THE EFFECTIVE ROOT GROWTH POTENTIAL OF JACK PINE (*Pinus banksiana* Lamb.) CONTAINER STOCK

by

© Alan M. Wiensczyk ©

Submitted In Partial Fulfillment
of the Requirements for the
Degree of Masters of Science in Forestry

School of Forestry
Lakehead University
Thunder Bay, Ontario
August, 1989

ISBN 0-315-55723-0

A Caution to the Reader

This M.Sc.F. thesis has been through a semi-formal process of review and comment by several members of the faculty of the School of Forestry, Lakehead University, as well as an external examiner.

It is made available for loan by the faculty for the purpose of advancing the practice of professional and scientific forestry.

The reader should realize that opinions expressed in this document are the opinions and conclusions of the student and do not necessarily reflect the opinions of either the supervisor, the faculty or the University.

ABSTRACT

Wiensczyk, A.M. 1989. The Effective Root Growth Potential of Jack Pine (*Pinus banksiana* Lamb.) Container Stock. 154 pp. Major Advisor; R.J. Day.

Key Words: Root Growth Potential, *Pinus banksiana* (Lamb.), Can-Am #2 Multipot, FH-408 Paperpot, container stock.

The effective root growth potential (RGP) of both potted and outplanted jack pine seedlings grown in Lannen-Sokeri FH-408 paperpots and Can-Am #2 Multipots was measured on three test dates during the summers of 1986 and 1987. Effective RGP refers to the potential of outplanted container seedlings to extend new white roots into the surrounding soil. In 1987 two crop types, overwinter and current crops, were also compared. Effective RGP was measured in three zones: 1, the upper half of the cylindrical area containing the container plug; 2, the lower half of the same area; and 3, the bottom of the plug. The number and length of white root tips projecting from the plug were counted and measured to determine root number (RN) and total root elongation (TRE) in cm from each zone for each container type. Seedlings grown in the Can-Am #2 Multipot had a significantly higher effective RGP than seedlings grown in the FH-408 Paperpot at all three test dates for both data sets in 1986 and 1987. Effective RGP was highest from root zone 3 for seedlings grown in both container types. The overwinter crop also had a higher effective RGP than the current crop seedlings. This difference was significant only in the potting trial.

The morphological development of the three crops of seedlings used in this study was also monitored. Seedling height, root collar diameter and shoot and root dry weights were measured at two week intervals throughout the greenhouse production phase. The Can-Am #2 Multipot stock showed both superior morphological characteristics and regenerated far more roots after outplanting than stock grown and outplanted in Japanese Fh-408 Paperpots. The results of this study support the hypothesis that seedlings grown in a container-free plug system such as the Can-Am #2 Mulitpot which are planted with an unrestricted rootball will exhibit a higher level of root egress as expressed by higher effective RGP values than those seedlings grown in the FH-408 Paperpot which are planted with the paper barrier of the container still surrounding the rootball.

It is recommended that serious consideration be given to converting from the use of restrictive containers like the FH-408 Paperpot to container-free plugs for the production of forest tree seedlings. Some recommendations for future research are also made.

TABLE OF CONTENTS

Page

Page

Page

LIST OF TABLES

LIST OF FIGURES

Page

Page

ACKNOWLEDGEMENTS

I would like to thank Professor R.J. Day for his assistance with the development, funding proposal and preparation of this thesis. Thanks are also due to Dr. K.M. McClain and Dr. H.G. Murchison for their advice and assistance in this study as well as to Dr. R.W. Tinus for his external review of this thesis.

I would also like to thank Mr. Tim Lukinuk and Canadian Pacific Forest Products Ltd. for providing the outplanting sites used in this study.

Thanks are also due to Ms. Maria Vella and Mr. James (Budd) Carter for their assistance with the practical aspects of this project as well as the other labratory assistants for their help with the tedious root counting and measuring.

I would also like to thank Hills' Greenhouses Ltd. and Hodwitz's Greenhouses for providing space in their greenhouses to grow the crops of seedlings used in this study.

Finally, I would like to thank the Ontario Renewable Resource Research Grant Program for providing the funding necessary to complete this research project and Can-Am Containers Limited for their contribution to the funding and for supplying the necessary containers used in the study.

INTRODUCTION

In 1988 approximately 41.7 million jack pine (*Pinus banksiana* Lamb.) container stock were produced for reforestation in Ontario (For. Resources Group, Sault St. Marie, 1989, pers. comm.). Most of this stock were grown in Japanese FH-408 Paper Pots (70 ml in volume) and were outplanted with the cylindrical wall of the pot intact. There is concern, however, about the adequacy of the root development of paper pot stock after outplanting because of the limitations to root development imposed by the paper wall of the pot. Furthermore, the restricted root development wrought by this production system has, in some instances, led to subsequent instablity.

In eastern Canada, many of the forest companies have converted from paper pots to container-free plugs such as the Can-Am #2 Multipot (67 ml in volume) to improve the root form of stock and stability of plantations. For example, owing to acute difficulties with the root form and stability of young jack pine plantations grown from stock produced in FH-408 Paper Pots, J.D. Irving Ltd., a forest resource company in St. John, New Brunswick replaced their system of seedling production with container-free plugs in 1982. In British Columbia and in the Maritime Provinces of Canada, the production of container-free plugs now exceeds that of paper pots (Smyth and Brownright, 1983).

Stability problems reported for older jack pine plantations established using container stock grown in Japanese FH-408 Paperpots often begin as a result of poor initial root egress caused by the barrier imposed by the paper wall of the Paperpot container. This barrier results in a low *effective* root growth potential (RGP) which also has an effect on the initial survival and growth of these seedlings as it has been shown that RGP has a major influence on seedling survival and growth after outplanting (Ritchie, 1985). Ritchie (1985) states that it is imperative that a seedling extend new roots into the surrounding soil matrix in order that new reserves of soil moisture and nutrients, which are essential for seedling growth, can be tapped. Day *et al.* (1976) stated that RGP is one of the most critical indicators of the physiological condition of the stock. It is important to note that a seedling may have a high RGP at the time of outplanting and still have a low 'effective' RGP if the roots do not egress from the container plug into the soil.

Seedling RGP may also be influenced by seedling morphology, especially root dry weight. It has been found in several studies (Arnott, 1974; Scarratt, 1974; Armson, 1975 and Barnett, 1984) that seedling size has an affect on seedling survival and rates of growth after outplanting.

RGP can be defined as "the potential of transplanted or outplanted nursery stock root systems to initiate or elongate new white roots shortly after transplanting or outplanting" (Day, 1981). The terms Root Regeneration/Regenerating Potential (RRP) and Root Growth Capacity (RGC) have also been used throughout the literature to describe the same measure of seedling physiology. Effective RGP refers to the potential of outplanted container stock to initiate or elongate new white roots from within the container plug into the surrounding soil shortly after outplanting. The effective RGP of seedlings not only depends on the physiological state of the seedlings at the time of outplanting, but it also depends on the presence of any physical barriers which inhibit root egress such as, the paper wall of the paperpot container. Regrettably, little is known about the RGP or the effective RGP and subsequent development and egress of the roots of trees produced in container-free plugs owing to lack of research.

It is hypothesised by the author that seedlings grown in a container-free plug system such as the Can-Am #2 Multipot which are planted with an unrestricted rootball will exhibit a higher level of root egress as expressed by higher effective RGP values than those seedlings grown in FH-408 Paperpots which are planted with the paper barrier of the container still surrounding the rootball.

The above hypothesis was evaluated in terms of the following objectives:

Principal Objectives:

1. To evaluate the effective RGP of jack pine container stock grown in Japanese FH-408 Paperpots and Can-Am #2 Multipots for both a current crop and an overwinter crop and potted over three test dates during the outplanting season under controlled-environment conditions.

2. To determine the effects of the field environment on the expression of the effective RGP of jack pine container stock produced under the two crop schedules.

Secondary Objective:

3. To monitor the progression of seedling height, root collar diameter, shoot dry weight and root dry weight during the greenhouse production phase of jack pine container stock grown in Japanese FH-408 Paperpots and Can-Am #2 Multipots as a current and overwinter crop in order to evaluate differences in seedling morphology between seedlings grown under the two crop schedules in the two container types.

As there has not been any research to date on the RGP of jack pine container stock and as there has been little research on its development of vigorous and stable root systems after outplanting, the proposed research is critical for the continued development of container reforestation programs with this economically important species.

LITERATURE REVIEW

INTRODUCTION

Concern has been expressed for decades about the survival and growth of outplanted nursery stock (Sutton, 1983). Many authors have indicated that establishment appears to be dependant upon the ability of nursery seedlings to initiate and extend new roots after outplanting or, in other words, on the RGP of the stock (Stone, 1955; Tinus, 1974; Burdett, 1979a; Ritchie and Dunlap, 1980; Sutton, 1983; Ritchie, 1985; Navratil *et. al.*,1986; Burdett, 1987). Ritchie (1985) gives the rationale for this premise. He stated that when a seedling is planted it has a finite root system which is capable of utilizing the moisture and nutrients in its immediate vicinity. Ritchie (1985) added that these reserves are soon depleted and in order for a seedling to survive new nutrient and moisture reserves must be tapped. It is, therefore, imperative that the seedling produce new roots quickly after outplanting. This is especially so as Day and Harvey (1982) noted that bareroot stock often loses up to 20% or more of its original root system three weeks after outplanting.

New root production may include initiation and elongation of new lateral roots, regrowth of inactive roots or the development of adventitious roots (Ritchie and Dunlap, 1980). The majority of the cited papers have dealt specifically with bare-root seedlings as the literature on the RGP of bareroot stock is extensive (Day *et al.* 1985; Ritchie 1985). To date, there is little published information on the RGP of any species of coniferous container stock. An exception is a paper by Johnson-Flanagan and Owens (1985b) who worked with white spruce (*Picea glauca* (Moench.) Voss.) grown in Styroblocks in British Columbia.

It has generally been accepted that RGP tests conducted under standard conditions in a greenhouse or controlled-environment cabinet (lab RGP) are a good predictor of the RGP of seedlings in the field

(field RGP). To date there is no published evidence on the relationship between lab RGP and field RGP (Burdett, 1987). Ritchie (1985) also noted the lack of data on the relationship between RGP and post planting performance. He said, however, that there are about 20 such studies, e.g.(Stone, 1955; Rhea, 1977; Stone and Norberg, 1979; Burdett, 1983) and that in many cases good agreement was reported between lab RGP and survival in both field and greenhouse tests. Ritchie also added that RGP has also been a good predictor of growth in some cases e.g.(Von Althen and Webb, 1978; Burdett *et al.*, 1983). Ritchie also cited two studies for which there was little correlation between RGP and field survival. The first one by Brissette and Roberts (1984) reported low correlations between the RGP of loblolly pine (*Binus taeda* L.) seedlings and survival and height growth in the field. In the second study by Sutton (1983), field survival showed poor correlation with the RGP of both jack pine and black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings. Ritchie (1985) did conclude however, that the information available does indicate a strong relationship between RGP and field survival. In a later study, Sutton (1987) found that for jack pine seedlings, RGP, as measured by the mean length of roots greater than 1 cm, correlated well with field root growth for both the number of new roots and the length of those roots and with third year total height. He also found high correlations between RGP and third year field performance for both jack pine and black spruce seedlings. Sutton found little correlation between lab RGP and seedling survival when seedlings were planted in the nursery because survival was 100%.

This last finding supports an earlier statement by Sutton (1983) and Day and Harvey (1984) who said that correlation between RGP in the lab and survival in the field is often site specific. Sutton (1983) was not able to demonstrate the relationship between RGP and field survival because of diverse weather and outplanting site conditions. Under ideal field conditions, adequate soil moisture and optimum soil temperature, seedlings with low RGPs at the time of outplanting may survive and grow just as well as seedlings with high RGP. However as site conditions deteriorate, the higher the RGP the more probable is seedling survival. In contrast, under extremely adverse conditions even seedlings with high RGP at the time of outplanting may not survive (Burdett, 1987). Sutton (1980) also stated that "two trees or batches of trees may produce equal amounts of new root growth in unstressful test conditions and yet may differ greatly in this regard under stress." So it appears to be very difficult to correlate the RGP of seedlings grown under ideal conditions in controlled-environment cabinets with the RGP that occurs in the field.

ENVIRONMENTAL FACTORS

Several environmental factors have been thought to influence the expression of the RGP of outplanted nursery stock. These factors include the soil factors, moisture, temperature and compaction; as well as the climatic factors, air temperature, light intensity and photoperiod. Of these factors soil moisture and soil temperature seem to be the most critical (Tinus, 1974; Ritchie and Dunlap,1980).

Soil Moisture

Soil mositure has been shown by many authors to be one of the most critical factors limiting the expression of seedling RGP. Unfortunately soil moisture has been expressed using a variety of terms which include Total Soil Moisture Content (TSMC), Available Soil Moisture Content (ASMC), Soil Moisture Tension (TMS) and Soil Water Potential (SWP). The reader should be cautioned about this in the review that follows.

Soil water plays a key role in all physiological processes such as, cell expansion and growth (Villee, 1977) and plant photosynthesis (Hsiao, 1973; Larcher, 1980). Several studies were initiated by Day *et al.* (Day and Stupendick, 1974; Day and Butler, 1975; Day and MacGillivray, 1975; Polhill, 1975; Day and Breunig, 1977) which study the effects of soil moisture and lifting date on the RGP of black and white spruce and jack pine bare root seedlings. These studies examined the effects of total soil moisture content (TSMC) levels of 15, 10 and 8% (-0.1, -0.6 and -1.5 bars soil water potential (SWP)) on root growth potential. RGP was generally found to be the best at 15% TSMC (100% ASMC) for all species and the worst at 8% TSMC, although the effect of soil moisture was somewhat dependant on lifting date. Those seedlings lifted in May when RGP was high showed little difference in RGP between moisture levels whereas seedlings lifted in August when RGP was low were profoundly affected by soil moisture. Jack pine seedlings seemed to be the least affected by soil moisture levels when RGP was high but were the most adversely affected by changes in soil moisture when RGP was low.

Stone and Jenkinson (1970) found the same effect to hold true for ponderosa pine (*Pinus ponderosa* Laws.) transplants. They encountered severe seedling mortality levels for seedlings transplanted into soils in which the available soil moisture content was 15% or less. They also found that root elongation increased up to an available soil moisture level of 50% and that beyond that point root elongation remained the same or was less depending on the month of testing. However, they found that shoot growth increased proportionally to available water up to 100% available soil moisture. Merritt (1967) found that for red pine (*Pinus resinosa* Ait.) seedlings, soil moisture levels of less than 10% induced cessation of root growth. Tinus (1974) also stated that plant moisture stress of 4 to 12 bars, depending on the species, stopped root growth. Mahon (1976) found that for white spruce, root and shoot growth decreased as total soil moisture content (TSMC) and soil water potential (SWP) decreased from 15 to 5% and -0.1 to -6.0 bars respectively. He also stated that bud break and root growth initiation were also delayed at low TSMC levels. Hauranek and Benecke (1978) found that *Larix decidua* (Mill.), *Picea abies* ((L.) Karst.) and *Pinus cembra* L. seedlings utilized a large portion of soil moisture down to -1.5 bars soil water potential. Pine seedlings began a gradual reduction in gas exchange below a soil water potential of -0.4 bars but in spite of this early and sensitive reduction in gas exchange, the pine seedlings maintained the highest net photosynthesis/transpiration ratio. This would seem to indicate that even at low soil moisture levels photosynthate would still be available for root and shoot growth of pine seedlings. Larch seedlings maintained the highest gas exchange levels until soil water potential fell to -3.5 bars after which shutdown in gas exchange was rapid. Spruce seedlings followed a similar pattern to larch but shutdown occurred at a soil moisture level between that for the pine and larch. Pine seedlings used the limited available moisture more slowly and economically than the other two species and thus were the least affected by a reduction in soil moisture.

Sutton (1978) states that soil moisture status is intimately related to the mineral nutrition of plants, as water is the major transport mechanism of nutrients into plant roots, and that new outplants begin to experience nutrient stress before any serious moisture stress is developed. However, Nambiar (1980) stated that the nutrient status of the soil has little effect on root growth except at high deficiency levels. Burdett *et al.* (1974) also stated that in the first year after outplanting soil moisture is the limiting factor in seedling growth whereas in the second year after outplanting nutrient levels become limiting. Soil moisture availablity and the plants ability for moisture absorption has a direct effect on the uptake of mineral nutrients.

The studies cited above indicate that a total soil moisture content of between 10 and 15% is considered non-limiting in terms of seedling root development for the majority of tree species.

Soil Temperature and Compaction

Soil temperature appears to be a particularly important factor controlling RGP in cool temperate, warm temperate and tropical regions. The threshold temperature for RGP appears to be related to the regional climate.

Kaufman (1945) found that for natural stands of jack pine in the Cloquet Forest in Minnesota root growth resumed in the spring when the temperature of the upper 15cm of soil rose above $4^{o}C$ ($40^{o}F$) but that root growth was limited until the temperature was over $10^{o}C$ ($50^{o}F$). Hoffman (1971) (*cited in* Tinus (1974)) said that the roots of most species do not grow much below soil temperatures of 5^{o} to $7^{o}C$. However, Larsen *et al.* (1986) reported that "some species may exhibit root growth even when soil temperatures are below $5^{o}C$." Ritchie and Dunlap (1980) said that root sensitivity to soil temperature also seems to vary seasonally. They cited a study by Stone and Schubert (1959a) who found that ponderosa pine seedlings seemed to regenerate new roots at lower temperatures in the spring than in the fall.

Aubez (1971) working with Corsican pine (*Pinus nigra* Arn., var.

laricio), a warm temperate species, found that soil temperature seemed to control the beginning and end of root growth and that the rate of root growth and the number of growing root tips reached a maximum when soil temperature was the highest. Nambiar *et al.* (1979) found that there was little root growth below soil temperatures of 10°C for radiata pine (*Pinus radiata* D.Don.) seedlings and that the optimum soil temperature for root growth was at 20°C. Stupendick and Shepherd (1979) also found that for radiata pine seedlings the best root growth occurred between 20° and 30°C and that at soil temperatures above 30°C root growth declined. Barney (1951) found that 20°C was the optimum soil temperature for the root growth of loblolly pine seedlings from Louisiana but that seedlings from N. Carolina exhibited the best root growth at a soil temperature of 25°C. Stone and Schubert (1959a) reported that the amount of new root growth varied with soil temperature. For ponderosa pine seedlings RGP was poor at a soil temperature of 10°C but increased to a very high level at a soil temperature of 25°C. Ritchie and Dunlap (1980) concluded from several studies that generally the root growth of undisturbed seedlings was the best in soils with a temperature between 18° and 25°C, depending on the species.

Abod *et al.* (1979) found that the soil temperature effect was independant of air temperature and that the best root growth was obtained at a soil temperature of 25°C for two tropical pines, *Pinus caribaea* var. Hondurensis and *P. kesiya* seedlings. At the optimum soil temperature the main response of roots was the initiation of new lateral roots whereas at less than optimum temperatures root regeneration was mainly from old root ends for these two species. Stupendick and Shepherd (1979) also noted changes in root morphology in response to changes in soil temperature for radiata pine (*Pinus radiata* D.Don.) seedlings. They found that at low soil temperatures newly formed roots were thick, white and brittle. At higher soil temperatures thin, flexible suberized roots were produced.

Root growth for the majority of tree species appears to be limited in soils with temperatures below 10°C and optimal when soil temperature is between 18 and 25°C.

Soil compaction has also been thought to influence the expression of the RGP of outplanted seedlings, but to date there is no published information that examines this effect (Ritchie and Dunlap, 1980).

Air Temperature

Air temperature was also found to affect the expression of root growth potential of outplanted seedlings (Abod, 1978; Abod *et al.*, 1979; Stupendick and Shepherd, 1979). Higher air temperature, up to a certain point, increases enzymatic and cellular activity and generally results in higher rates of respiration and growth. Abod (1978) found that root growth at high soil temperatures were further enhanced by high air temperatures. In a later paper, Abod *et al.* (1979) found that optimum root growth occurs at a day air temperature of 27°C for *Pinus caribaea* var. Hondurensis seedlings and at a day air temperature of 24°C for *P. kesiya* seedlings. They also found that the RGP of seedlings was not related to the diurnal variation in temperatures. Stupendick and Shepherd (1979) found that optimum root growth occurred at a temperature of about 27°C for radiata pine seedlings. They also noted that at differing night temperatures there were no significant differences in the number of white roots > 1.5 cm, but that there were significant differences in the length of new white roots > 1.5 cm produced. They felt that this suggested low night temperatures favoured root initiation, but not root elongation. They also stated that the most favourable temperature for root growth was similar to the optimum temperature for the growth of the seedling as a whole.

Light Intensity and Photoperiod

Several authors have also found light intensity to have an effect on the RGP of transplanted seedlings (Barney, 1951; Abod *et al.*,1979). Light intensity affects root growth indirectly by influencing the amount of photosynthate produced by the seedling which is available for growth. Barney (1951) found that the lowest light intensity at which root growth took place was between 1 300 and 3 200 lux. Abod *et al.* (1979) found that as light intensity increased from 11 000 lux to 23 000 lux, RGP of *Pinus caribaea* var. Hondurensis and *P. kesiya* seedlings also increased. They also found that, in a separate experiment, increasing light intensity from 16 - 50% of full sunlight (approx. 16 000 to 50 000 lux) increased RGP markedly wheras a further increase in light intensity to

100% full sunlight (approx. 100 000 lux) had little effect on the RGP of the seedlings and even caused a slight reduction in root growth. Unfortunately, differences in light measuring units make it difficult to compare the results of these studies.

Ritchie and Dunlap (1980) suggested that photoperiod may also affect the RGP of seedlings but there is no published information available relating this factor to the RGP of outplanted seedlings.

SEASONAL PERIODICITY

Environmental factors alone cannot fully explain the variation in the RGP patterns of seedlings. It has long been believed that the gross pattern of root activity is endogenously controlled and that environmental factors serve only to influence an internal periodicity in seedling RGP (Aubez, 1971). Merritt (1967) noted that the environment may influence the intensity and timing of events but that the basic pattern in RGP is the expression of an identifiable endogenous rhythm.

Stone and Schubert (1959a) reported that ponderosa pine bare-root seedlings grown in California exhibited a definite seasonal periodicity. They found that the RGP of the seedlings was low throughout the summer months of July and August. It then increased throughout the fall and winter months and peaked in the spring just prior to bud break. After terminal bud break there was a sharp initial decrease in the RGP of the stock followed by a gradual decrease throughout the spring until the summer low. They also noted that root initiation was only evident between December and June and that root elongation occurred during all months of the year except for July and August.

