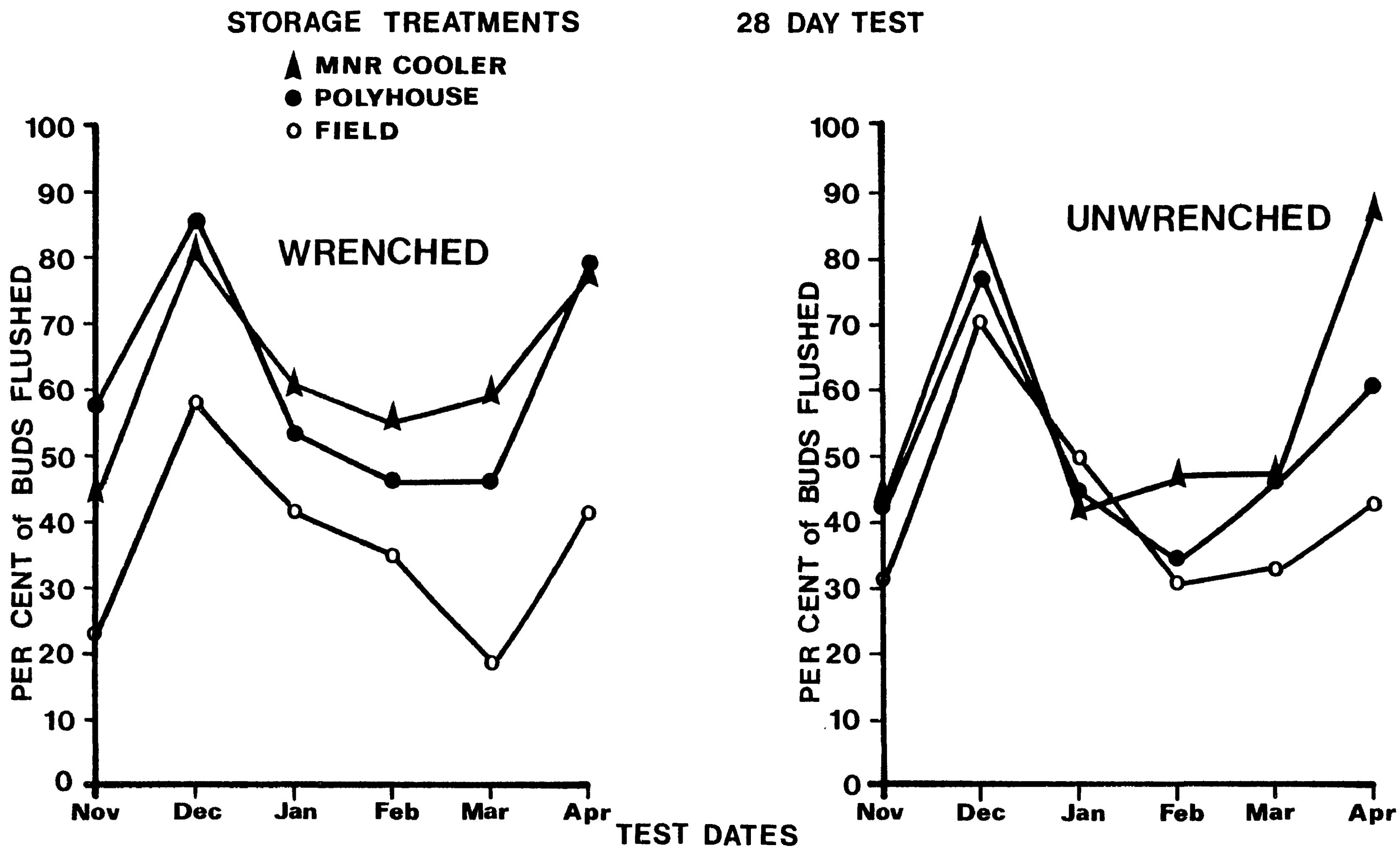

Figure 11. The percentage of buds flushed on wrenched and unwrenched stock from 3 storage treatments after a 28 day bud flushing test taken at monthly intervals.

fewer buds flushed than the other two storage treatments.

The results of ANOVA indicated that wrenching significantly increased the percentage of flushed buds after 28 days (Table 6).

ANOVA also indicated that there were significant differences between storage treatments. Stock from the Field storage environment had significantly fewer buds flushed after 28 days than stock from the other two storage environments. There were no significant differences between the percentage of buds flushed from stock from the other two storage environments (Table 7).

The results of ANOVA and SNK tests showed that there were significant differences between dates. The percentage of buds flushed in December and April was significantly greater than those for the remaining 4 months (Table 8).

The results of ANOVA and SNK tests for wrenching X storage interactions are given in Table 9. These tests showed that the wrenched Field stock had significantly fewer buds flushed at 28 days than most of the other treatments. Wrenched stock from the MNR Cooler and Polyhouse had significantly more buds flushed at 28 days

Table 6. The mean total percentage of buds flushed on wrenched and unwrenched stock after a 28 day test.

TREATMENT	MEAN % OF BUDS FLUSHED	SIGNIFICANCE[1]
Wrenched	54.16	*
Unwrenched	51.30	*

Table 7. The mean total percentage of buds flushed from stock overwintered in 3 storage regimes after a 28 day test.

STORAGE REGIME	MEAN % OF BUDS FLUSHED	SIGNIFICANCE[2]
MNR Cooler	61.2	b
Polyhouse	56.3	b
Field	40.6	a

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1. * significantly different at p=0.05

2. Treatments that were not significantly different at p=0.05 are assigned the same letter

Table 8. The effect of date on the mean total percentage of buds that flushed after a 28 day test.

DATE	MEAN % OF BUDS FLUSHED	SIGNIFICANCE [1]
November	40.0	a
December	61.4	b
January	45.1	a
February	40.2	a
March	40.0	a
April	54.9	b

Table 9. The effect of wrenching X storage treatment on the mean total percentage of buds that flushed after a 28 day test.

STORAGE	MEAN % OF BUDS FLUSHED	SIGNIFICANCE
MNR Cooler		
Wrenched	53.37	c
Unwrenched	51.04	bc
Polyhouse		
Wrenched	52.77	c
Unwrenched	45.87	b
Field		
Wrenched	38.68	a
Unwrenched	41.11	ab

----

1. Treatments that were not significantly different at p=0.05 are assigned the same letter.

than most of the other treatments. The remaining treatments fell in between these and were in two overlapping groups.

The results of ANOVA for wrenching X date interactions showed that there were no significant differences between these treatments.

The results of ANOVA and SNK tests for storage X date interactions are given in Table 10. These results showed that the Field stock from the March bud flushing test had significantly fewer buds flushed than most other treatments. MNR Cooler stock from the April bud flushing test had significantly more buds flushed than most other treatments. The remaining treatments were in 6 overlapping groups.

The results of ANOVA showed that there were significant differences between specific treatments (pre-conditioning x storage x date). The results of the SNK test shown in Table 11 indicate which treatment means were signicantly different. Because of the number and the complexity of the significant differences, they will not be discussed in detail.

Fiqure 12 shows both the rate of bud flushing for the

Table 10. The effect of storage treatment and date on the mean total percentage of buds that flushed after a 28 day test.

DATE	MEAN % OF BUDS FLUSHED		
	OVERWINTER STORAGE REGIME		
	MNR Cooler	Polyhouse	Field
November 16	44.4 b[1]	49.5 bc	30.1 ab
December 16	82.6 ef	81.9 ef	64.6 cd
January 19	52.0 bcd	56.3 bcd	46.2 b
February 22	52.0 bcd	40.5 b	33.7 ab
March 31	53.7 bcd	46.7 bc	26.4 a
April 25	82.7 f	69.8 de	42.9 b

----

1. Treatments that were not significantly different at p=0.05 are assigned the same letter.

Table 11. The percentage of buds that had flushed at 28 days.

Treatments: Precondit.	Storage	Date	Flushed Buds (%)	Sig.[1]
Wrenched	Field	March	19.1	
Wrenched	Field	November	28.3	
Unwrenched	Field	November	31.9	
Unwrenched	Field	February	32.0	
Unwrenched	Field	March	33.6	
Unwrenched	Poly-house	February	36.5	
Wrenched	Field	February	37.0	
Unwrenched	Poly-house	November	42.0	
Wrenched	Field	January	42.3	
Unwrenched	Cooler	January	42.4	
Wrenched	Field	April	42.5	
Unwrenched	Field	April	43.4	
Wrenched	MNR Cooler	November	44.0	
Unwrenched	MNR Cooler	November	44.7	
Unwrenched	Poly-house	January	45.1	
Wrenched	Poly-house	February	45.7	
Wrenched	Poly-house	March	46.1	
Unwrenched	Poly-house	March	47.2	
Unwrenched	MNR Cooler	February	47.5	
Unwrenched	MNR Cooler	March	47.9	
Unwrenched	Field	January	50.2	
Wrenched	MNR Cooler	February	50.3	
Wrenched	Poly-house	January	53.5	
Wrenched	Poly-house	November	57.0	
Wrenched	Field	December	58.7	
Wrenched	MNR Cooler	March	59.4	
Unwrenched	Poly-house	April	60.5	
Wrenched	MNR Cooler	January	61.6	
Unwrenched	Field	December	70.5	
Unwrenched	Poly-house	December	77.3	
Wrenched	MNR Cooler	April	77.9	
Wrenched	Poly-house	April	79.1	
Wrenched	MNR Cooler	December	80.6	
Unwrenched	MNR Cooler	December	84.6	
Wrenched	Poly-house	December	86.5	
Unwrenched	MNR Cooler	April	87.4	

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1. Treatments that were not significantly different at p=0.05 are joined by a line.

storage treatments during the 30 day bud flushing tests and the time required to initiate bud flushing after stock was taken out of storage. Both the rate and the initiation date determined the percentage of buds that flushed or burst after 28 days.

In November after stock was in the cold storage for 25 days, 21 days were required to initiate bud flushing in stock from all three storage environments. In December after stock was in cold storage for about 56 days the time required to initiate bud flushing fell to 7 to 14 days and it remained so through to the last bud flushing test in April.

The rate of bud flushing was fastest in December and April and much slower in January, February and March for stock from all three storage environment. In November because the bud flushing initiation was so long a 28 day test was not of sufficient duration to establish a bud flushing rate.

Throughout the six dates that bud flushing was evaluated, the MNR Cooler stock had the fastest rate of flushing, followed by the Polyhouse. Trees from the Field had the overall slowest rate of bud flushing (Fiqure 12).