Stone *et al.* (1962) also reported the same type of pattern in the RGP of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco.) seedlings. They found that seedling mortality was high between May and August when RGP was low, was moderate between February and April when RGP was moderate and was low between November and January when RGP was high.

Day *et al.* (1976) found that similar patterns existed for black and white spruce seedlings lifted throughout the northern Ontario growing season. RGP was high in the spring, low and somewhat erratic throughout the summer and then rose again in the fall. Jack pine seedlings also exhibited a strong seasonal periodicity. For this species RGP declined from mid-June to late-August to nil and then began to increase (Stupendick, 1973).

Some variation in RGP periodicity has been reported. Stone and Schubert (1959a) reported that the RGP of seedlings was affected by seed collection zone and by the nursery at which the seedling was raised. Stone *et al.* (1963) found some variation in the RGP of ponderosa pine seedlings grown at four different nurseries in California. At a more northern nursery; it was also at a higher elevation, the autumn increase in RGP began earlier and the spring peak and subsequent decline occurred later than for seedlings grown at more southern nurseries. Differences in the intensity of RGP have also been found between species, seed lots, families and stock types (Ritchie, 1985).

Most species of bareroot forest tree seedlings exhibit a definite seasonal periodicity in RGP. Jack pine bare-root seedlings have been shown to exhibit a peak in RGP occurring prior to spring bud break followed by a steady decline over the summer months until the fall at which point RGP began to increase again.

ENDOGENOUS CONTROLS

Several endogenous factors have been thought to control the RGP of tree seedlings. These include bud dormancy, stored carbohydrate reserves and current photosynthate availability as well as some hormonal controls of root growth. It has also been noted that initiation and elongation of new roots may be under different endogenous and exogenous controls (Ritchie and Dunalp, 1980). Opinions among authors regarding the relative importance of any of these factors and their effect on RGP are extremely variable. These endogenous factors may also be interrelated and subject to the effects of the exogenous factors discussed earlier.

Ritchie and Dunlap (1980) reported that RGP appears to be closely linked to bud dormancy and that RGP peaks when the chilling requirement for dormancy release is fulfilled. Kreuger and Trappe (1967) reported that for Douglas fir seedlings rapid root growth did not coincide with shoot elongation but both preceded and followed it. They found a strong correlation between root activivty and lower reducing-sugar concentrations in seedling roots. Webb (1977) also found a relationship between bud dormancy and root regeneration of sugar maple (*Acer saccharum* Marsh.) and white ash (*Fraxinus americana* L.) seedlings. He reported that increased root regeneration coincided with the loss of bud dormancy and that maximum root regeneration was observed after 3500 hrs of chilling for both species. This supports a statement by Stone and Norberg (1971) that RGP is closely correlated with hours of cumulative exposure to low air temperatures. Krugman and Stone (1966) found that exposure of ponderosa pine seedlings to 150 consecutive cold nights ($<10^{o}$C) increased the number of newly initiated roots significantly. Fraser (1976) also reported that the cooling of the root zone expressed in degree hardening days (Base temperature 10^{o}C) was highly correlated with the spring root elongation of the overwinter stored red pine (*Pinus resinosa* Ait.) seedlings. He found that the seedlings required a minimum of 325 degree hardening days before the seedlings were lifted in the fall in order to ensure acceptable post planting levels of spring root growth.

Ritchie and Dunlap (1980) suggested that seedling root growth in response to bud dormancy and chilling may be related to the internal allocation of photosynthate between the shoots and roots. A spring reduction in root growth is commonly associated with renewed shoot activity. This may be related to the competetion between the roots and shoots for carbohydrates or on their relative sink strengths (Ritchie and Dunlap, 1980). The carbohydrates needed for root and shoot growth may come from two sources; 1) carbohydrates that are stored in the plant, and 2) carbohydrates produced by current photosynthesis.

Kreuger and Trappe (1967) stated that the concentration of two sugars, sucrose and raffinose, increased during the early winter and were apparently converted to starch in the spring prior to the growth of Douglas fir seedlings. Webb and Dumbroff (1978) stated however that several studies have shown that root elongation of the first year seedling is strongly dependant on the continued production of current photosynthate for most hardwood species. Van den Driessche (1978) stated that conifers do not store starch during the dormant season to the same extent as many hardwoods and that new root growth is dependant on current photosynthate availability. Van den Driessche (1978) compared seasonal changes in RGP and carbohydrate concentrations in red pine and white spruce nursery seedlings. He reported that it was unlikely that stored carbohydrate concentrations had any direct relationship to changes in RGP since similar patterns of carbohydrate change occurred in both species while seasonal patterns in RGP were different. Van den Driessche (1978) found that girdling, defoliation and debarking of red pine seedlings reduced their RGP and he concluded that current photosynthates were essential for new root growth of this species. In a later study Van den Driessche (1987) used radioactive $^{14}CO_2$ to investigate the role of current photosynthate on seedling growth. He found that levels of radioactive carbon in the roots indicated that current photosynthate was the primary carbon source for new root growth.

Johnson-Flanagen and Owens (1985b) also stated that the failure of aerial tissue to replenish carbohydrates to the roots may induce and sustain quiescence in individual roots of white spruce seedlings. They added that either an increase in the sink strength in the shoot or lack of photosynthate production could cause this phenomenon. This conclusion supports the positive correlation found by Van den Driessche (1978) between light intensity and root growth of root pruned red pine seedlings. He believed that the rate of photosynthesis was the most important factor in regulating root growth.

Webb and Dumbroff (1978) have stated that hormonal controls of photosynthate transport may mediate the competition between the roots and shoots for growth materials. Ritchie and Dunlap (1980) reported that considerable study has been done on the effect of plant growth regulators on root initiation. They stated that it has been well established that auxins are of prime importance in regulating root growth directly and indirectly by acting on the other hormones related to RGP. Zaerr (1967) however found that even though both diffusable auxin concentarions and RGP showed seasonal peaks they were out of phase and poorly correlated. He concluded that the results of his study suggest that auxin may have some function in root growth, but that it had little influence on the RGP of transplanted ponderosa pine seedlings.

Webb and Dumbroff (1978) reported that indolacetic acid (IAA) and auxins were found to influence root growth in some hardwoods. They also found that seasonal patterns in the concentration abscisic acid (ABA) in the roots were inversely related to the root growth pattern for sugar maple seedlings. Ritchie and Dunlap (1980) stated that ABA is synthesized in the root cap and that it appears to strongly inhibit root initiation and elongation. They also reported that cytokinins are involved in bud burst and that this may indirectly influence the RGP of seedlings. Ethylene may also indirectly affect root growth through its affect on shoot growth and gibberelins may also have an indirect effect on root growth through their influence on the distribution of photosynthate (Ritchie and Dunlap, 1980).

Togoni and Lorenzi (1972) found higher concentrations of an acid phase of methanolic extracts (Rf 0.9-1.0) in difficult to root cultivars of white spruce (*Picea glauca* var.•albertiana) than in easy to root cultivars of *Chamaecyparis sp.*. They reported an interesting relationship between concentrations of this hormone and IAA and root growth and concluded that root initiation may be determined by a hormonal balance rather than by any single hormone.

All of these endogenous factors including bud dormancy, stored carbohydrate reserves and current photosynthate availability as well as some hormonal controls are thought to influence seedling root growth. However, the relative importance of any of these factors and the relationships amongst them are not well defined.

CULTURAL PRACTICES

Several cultural practices have also been shown to influence the RGP of seedlings. Root pruning, a common practice in bare-root nurseries has been found to increase the fibrosity of the root system (Stupendick and Shepherd, 1980) and to increase the RGP of the seedlings (Harvey, 1984). Duration of cold storage has also been known to influence the RGP of tree seedlings. Ritchie and Dunlap (1980) reported that cold storage probably affects RGP through its interaction with bud dormancy and carbohydrate reserves. They stated that the effects of cold storage on the RGP of seedlings depends on storage temperatures, lifting date and the duration of storage. They noted that storage temperatures outside the range of -2^{o} to $+5^{o}C$ are generally detrimental to seedling physiology and vigour. They also added that prolonged exposure to sub-freezing temperatures may cause tissue desiccation and cell damage. Harvey (1984) and Buse (1987) working with white spruce both give an ample review of the literature dealing with overwinter storage and its effect on the RGP of seedlings.

Mullin (1974) found that exposure of the roots to the air prior to planting can significantly reduce survival and growth presumably due to desiccation and the resulting dieback of the root system. He also found that the effect of exposure was offset by the relative humidity of the air during the period of exposure.

The survival and growth of seedlings after outplanting has also been shown to be affected by seedling size i.e. height, root collar diameter and dry weight. Differences in the morphological attributes of seedlings at the time of outplanting are often still apparent several years later. Arnot (1974) found that in field trials with Douglas Fir bullet seedlings, differences in survival and height growth between 'small' and 'large' seedlings, paired for comparison, were immediately apparent and continued to be significant in the 5th year assessment. Larger seedlings have been shown to exhibit higher survival percentages and are more able to compete with unwanted vegetation than smaller seedlings. McMinn (1981) found that in trials with white spruce container stock, seedling size and site conditions significantly affected survival and growth of outplanted seedlings. He concluded that small seedlings may perform poorly after outplanting on sites with the potential for dense competing vegetation unless vegetation is controlled by site treatments. Armson (1975) found that small and large black spruce seedlings at the time of outplanting remained small and large after the tenth growing season. Scarratt (1974) also noted a relationship between tree size and container seedling performance. He concluded that many early plantation failures were a result of small trees being planted which could not compete with other vegetation and resulted in the seedlings becoming supressed and exhibiting growth rates relative to seedling size or dieing. Barnett (1984) also found that larger seedlings grown in Styroblock 2's and 4's exhibited greater rates of annual growth and performed much better than smaller seedlings. However, he also added a note of caution in that, it is expected that a point exists after which larger seedlings do not result in greater field growth and that there are biological as well as economical limitations as to how large seedlings should be before outplanting.

Seedling size may also have an effect on the expression of the physiological attributes of the seedlings, especially root growth potential. Larger seedlings would generally exhibit a higher RGP than smaller seedlings, although the relative RGP would be similar, as larger seedlings would have more root mass from which to elongate and initiate new roots. This assumes that both large and small seedlings are at the same stage of physiological development.

Root pruning and cold storage conditions have both been shown to have an effect on the RGP of forest tree seedlings. Seedling size has been found to affect seedling survival and growth after outplanting and may also have an effect on the RGP of the stock.

RGP MEASUREMENT

Several different methods of measuring RGP have been developed over the past three decades. RGP measurement involves several steps:

1) placing seedlings into an environment favourable for root growth, such as a warm greenhouse or controlled-environment cabinets,

2) growing the seedlings for a standard period of time, and

3) assessing the amount of root growth which has occurred during the standard time period.

The majority of RGP tests have been conducted in either controlled-environment cabinets or greenhouses and others have been conducted in the field. Changing field conditions have made the results from these tests very difficult to interpret without the availability of weather monitoring data. Controlled-environment cabinets or growth chambers have the advantage in that growth conditions can be strictly monitored and are generally less variable than either conditions in a greenhouse or in the field. Ritchie (1985) stressed a key point in that it is imperative that the test environment remain constant from test to test and in this regard controlled-environment cabinets are the most suitable. The homogeneity of test conditions are imperative in order that comparisons can be made between different stock lots within the same growing season and between crops grown in different years.

Test environment conditions have been relatively consistant although there have been some minor variations between investigators. The generally accepted test conditions include a 16-hour photoperiod with 30,000 to 50,000 lux illumination. Day temperatures range between 25° to 30°C with relative humidity of 50 to 60% while night temperatures of 20° to 25°C and a relative humidity of 80 to 100% are standard.

Seedlings have been grown under a wide variety of rooting conditions. These include testing the seedlings after potting them in a soil mix, growing them hydroponically or aeroponically. The potting test is most often used. Seedlings are potted in a soil mix in standard greenhouse pots. Soil media have ranged from straight peat to straight vermiculite or perlite. A 2:1 mix of peat:vermiculite is the most common soil medium used today as it provides adequate soil moisture retention and adequate soil aeration. Bloomberg (1963) used glass beads in an 8 X 4 X 1 cm container as a medium so that he could observe roots and root organisms is situ. Several authors have also used glass-faced planting boxes in which seedlings are planted vertically into a box having a glass bottom or side inclined at a 30° to 45° angle. The roots because of geotropism grow against the glass face and therefore root development can be traced (Lavin, 1961; Larson, 1962; Muzik and Whitworth, 1962; Mullin, 1963; Stupendick, 1973: MacDonell, 1980).

Seedlings have also been grown hydroponically in either aerated water or in an aerated nutrient solution in glass aquariums. Ritchie (1985) reported that this method correlated well with the potting method of measuring RGP. He listed several advantages of this method for monitoring the RGP of bare-root stock. These are:

1) Root growth can be monitored continuously over the test period.

2) There is no potting and unpotting of seedlings required.

3) A greater spatial and temperal uniformity is achieved.

4) Assessment of new root is more accurate because,
    a) new roots are clean and easily distinguished, and
    b) there is little chance of breakage of roots in the unpotting process.

5) Alternative methods of root counting can be used, such as photography and liquid displacement.

6) Less bench space is needed.

7) The seedlings require minimal amounts of maintenance.

The disadvantage of the hydroponic method is that it can only be used for bare-root stock or container stock in which the container and soil have been removed.

Day (1981) developed the aeroponic method of the Root Mist Chamber (RMC) for measuring seedling RGP. Seedlings are suspended vertically in a fixed frame with their root hanging down into an enclosed chamber. Spray jets spray the seedling roots with a fine mist of water for 5 seconds every 30 minutes. The root mist chamber is placed in a controlled-environment cabinet for the period of the RGP test. This method is also limited in its use to bare-root seedlings and container seedlings in which the container and soil have been removed.

Day (1981) also outlined a root growth box methodology for measuring RGP. Seedlings are slipped between sleeves of polyethylene and on top of a pad of polyurethane foam. The roots of the seedlings are spread carefully and the planted pads are packed tightly between polyfoam 'spacers' so that the vertical orientation of the seedlings is maintained. The polyurethane is irrigated to keep the roots moist and the root growth boxes are placed in controlled-environment cabinets. This last method of measuring RGP is not commonly used because of the difficulty of keeping the polyfoam moist.

The length of RGP tests have also varied among investigators. Growing times anywhere from 7 days (Burdett, 1979) to 60 days (Stone, 1955) have been used. The most common test period used is 21 days. A shorter test period is beneficial for practical reasons as the seedlings at the end of the test are still physiologically similar to those at the beginning of the test. In this regard the 7 day test is preferable. However, Harvey (1987) found that the 7 day test was insufficient for testing the RGP of white spruce and jack pine bare-root stock and recommended that a 14 day test be used.

Several different methods of quantifing the RGP of seedlings have also been used. RGP is usually estimated from one or more of the following attributes;

1) Root Number (RN),

2) Root Elongation (RE),

3) Root Area Index (RAI), and

4) Root Volume (RV).

Root number is determined by counting the number of new white root tips. Sometimes only the number of roots greater than a certain length, such as 1 cm, are counted and those less than 1 cm are either ignored or their numbers are estimated and are then put into a root number class and are coded for each seedling using codes such as those put forward by Day and Harvey (1985). Total root number may also be counted and put into class as in the case of Burdett's code (1979).

Root elongation can also be determined and is usually expressed as the total length of white root tips greater than a certain length. Smaller roots may also be classified into codes as well (Day *et al.*, 1985). Root elongation may also be combined with root number to express RGP as the mean white root length per seedling.

RGP can also be measured as the increment or decrement in Root Area Index. Root Area Index is measured using a rhizometer developed by Morrison and Armson (1968). The rhizometer basically consists of a light source, an aperature in which the seedling may be placed, a photocell to measure the reduction in light due to the roots and a galvanometer which in turn measures the decrease in output from the photocell (Morrison and Armson, 1968). The roots are spread out on a glass plate and the decrease in light recieved by the photocell is equated to a root area. Seedlings are measured before and after the test to determine the change in root area.

Changes in root volume can also be used as a measure of seedling RGP. Seedlings are dipped to the root collar in a container of water that has been placed on an electronic balance. The amount of water displaced is recorded by the balance and is equated to a root volume based on the premise that 1 cm^3 of water weighs 1 g. Again this is done before and after the test period and the net change in volume is a measure of the seedlings RGP. The last two methods have the advantage in that they are less time consuming but have the disadvantage in that they are not as accurate as the actual counts and measurements of root number and root elongation. Seedlings have also been known to exhibit a 20% reduction in RAI while still extending new white roots (Day and Harvey, 1982).

Prior to testing the existing white root tips are sometimes pinched off so as not to confuse existing root growth with new root growth. However this process is very time consuming and tedious and injurious to the plant and is seldom done in practice anymore (Day, 1988 pers. comm.). Johnson-Flanagen and Owens (1985b) also disagreed with this practice of pinching off existing white root tips and developed a modified RGP test. They felt that the removal of all white root tips prior to the standard RGP test could lead to erroneous assessment of the potential for root growth. They also felt that the total number of white roots after the modified RGP test may be a better indicator of seedling survival. They suggested that there may be poor correlation between RGP and seedling survival during periods of natural root growth.

According to Ritchie (1985) data should also be collected on seedling height, caliper and weight as well as on RGP and that the data should be analyzed using the morphological attributes as covariates. Sutton (1983) found poor correlations between top height, stem diameter and root area index as the independent variables with root number and root elongation for both jack pine and black spruce seedlings.

Problems with the interpretation of RGP data have evolved because of the high variablity in seedlings to produce white roots. Several authors have commented on this variability. Sutton (1978) reported that the root systems developed by Norway spruce (*Picea abies* Karst.), Colorado spruce (*Picea pungens* Engelm.) and white spruce were extremely variable and that root system variability increased with seedling age. Sutton (1978) cited his 1968 study in which the variability of 2+2 stock within outplanting areas was so great as to mask the treatment effects. Stone *et al.* (1962) also noted the high degree of variability among seedlings lifted at the same time of the year. Stone *et al.* proposed that this variability may be due in part to genetic differences. Webb (1977) also reported wide variations in the level of root regeneration at any particular time even though the environmental parameters were standardized for all seedlings. Navartil *et al.* (1986) suggested that treatment sample size consist of a minimum of 3 to 5 replications of 5 seedlings each in order to minimize the effects of this variability on the analysis.

CONTAINER STOCK

Container grown seedlings have the advantage over bare-root seedlings in that intimate contact between the soil in the container and the roots of the seedling is maintained throughout the planting process (Tinus, 1974). Furthermore, this intact and undisturbed root system is purported to be responsible for the superior initial survival and growth of container stock over bare-root stock. Tinus also noted that container seedlings can have an external supply of nutrient reserves and moisture in addition to its internal supplies. This may, therefore, reduce the degree of moisture and nutrient stress experienced by the container seedling after outplanting. It is still imperative, however, that the seedling rapidly extend new roots into the surrounding soil.

According to Kinghorn (1974), virtually all containers modify the root structure of the seedlings grown in them. He states that the objective of container stock production therefore should be to "grow a root form that has the least risk of altering root structure in a way that may cause death, reduced growth rates or toppling of trees at a later date."

Problems with the root form of container seedlings were first reported in the late seventies. Trees that had been planted in smooth-walled cylindrical containers and those that had been planted with the container still encircling the root ball showed a high degree of root spiralling, container compression and high numbers of kinked roots (Carlson and Nairn, 1977). This led to concerns about the stability and growth of these seedlings. In order to overcome the root spiralling problem vertical ribs were added to the inside of the smooth-walled containers in order to direct root growth downward (Carlson and Nairn, 1977). The addition of these ribs seemed to work as Long (1978) reported that root coiling was much less in the ribbed containers than for the smooth-walled containers. Stefanson (1978) also found that the ribs reduced the degree of root spiralling and the subsequent risk of failure.

Seedling root morphogenesis in containers has also been reported to be controllable through the use of chemicals (MacDonald *et al.*, 1980). They found that the application of copper carbonate mixed with a latex paint to the inner walls of plastic containers resulted in a proliferation of root tips along the container wall. These root tips grew radially outward when outplanted resulting in a better root distribution and thus leading to better tree stability.

In Ontario, the most common container type used in the production of container stock is the Japanese FH-408 Paper Pot (Smyth and Brownright, 1983). The paper from these containers has been found to remain intact around the root ball for a minimum of 3 years after outplanting in the field (Carlson and Nairn, 1977) and to limit the egress of roots from the container. Segaran *et al.* (1978) also reported a very slow rate of decomposition of the paperpot on dry sites in southeastern Manitoba. Ben Salem (1978) reported that after 16 months in the field the paper of the paperpot container was still not permeable to root egress. He found that for *Pinus pinea* L. seedlings, primary lateral roots grew downward and no lateral root emergence was evident. Spencer (1974) noted that the basic design of the container system should include container walls that are either a) unrestrictive to root growth or b) removed completely at the time of outplanting. The paperpot does not seem to fit into either category and thus the lateral roots that are essential in maintaining tree stability are absent. Carlson and Nairn cited Bergman and Haggstrom (1976) who stated that the presence of the paper of the paperpot container for an extended period of time after outplanting has led to severe root deformities which may inhibit root development and cause instability, early windfall or even kill the seedling. Serious problems are now occurring with tree plantations greater than 7 years old on the J.D. Irving limits near Sussex, N.B. This has caused the Irving Co. to end stock production in FH-408 Paper Pots in 1982 and to produce stock in BC/CFS Styro block 4 and 8 and the Can-Am #2 Multipot containers (Smyth and Brownright, 1983).

As the paper of the FH-408 pot is a barrier to root egress (Ben Salem, 1978), stock produced in Can-Am #2 Multipots and planted with bare root balls may be able to regenerate roots more effectively than those grown in paperpots. Unfortunately little is currently known about the RGP and subsequent root egress of stock grown in Multipots although Rischbieter (1978) did report on a study in which he investigated the effects of the glazing of the dibble hole by the dibble tool on the root egress of plug seedlings. For the purpose of his study Rischbieter divided the container seedling plug into 4 horizontal and 3 vertical zones plus an additional zone encompassing the bottom of the container for a total of 13 root zones. He found that 95% of the excavated seedlings had a 4-sided root system and fewer than 1% of the seedlings were 2-sided or less. He concluded that the glazing of the dibble hole by the dibble tool did not affect root egress.

Container stock production in Ontario is often based on a two crop system in which the current crop is sown on approximately February 7, grown in greenhouses for 16 weeks, hardened for 2 to 3 weeks and then is outplanted in the field between approximately June 7 and July 7 (Day, 1984). The overwinter crop is sown on approximately June 7, grown for 16 weeks and is subjected to extended greenhouse treatment until approximately October 21 to promote the development of bud primordia and frost hardiness (Colombo *et al.* 1984). The overwinter crop is then stored and outplanted between May 21 and July 7 the following spring.

The poor root development of container stock that sometimes occurs after outplanting may be caused by either a barrier to root egress (e.g. by the paper wall of the Fh-408 pots) or by high RGP and subsequent root extension taking place in the container between the end of the nursery production phase and outplanting in the field. Many container crops that are held in the nursery for more than the optimum period suffer from root spiralling and binding. This effect is particularly likely to occur in the overwintered crop in the late winter and early spring. At this time dormancy release is complete and root growth will begin as soon as the temperature in the container rises to more than $1^{o}C$ (Day, 1985). As jack pine bare root stock has been shown to have a single pulse of RGP in the early spring (Stupendick, 1973), it is possible that the overwintered crop will regenerate roots in the containers before it can be shipped to the field for outplanting. Root growth of this type will cause acute spiralling and binding in the pot and may lead to the types of root deformity described by Carlson and Nairn (1977). The overwinter crop may also be subject to root damage and root dieback if there is insufficient protection of the root system from low temperatures. This type of damage may result in the reduction or the elimination of the potential for root extension after outplanting (Van Eerden and Arnot, 1974).

METHODS

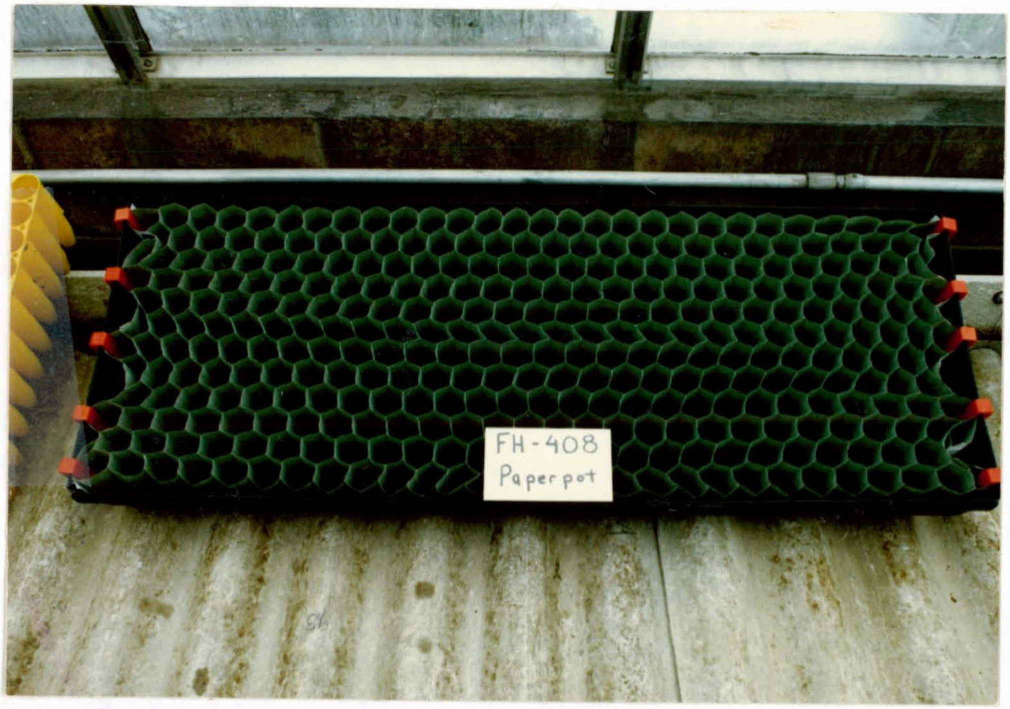
GREENHOUSE PRODUCTION PHASE

Three crops of jack pine container stock were grown for this study by two growers in the Thunder Bay area. The 1986 current crop and the 1986/87 overwinter crop of seedlings were grown at Hills' greenhouses near Murillo, Ontario. The 1987 current crop of seedlings was grown at Hodwitz's greenhouses located on Highway 130, 10 km southwest of Thunder Bay. It was necessary to change growers as Hills' greenhouses was not contracted to grow a current jack pine crop in 1987.

The crops were grown in two container types, the FH-408 Paperpot and the Can-AM #2 Multipot. The seedling cavities of the FH-408 Paperpot have a volume of 70 ml and are 7.6 cm deep and 3.8 cm in diameter (Tinus and McDonald, 1979). The Paperpot container is made out of a special paper which is stretched to fit into a 35 cm by 94 cm molded plastic tray (Figure 1a). The Paperpot tray has 336 seedling cavities per tray. The seedling cavities of the Can-Am #2 Multipot have a volume of 67 ml and are 12.2 cm deep and have an upper diameter of 3.4 cm which tapers to a bottom diameter of 1.2 cm (Sutherland, 1984). The Multipot tray is made out of molded plastic and has 67 cavities per tray (Figure 1b). Four Multipot trays will fit into a Paperpot tray holder.

1986 Current Crop

The 1986 current crop of seedlings used in this study was grown at Hills' greenhouses. The seedling trays were filled with a standard 2:1 peat-vermiculite mix. The FH-408 Paperpot trays were filled using Hills' mechanical filling line and were removed from the line prior to seeding.



a.

b.

Figure 1. Containers used to evaluate root growth potential of jack pine; a) FH-408 Paperpot container; b) Can-Am #2 Multipot container.

The Can-Am #2 Multipot trays were filled by hand using the same standard potting medium. Care was taken to ensure approximately equal compaction levels between the two container types.

The container cavities were seeded by hand on February 21, 1986 with approximately 2-3 seeds per cavity. Seed for the experiment was obtained from the Ministry of Natural Resources and was from seed lot 44-25-0-00[1]. This seed lot was used throughout the entire study. The cavities were then covered with a thin layer of silica grit in accordance with standard greenhouse procedure and placed in the greenhouse. Conveniently four Multipot trays fit into a Paperpot holder so alterations of the greenhouse benching were not required. The trays were set up in the greenhouse in 2 rows of 6 trays each with blocking across the rows. Each block consisted of a Paperpot tray and four Multipot trays in a Paperpot holder (Figure 2).

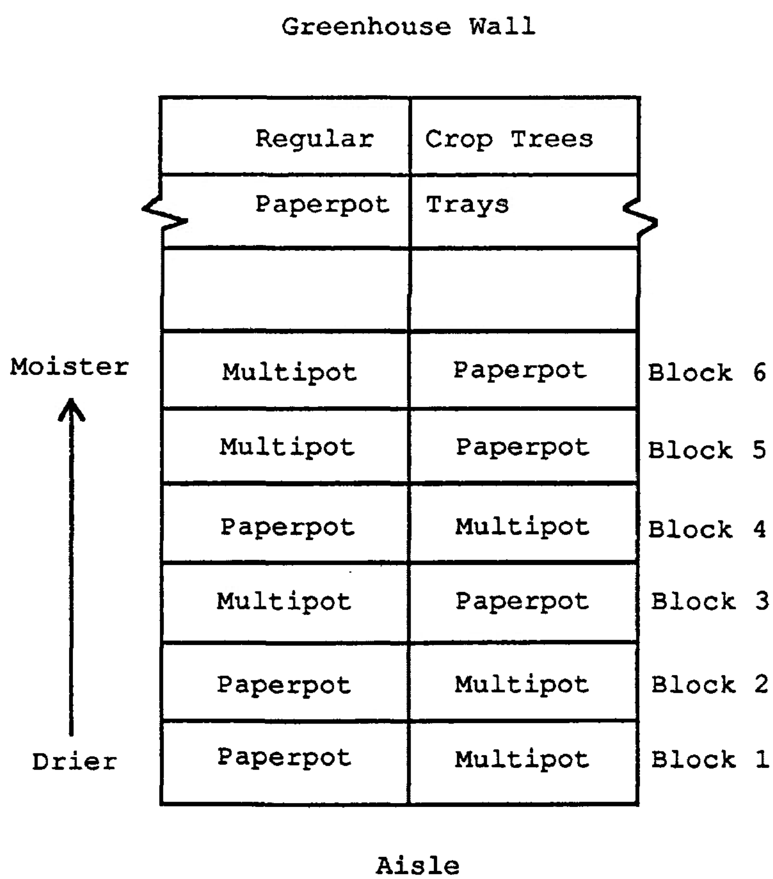


Figure 2. Blocking set-up in the greenhouse.

---

[1](Site Region - Geographic location - Seed Collection Agency - Seed collection area: 4W - Thunder Bay - O.M.N.R. - general collection.

This blocking was done to account for a potential soil moisture gradient that might occur between the aisle to the centre of the bench. It has been found that seedlings in trays along the aisle tend to be drier than centre trays because of the increased air movement along the aisle.

The crop was treated as a regular jack pine Paperpot crop with regard to irrigation and fertilization (Figure 3). A more detailed description of the irrigation and fertilizer schedules used for the crops grown for this study is given in Appendices XVI, XVII and XVIII. Eighty percent germination was achieved on March 2. The crop was thinned to one seedling per cavity and empty cavities were refilled with transplanted germinants ten days later on March 12. At the time of thinning seedlings within each tray were marked at random with coloured 15 cm plastic rods and sub-divided into three groups.

The three groups corresponded to the three purposes for which the seedlings would be used: 1) growth measurements, 2) growth chamber trials and 3) outplanting trials. This pre-allocation of seedlings was done so that sampling for one of the three purposes would have no effect on the sample base for the other two uses.

The crop was grown for 12 weeks and was removed from the greenhouse on May 29, 1986 and placed in shadehouses. The seedlings remained outside until used in the growth chamber and outplanting trials.

1986/87 Overwinter Crop

The 1986-87 overwinter crop used in the study was also grown at Hills' greenhouses. The filling and seeding procedures were the same as with the 1986 current crop. The seedling trays were also placed in the greenhouse using the same blocking set-up. The crop was sown on June 9, 1986 and had achieved 80% germination by June 14. Ten days later the crop was thinned and the empty cavities were refilled with transplanted germinants. The crop was marked with the coloured plastic rods as per the 1986 current crop. The crop was again treated as a regular jack pine crop with respect to irrigation and fertilization (Figure 2). The seedlings were grown in the greenhouse for 14 weeks and were moved

NURSERY MANAGEMENT OF JACK PINE CONTAINER STOCK

PRODUCED BY THE DOUBLE CROPPING SYSTEM

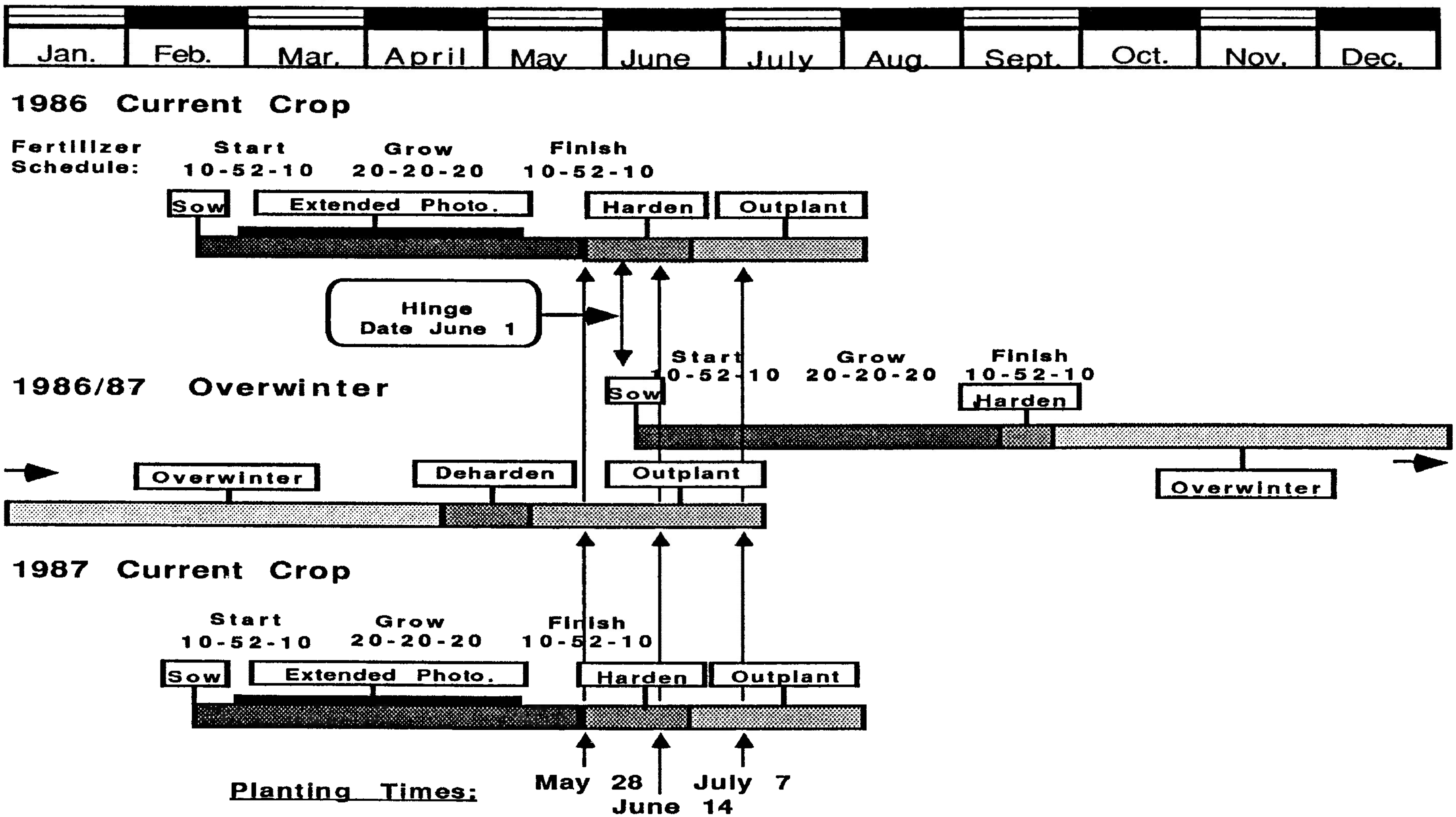


Figure 3. The cropping systems used for the production of the jack pine container stock in this study. (Specific Fertilizer Regimes see Appendices XVI, XVII and XVIII).

outside and placed in shadehouses on Sept. 24. The seedlings were overwintered outside in the shade area until planting and RGP measurements the following spring.

1987 Current Crop

The 1987 current crop was grown at Hodwitz's greenhouses. Again similar filling and seeding procedures were used, except that the Can-Am trays were filled mechanically. The greenhouse set-up was similar to that of the two previous crops. The 1987 current crop was sown on February 16 and had achieved 80% germination 6 days later on Feb. 22. The crop was thinned eleven days later and the empty cavities were refilled with transplanted germinants. The crop was again marked with coloured plastic rods at this time. Irrigation and fertilization regimes were the same as with the regular jack pine crop (Figure 2). The crop was grown for 12 weeks and was removed from the greenhouse on May 20, 1987 and placed in shadehouses. The seedlings remained outside until used in the growth chamber and outplanting RGP trials.

Experimental Design

The experimental design used was a factorial randomized complete block design with subsampling. The experimental units were the flats of seedlings. The subsampling units were the individual tree seedlings. The statistical models and expected mean squares tables for the greenhouse production phase experiments are given in Appendix I and II.

Sampling Procedures

Two weeks after germination and every two weeks thereafter during the greenhouse production phase, replicated samples of 5 seedlings per experimental unit were taken at random from (each container type) within the designated colour and were measured for the morphological attributes of height (cm), root collar diameter (mm), shoot dry weight (mg) and root dry weight (mg) for each of the three crops.

The sampling of the 1986 current crop every two weeks continued for two sampling dates after they were moved outside. The 1987 current crop was only sampled once more after they were placed outside. The 1986/87 overwinter crop was sampled in the spring of 1987 prior to bud break to determine the effects of overwintering the crop on the morphological attributes of the seedlings.

Analytical Methods

The mean of each morphological attribute was plotted over time to give a progression of the growth of the seedlings in each container type for each of the three crops studied.

Two sets of analyses were conducted on the greenhouse production phase's data. In the first analysis, an analysis of variance (ANOVA) was conducted on each of the morphological attributes measured at the end of the greenhouse production phase within each of the three crops to determine if there were any significant differences between the seedlings grown in the two container types. The data was tested for non-homogeneity of variance using the Bartlett's test (Steel and Torie, 1980) before it was subjected to analysis of variance (ANOVA). If the data was found to have non-homogeneous variances, several transformations were attempted to improve its homogeneity and ANOVA was conducted on the transformed data.

In the second analysis comparisons were made graphically between all three crops grown for the study for all of the morphological attributes measured. ANOVA was conducted on the 'week 14', end of the greenhouse production phase, data for each attribute in order to determine if any differences existed between; a) the two current crops, and b) the 1987 current crop and the 1986/87 overwinter crop. Tests for non-homogeneity of variance were also conducted on these data sets prior to analysis.

Statistical analysis of the data was done on the Vax 11/780 main-frame computer at Lakehead University using the SPSSX statistical package (SPSS Inc., 1986).

ROOT GROWTH POTENTIAL METHODOLOGY FOR CONTAINER STOCK

Root Growth Potential (RGP) tests for container stock were carried out on stock grown in the FH-408 Paperpot and the Can-Am #2 Multipot using a modification of the methods developed by Day et. al. (1985) for bareroot stock. RGP tests in this experiment were carried out in two test environments; 1) the standard growth chamber environment and 2) the field environment. In both environments seedlings were grown for 21 days and then carefully excavated so as not to damage the seedling roots. The specific details for each environment follow under the appropriate headings.

After the 21-day test period for potted and outplanted seedlings the effective RGP was determined by counting the number of white root tips greater than 10.0 mm in length projecting from the plug to determine Root Number (RN) and by measuring the length of the same roots to determine Root Elongation (RE). Root tips less than 10.0 mm in length were classified into two categories: 1) small (root tips 0.0 to 2.0 mm in length) and 2) medium (root tips > 2.0 to 10.0 mm in length). The number of small and medium root tips were counted and classified in decile ranges (i.e. 0, 1 to 10, 11 to 20,... >80) to determine small and medium RN values after methods proposed by Day *et al.* (1985). These values were then equated to an equivelant RE value using Day and Harvey's codes. The small, medium and long RE values were then summed to give a Total Root Elongation (TRE).

For the purpose of this study the container plug was left intact and was divided into three zones. Zone 1 was the upper half of the cylindrical area containing the container plug, Zone 2 was the lower half of the same area and, Zone 3 was the bottom of the plug (Figure 4). RN was determined and TRE was calculated for each of the three zones for each container type.

Seedlings were also measured for height and root collar diameter after the 21 day test period.

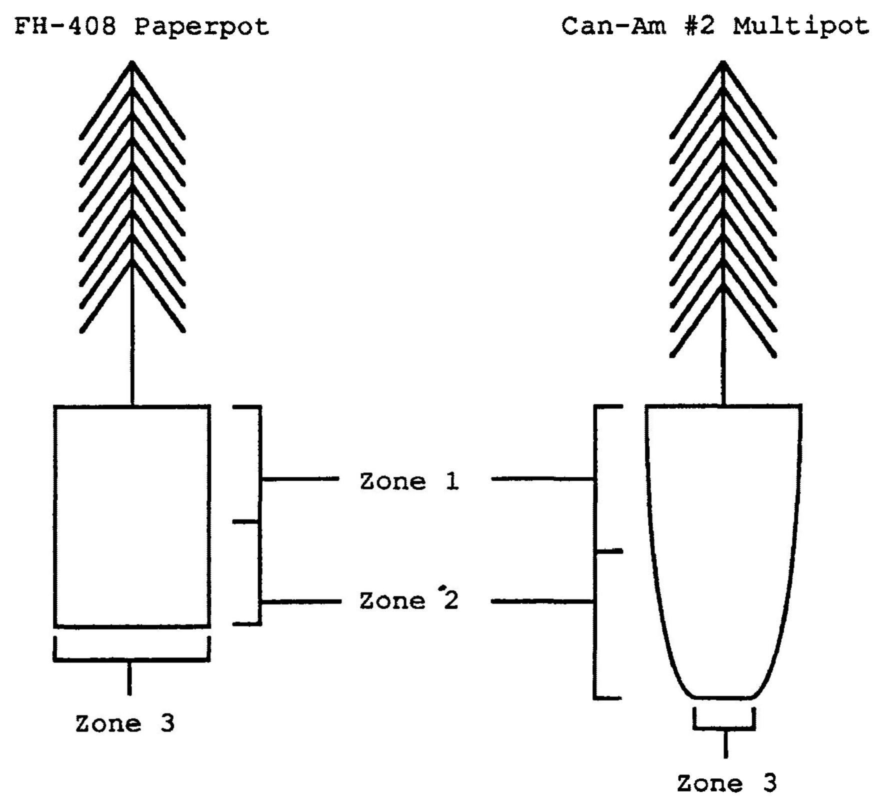


Figure 4. Depiction of the three root zones for each container type.

GROWTH CHAMBER TRIALS

The 1986 and 1987 tests for seedling RGP under controlled-environment conditions were conducted in growth chambers located in the basement of the Lakehead University greenhouse complex.

Experimental Design

The experimental design used for the growth chamber trial data for both years was a factorial randomized complete block design with subsampling. The experimental units were the flats of seedlings from which the subsample of individual seedlings was selected. The statistical models and expected mean squares tables for both the 1986 and 1987 growth chamber trials are presented in Appendices III and IV.

Sampling Procedures

In 1986, samples of twelve seedlings per experimental unit were selected at random from the appropriately marked cavities on three test dates, May 30, June 26 and July 21. These seedlings were then potted in three 1 litre pots (4 seedlings per pot) filled with a peat-vermiculite mixed soil. They were then placed in the controlled environment cabinet set at a 25°C (day) and 20°C (night) temperature for the 21-day test period. Seedlings were watered every 2 to 3 days with regular tap water to the point of saturation throughout the test period. The seedlings were then subjected to the RGP measurements described above.