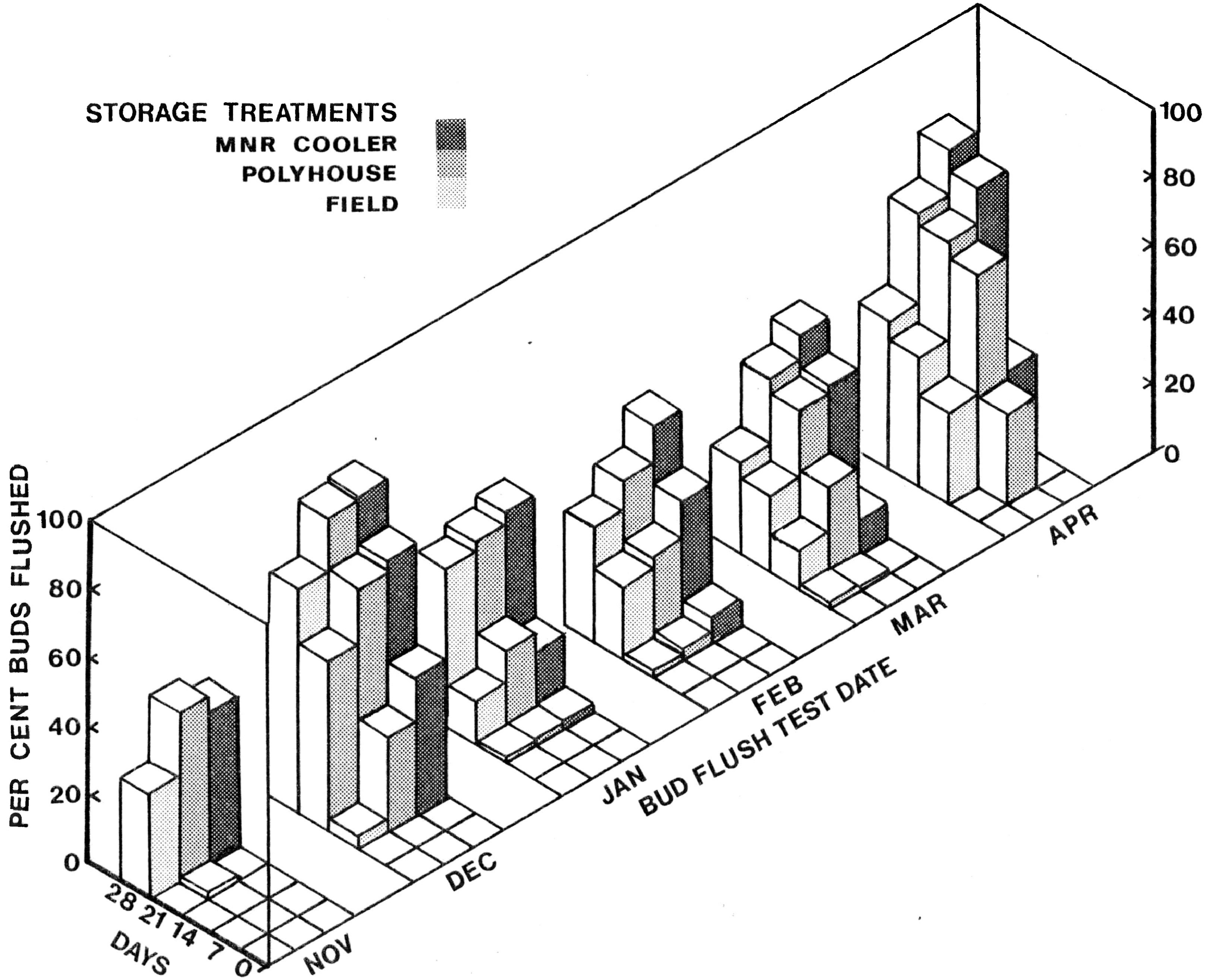

Figure 12. The percentage of buds flushed at 7 day intervals during a 28 day bud flushing test using wrenched and unwrenched stock taken from the 3 storage treatment at monthly intervals.

By the time stock given these three overwinter cold storage treatments was outplanted in the field in late May it was observed that stock from the Field flushed first and stock from the MNR Cooler was the last to flush.

The temperatures that buds were exposed to while in each of the three cold storage environments is given in Appendix A 1a, 2a, and 4a. The temperature in the MNR Cooler was the most uniform and the Field the least uniform. The MNR Cooler remained at -2^{o} C until early April at which time the temperature was increased to $+2^{o}$ C. The Polyhouse environment was intermediate to the MNR Cooler and Field in terms of cold temperature extremes. Temperature fluctuations increased in this storage environment in the spring as incoming solar radiation became more intense and increased day time heating. Nursery stock in the field was exposed to severe temperature fluctuations and very low temperatures accompanied by desiccating winds and sunlight. Snow cover in the nursery bed varied from a few cm in mid-December to 45 cm in February. Because of variable snow cover the air temperature data given in Appendix A will not always correctly express the temperatures that may have influenced bud flushing dormancy patterns for the Field stock.

The bud dormancy of both wrenched and unwrenched nursery stock while in the three overwinter cold storage environments is summarized as follows:

BUD DORMANCY PHASES

1) Late Fall — This is a characterized by a long slow bud flushing period.

2) Early Winter — This is characterized by a short bud flushing initiation period and a fast bud burst rate.

3) Mid- to Late Winter — This is characterized by a short bud flushing initiation period and a slow bud burst rate.

4) Early Spring — This is characterized by a short bud flushing initiation period and a fast bud burst rate. This period is very similar to bud dormancy phase #2.

2.3 Bud Dormancy And RRP

Fiqures 13 and 14 show the patterns of RRP and bud flushing using the percentage of buds flushed after a 28

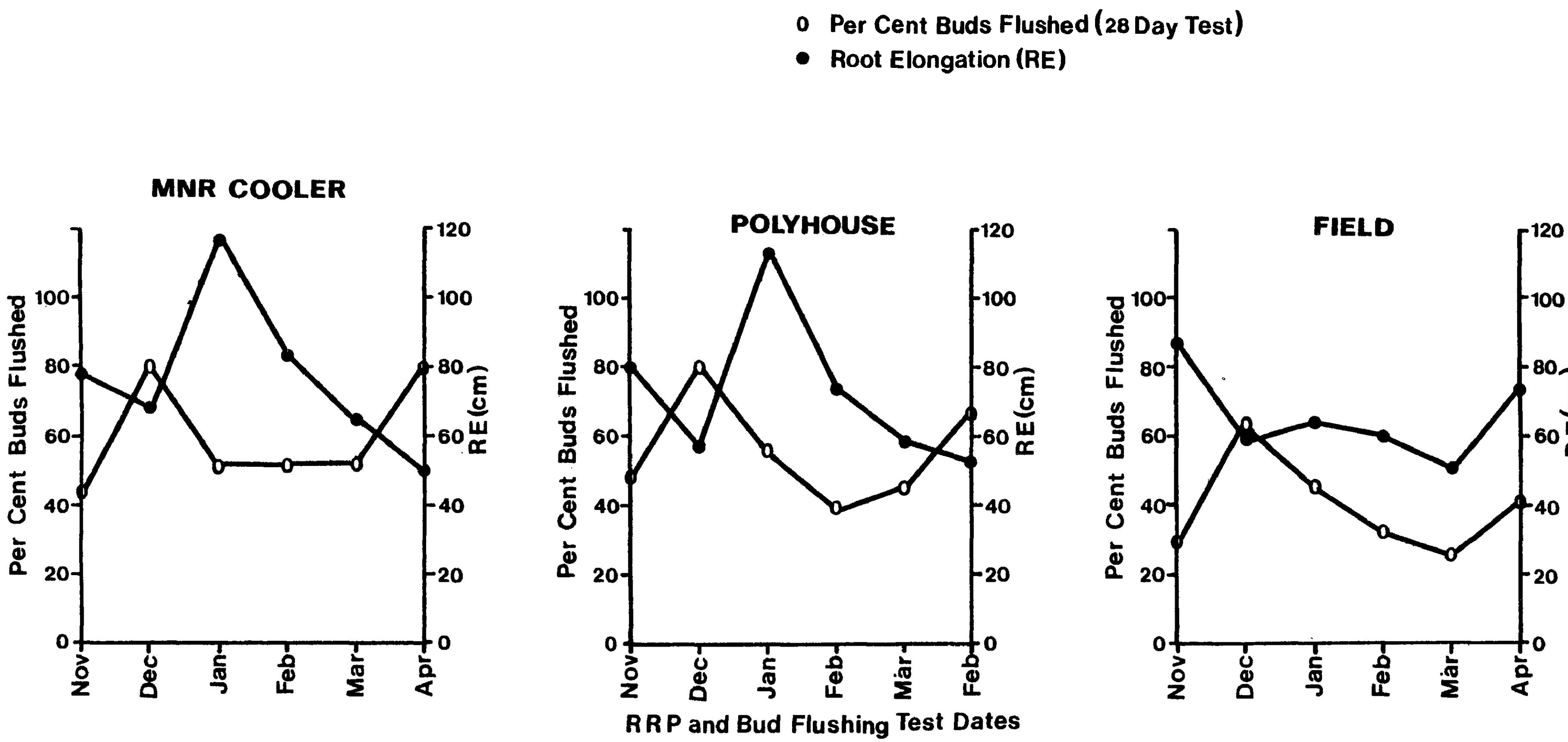

Figure 13. The relationship between bud dormancy and total root elongation over a 6 month period using pooled wrenched and unwrenched stock from the 3 storage treatments.

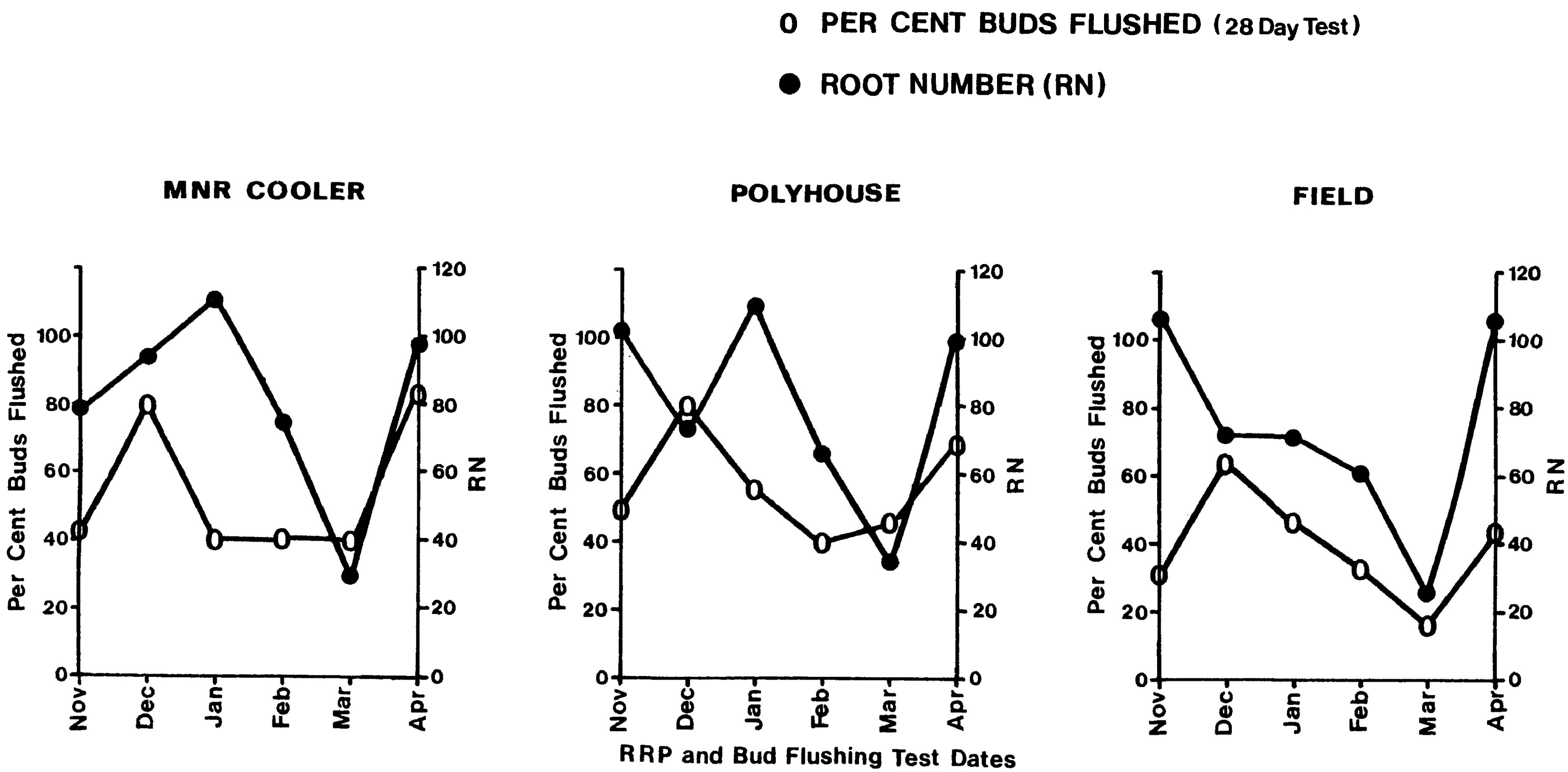

Figure 14. The relationship between bud dormancy and total root number over a 6 month period using pooled wrenched and unwrenched stock from the 3 storage treatments.

day test and the total RN after a 30 day RRP test. This is for combined wrenched and unwrenched stock from each of the three overwinter cold storage regimes.

Stock from all three storage regimes showed a peak in the percentage of buds flushed in mid December. This was followed by a peak in RE in January for stock in the MNR Cooler and the Polyhouse but not for stock in the Field (Figure 13). Stock from all three storage regimes generally had declining patterns of Bud flushing and RE from February through March. In April stock from the MNR Cooler and the Polyhouse had an increase in rate of bud flushing and slightly declining RE. In April stock from the Field had an increase in both bud flushing rate and RE.

The results for total RN and bud flushing were the same as those described for RE and bud flushing, except for the April test period (Figure 14). Total RN and rate of bud flushing both increased in April for stock from all three storage treatments.

3 THE OUTPLANTING TRIAL

ROOT ELONGATION at SPRING PLANTING

Table 12. The mean total R.E. of wrenched and unwrenched stock from 3 overwinter storage regimes at spring planting time.

STORAGE TREATMENTS	R E (cm)
Unwrenched MNR Cooler	24.50 a[1]
Wrenched MNR Cooler	80.18 c
Unwrenched Polyhouse	63.69 bc
Wrenched Polyhouse	44.97 ab
Unwrenched Field	42.88 ab
Wrenched Field	70.26 bc

[1] Treatments followed by the same letter are not significantly different by Student–Newman Kuels' Test.

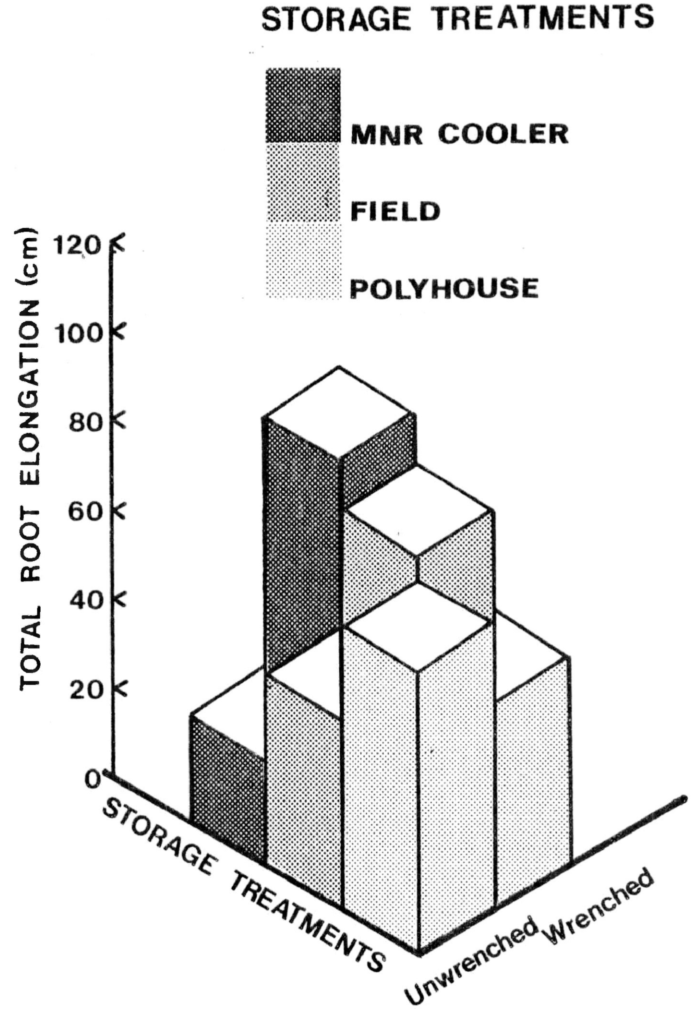

Figure 15. The total root elongation of wrenched and unwrenched stock from the 3 storage treatments after a 28 day RRP evaluation in late May at the time of spring planting.

ROOT NUMBER at SPRING PLANTING

Table 13. The mean total R.N. of wrenched and unwrenched stock from 3 overwinter storage regimes at spring planting time.

STORAGE TREATMENTS	RN
Unwrenched MNR Cooler	87.95 a[1]
Wrenched MNR Cooler	116.95 a
Unwrenched Polyhouse	95.40 a
Wrenched Polyhouse	96.25 a
Unwrenched Field	98.80 a
Wrenched Field	116.95 a

[1]Treatments followed by the same letter are not significantly different by Student–Newman Kuels' Test.

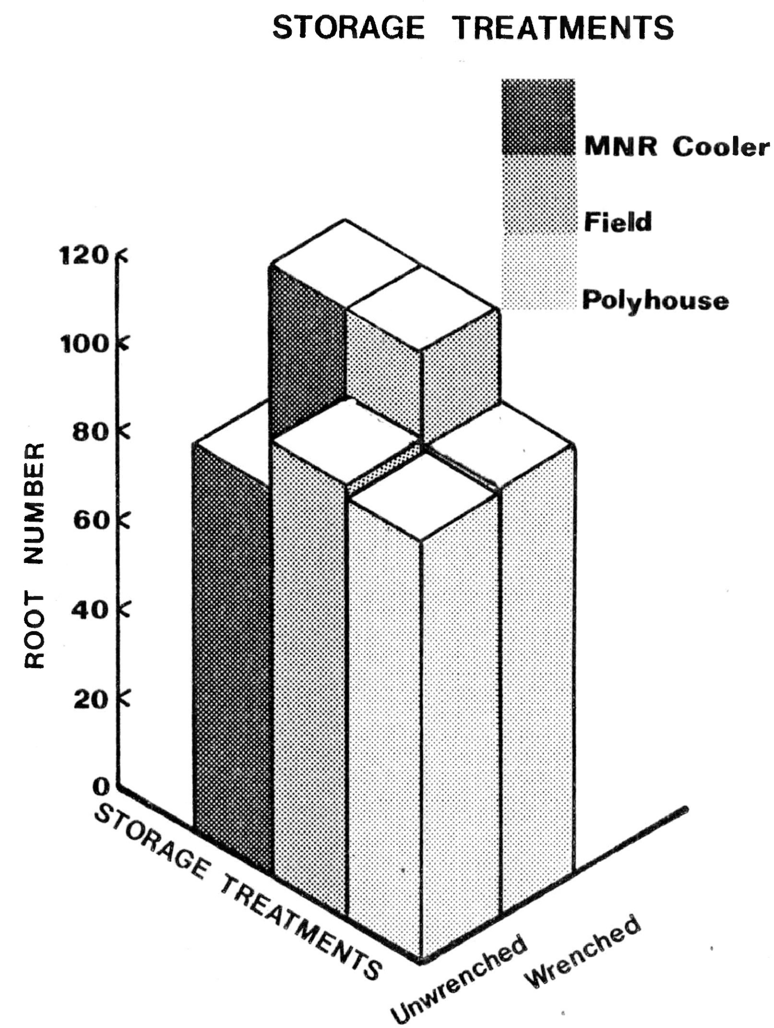

Figure 16. The total root number of wrenched and unwrenched stock from the 3 storage treatments after a 28 day RRP evaluation taken in late May at spring planting time.

The results of the May RRP test (Figures 15 and 16) were interpreted as a measure of the physiological readiness of the wrenched and unwrenched stock from the three overwinter cold storage environments for spring planting.

The results of Rankit plots showed that the May RRP data was normally distributed. When the RRP results for stock from the three overwinter cold storage treatments were combined, wrenched stock was found to have 15 per cent more RN and 34 per cent more RE than unwrenched stock. These differences were shown by ANOVA to be significantly different. There were no significant differences between the three storage treatments for either RE or RN. There were significant wrenching X storage treatment interactions for RE but not for total RN (Tables 12 and 13). The wrenched stock from the MNR Cooler had three times more RE than unwrenched MNR Cooler stock. This was shown by a SNK test to be significant. The remaining wrenching X storage treatments were in 3 overlapping groups.

An early afternoon plant moisture stress evaluation 21 days after outplanting showed that there were no significant differences in PMS between any of the treatments. The mean PMS values (Table 14) showed that the trees in the outplanting trial were under a moderate degree of moisture stress according to Day and Walsh (1980).

The survival of all the outplanting treatments was excellent (Table 14) with an overall survival rate of 99.5 per cent. ANOVA showed that there were no significant differences between the survival of stock from any of the treatments.