Several seedlings were also planted in clear acrylic plastic root study boxes (one seedling per box) filled with a sandy-loam soil so that root form could be photographed after each RGP test. These boxes were covered with black plastic to block light from the roots and were placed in another controlled environment cabinet for 21 days. At the end of the test period the soil was carefully washed out, the plastic was removed and the roots were photographed. The root study boxes consist of a 17.5 x 17.5 x 22.0 cm box, open at both ends, with nylon fishing line strung horizontally through the box at 2.0 cm vertical and 2.5 cm horizontal spacing. The nylon fishing line forms a network of crossed strands which serve to support the root system *in situ* when the growing medium is washed away (Lindstrom and Scarrett, 1982). Construction time limited the use of the boxes to the third potting time in the 1986 trial.

In 1987, samples of eight seedlings per experimental unit were selected at random from the appropriately marked cavities on three test dates, May 29, June 22 and July 13 and were potted as in 1986. Eight seedlings per experimental unit were used this year due to the addition of the crop treatment and limited growth chamber space. The use of eight seedlings per experimental unit allowed all pots to fit in one growth chamber and thereby avoid the confounding factor of different growth chambers in the analysis. Two seedlings from each container and crop type were also planted in the root study boxes at each of the three RGP test dates and were photographed at the end of the 21-day test period.

Analytical Methods

An analysis of variance was carried out on the 1986 RGP data for the variable Total Root Elongation (TRE) using a 1 (crop) X 3 (potting date) X 2 (container type) X 3 (root zone) factorial randomized complete block design with subsampling to test the effect of container type, potting date and root zone on the RGP 21 days after potting.

In 1987 a similar ANOVA was carried out using a 2 (crop) X 3 (potting date) X 2 (container type) X 3 (root zone) factorial randomized complete block design with subsampling for the same purpose as in 1986.

The data for both years was tested for non-homogeneity of variance using the Bartlett's test (Steel and Torie, 1980) before it was subjected to analysis of variance (ANOVA). If the data was found to have non-homogeneous variances, several transformations were attempted to improve its homogeneity and ANOVA was conducted on the transformed data. When ANOVA showed that there were significant differences between treatment means a Student-Newman-Keul's test (Steel and Torie, 1980) was used to identify them.

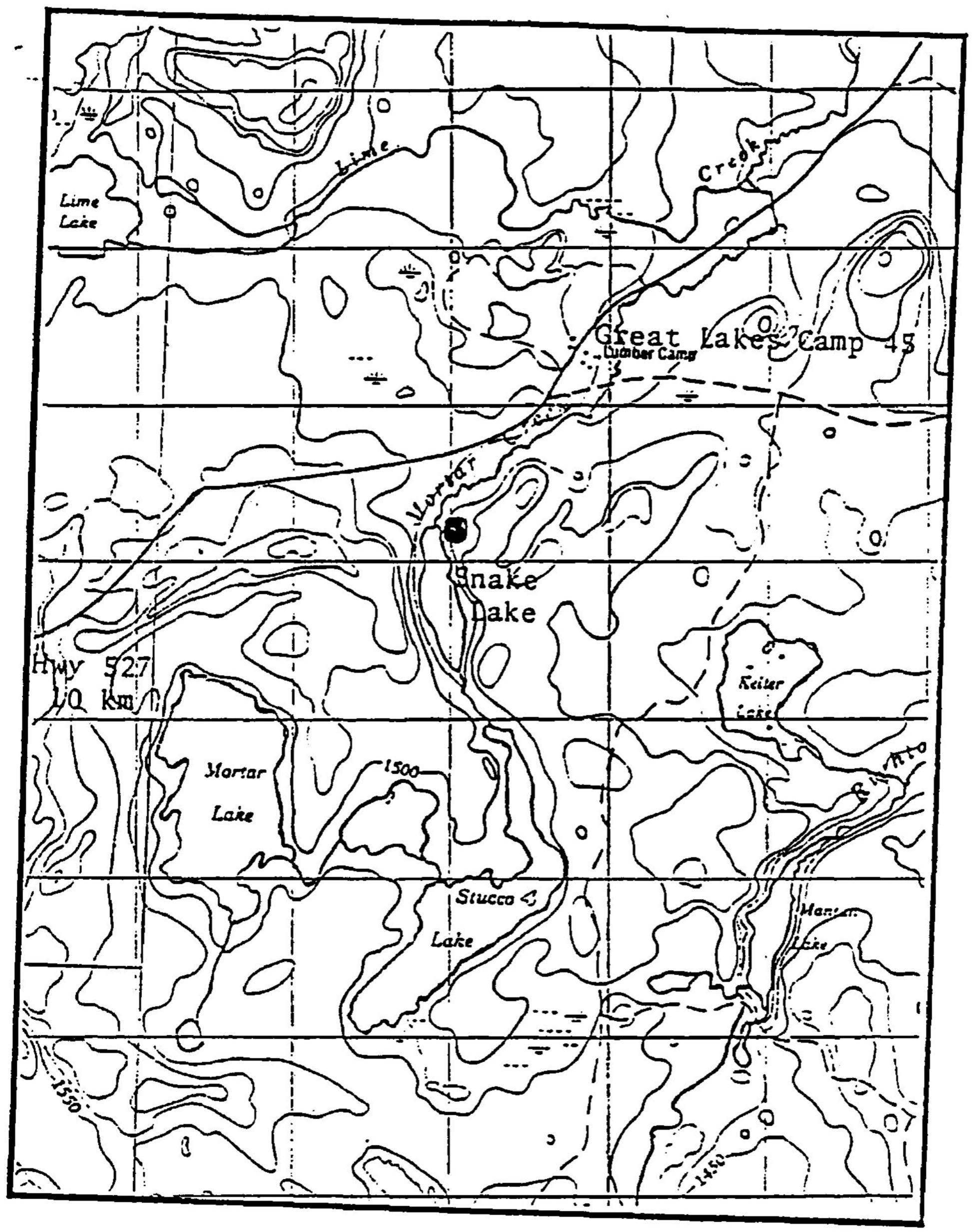
In both 1986 and 1987 the two-way interactions for TRE were plotted to graphically illustrate the interaction between treatment combinations.

A regression was also carried out with total root elongation over root number to determine the correlation between the two variables to see if multivariate analysis was required. If the correlation between the two variables was not significant, multivariate analysis would be required (Green, 1978).

OUTPLANTING TRIALS

1986 Outplanting Site

The 1986 outplanting site is located 120 km north of Thunder Bay adjacent to Snake Lake near Canadian Pacific Forest Product's Camp 45 (49^{o} 13' N. Lat., 89^{o} 12' W. Long.) (Figure 5). The site had originally



Scale: 1:50,000

Figure 5. Map showing the location of the 1986 Outplanting site (49° 13' N. Lat., 89° 12' W. Long.).

supported a mixed forest of aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balsamea* (L.) Mill.) and white spruce and was harvested in 1983 using a Koehring shortwood harvester. The site was prepared in the fall of 1984 using a crawler tractor and Young's teeth spaced at approximately 2 m intervals.

The slash load on the site was heavy with patches of residuals still remaining and little advanced growth. Competetion on the site was dense with the main competetive species being *Carex* spp.(L.) and raspberry (*Rubus ideaus* L.) with some beaked hazel (*Corylus cornuta* Marsh.). The planting site is situated on a slight westward slope and has a heavy clay-loam soil.

1987 Outplanting Site

The 1987 outplanting site is located 30 km west of Thunder Bay near Kakabeka Falls (48^{O} 24' N. Lat.,89^{O} 42' W. Long.) on lot 48A on the Paipoonge-O'Conner townline road (Figure 6). The original forest on the site was Site Class I (Plonski, 1981) jack pine. The original jack pine stand was cut, the stumps were grubbed out and the site has been under cultivation as a Christmas tree farm for 20 years.

The site was prepared using a mouldboard plow attached to a farm tractor in the early spring prior to outplanting. The soil was completely cultivated and there was no slash on the site. Competition on the site was nil in the spring but increased with the invasion of annual weeds toward the end of the summer. The competition is minimal and is confined to only two blocks. The site is relatively flat and has a medium-grained sandy loam soil.

Experimental Design

In 1986 prior to planting the site was divided into 6 blocks corresponding to the 6 blocks in the greenhouse. Each block was then marked at random with coloured planting pins at a 1 m X 1 m spacing to ensure a complete randomization of the treatments within each block. There were 6 colours of pins corresponding to the 6 treatment levels (3

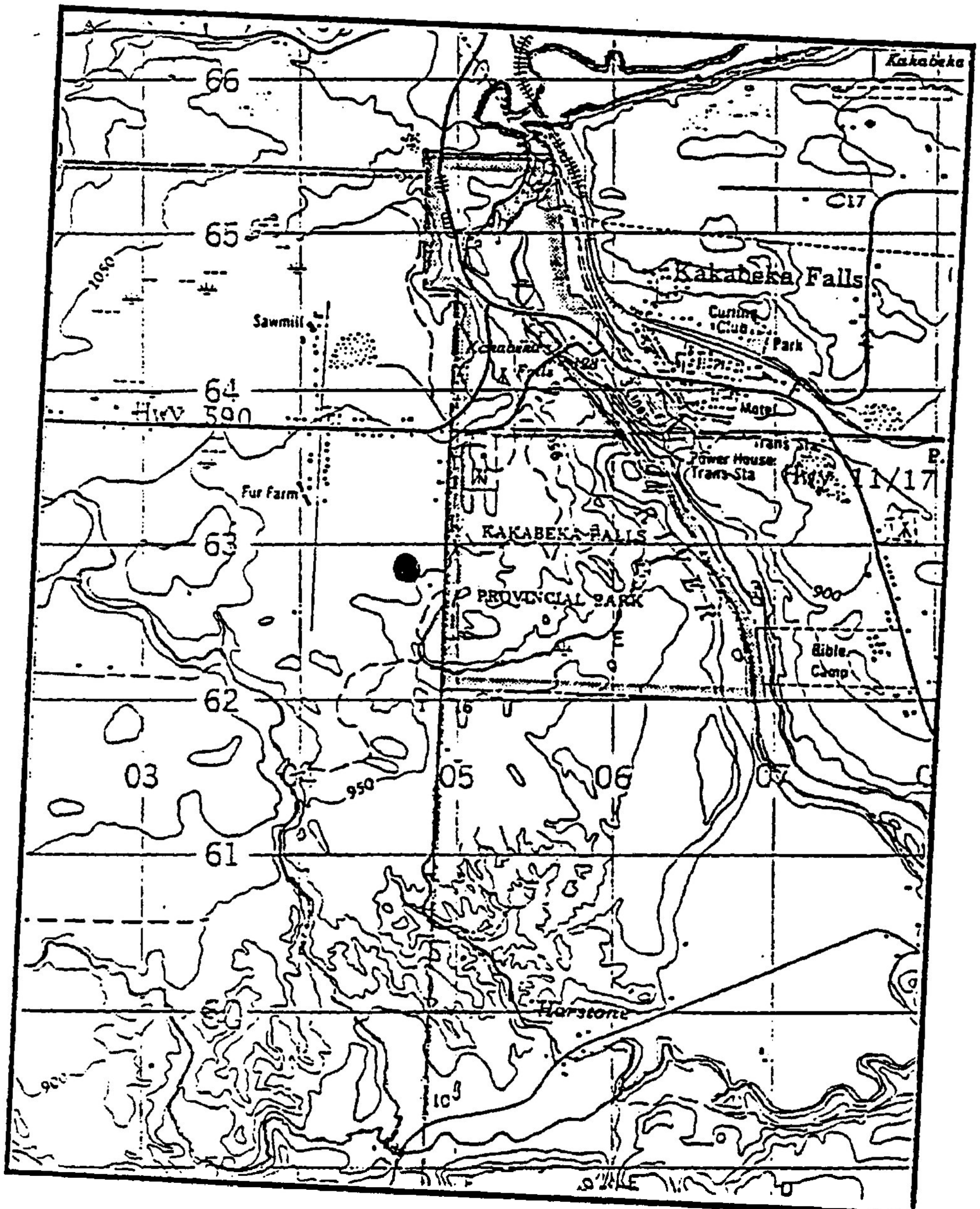


Figure 6. Map showing the location of the 1987 Outplanting site (48° 24' N. Lat., 89° 42' W. Long.).

planting dates X 2 container types).

In 1987, the site was again divided into 6 blocks and marked with coloured planting pins. Twelve startling colours of planting pins were used in 1987 corresponding to the twelve treatment levels (2 Crops X 3 Outplanting Dates X 2 Container Types).

The experimental design used in both 1986 and 1987 outplanting trials was a factorial randomized complete block design with subsampling. The experimental units were again the flats of seedlings and the subsamples were the individual seedlings. The statistical models and expected mean squares tables are given in Appendix V and VI.

Sampling Procedures

Forty seedlings per experimental unit were outplanted on May 28, June 18 and July 7 of 1986 and May 25, June 15 and July 6 of 1987. Differences between these dates and the potting dates are due to logistic problems and the time required for root measurements. Seedlings planted at the first planting date were removed from the greenhouse a week before planting and placed in shadehouses to allow for the aclimatization of the stock. Seedlings grown in the FH-408 Paperpot were planted using a Pottiputki while seedlings grown in the Can-Am #2 Multipot were planted using a dibble bar. After the 21-day test period subsamples of 15 seedlings per experimental unit were selected at random, excavated and subjected to RGP measurments described earlier. The extra 25 seedlings per experimental unit were planted to guard against the possibility of seedling mortality and to provide trees for later study.

Soil moisture was monitored throughout the outplanting trial using static soil moisture tensiometers installed at 15 cm depth. A tensiometer was placed in the center of each block and was checked every few days.

Analytical Methods

As in the growth chamber trial, an ANOVA was carried out on the

1986 RGP data for TRE using a 1 (crop) X 3 (planting date) X 2 (container type) X 3 (root zone) factorial randomized complete block design with subsampling to test the effect of container type, outplanting date and root zone on the RGP of the stock 21 days after outplanting.

In 1987 a similar ANOVA was carried out using a 2 (Crop) X 2 (Container Type) X 3 (Outplanting Date) X 3 (Root Zone) factorial randomized complete block design with subsampling for the same purpose as the 1986 analysis.

Analysis of the data was carried out in the same manner as in the potting trials.

In both 1986 and 1987 the two-way interactions for TRE were plotted to illustrate the interaction between treatment combinations graphically.

A regression was also carried out with total root elongation over root number to determine the correlation between the two variables.

RESULTS

GREENHOUSE PRODUCTION PHASE

1986 Current Crop

Seedlings grown in the Can-Am #2 Multipot were significantly larger in shoot and root dry weight than seedlings grown in FH-408 Paperpots at the end of the 16-week greenhouse production phase (Table 1). There were

Table 1. Comparison of the morphological attributes of the FH-408 Paperpot and Can-Am #2 Multipot stock at the end of the 16-week greenhouse production phase for the 1986 current crop.

Attribute		FH-408 Paperpot (a)	Can-Am #2 Multipot (b)	Percent Difference % (b-a)/a X 100
Height (cm)	x	22.567	20.527	-9.04 N.S.
	s_x	0.556	0.616	
Root Collar Diameter (mm)	x	2.051	2.236	+9.02 N.S.
	s_x	0.074	0.049	
Shoot Dry Weight (mg)	x	736.87	951.70	+29.17 *
	s_x	62.18	45.62	
Root Dry Weight (mg)	x	203.24	346.29	+70.44 ***
	s_x	16.12	15.12	

N.S. - non-significant
* - significant at the 0.05% level.
** - significant at the 0.01% level.
*** - significant at the 0.001% level.

however, no significant differences in height or root collar diameter between the seedlings grown in the two container types (Table 1). A complete analysis of variance (ANOVA) table of each attribute measured for the 1986 Current crop is given in Appendix VII.

The growth progressions for the height of the stock grown in the two container types during the 16-week greenhouse production phase followed the same pattern throughout this period with no real differences occuring until week 16 (Figure 7). At the end of the greenhouse production phase the Multipot stock was about 9% shorter in height than the Paperpot stock (Table 1). This difference was not found to be significant by ANOVA.

Divergence between the root collar diameter growth progressions of the seedlings grown in the two container types began as early as week 6 with the Multipot seedlings showing a visually faster rate of growth than the Paperpot seedlings (Figure 8). At week 16 the Multipot stock was 9% larger in root collar diameter than the Paperpot stock (Table 1). However this difference in root collar diameter between the seedlings grown in the two container types was not found to be significant when tested by ANOVA.

Divergence between the shoot dry weight growth progressions of the Multipot and Paperpot stock also began at week 6 with the Multipot stock again showing the faster rate of growth (Figure 9). At the end of the 16-week greenhouse production phase the Multipot stock also had a 29% larger top dry weight than the Paperpot stock which was found to be significant ($P<0.045$) by ANOVA (Table 1).

Divergence between the root dry weight growth progressions between seedlings grown in the two container types again began at week 6 with stock grown in the Multipot exhibiting the faster rate of growth (Figure 10). By the end of the 16 week greenhouse production phase the root dry weight of the Multipot seedlings was approximately 70% larger than that of the Paperpot seedlings (Table 1). This difference was found to be significant ($P<0.001$) when tested by ANOVA.

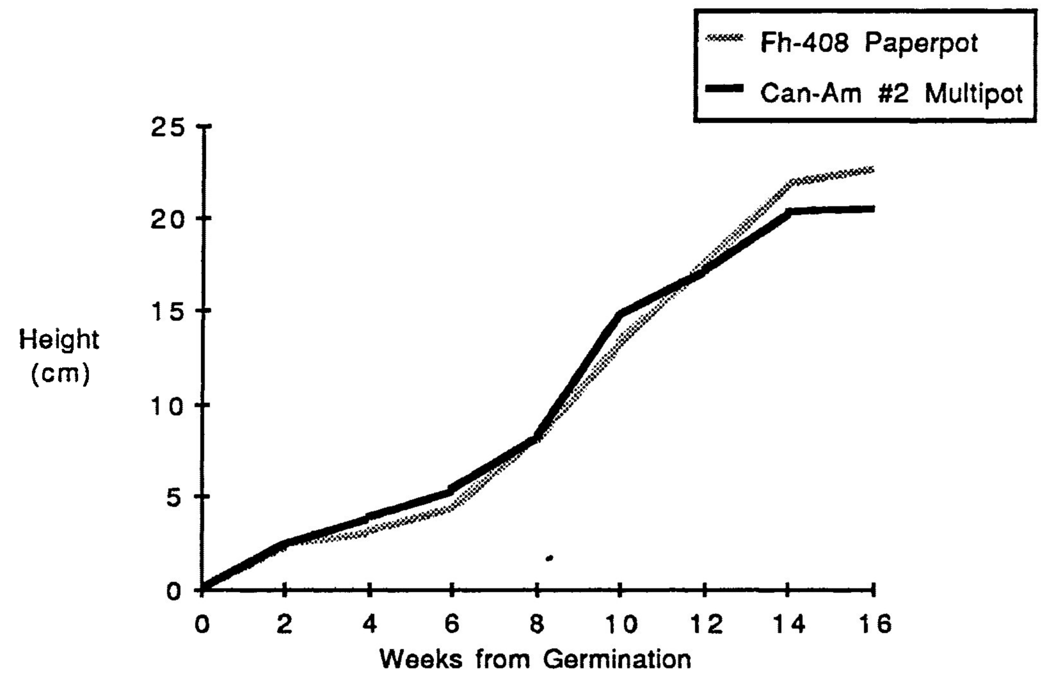


Figure 7. Progression of height for the 1986 current crop at Hill's greenhouses.

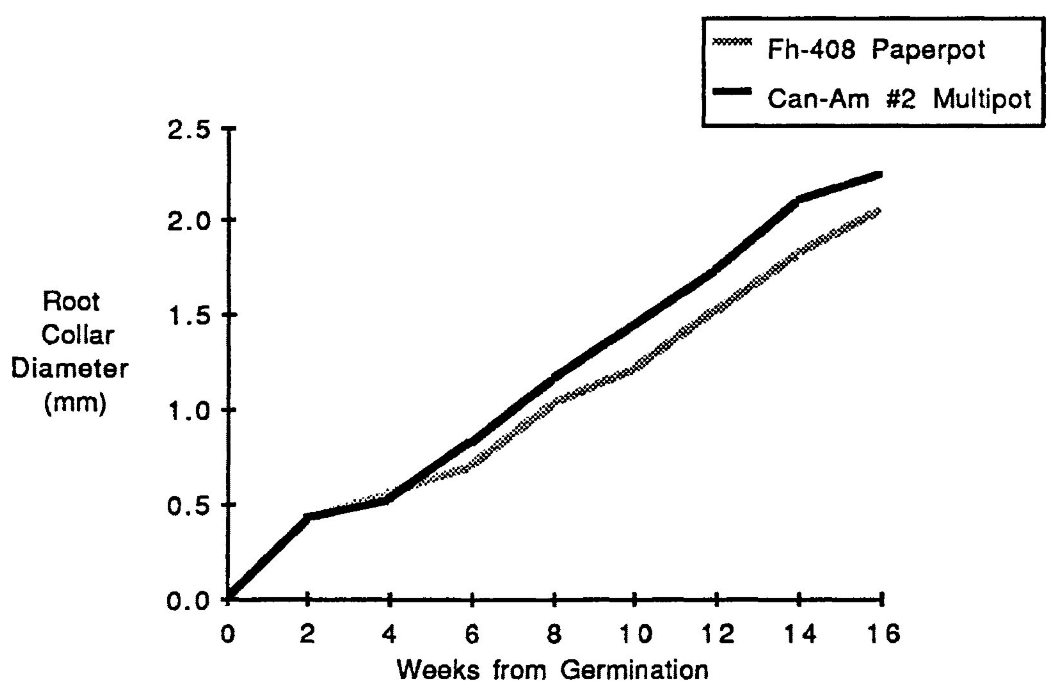


Figure 8. Progression of root collar diameter for the 1986 current crop at Hill's greenhouses.