Frost damaged the leader shoots of outplanted stock in June. The on site weather station recorded a night time temperature of $-4^{o}C$ two weeks after outplanting. The wrenched trees had fewer frost damaged leader shoots than the unwrenched trees (Figure 17) but ANOVA showed that this was not significant. The results of ANOVA and SNK tests found differences in the percentage of frost damaged leaders between stock from different storage treatments (Table 15). Nursery stock overwintered in the Field suffered severe frost damage and had significantly more frost damage than stock from the other two storage units. The stock from the MNR Cooler suffered no frost damage while the Polyhouse stock suffered slight frost damage; however this difference was not significant.

Table 14. The morphological and physiological condition of wrenched and unwrenched 2+2 white spruce after outplanting.

ATTRIBUTE	WRENCHED	UNWRENCHED	SIGNIFICANCE [1]
Survival (%) [2]	99.5	99.5	NS
Early Afternoon [3] Internal Moisture Stress (KPa)	1503.74	1412.25	NS
Mean Height Increment (cm)	5.22	5.94	NS
Adjusted Mean [4] Height Increment (cm)	5.97	7.60	**
RCD (mm)	6.8	7.7	**
% of Frost Damaged Leaders	29.8	33.8	NS
Root ODW (mg)	62.5	65.9	NS
Top ODW (mg)	124.8	160.4	**
Total ODW (mg)	187.3	226.9	**
Top/Root	2.0	2.5	**

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1. NS Not Significantly different; ** Significantly different at $p=0.01$

2. All attributes except internal moisture stress were evaluated at the end of the first growing season.

3. Internal moisture stress was evaluated 21 days after outplanting.

4. Adjusted mean height increment evaluated using trees not damaged by frost.

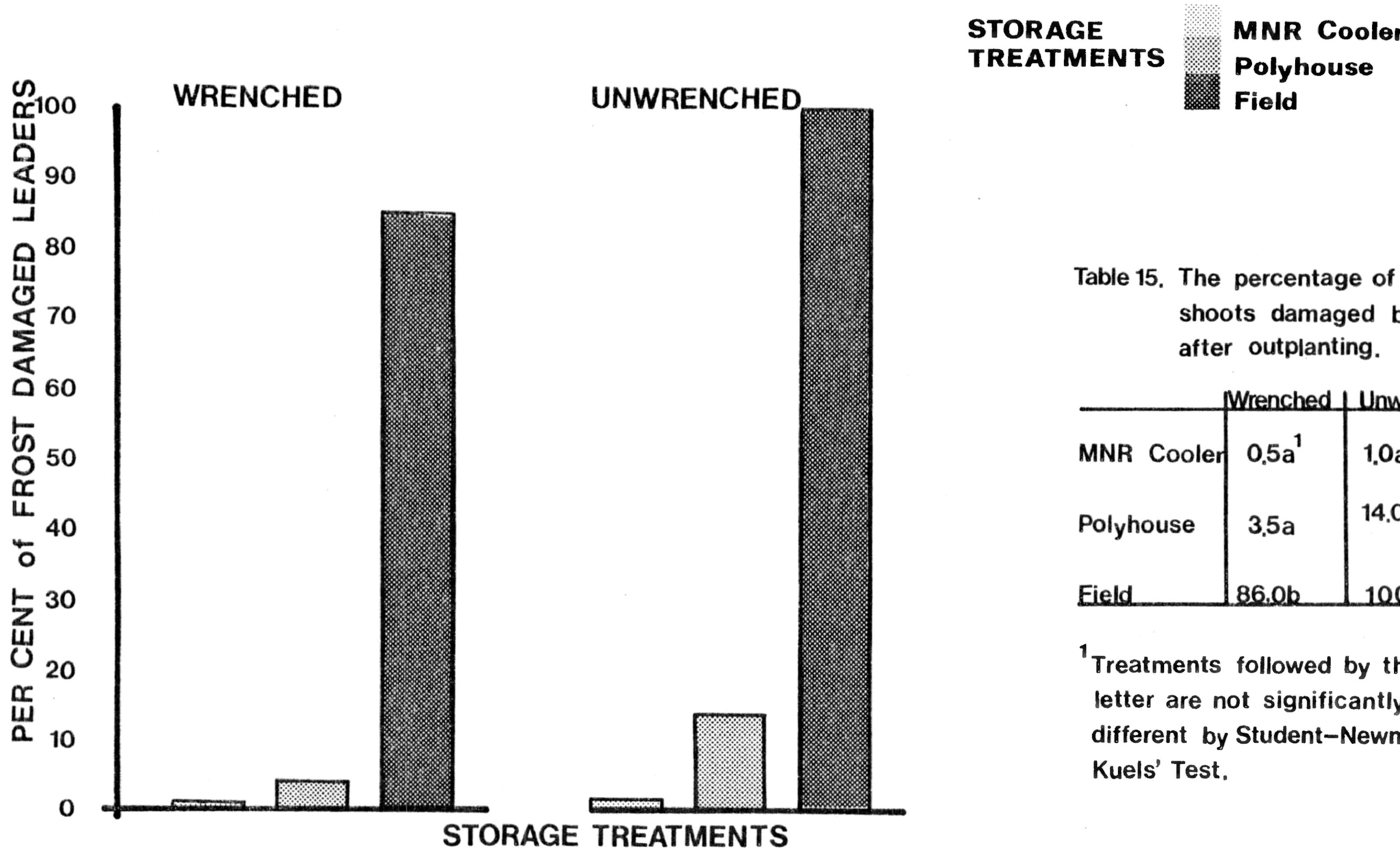

Table 15. The percentage of leader shoots damaged by frost after outplanting.

	Wrenched	Unwrenched
MNR Cooler	0.5a[1]	1.0a
Polyhouse	3.5a	14.0a
Field	86.0b	100b

[1] Treatments followed by the same letter are not significantly different by Student–Newman Kuels' Test.

Figure 17. Percentage of leader shoots damaged by frost after wrenched and unwrenched stock from the 3 storage treatments was spring outplanted.

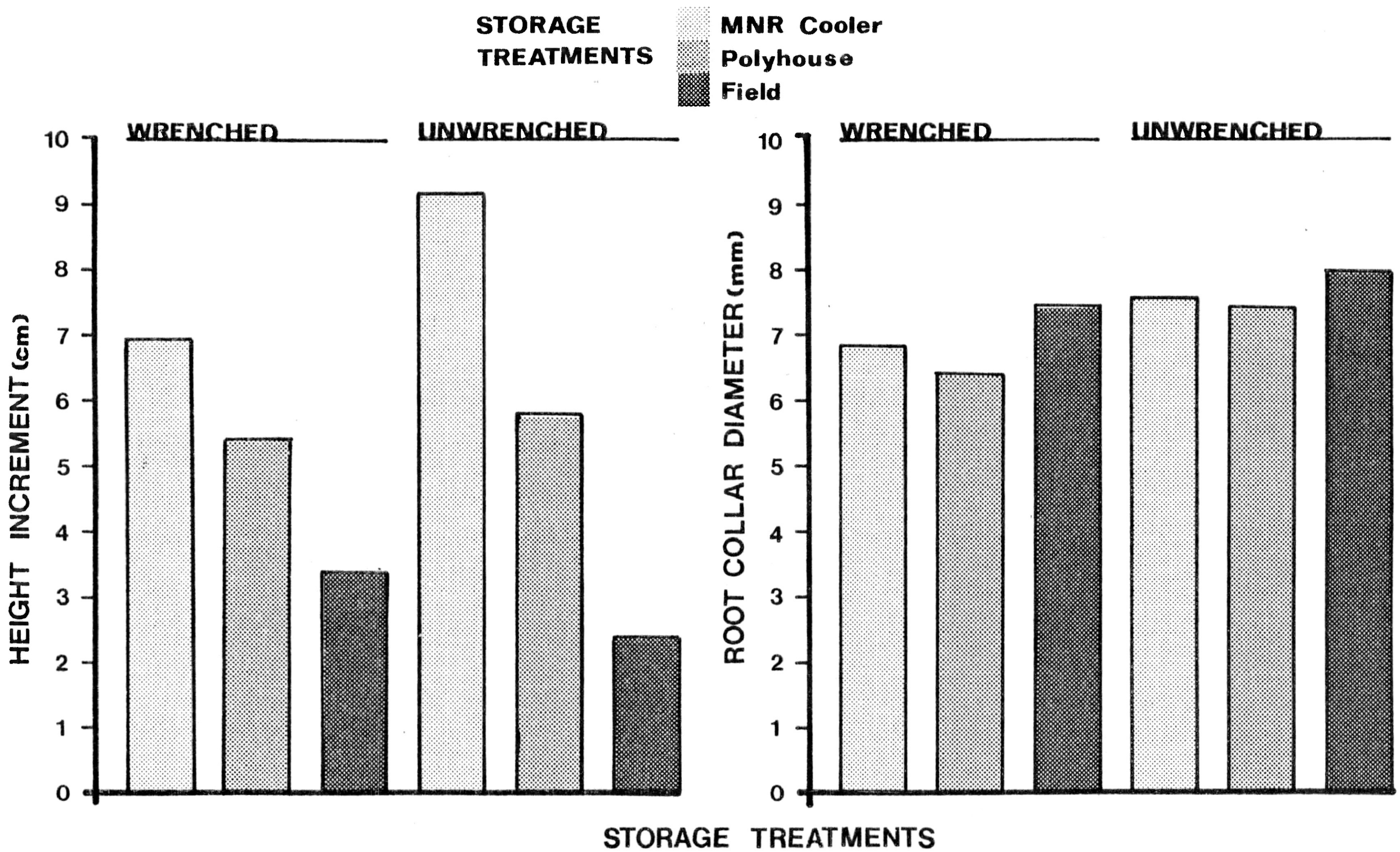

Figure 18. Height growth and root collar diameter of wrenched and unwrenched stock from the 3 storage treatments one growing season after ouplanting.

Wrenching significantly reduced the height increment of trees not damaged by frost by 21 per cent the growing season after outplanting. When frost damaged trees were included in this evaluation (Fiqure 18) there was only a 12 per cent reduction in the height increment of wrenched stock. ANOVA and SNK tests that included the height increments of frost damaged trees showed that wrenching did not significantly affect height increment as shown in Table 14. Storage treatment did significantly affect height increment (Table 16). The height increment of stock from all three storage treatments was significantly different. Stock from the MNR Cooler had the highest height increment, the Polyhouse was intermediate and the Field had the lowest height increment. ANOVA and SNK tests showed that storage X wrenching interactions did significantly affect height increment (Table 17). The unwrenched stock from the MNR Cooler had significantly more height increment than any other treatment. The wrenched and unwrenched stock from the Field had significantly lower height increment than stock from the remaining treatments. The remaining three treatments were in two overlapping intermediate groups.

The results of ANOVA showed that the RCD of the wrenched stock was significantly reduced by 12 per cent over that of the unwrenched stock (Figure 18 and Table

Table 16. The effect of storage treatment on the current season's height increment and the total RCD of stock one growing season after outplanting.