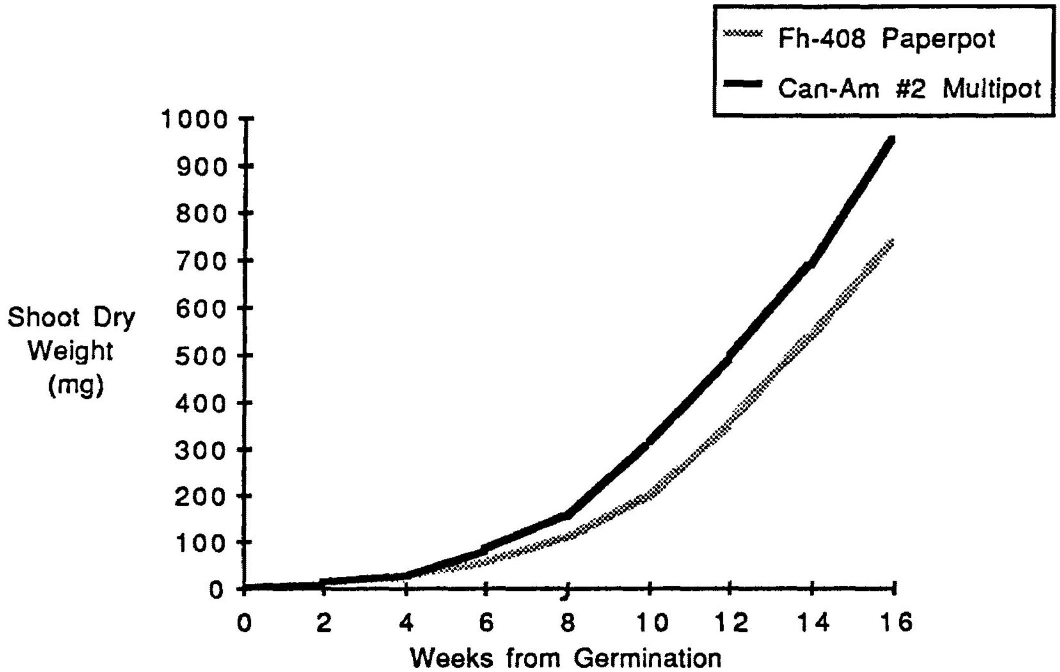


Figure 9. Progression of shoot dry weight for the 1986 current crop at Hill's greenhouses.

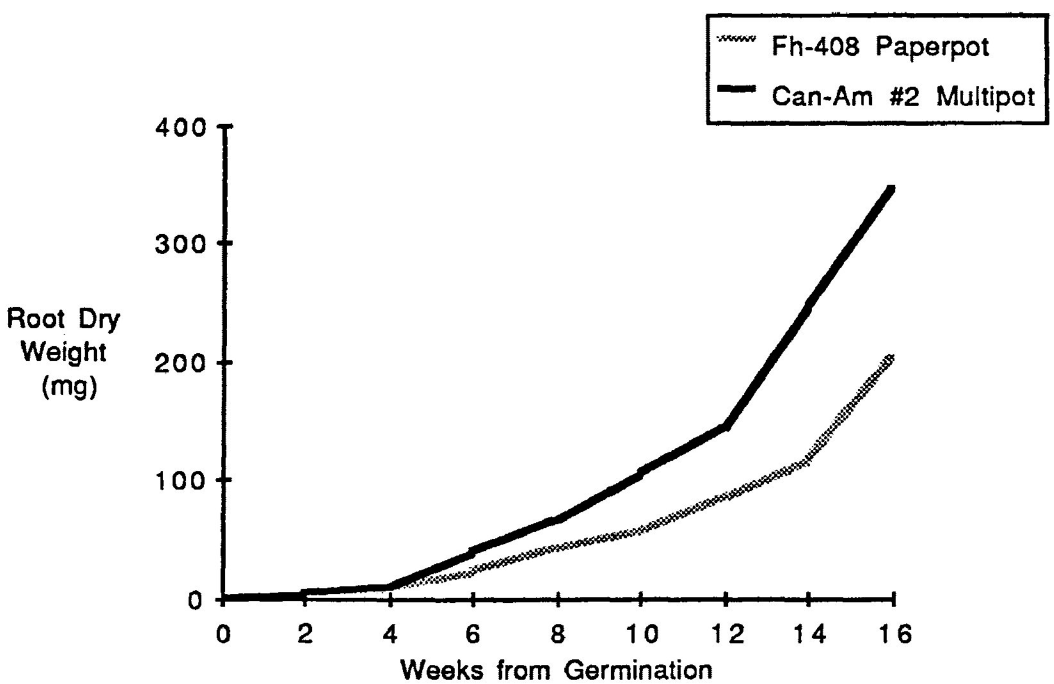


Figure 10. Progression of root dry weight for the 1986 current crop at Hill's greenhouses.

1986/87 Overwinter Crop

As with the 1986 current crop seedlings grown in the Can-Am #2 Multipot were significantly larger in shoot and root dry weight than seedlings grown in the FH-408 Paperpot at the end of the 14-week greenhouse production phase (Table 2). Again there were no significant differences in height or root collar diameter between the seedlings grown in the two container types (Table 2). Complete ANOVA tables for

Table 2. Comparison of the morphological attributes of the FH-408 Paperpot and Can-Am #2 Multipot stock at the end of the 14-week greenhouse production phase for the 1986/87 overwinter crop.

Attribute		FH-408 Paperpot (a)	Can-Am #2 Multipot (b)	Percent Difference % (b-a)/a X 100
Height (cm)	x	14.547	14.537	-0.07 N.S.
	s_x	0.611	0.352	
Root Collar Diameter (mm)	x	1.614	1.626	+0.74 N.S.
	s_x	0.072	0.039	
Shoot Dry Weight (mg)	x	402.77	527.44	+30.77 *
	s_x	31.58	22.16	
Root Dry Weight (mg)	x	107.49	189.08	+75.00 ***
	s_x	9.59	7.49	

N.S. - non-significant
* - significant at the 0.05% level.
** - significant at the 0.01% level.
*** - significant at the 0.001% level.

the 1986/87 Overwinter Crop are given in Appendix VIII.

The height growth progressions of the stock grown in the Multipots and Paperpots as shown in Figure 11 followed the same pattern throughout the greenhouse production phase with only a few minor deviations. At week 14 there was no significant difference in height between the seedlings grown in the two container types. The week 42 measurements refer to measurements made on the stock in the spring after overwintering the crop outside. These measurements were made to determine the effects of overwintering on the morphology of the stock. The slight drop in height at week 42 can be attributed to sampling error rather than as an actual drop in height.

There were no significant differences in root collar diameter between stock grown in the Can-Am #2 Multipot and the FH-408 Paperpot containers at week 14 (Table 2). The two stock types followed the same basic growth pattern in root collar diameter throughout the greenhouse production phase with only a few minor deviations (Figure 12). Again the slight decrease in root collar diameter at week 42 is probably due to sampling error (Figure 12).

Divergence in the shoot dry weight growth progressions between seedlings grown in the two container types were again evident as early as week 6 (Figure 13). The Multipot stock had the faster growth rate and at the end of the 14-week greenhouse production phase were 31% larger in top dry weight than the seedlings grown in the Paperpots (Table 2). This difference was significant by ANOVA ($P<0.018$).

Divergence in the root dry weight growth progressions between the Multipot and Paperpot stock also began at week 6 with the Multipot seedlings showing the faster rate of growth (Figure 14). However this difference was more pronounced than that of shoot dry weight and at the end of the greenhouse production phase the Mulipot seedlings were found to have a 75% larger root dry weight than the Paperpot seedlings (Table 2). This difference was statistically significant ($P<0.001$). Of note in Figure 14 is the slight, but statistcally non-significant, decrease in the root dry weight of the Multipot seedlings at week 42. This may be due, as was the case for height and root collar diameter, to sampling error but it may also have been caused by freezing injury and resulting dieback of the root system.

1987 Current Crop

Seedlings grown in the Can-Am #2 Multipot were significantly larger in height and root dry weight than seedlings grown in the FH-408

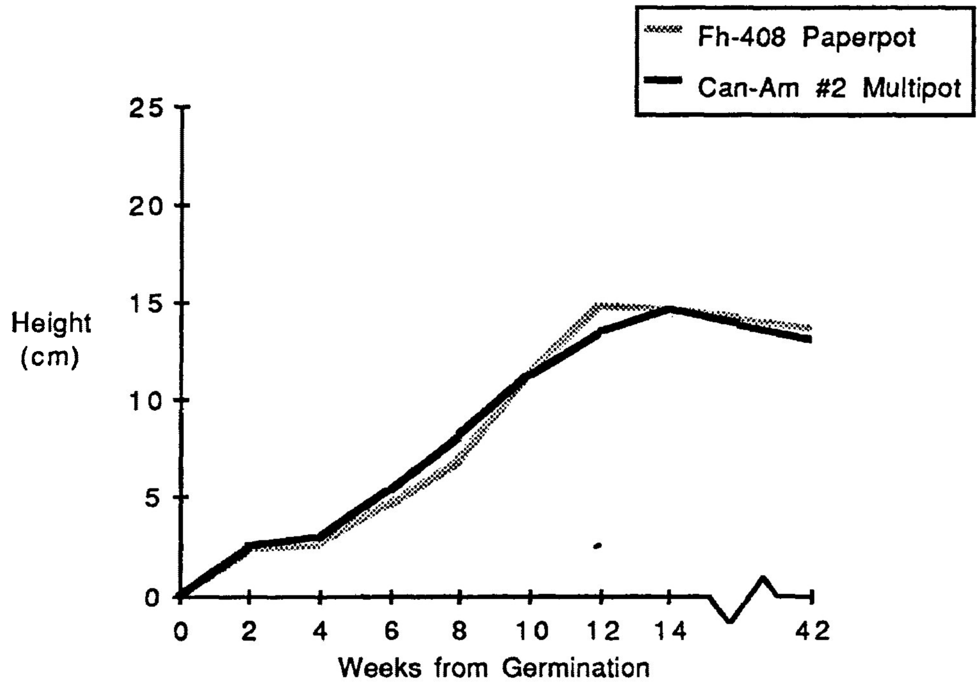


Figure 11. Progression of height for the 1986/87 overwinter crop at Hill's greenhouses.

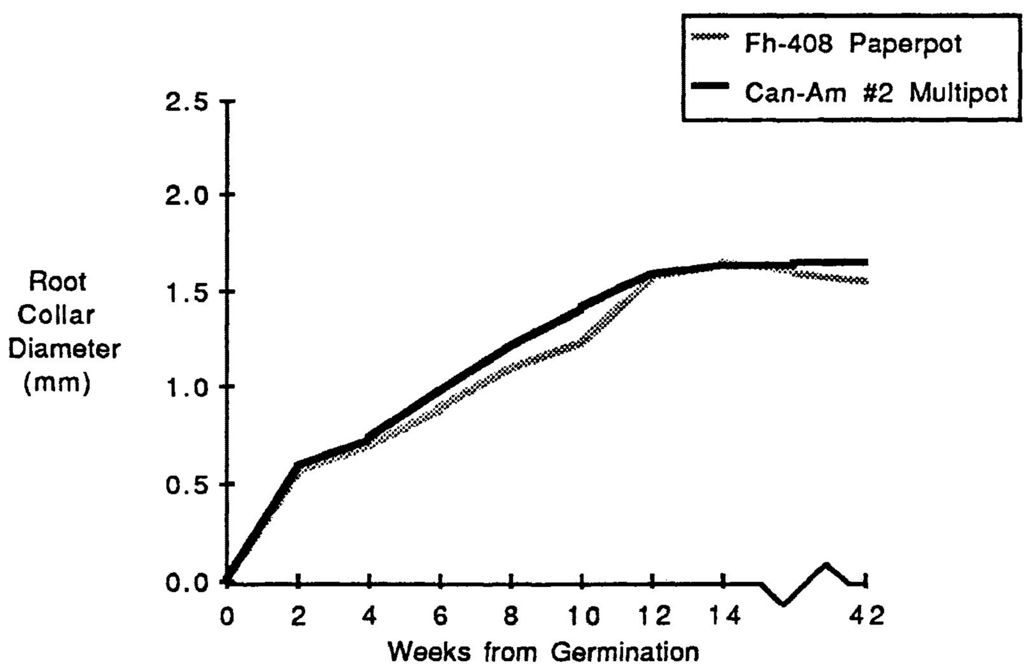


Figure 12. Progression of root collar diameter for the 1986/87 overwinter crop at Hill's greenhouses.

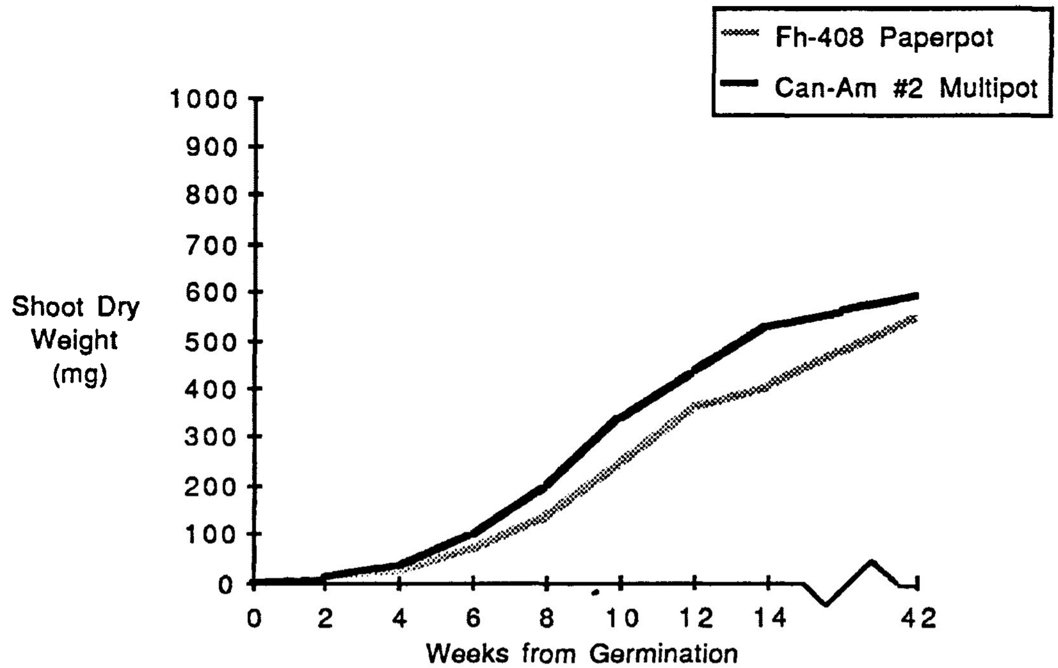


Figure 13. Progression of shoot dry weight for the 1986/87 overwinter crop at Hill's greenhouses.

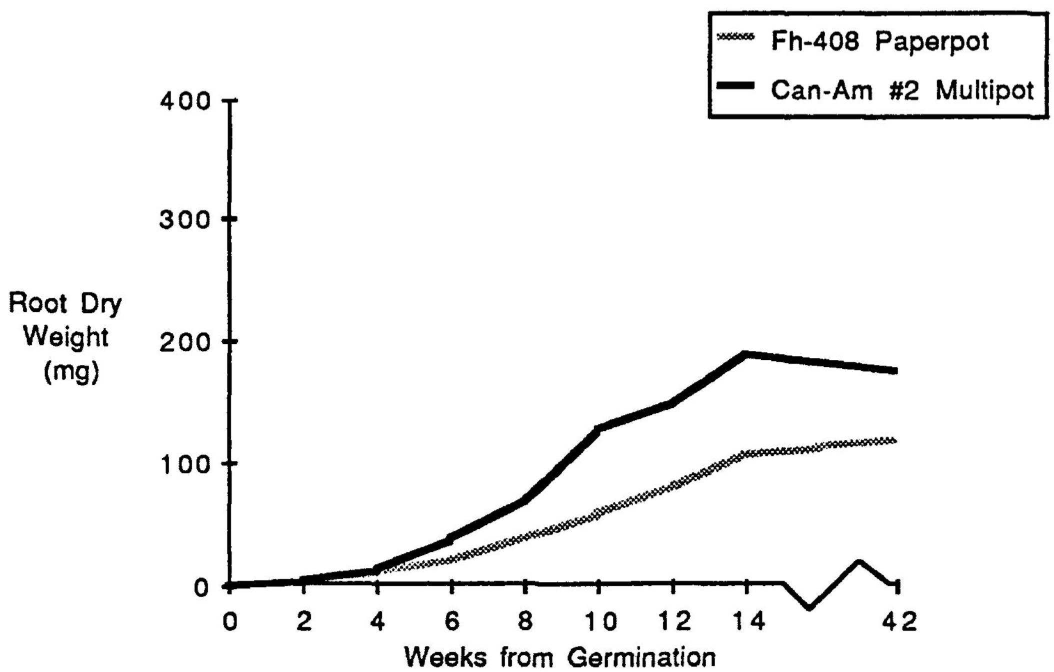


Figure 14. Progression of root dry weight for the 1986/87 overwinter crop at Hill's greenhouses.

Paperpot at the end of the 14-week greenhouse production phase for the 1987 current crop (Table 3). There was no significant difference in root collar diameter or shoot dry weight between seedlings grown in the two container types (Table 3). Complete ANOVA tables for the 1987 Current crop are given in Appendix IX.

Unlike the 1986 Current Crop and the 1986/87 Overwinter Crop there was a significant difference ($P<0.001$) in height between seedlings grown in the FH-408 Paperpot and the Can-Am #2 Multipot for the 1987 Current Crop (Figure 15). Divergence in the seedling height growth progressions

Table 3. Comparison of the morphological attributes of the FH-408 Paperpot and Can-Am #2 Multipot stock at the end of the 14-week greenhouse production phase for the 1987 current crop.

Attribute		FH-408 Paperpot (a)	Can-Am #2 Multipot (b)	Percent Difference % (b-a)/a X 100
Height (cm)	$\bar{x}$	17.443	13.477	-22.74 ***
	$s_{\bar{x}}$	0.454	0.327	
Root Collar Diameter (mm)	$\bar{x}$	2.010	2.048	+1.89 N.S.
	$s_{\bar{x}}$	0.058	0.035	
Shoot Dry Weight (mg)	$\bar{x}$	516.45	638.87	+23.72 N.S.
	$s_{\bar{x}}$	36.19	25.14	
Root Dry Weight (mg)	$\bar{x}$	154.53	290.37	+88.02 ***
	$s_{\bar{x}}$	11.46	9.28	

N.S. - non-significant
* - significant at the 0.05% level.
** - significant at the 0.01% level.
*** - significant at the 0.001% level.

between the two container types began at week 10 after seed germination with the Paperpot stock showing the increased rate of growth. At the end of the 14-week growth phase the Paperpot stock was 23% taller than the Multipot stock (Table 3).

Root collar diameter showed a similar growth pattern to the two previous crops with some minor differences between the growth rates of seedlings grown in the two container types occurring between weeks 4 and 12 after germination. By week 14 the root collar diameter of the Paperpot stock had increased so that it was comparable to that of the Multipot stock (Figure 16).

Divergence between the shoot dry weight growth progressions of the stock grown in the two container types began at week 6 after germination (Figure 17). The rate of growth remained relatively constant throughout the greenhouse production phase for both Multipot and Paperpot seedlings. At the end of the 14-week growth phase there was no significant difference in top dry weight between seedlings grown in the two container types although the Multipot seedlings did have a 24% larger top dry weight than did the Paperpot seedlings (Table 3).

The pattern of root dry weight growth for the 1987 Current Crop was similar to both the 1986 Current and the 1986/87 Overwinter Crops. Figure 18 shows that a divergence in the growth progressions between the seedlings grown in the two container types began after the 4th week from germination and increased dramatically over the greenhouse production phase. At the end of the 14-week growth phase the Multipot seedlings had an 88% larger root dry weight than the Paperpot seedlings (Table 3). This difference was found to be significant by ANOVA ($P<0.001$).

Crop Comparisons

1986 Current Crop vs 1987 Current Crop

Seedlings grown in the 1986 Current crop at Hills' greenhouses were significantly taller in height ($P<0.001$) but were significantly smaller in root dry weight ($P<0.002$) at the end of the greenhouse production phase than seedlings grown in the 1987 Current crop at Hodwitz's greenhouses. There were no significant differences between the seedlings grown in the two crops in root collar diameter and shoot dry weight although the seedlings grown in the 1986 Current crop were larger in both of these two attributes. The complete ANOVA tables for these comparisons are given in Appendix X.

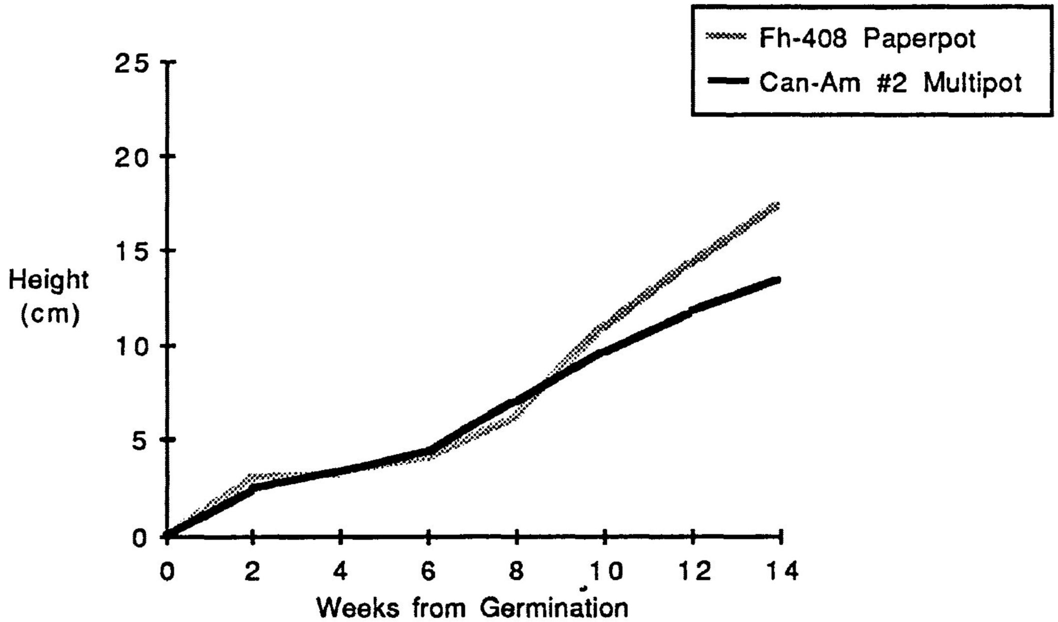


Figure 15. Progression of height for the 1987 current crop at Hodwitz's greenhouses.