STORAGE	HEIGHT INCREMENT (cm)	RCD (cm)
MNR Cooler	8.11 c[1]	0.72 a
Polyhouse	5.68 b	0.70 a
Field	2.91 a	0.78 b

Table 17. The height increment of wrenched and unwrenched white spruce one growing season after outplanting.

	HEIGHT INCREMENT (cm)	
STORAGE	WRENCHED	UNWRENCHED
MNR Cooler	6.99 c	9.24 d
Polyhouse	5.49 b	5.89 bc
Field	3.47 a	2.34 a

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1. Treatments that were not significantly different at p=0.05 are assigned the same letter.

14). The results of ANOVA and SNK tests also showed that the RCD of the stock from the Field was significantly greater than that from the other two storage treatments (Table 16). There were no significant differences between any of the storage X wrenching interactions.

The effects of wrenching on ODW after one growing season in the field are given in Figures 19 and 20 and Tables (18 and 19). ANOVA found that wrenched stock had significantly reduced top and total ODW over that of unwrenched stock, but root ODW was not significantly reduced by wrenching. The top/root ratios were also shown to be significantly reduced by wrenching. The ANOVAs showed that storage treatments and storage X wrenching interactions had no significant effect on ODW.

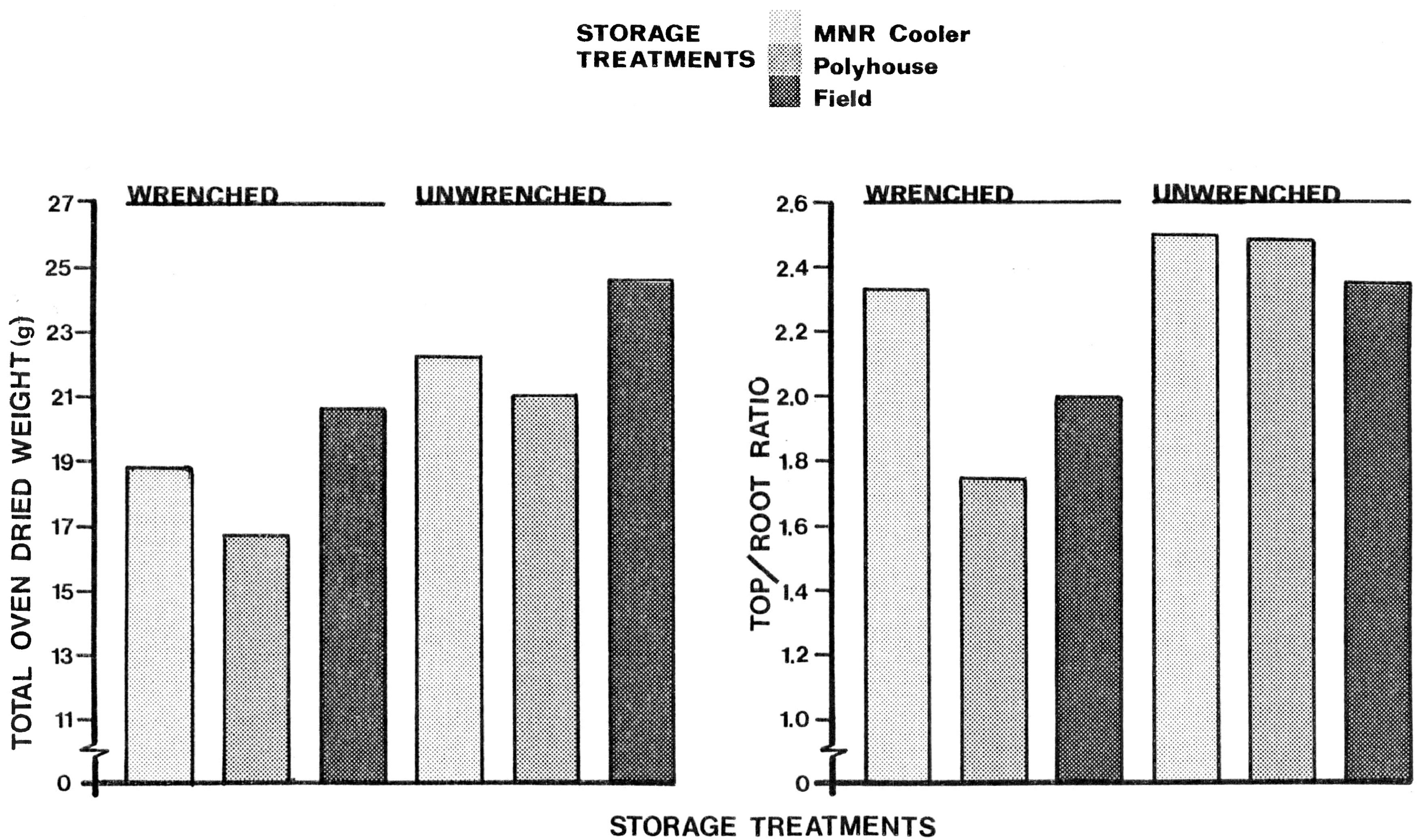

Figure 19. Total oven dry weight and top/root ratio of wrenched and unwrenched stock from the 3 storage treatments one growing season after outplanting.

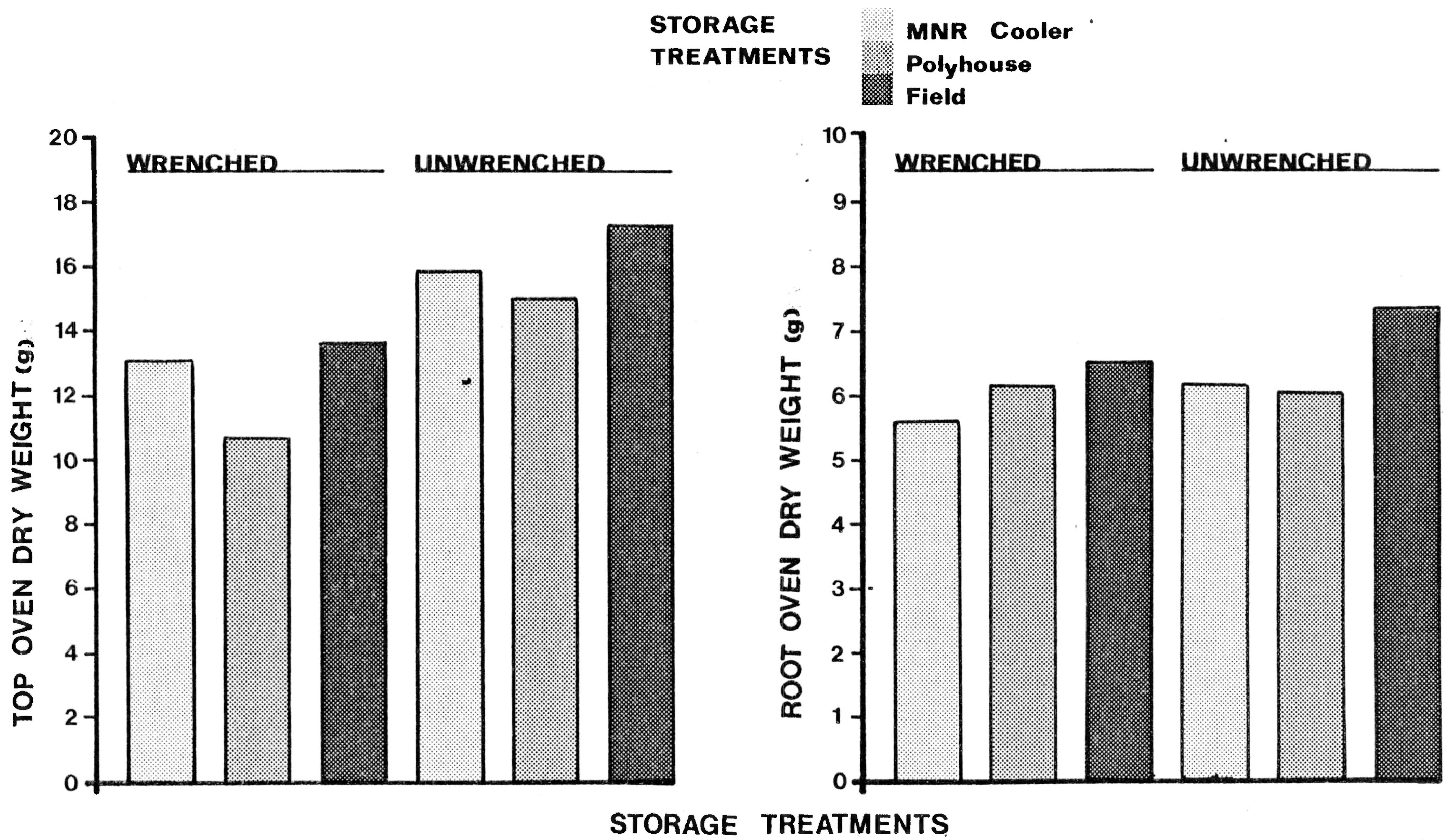

Figure 20. Top and root oven dry weight of wrench and unwrenched stock from the 3 storage treatments one growing season after outplanting.

Table 18. The mean total top and root oven dry weight of wrenched and unwrenched white spruce one growing season after outplanting.

STORAGE	TOP ODW (g)		ROOT ODW (g)	
	WRENCHED	UNWRENCHED	WRENCHED	UNWRENCHED
MNR Cooler	13.2 ab[1]	15.9 b	5.7 a	6.4 a
Polyhouse	10.7 a	15.0 ab	6.1 a	6.1 a
Field	13.7 ab	17.3 b	7.0 a	7.4 a

Table 19. The mean total oven dry weight and top/root ratio of wrenched and unwrenched white spruce one growing season after outplanting.

STORAGE	TOTAL ODW (g)		TOP/ROOT RATIO	
	WRENCHED	UNWRENCHED	WRENCHED	UNWRENCHED
MNR Cooler	18.8 a	22.2 a	2.33 ab	2.50 b
Polyhouse	16.7 a	21.0 a	1.74 a	2.48 ab
Field	20.6 a	24.6 a	1.95 ab	2.35 ab

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1. Treatments that were not significantly different at p=0.05 are assigned the same letter.

DISCUSSION

1 NURSERY BED WRENCHING TRIALS

The results of the nursery bed wrenching trials are generally in agreement with other wrenching studies (van Dorsser and Rook 1972 and Bunting and Mcleod 1984a, b and c).

The wrenching treatments which included a single early spring root pruning significantly changed and improved certain morphological attributes of the white spruce transplants. The most obvious morphological change that resulted from wrenching was a reduction in height increment the growing season wrenching was applied. Early summer wrenching in the nurserybed is an effective and practical method of reducing the height increment when a reduced above-ground size of planting stock is desired. If a reduction in height increment is not required, wrenching should not be started until mid summer when the height growth of northern conifers is usually complete (Bunting and Mcleod 1984b). By adjusting the timing and the frequency of wrenching treatments nurserymen may use wrenching as a means of adjusting current height increment.

Wrenching the growing season before outplanting reduced the height increment the growing season after outplanting. This was likely related to the significant 16.5 per cent reduction in needle leaf and stem unit primordia production that resulted from wrenching. According to Cannell (1976) the number of needle leaf and stem unit primordia in winter buds largely determines the potential for shoot extension the following spring and summer. Because bud development and needle leaf initiation continues throughout the growing season in northern conifers (Owens <u>et al.</u> 1977) wrenching at any time during the spring or summer is likely to reduce the height increment of nursery stock the next growing season.

Wrenching at any time during the growing season will probably reduce stem diameter but this may be balanced by reductions in height. Some of the reduction in stem diameter could be related to a reduction in water content and radial shrinkage of plant tissues that has been associated with nursery treatments such as root pruning that disrupt root systems (Day 1979).

The most positive morphological changes caused by wrenching are an increase in RAI and a reduction in top/root ratio. Both these attributes may have the potential to improve the internal water balance of outplanted wrenched nursery stock especially on droughty planting sites. The 1983 wrenching treatment increased RAI by 31 per cent but the 1982 wrenching treatments did not have any effect on RAI. There is no apparent explanation for these differing results. In relation to top size the RAI of the wrenched trees was bigger than that of the unwrenched trees in both years. Visual observations confirmed that the increase in the RAI of wrenched stock was due to the more fibrous nature of the root systems of wrenched stock. Root dry weight was not significantly changed by wrenching in 1982 or 1983 so that changes in RAI between wrenched and unwrenched stock must be the result of changes in root morphology, not absolute size. As the root ODW was unchanged by wrenching the reduction in top/root ratio of wrenched stock was due to reductions in top ODW and unchanged root size.

Rook (1971) and Bacon and Bachelard (1978) found that some species of pine when wrenched translocate a greater proportion of current photosynthate to the root system than unwrenched or less frequently wrenched stock. The allocation of a limited supply of current photosynthate that favours the roots at the expense of the shoots may explain why wrenching reduced top ODW but had no effect on root ODW. However this does not explain why the RAI increased and root fibrosity improved after wrenching. Possibly wrenching changes root system morphology by altering the balance of phytohormones that control root growth. Ritchie and Dunlap (1980) suggested that when root tips are severed by wrenching, abscissic acid levels (a root growth inhibitor) are reduced so stimulating root system development.

A reduction in top growth and bud development after wrenching may be related to moisture stress. Stupendick and Shepphard (1980) and Duryea and Lavender (1983) found that moisture increased following wrenching treatments.

The results given in Table 3 for the 1982 and 1983 nursery-bed wrenching trials show some variability in the response of stock to wrenching between the two years. Top and total ODW were reduced more in 1982 than 1983 by wrenching and RAI was only increased by wrenching in 1983. This may be because stock used for the 1982 trial was larger than the 1983 stock. Other possible reasons for year to year variation may be related to differences in the nursery compartments used, climatic variation and possible changes in fertilizer and irrigation programs. It must not be assumed that the response of nursery stock to wrenching will be the same for different tree species, between nurseries, or from year to year.

Before setting out a root culturing program on a nursery, preliminary work should be done to establish a series of root pruning and wrenching treatments that produces stock that meet the morphological quality standards and objectives of the nursery. By monitoring stock quality throughout a root culturing program it should be possible to adjust root pruning and wrenching programs to manipulate growth patterns and fulfill stock quality objectives. Care must be taken not to apply too intensive a root culturing program. According to size standards suggested by Mullin and Christl (1981) the wrenched stock from the 1983 nursery bed trial had slightly less total height than is desirable for 2+2 white spruce shipping stock. Possibly the root culturing program in this case should have been less intensive or timed differently to allow for more height growth.

From the morphological analyses of wrenched and unwrenched stock using the stock quality indices it was shown that the overall morphological condition of nursery stock was changed by wrenching. The SI value was lowered by wrenching in 1982 and 1983 but the significance of this to stock quality has not been determined for white spruce transplants grown in northern Ontario. The results from the stock quality evaluation using the MSD method indicate that 1982 unwrenched stock was very large in terms of height RCD and RAI by northern Ontario standards. It was so large that it could not be fitted easily into the kraft packing cartons. The wrenched stock was a little smaller and fitted easily into the cartons. This is an example of how wrenching can be used to modify the size of stock to help improve the efficiency of nursery operations. The results of the MSD method also indicate that wrenching modified and supposedly improved the morphological condition of the nursery stock. This was because wrenching changed the morphological balance of the stock; it did not increase the size. Wrenching moved the nursery stock from a medium to a high morphological grade in 1982 and 1983. Because these stock quality morphological grades have not been tested in long term replicated field trials it may only be assumed that the wrenched stock that scored a high morphological grade was actually of better planting stock quality than the unwrenched stock. According to Sutton(1979b) it is the field performance not the appearance of planting stock that really determines stock quality.

2 OVERWINTER COLD STORAGE

2.1 Bud Dormancy

Nursery stock given all three storage treatments had the same general pattern of bud dormancy progression from November until April. In November the buds were in the dormancy release transitional state and were slow to flush. By December bud dormancy chilling requirements were satisfied. The buds had progressed into the non-dormant steady state by this time and buds flushed much sooner than in November. Buds began flushing 14 days earlier in December than in November. This supports work by Nienstaedt (1966 and 1967) who found that white spruce growing in northern Minnesota required 8 weeks of chilling to overcome bud dormancy requirements of the dormancy release transitional state. The nursery stock used for the dormancy evaluation in this study likely had about two weeks of its bud dormancy chilling requirements satisfied while it was in the field prior to lifting. The remaining six weeks of chilling required to satisfy bud dormancy chilling requirements occurred simultaneously in the MNR Cooler, the Polyhouse and the Field.

This study would seem to indicate that the irregular mean daily maximum temperatures in November and December that ranged from +13 ^{o}C to -11 ^{o}C in the Field had much the same effect on bud dormancy chilling requirements as the constant -2 ^{o}C temperatures in the MNR Cooler. Stock in total darkness showed the same progression of dormancy release as stock in the Field and Polyhouse storage facilities where stock was exposed to natural photoperiods. This suggests that photoperiod has no significant effect on the early winter progression of dormancy. Fall lifting operations and placement into the Polyhouse and MNR Cooler storage environments did not have any significant effect on the progression of early winter dormancy.

During the January to March period nursery stock in the MNR Cooler, Polyhouse and Field was kept at below -0 ^{o}C. This maintained the stock in the non-dormant steady state of dormancy progression throughout this period. Accepted concepts of dormancy suggest that bud flushing patterns would remain reasonably constant throughout this period. However, in this study while the time required for the first buds to flush was constant and remained the same as in December the rate of bud flushing declined to below the December rate for stock in all 3 storage environments. Is it possible that this reduced rate of bud flushing is related to a depletion of non structural carbohydrates that is known to occur as time in cold storage increases (Ritchie 1982). Stock in the MNR Cooler most likely did have a reduction in total non structural carbohydrates as time in storage increased. It is tempting to suggest this may explain changes in the rate of flushing. Currently, however there is no strong body of evidence to support this hypothesis.

Possibly the different temperatures in the three storage regimes are related to the different rates of flushing. The rate of bud flushing of stock in all three storage regimes fell in January but was still greatest for MNR Cooler stock and lowest for Field stock. The warmer more stable temperatures and moist conditions in the MNR Cooler may have maintained the stock in a physiological state more suited to rapid bud flushing than stock from the Field. The Field was subjected to extreme cold and some desiccation under conditions of very low absolute humidity and drying winds

In April, stock in all three storage regimes had an increase in the rate of bud flushing but the MNR Cooler stock had the fastest and the Field stock the slowest rate. Temperatures in all three storage regimes were increased in April and this likely caused the increase in the bud flushing rate. The Polyhouse stock had the warmest April temperatures and natural spring photoperiods but the rate of flushing was still slower ($p=0.05$) than for MNR Cooler stock that was stored in the dark and at cooler temperatures.

When stock given the three overwinter cold storage treatments was outplanted in late May, the Field stock had the earliest bud flushing initiation date followed by Polyhouse stock and lastly the MNR Cooler stock. In May the +5 °C to 20 °C plus air temperatures in the Field reduced the initiation time required for bud flushing to begin and the +2 °C temperatures in the MNR Cooler effectively held back bud flushing processes. The stock held in the shaded Polyhouse and in a cooler environment than that experienced by Field stock, had a bud flushing initiation date similar to but slightly ahead of stock from the MNR Cooler. In late May exposure of stock to high temperatures is the dominant environmental factor controlling bud flushing initiation date.

The progression of bud dormancy was not adversely affected by the standard fall lifting and overwinter cold storage practices used in Ontario.The MNR Cooler treatment increased the rate of bud flushing in the winter but slowed down bud flushing after planting and this helped reduce damage from late spring frosts. The absence of exposure of overwinter cold stored nursery stock to long day photoperiods prior to planting did not have any significant effect on planting stock quality in this study.

2.2 RRP

During the November to February period monthly RRP tests with high total RE also had high total RN and periods of low RE were also periods of low RN. During March RN was low and RE was moderate. This was due to an absence of short roots while some long roots continued to elongate. It is possible that during March very little new root initiation was occurring and that RE was made up mostly by the reelongation of existing long roots. In April and May this trend was reversed so that RN was very high while RE remained moderate. Possibly in April and May the elongation of existing roots continued to occur but at a relatively low rate compared to the early development of very short roots. These phenomena in the RRP of stock tested in April and May were visually observed as a proliferation of short roots.

During the seven month RRP test period, storage treatment had a significant effect on the patterns and levels of RRP. The RE and RN of stock from the the MNR Cooler and the Polyhouse peaked in January while stock from the Field did not have a clearly defined peak. This January RRP peak was observed in Douglas fir lifted from the nursery bed in January by Ritchie (1982). An examination of temperatures that the roots were exposed to showed that these were likely just below freezing in all three storage environments even in the Field where snow cover helped insulate soil from the cold air temperatures. This would suggest that the temperatures surrounding the roots was not the major factor that caused the Field stock to have a different pattern of RRP than stock from the other two storage treatment. However the air temperatures that shoots were exposed to showed considerable variation between storage treatments. Differences in temperature may have changed the dormancy processes of shoot buds and the level of physiological activity in the shoots. It may be that there is a relationship between the bud dormancy status, level of shoot physiological activity and RRP. The dormancy status of buds has been linked to RRP in northern hardwoods (Farmer 1975 and Webb 1976 and 1977) and northern conifers (Ritchie and Dunlap 1980 and Ritchie 1982). It may also be worth noting that during the mid winter period the Field stock in this study had both the slowest rate of bud flushing and the lowest over all RRP.