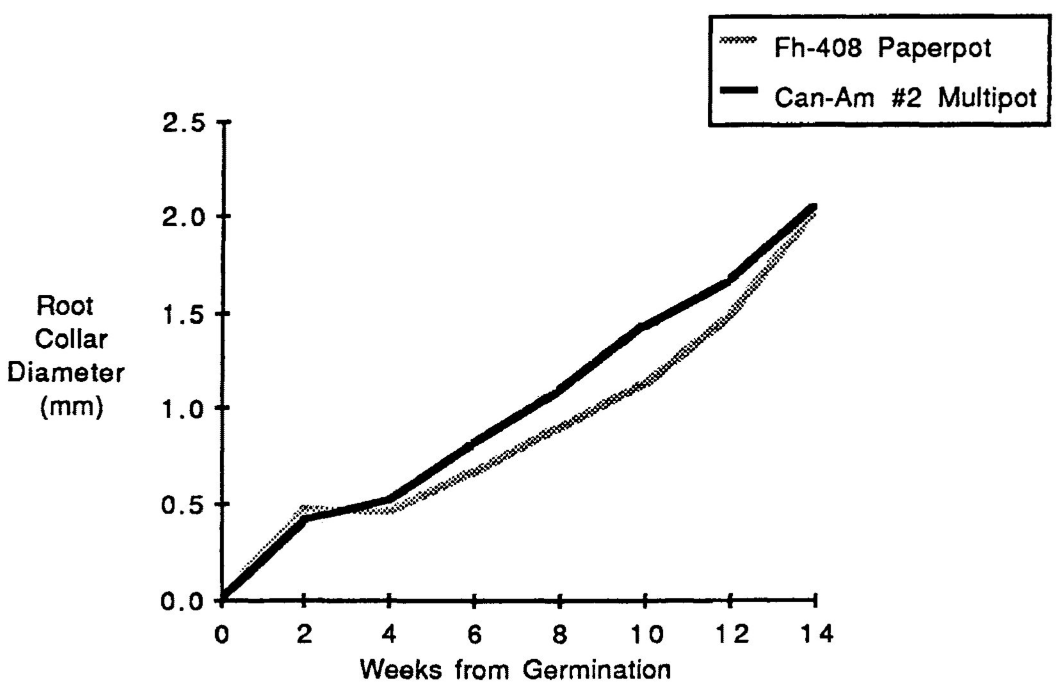


Figure 16. Progression of root collar diameter for the 1987 current crop at Hodwitz's greenhouses.

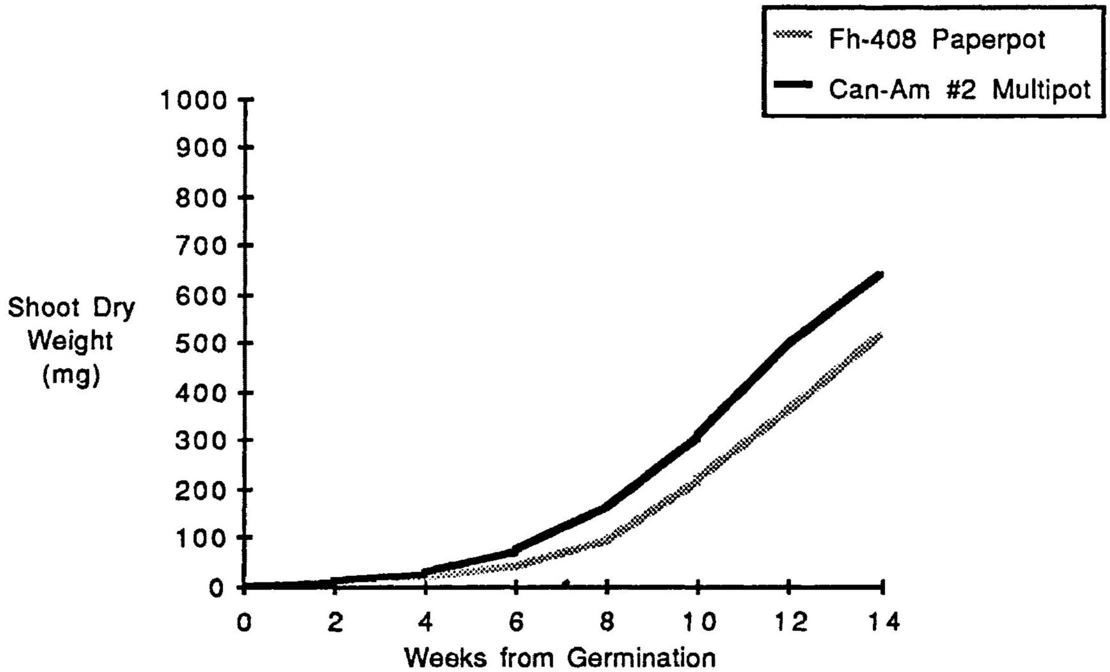


Figure 17. Progression of shoot dry weight for the 1987 current crop at Hodwitz's greenhouses.

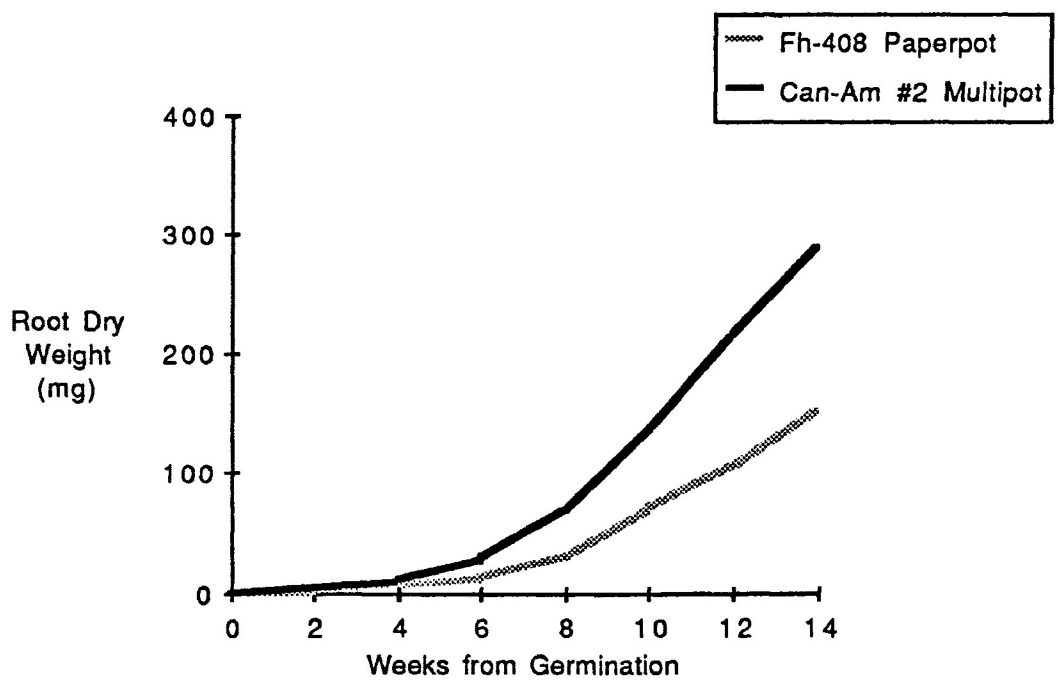


Figure 18. Progression of root dry weight for the 1987 current crop at Hodwitz's greenhouses.

1986/87 Overwinter Crop vs 1987 Current Crop

The 1987 Current crop and the 1986/87 Overwinter crop were compared as they were subjected concurrently to growth chamber and field RGP tests. An ANOVA done on the morphological attributes at the end of the greenhouse production phase showed that the 1987 Current crop was significantly larger in root collar diameter ($P<0.001$), shoot dry weight ($P<0.002$) and root dry weight ($P<0.001$). The seedlings in the 1987 Current crop were also taller in height than the seedlings grown in the 1986/87 Overwinter crop although this difference was not found to be statistically significant by ANOVA. The complete ANOVA tables for these comparisons are given in Appendix XI.

Table 4 shows a comparison between size of the crops grown for this study and an average size compiled from data supplied to the Ministry of Natural Resources from the private greenhouses in the North Central Region of Ontario. Since detailed data are lacking, statistical comparisons were not undertaken. The averages for the four crops presented, based on Ministry data, are not based on the average crop size of all growers in the region as different growers produced different crops, species grown and length of growing time, in different years. In order to make comparisons between the privately grown crops and the crops grown for this study only measurements from jack pine seedlings grown for 14-16 weeks are included in the table.

Although the data in the Table 4 are too general for statistical analysis some comparisons can be made. In general the crops grown for this study were comparable in morphological attributes to those crops produced by the private growers in the North Central Region, although minor differences did occur. The Current crops of seedlings grown in the FH-408 Paperpot in this study were, on average, similar in root collar diameter and shoot and root dry weights to the average current crop produced by the private growers but were slightly taller in height (Table 4). The 1986/87 overwinter crop grown in the paperpots in this study was similar in height and root collar diameter to those overwinter crops produced by the private growers but were smaller in shoot and root dry weights (Table 4). The Current crops of seedlings grown in the Can-Am #2 Multipots in this study were, on average, similar in height

Table 4. Comparison between growth measurements of the seedlings grown in private greenhouses in the North Central Region and of the seedlings grown for this study.

Date	Height (cm)	Root Collar Diameter (mm)	Shoot Dry Weight (mg)	Root Dry Weight (mg)	Seedling Dry Weight (mg)
1) Private Growers					
a) Current Crops					
1985	15.1 (1)	1.95 (1)	712.15 (1)	161.85 (1)	874.0 (1)
1986	20.1 (2)	2.30 (1)	612.89 (1)	175.11 (1)	788.0 (1)
Mean	17.8	2.12	662.52	168.48	831.0
b) Overwinter Crops					
1985/86	11.7 (1)	1.70 (1)	551.74 (1)	153.26 (1)	705.0 (1)
1986/87	17.5 (2)	1.69 (2)	658.69 (2)	135.82 (2)	794.5 (2)
Mean	14.6	1.70	605.22	144.54	749.8
2) This study					
a) Current Crops					
i) Paperpot seedlings					
1986	22.6	2.05	737.00	203.00	940.0
1987	17.4	2.01	516.50	154.50	671.0
Mean	20.0	2.03	626.75	178.75	805.5
ii) Multipot seedlings					
1986	20.5	2.24	952.00	346.00	1298.0
1987	13.5	2.05	639.00	290.50	929.5
Mean	17.0	2.14	795.50	318.25	1113.8
b) Overwinter Crop					
i) Paperpot seedlings					
1986/87	14.5	1.61	403.00	108.00	511.0
ii) Multipot seedlings					
1986/87	14.5	1.63	527.0	189.00	716.0

Numbers in brackets refer to the number of growers upon which the mean is based.
Source: Ministry of Natural Resources, Regional Office, Thunder Bay. 1988.

and root collar diameter to those crops produced by the private growers but were much larger in shoot and root dry weights (Table 4). The overwinter multipot seedlings in this study were similar in height and root collar diameter, smaller in shoot dry weight but larger in root dry weight to those produced by the private growers (Table 4).

ROOT GROWTH POTENTIAL TESTS

The root growth potential data was subject to non-homogeneity of variance owing to considerable variablity of seedlings in their ability to initiate and elongate new white roots. Because of this, various transfromations were used in an attempt to homogenize the variance of the data. The natural log (ln) transformation was found to be the best in reducing the non-homogeneity of variance in three of the four data sets. The exception was the 1986 growth chamber data in which the square-root transformation was found to be the best by the Bartlett-Box test. Analysis of variance and Student-Newman-Keul (SNK) tests were conducted on the transformed data sets.

Analysis of variance was not conducted on root number as it was found that root number and total root elongation were very highly correlated for all four data sets making the results from either root number or total root elongation similar. Table 5 shows the correlation

Table 5. Correlation coefficients between root number and total root elongation for the four root growth potential data sets analysed in this study.

Data set	Correlation Coeficient
1) 1986 Growth Chamber Trial	0.90
2) 1987 Growth Chamber Trial	0.94
3) 1986 Outplanting Trial	0.95
4) 1987 Outplanting Trial	0.94

coefficients for each of the four data sets. All correlations were significant at the 0.001% level of probability.

Growth Chamber Trials

1986 Results

The results of the ANOVA for total root elongation showed significant differences between the main effects of potting dates, container types and root zones for seedlings grown in controlled-environment cabinets. The ANOVA table for the 1986 growth chamber trial is given in Appendix X.

The total root elongation interactions are shown graphically in Figures 19 to 21 for the growth chamber trial. The potting date by container type interaction illustrated in Figure 19 was significant by ANOVA ($P<0.027$). Total root elongation increased over the three test dates for seedlings grown in both container types with the seedlings grown in the Can-Am #2 Multipot exhibiting the greater length of new

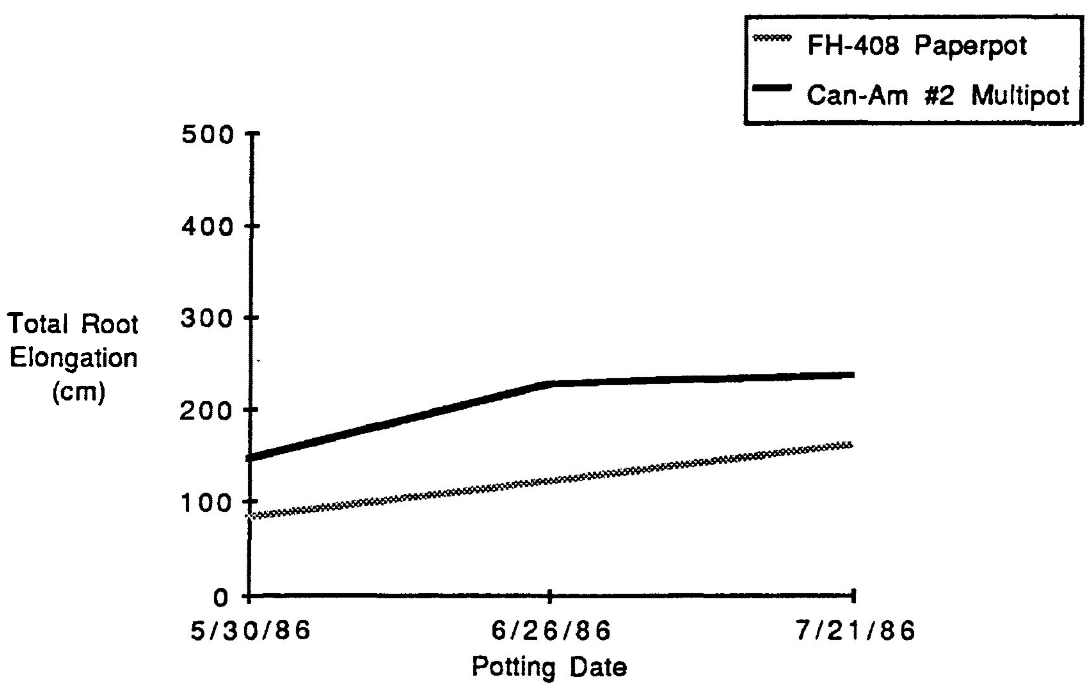


Figure 19. Mean total root elongation by Potting Date and Container Type for the 1986 Growth Chamber Trial.

white roots than those grown in the FH-408 Paperpot at all three potting dates. This difference was the greatest at the second potting date.

Figure 20 shows the potting date by root zone interaction for the 1986 growth chamber trial. This interaction was found to be significant when tested by ANOVA (*P*<0.001). The TRE of roots from root zone 3 was significantly higher than that from the root zones 1 and 2 at all three potting dates. The length of new white roots elongating from root zones 1 and 2 remained relatively constant over the three test dates while the length of new white roots originating from root zone 3 increased

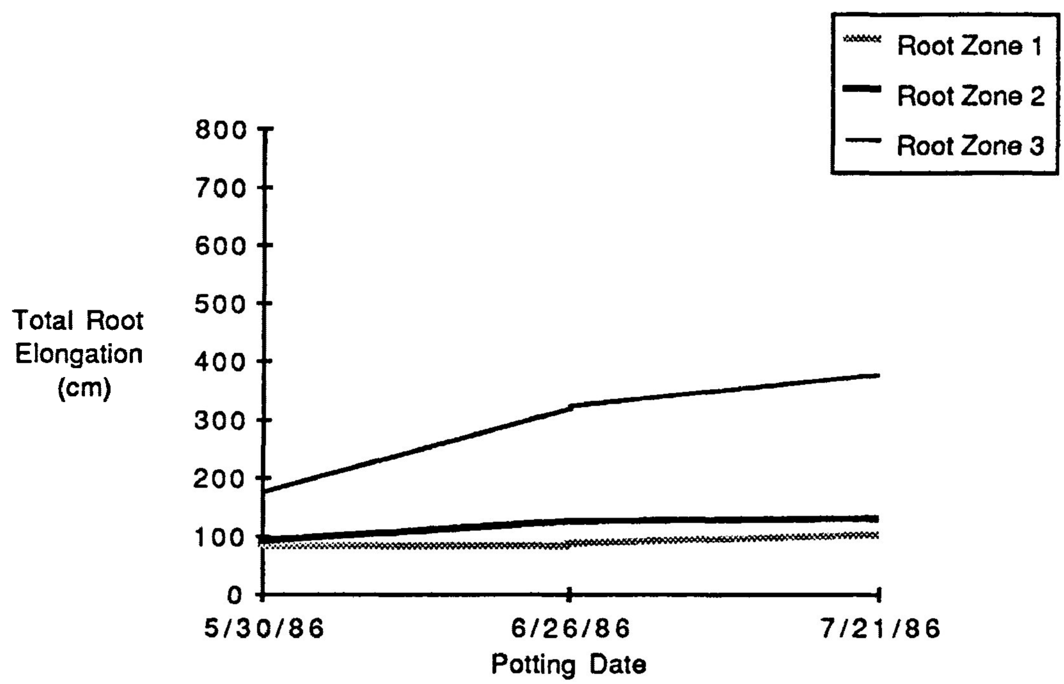


Figure 20. Mean total root elongation by Potting Date and Root Zone for the 1986 Growth Chamber Trial.

substantially. This may be caused by continued root growth when the seedlings remain in the containers for longer periods of time as was the case for the second and third potting dates. A longer time in the container causes more roots to reach the bottom of the plug (root zone 3) and hence elongate from there after outplanting.

The root zone by container type interaction shown in Figure 21 was also found to be significant (*P*<0.001). The Mulitpot seedlings exhibited a constant and steady increase in the length of white roots produced over the three root zones with greatest length of new white roots originating from root zone 3. The Paperpot seedlings also exhibited high root production from root zone 3, but the amount of new white roots elongating from root zones 1 and 2 was significantly less.

The potting date by container type by root zone interaction was found to be significant ($P<0.001$). This was due to the low total root elongation from root zone 2 at all three potting dates for the Paperpot seedlings. Total root elongation for the Paperpot seedlings was the highest from root zone 3, medial from root zone 1 and the lowest from root zone 2 at all three potting dates. The total root elongation for

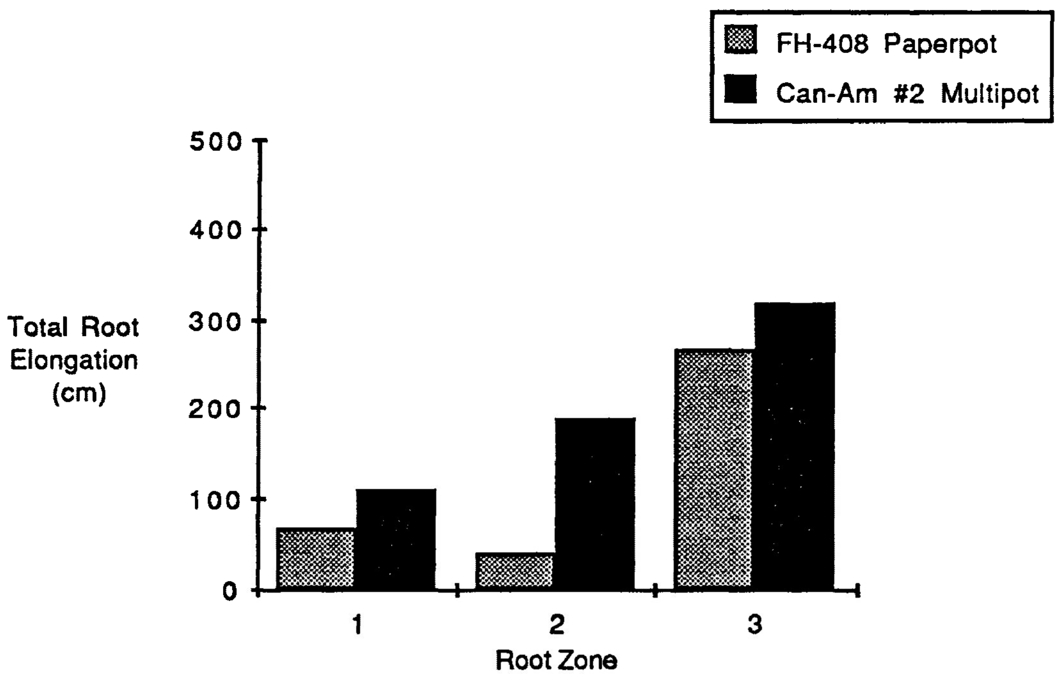


Figure 21. Mean total root elongation by Root Zone and Container Type for the 1986 Growth Chamber Trial.

the Multipot seedlings was also the highest from root zone 3 but was medial from root zone 2 and the lowest from root zone 1 at all three potting dates.

1987 Results

As in 1986, the results of ANOVA for total root elongation indicated very highly significant differences within the main effects of potting dates, container types and root zones for the 1987 growth chamber trial. The comparison between the 1986/87 Overwinter Crop and the 1987 Current Crop investigated in the 1987 study was also found to be very highly significant. The ANOVA table for the 1987 growth chamber trial is given in Appendix XI.

The total root elongation interactions for the 1987 growth chamber trial as presented in Figures 22 to 24 also show similar patterns to those results obtained in 1986.