There is considerable evidence that supports the hypothesis that RRP will increase once the dormancy chilling requirements of buds is complete. The evidence from this study supports this. Bud dormancy chilling requirements were satisfied by late December for stock in all three storage environments. This was followed by a very definite peak in RRP in January for stock from 2 of the 3 storage environments.

Ritchie and Dunlap (1980) showed that that the RRP of cold stored Douglas fir had a January peak in RRP that was then followed by a decline in RRP. This is exactly the pattern of RRP that was observed with the fall lifted cold stored stock in this study. Ritchie and Dunlap (1980) suggested that as the chilling requirements of shoot buds became satisfied RRP was promoted but as competition for available carbohydrates was increased by shoot growth activity, RRP began to decline. However, in this study stock showed an increase in RN at the same time as shoot metabolic activity was increasing in the spring and this would not appear to support Ritchie and Dunlap's concept.

Wrenching generally improved the overall RRP of stock from all three storage environments, especially prior to spring outplanting. The wrenched stock from the MNR Cooler had about three times the RE of unwrenched stock from the MNR Cooler when it was spring planted. This might be the result of the increased fibrosity of the roots of wrenched stock or it may be that wrenching conditions stock to maintain good over all vigour while in cold storage.

The spring warm up treatment in the MNR Cooler in this instance appeared to promote the proliferation of new root growth. It may be that the growth of many short roots in the spring is associated with increasing temperatures. This proliferation of root growth may be the result of both root primordia initiation and elongation or just the elongation of existing root primordia that were hidden within root cortical zones. The fall lifting and overwinter cold storage of nursery stock in the MNR Cooler and Polyhouse had no clearly defined adverse effect on RRP during the seven month storage period.

3 Outplanting Performance

The results of the RRP test at the time of outplanting indicated that the wrenched MNR Cooler stock had the best physiological planting stock quality, the unwrenched MNR Cooler stock the poorest and the other treatments were intermediate. The results of the RRP test did not reflect upon the overall performance of the stock after outplanting. All the wrenched and unwrenched stock from the three storage treatments had excellent survival. There were no big differences in height or diameter growth after the reduction in the initial size of wrenched stock was accounted for. In an adjacent outplanting trial survival was also exceedingly good even for stock types that in previous years had very poor survival (Day and Harvey 1984). The very cool and moist conditions that prevailed during the spring and early summer may account for the better than 99 per cent survival rate. The fact that there was no difference in the survival of wrenched and unwrenched stock or good and poor root regenerators is because moisture was plentiful and transpiration rates were low. The soil at this planting site although well drained appeared to have a good water holding capacity. Any advantages that wrenched stock may have had in terms of improved RRP, stomatal conditioning or reduced top/root ratios would not be expected to show up under these ideal conditions. Bunting and Mcleod (1984b) found that wrenching improved the outplanting survival of red pine only under dry post- outplanting conditions.

Fall lifted overwinter cold stored stock performed as well after outplanting as stock overwintered in the Field and fresh spring lifted. Outplanted stock from the MNR Cooler had a delay in bud flushing that prevented damage by late spring frosts.

The PMS evaluation 21 days after outplanting showed that there was no significant difference in PMS between any of the treatments. All the stock was within the moderate PMS range according to Day and Walsh (1980).

As expected from needle leaf and stem unit primordia counts of the terminal winter buds on the leader shoots, the wrenched stock had less height growth than the unwrenched stock. Wrenching does reduce the potential for growth the growing season after wrenching and this may result in less height increment after outplanting. This might be considered an undesirable side effect of wrenching but if survival is improved by wrenching a loss in height increment may be tolerated. The other seedling attributes that were measured the growing season after outplanting also indicated that because wrenched stock is smaller when it is planted it may be expected to remain smaller after outplanting at least for one year. In some cases wrenching has reduced the current height increment the first year after planting, but caused an increase in it the second year (Bunting and McLeod 1984c).

CONCLUSION

Wrenching and root pruning may be used to modify the morphological condition of bareroot transplant white spruce nursery stock. Wrenching treatments during the spring and summer; reduces current height increment, reduce primordia numder in winterbuds and next years height growth potential,increases root system fibrosity, reduce top/root ratio and in some instances increase root area index. Wrenching may also improve the root regenerating potential of fall lifted overwinter cold stored and fresh spring lifted, planting stock.

There was no evidence from this study that wrenching and over winter cold storage treatments condition nursery stock to maintain improved internal water balances after outplanting. Wrenching did not improve the survival rate of outplanted nursery stock. The outplanting evaluation of stock in this study took place after a cool moist spring . The results may have been different if the outplanting had taken place under drier conditions.

White spruce transplants in northern Ontario can be successfully fall lifted using the oscilloscope to indicate readiness for lifting and then successfully overwinter cold stored at -2 ^{o}C for seven months. When compared to stock overwintered in the field and spring lifted, overwinter cold storage at -2 ^{o}C; a) satisfies bud dormancy chilling requirements, b) delays bud flushing in the spring and c) may reduce spring frost damage after planting .It changes the mid winter patterns of root regenerating potential but does not reduce the root regeneration of spring planting stock.

In this study exposing stock to natural photoperiods while in overwinter cold storage did not significantly modify bud dormancy processes, root regenerating potential, or spring planting stock quality. The results of this study indicate that a spring warm up treatment of stock that was overwinter cold stored at -2 ^{0}C preconditions nursery stock for spring planting by stimulating a proliferation of new short roots.

Nurserymen growing white spruce may wish to consider the following operational nursery proceedures. These are based upon the results of this study and other white spruce cold storage studies by Day and Harvey (1983, 1984). 1) Root pruning and root wrenching may be used to modify and improve the morphological quality of white spruce transplants. 2) Root pruning and wrenching may be used to improve the RRP of overwinter cold stored white spruce transplants. 3) White spruce transplants may be fall lifted using the oscilloscope technique to determine readiness for lifting and overwinter cold storage. This stock should be overwinter cold stored at $-2^{o}C$ with a six week conditioning period at $+2^{0}C$ immediately prior to spring planting. 4) The polyhouse should be considered as an easy and inexpensive alternative for the overwinter cold storage of fall lifted nursery stock in northern Ontario.

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APPENDIX A

Temperature data for the overwinter cold storage treatment environments.

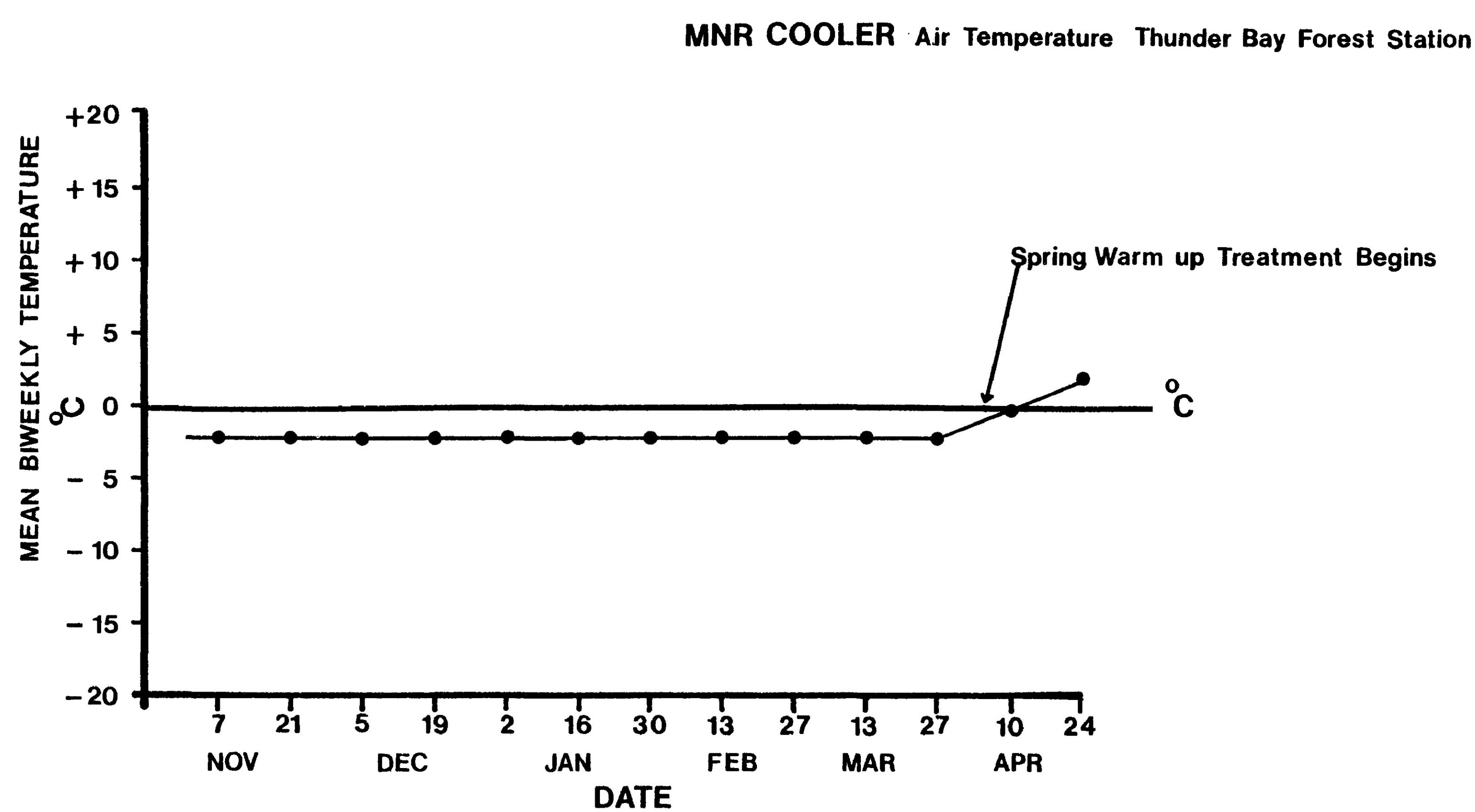

Figure 1A. **The mean biweekly air temperature in the MNR Cooler cold storage unit at the Thunder Bay Forest Station.**

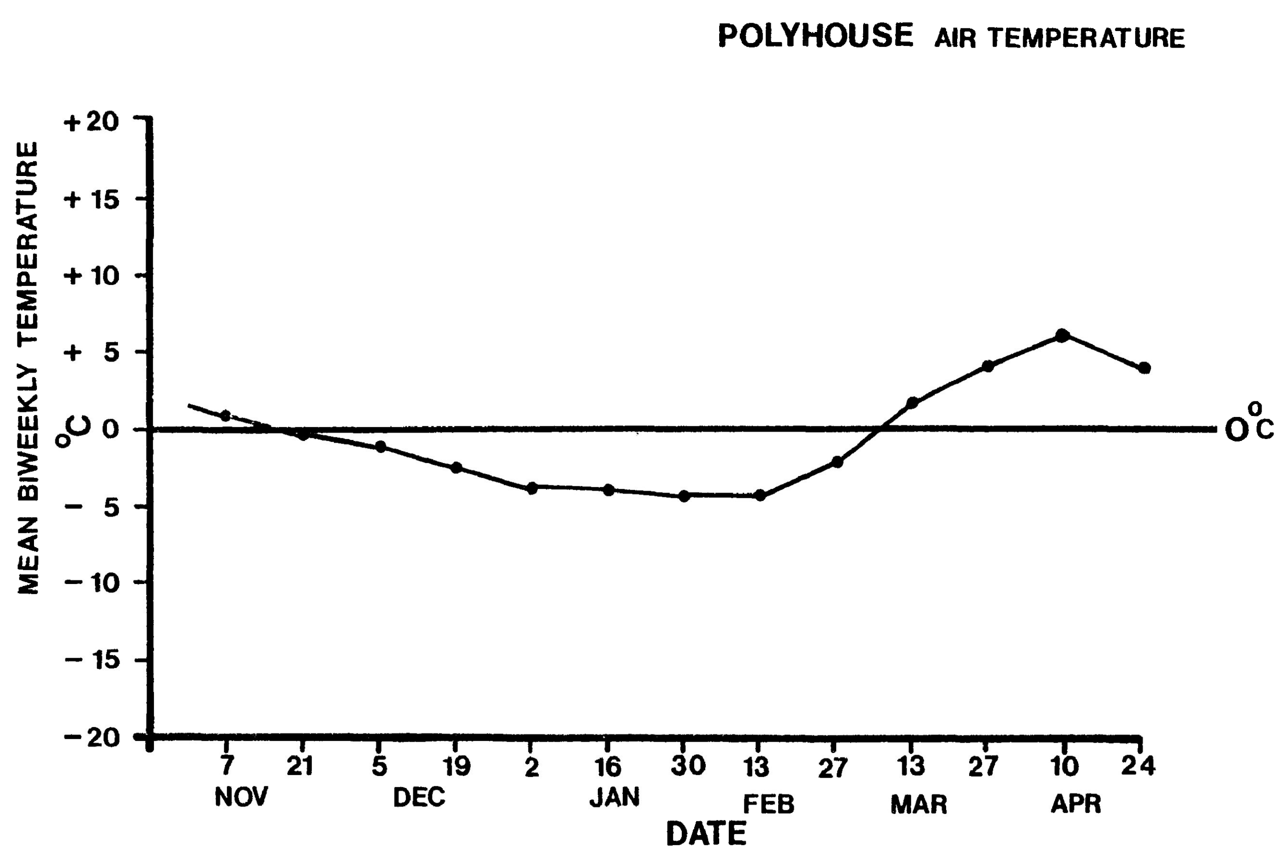

Figure 2A. The mean biweekly air temperature in the Polyhouse experimental storage unit in Thunder Bay Ontario.

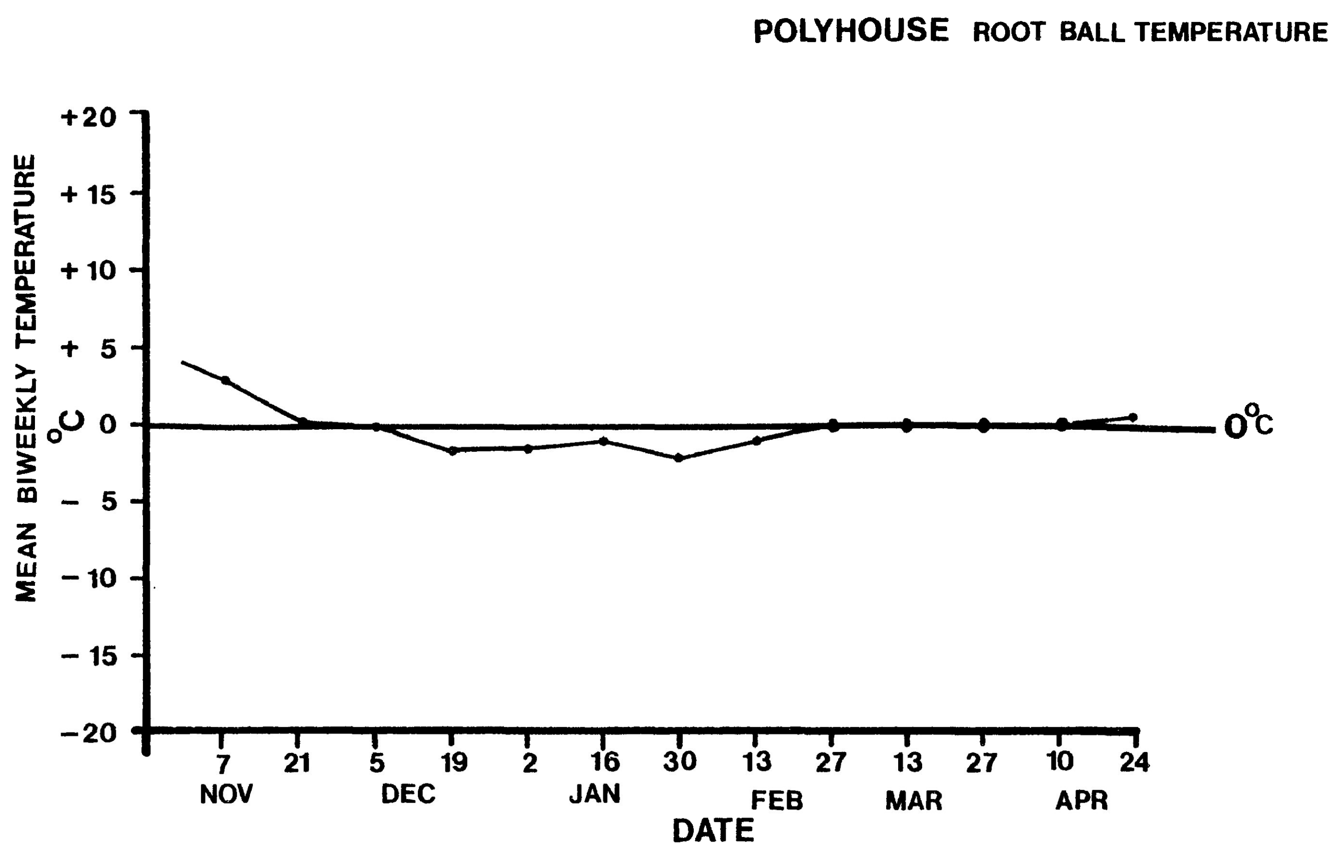

Figure 3A. The mean biweekly temperatures recorded for the roots of nursery stock in the Polyhouse experimental storage unit in Thunder Bay Ontario.

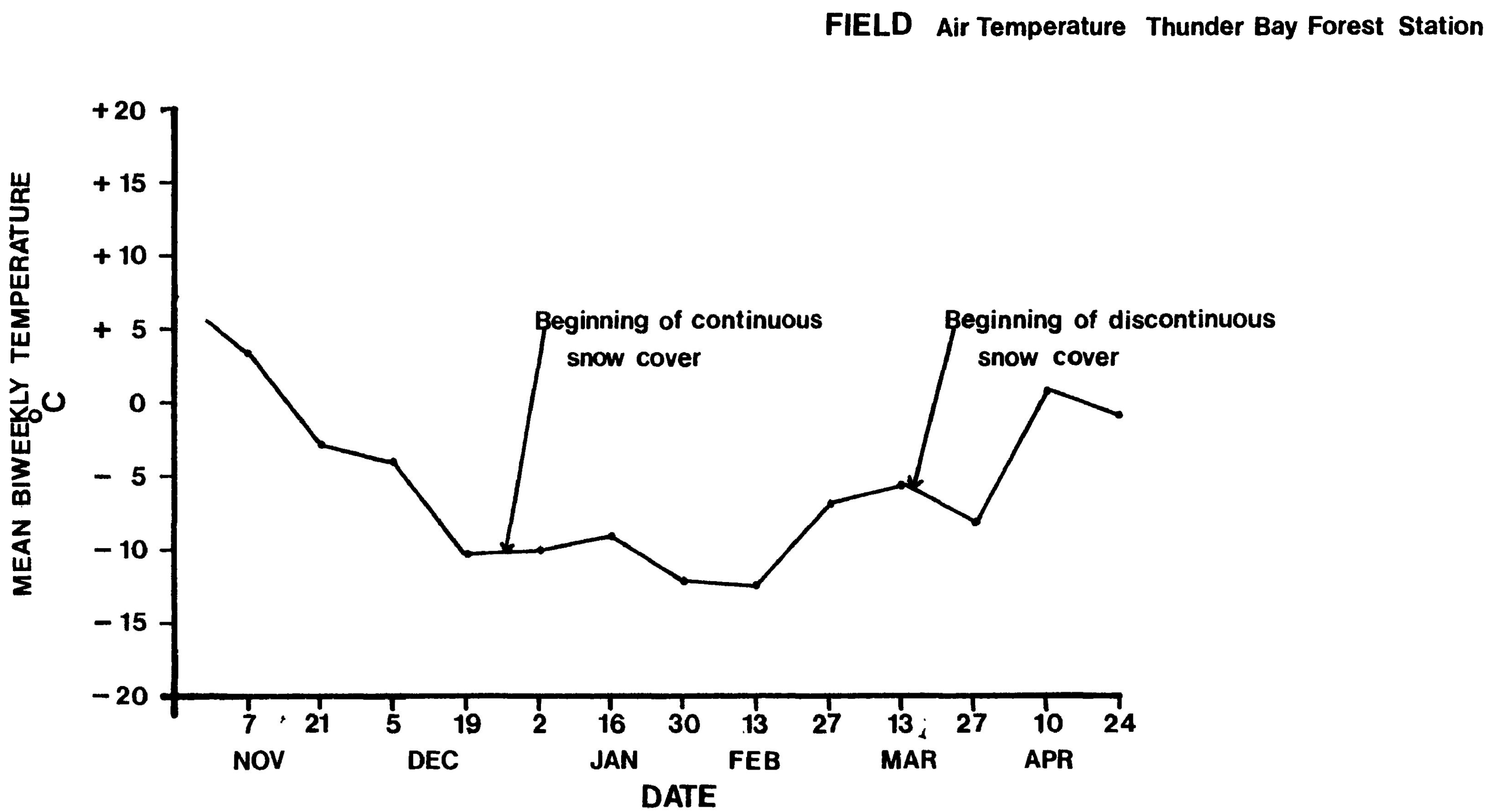

Figure 4A. **The mean biweekly air temperatures recorded 5km from the Thunder Bay Forest Station.**