The potting date by container type interaction presented in Figure 22 was not found to be significant. Seedlings grown in both container types showed increased total root elongation over the three test dates. The difference between seedlings grown in the two container types was not as evident as in 1986. In fact, the lines representing the total root elongation for each container type in Figure 22 are almost indistinguishable. It is important to note however, that the analysis of

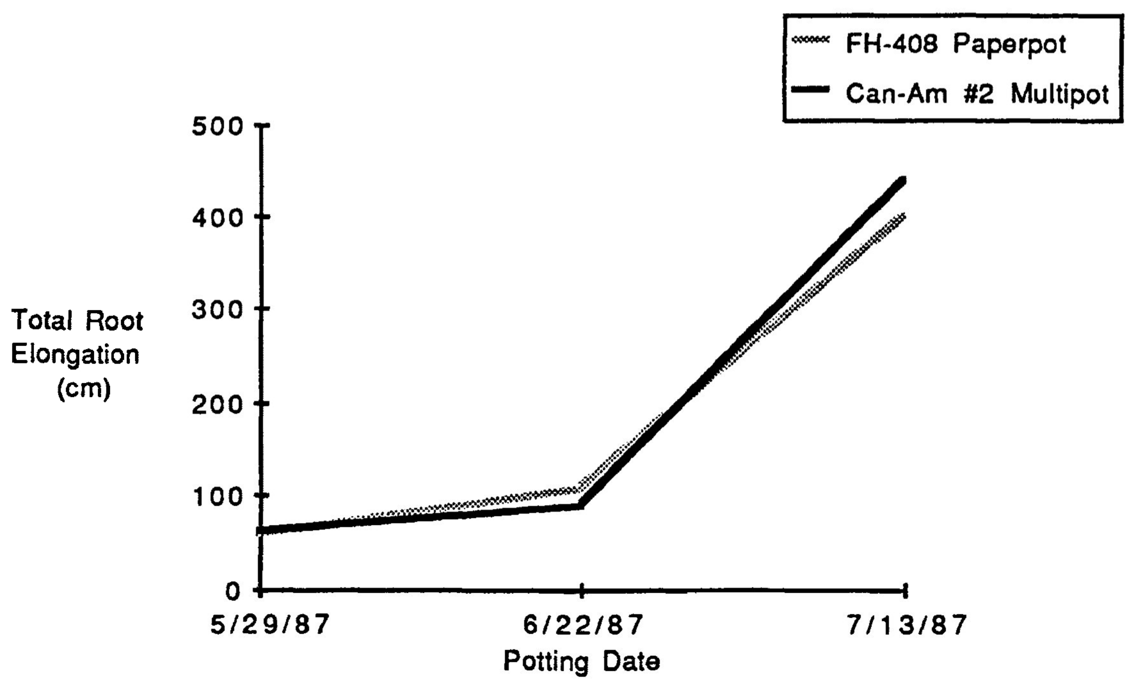


Figure 22. Mean total root elongation by Potting Date and Container Type for the 1987 Growth Chamber Trial.

variance was done on the transformed data while the data presented in Figure 22 is real. A graph of the transformed means shows a clear difference between the total root elongation of seedlings grown in the two container types with seedlings grown in the Can-Am #2 Multipot having a higher total root elongation at all three potting test dates.

The potting date by root zone interaction was found to be significant ($P<0.001$) (Figure 23). Total root elongation was the highest from root zone 3 at all three potting dates although the difference in TRE for all three zones was relatively equal at the first potting date. At the second potting date there was little increase in the length of new white roots elongating from root zones 1 or 2. However, the total root elongation for root zone 3 increased almost twofold. At the third potting date the total root elongation increased for all three zones with root zone 3 showing the most marked increase in total root elongation.

The root zone by container type interaction presented in Figure 24 was also found to be significant ($P<0.001$). As in 1986 the Mulipot seedlings exhibited a gradual increase in total root elongation over the

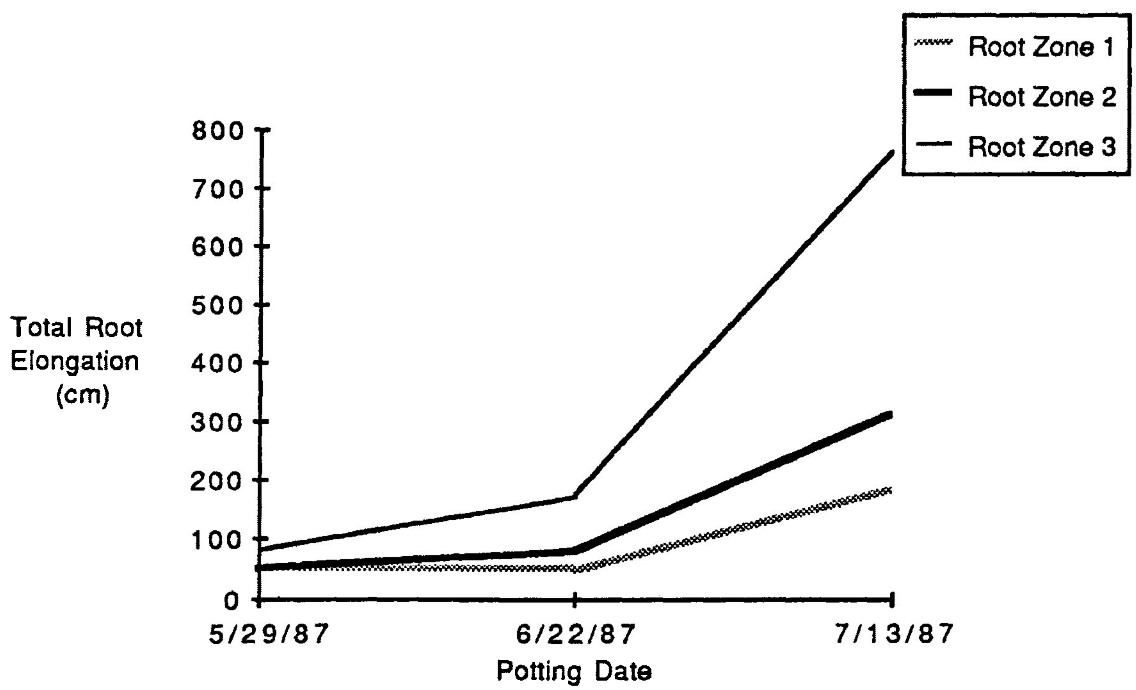


Figure 23. Mean total root elongation by Potting date and Root Zone for the 1987 Growth Chamber Trial.

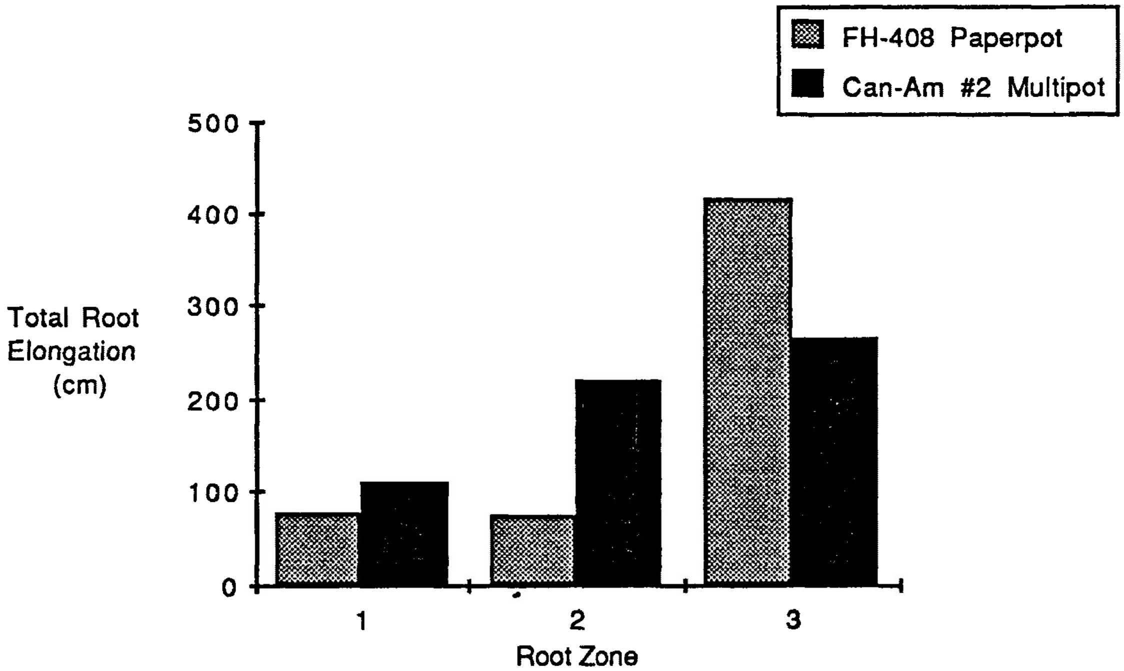


Figure 24. Mean total root elongation by Root Zone and Container Type for the 1987 Growth Chamber Trial.

three root zones. The Paperpot seedlings had little root elongation occurring from root zones 1 and 2 and as in 1986 there was a slight decrease in total root elongation from root zone 1 to root zone 2. Root zone 3 had a very high total root elongation for the Paperpot seedlings. The total root elongation from root zone 3 for the Paperpot seedlings was even greater than that of the Multipot seedlings for the same zone.

The remaining three Figures (25 to 27) present the effects of the crop type versus potting date, container type and root zone interactions for total root elongation of the 1987 growth chamber trial.

Figure 25 shows the potting date by crop type interaction. ANOVA indicated this interaction to be significant ($P<0.001$). The overwinter seedlings had a higher total root elongation at all three potting dates than the current seedlings. This difference was particularly evident at the third potting date where the overwinter seedlings had over twice as much new white root growth than the current seedlings.

The crop type by container type interaction shown in Figure 26 was not significant. The Multipot seedlings had a slightly higher total root elongation than the Paperpot seedlings for the current crop whereas this

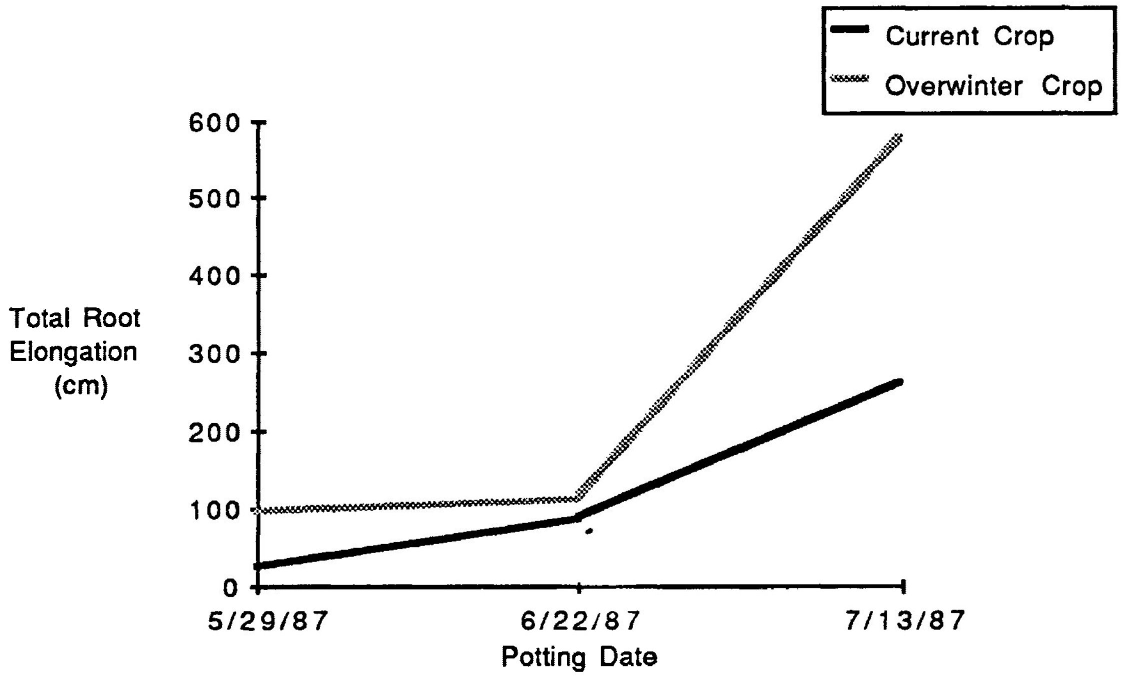


Figure 25. Mean total root elongation by Potting Date and Crop Type for the 1987 Growth Chamber Trial.

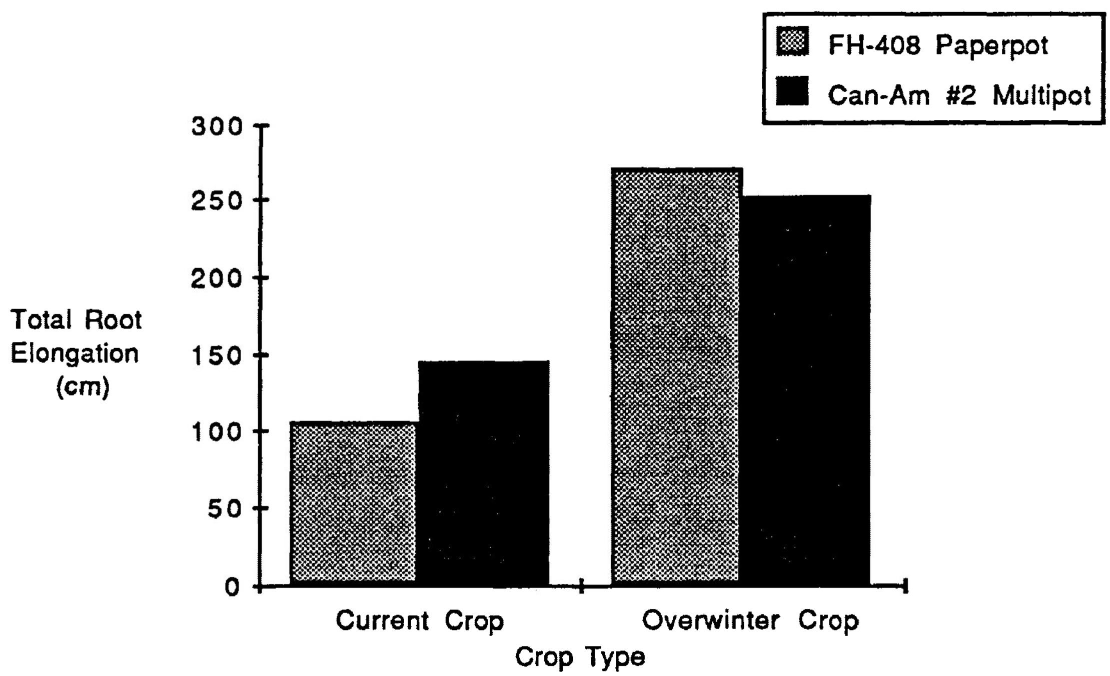


Figure 26. Mean total root elongation by Crop Type and Container Type for the 1987 Growth Chamber Trial.

was reversed for the overwinter crop. This can be related to the fact that since the overwinter crop is stored for a longer period of time than the current crop, more roots of the overwinter stock grow to the bottom of the plug.

This is further illustrated in the root zone by crop type interaction (Figure 27) which was also found to be non-significant by ANOVA. The overwinter seedlings had a higher total root elongation than the current seedlings from all three root zones. This difference was the most pronounced however for the third root zone in which the overwinter seedlings produced over twice as much new white root growth as the current seedlings.

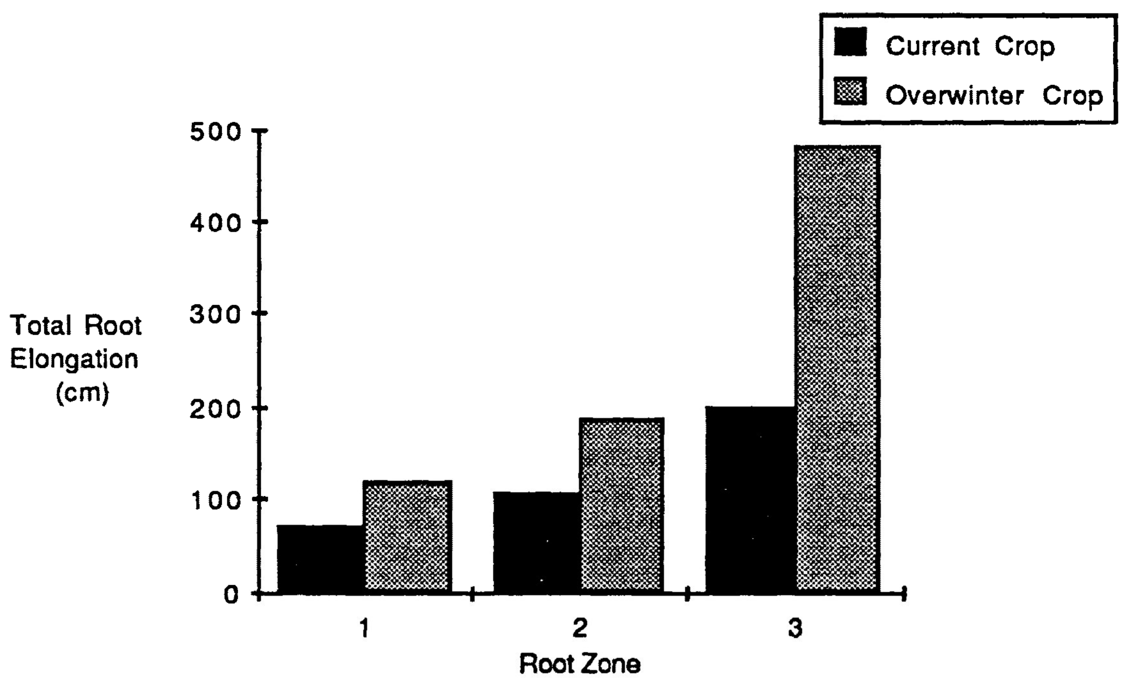


Figure 27. Mean total root elongation by Root Zone and Crop Type for the 1987 Growth Chamber Trial.

The crop type by container type by root zone interaction was also found to be highly significant by ANOVA ($P<0.001$). This was due to the low total root elongation from zone 3 for the overwintered Multipot seedlings relative to the current Multipot crop. This may be caused by freezing damage to the roots in the bottom of the Multipot container during overwinter storage. The overwintered Paperpot stock had a significantly higher total root elongation than the current Paperpot crop from root zone 3. All other 3rd order and higher interactions were not significant.

Outplanting Trials

1986 Results

The results obtained from the 1986 outplanting trial mainly support the results of the controlled environment study. One notable difference was that total root elongation was much higher for the seedlings tested in the growth chamber than for those outplanted in the field. This was expected and is probably related to the warmer and moister environment of the growth chamber. ANOVA indicated very highly significant differences within the main treatment effects of outplanting date, container type and root zone. A complete ANOVA table for the 1986 outplanting trial is given in Appendix XII.

The total root elongation interactions for the 1986 outplanting trial are presented in Figures 28 to 30.

Figure 28 shows the outplanting date by container type interaction. ANOVA indicated that this was not a significant interaction. The Can-Am #2 Multipot seedlings had a higher total root elongation than the FH-408 Paperpot seedlings at all three of the outplanting dates. Total root elongation for seedlings grown in both container types was the lowest at the first outplanting date, increased to a peak at the second outplanting date and then declined again at the third outplanting date.

The outplanting date by root zone interaction presented in Figure 29 was found to be significant by ANOVA ($P<0.029$). At outplanting date 1 there was no real difference in total root elongation from all three zones. However, at outplanting date 2 seedling root egress from root zone 3 had increased substantially while the increase from the other two zones was slight. All three root zones showed a slight decrease in total root elongation at the third outplanting date but the relative proportion of roots from each zone remained constant.

The root zone by container type interaction was found to be significant ($P<0.001$). The interaction is presented in Figure 30. As in

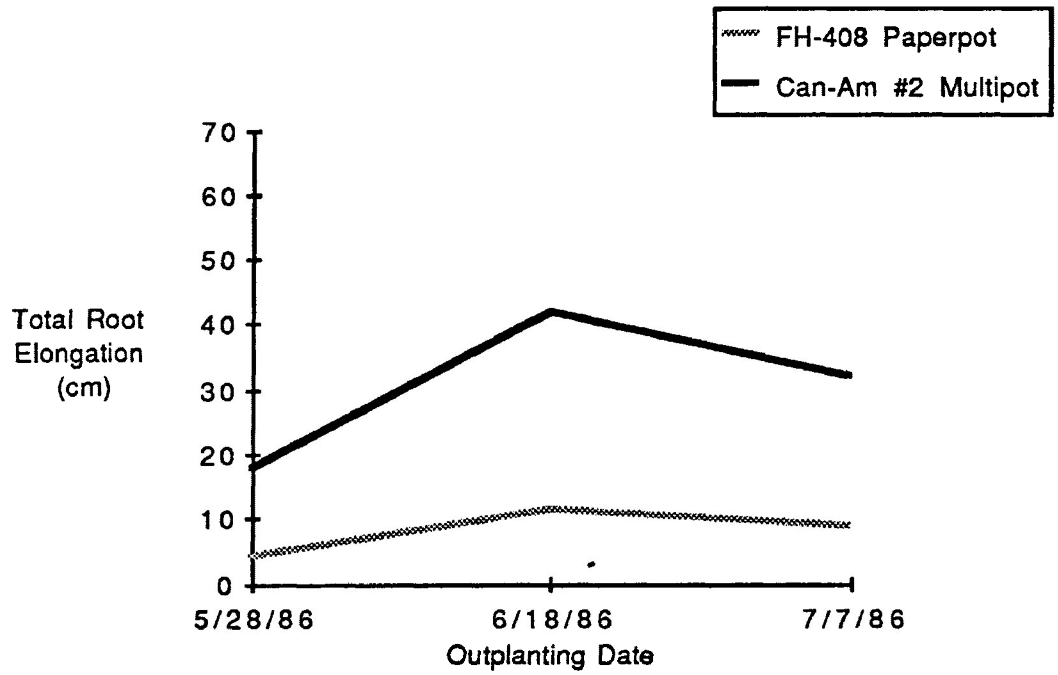


Figure 28. Mean total root elongation by Outplanting Date and Container Type for the 1986 Outplanting Trial.

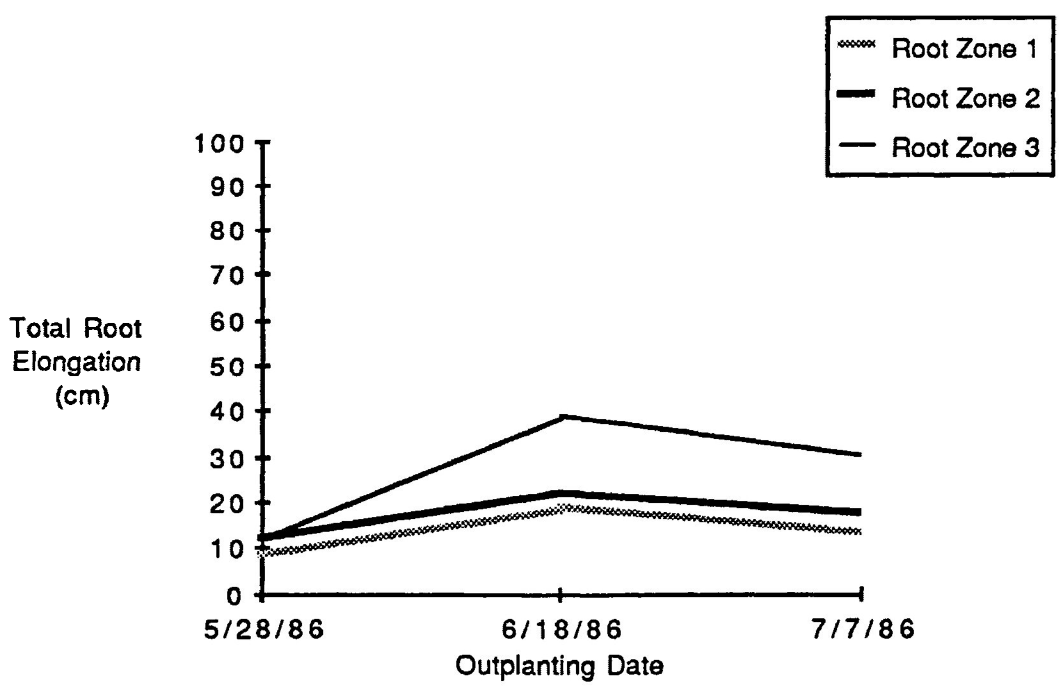


Figure 29. Mean total root elongation by Outplanting Date and Root Zone for the 1986 Outplanting Trial.

the growth chamber trials the Multipot seedlings exhibited a gradual increase in total root elongation over the three root zones. The Paperpot seedlings had a low total root elongation from root zones 1 and 2 and a significantly higher total root elongation from root zone 3. Similar to the growth chamber trials total root elongation from root zone 2 was the lowest for the Paperpot seedlings.

The outplanting date by container type by root zone interaction for the 1986 outplanting trial was not found to be significant.

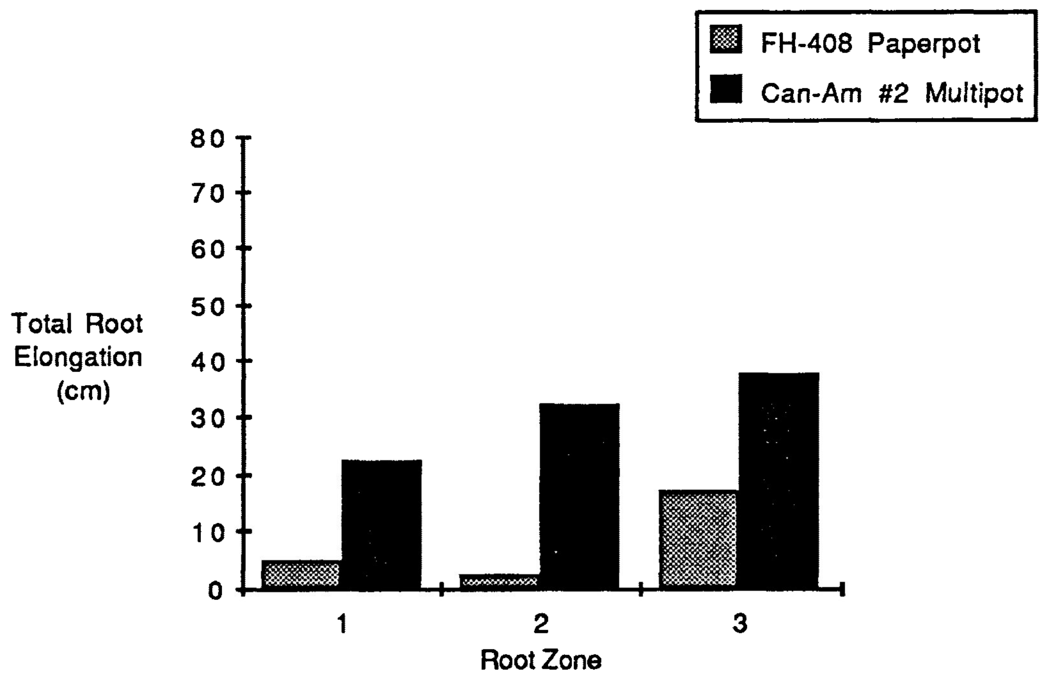


Figure 30. Mean total root elongation by Root Zone and Container Type for the 1986 Outplanting Trial.

1987 Results

The 1987 outplanting trial results were comparable to the 1986 outplanting trial results. The only difference between the two years was a slight difference in the scale for total root elongation. This is related to the better quality outplanting site used in 1987. The soil on the 1987 planting site is a sandy loam and thus was more favourable for jack pine seedling growth and root development than the heavier soil of the 1986 outplanting site.

ANOVA on the transformed data indicated significant differences within the main treatment effects of outplanting dates, container types and root zones. The crop effect, unlike the 1987 growth chamber trial, was found to be non-significant. The complete ANOVA table for the 1987 outplanting trial is given in Appendix XIII.

The total root elongation interactions as presented in Figures 31 to 33 also show similar patterns to those results obtained in 1986.

Figure 31 illustrates the outplanting date by container type interaction. This interaction was not significant. The graph shows that the Can-Am #2 Multipot seedlings had a higher total root elongation than the FH-408 Paperpot seedlings at all three outplanting dates. As in 1986, total root elongation for seedlings grown in both container types was the lowest at the first outplanting date, increased to a peak at the second outplanting date and then decreased at the third outplanting date.

The outplanting date by root zone interaction presented in Figure 32 was found to be significant (*P*<0.001). Root elongation from root zones 1 and 2 exhibited a slight increase over the three outplanting

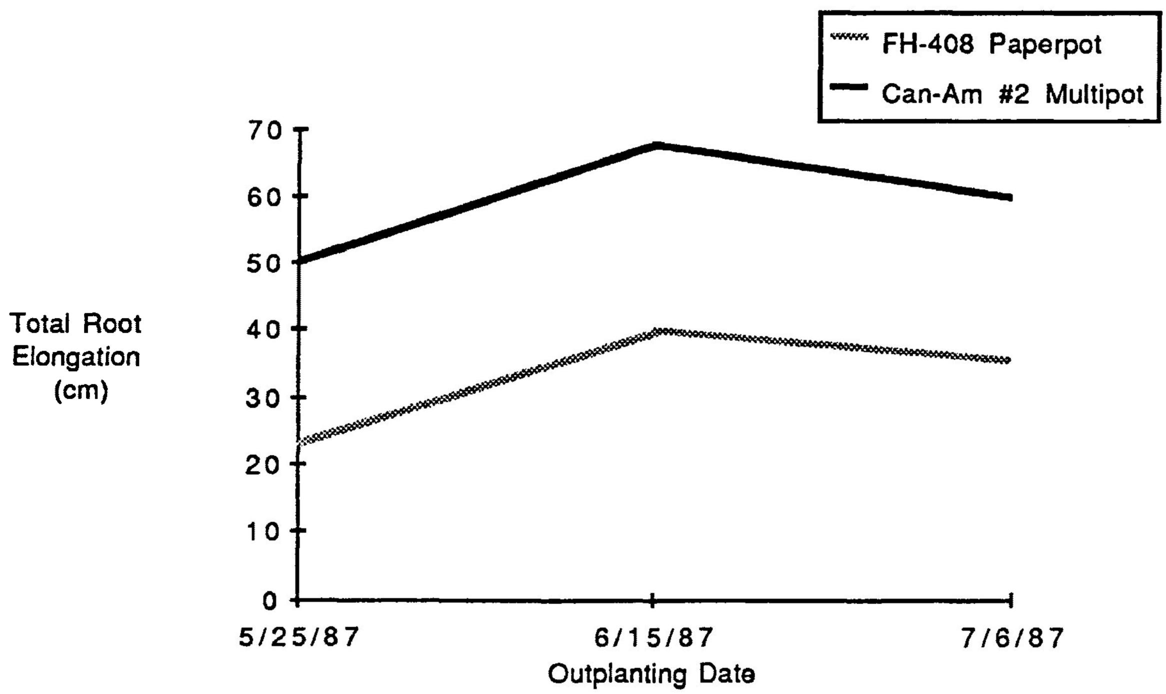


Figure 31. Mean total root elongation by Outplanting Date and Container Type for the 1987 Outplanting Trial.

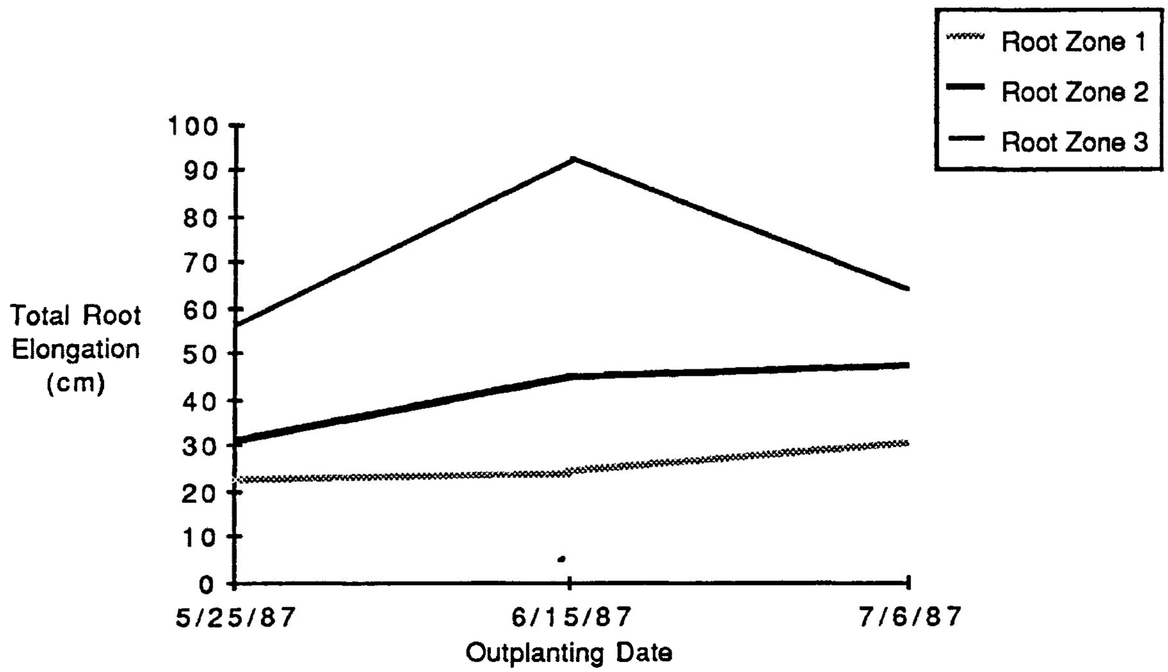


Figure 32. Mean total root elongation by Outplanting Date and Root Zone for the 1987 Outplanting Trial.

test dates. Total root elongation from root zone 3 was significantly higher at all three outplanting dates. The total root elongation from root zone 3 increased from the first outplanting date, peaked at the second outplanting date and then decreased to the first outplanting date level at the third outplanting date.

The root zone by container type interaction was also found to be significant (*P*<0.001). This interaction is shown in Figure 33. As in the previous three data sets, the Can-Am #2 Multipot seedlings exhibited a gradual increase in total root elongation from root zones 1 to 3. The Paperpot seedlings showed a relatively low total root elongation from root zones 1 and 2 and a significantly higher total root elongation from root zone 3. Total root elongation was the lowest from root zone 2 for the Paperpot seedlings.

Figures 34 to 36 show the crop type versus outplanting date, container type and root zone interactions for the 1987 outplanting trial data.

Both the crop type by outplanting date and the crop type by

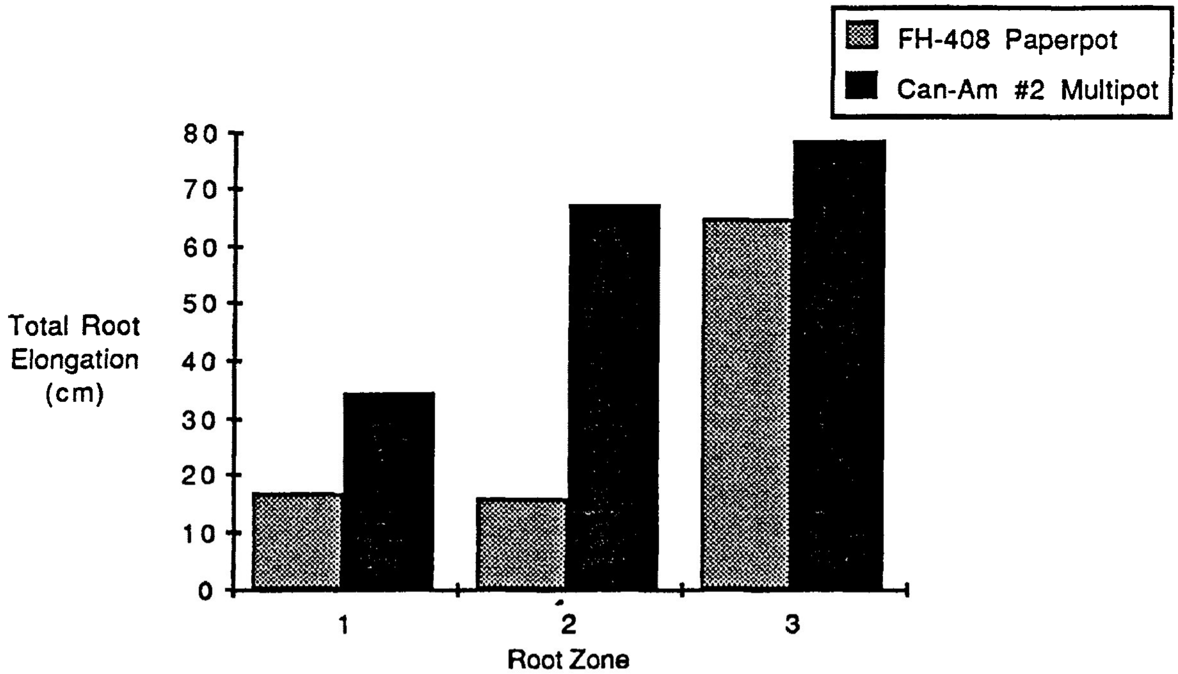


Figure 33. Mean total root elongation by Root Zone and Container Type for the 1987 Outplanting Trial.

container type interactions presented in Figures 34 and 35 respectively were not found to be significant. Total root elongation of seedlings grown under either crop schedule were generally the same at the first and second outplanting dates with a slight deviation occurring at the third outplanting date (Figure 34). This deviation would seem to indicate that some degree of significance should exist for this interaction. However, the means of the transformed data on which the analysis is based showed no deviation at the third outplanting date. Seedlings grown in the FH-408 Paperpot had a slightly higher total root elongation for the overwinter crop than for the current crop. The Can-Am #2 Multipot seedlings showed no discernable difference in total root elongation between either crop type and had a higher total root elongation than the Paperpot seedlings for both overwinter and current crops of seedlings.

Figure 36 illustrates the crop type by root zone interaction. This interaction was found to be significant ($P<0.017$). The current crop of seedlings had a slightly higher total root elongation egressing from

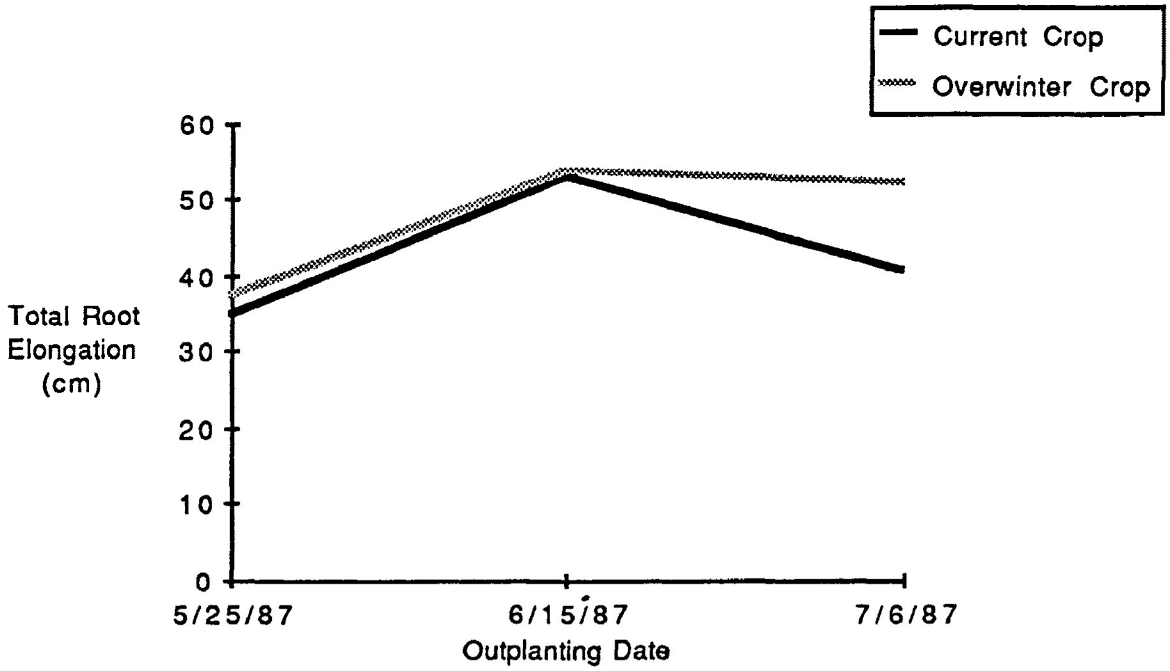


Figure 34. Mean total root elongation by Outplanting Date and Crop Type for the 1987 Outplanting Trial.

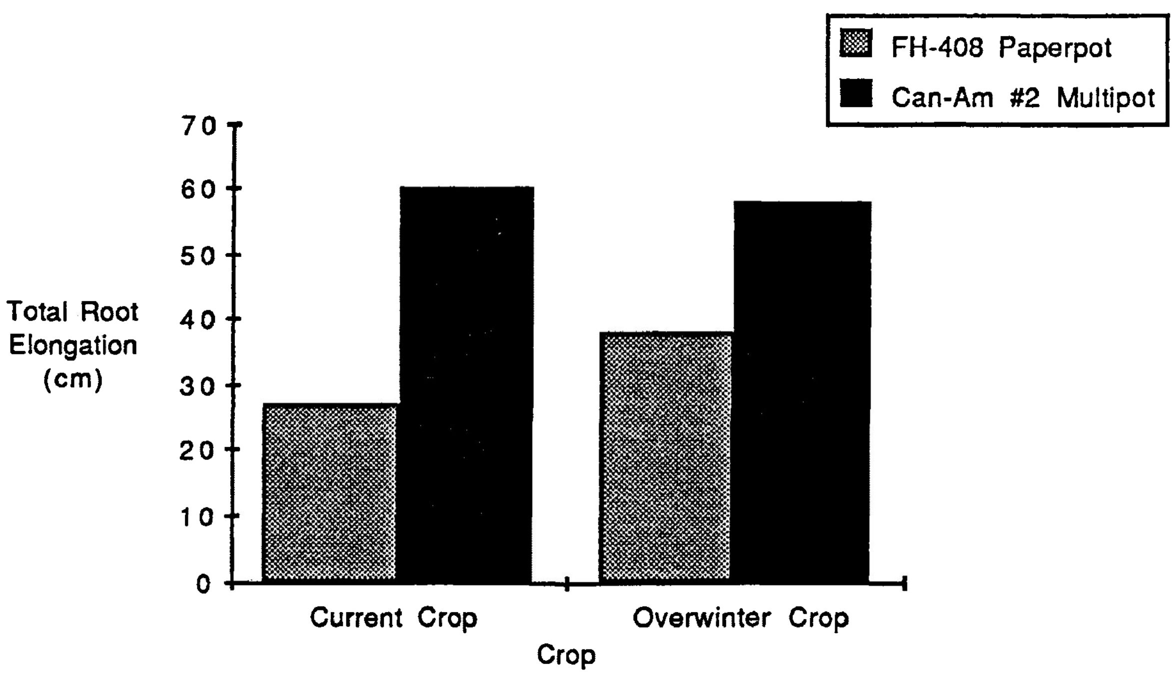


Figure 35. Mean total root elongation by Crop Type and Container Type for the 1987 Outplanting Trial.

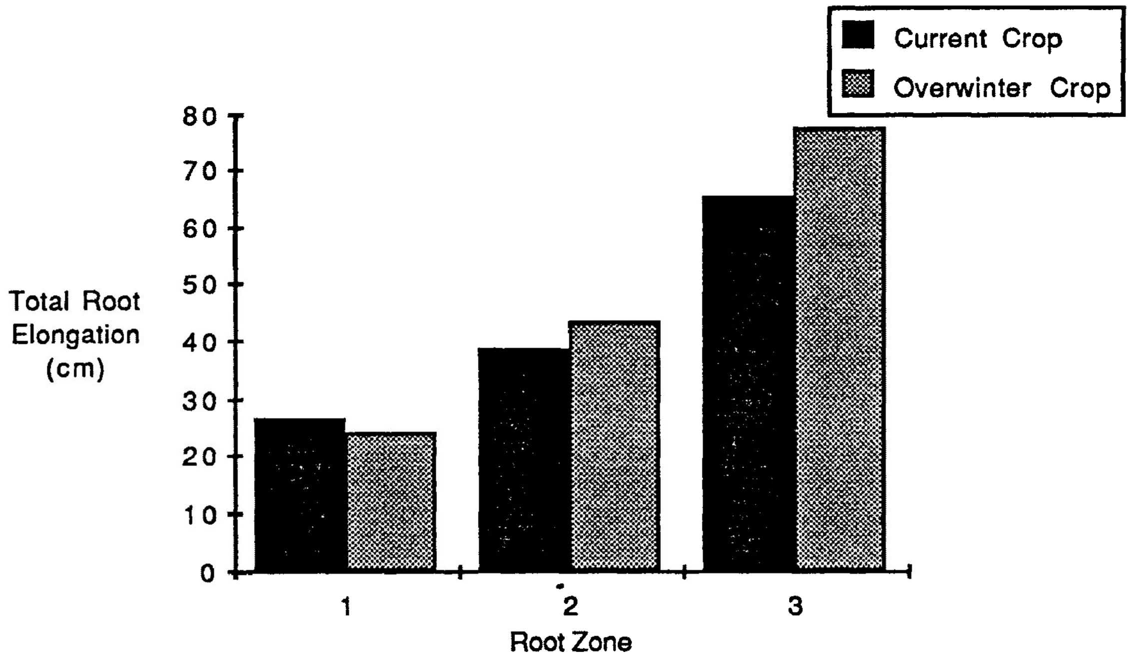


Figure 36. Mean total root elongation by Crop Type and Root Zone for the 1987 Outplanting Trial.

root zone 1 while the total root elongation from root zones 2 and 3 was higher for the overwinter crop of seedlings. This again is related to the length of time that the seedlings are kept in the containers. The longer the time in the container, as for the overwinter crop, the more time the roots have to grow to the bottom of the container plug and elongate from there after outplanting.

Similar to the growth chamber results the crop type by container type by root zone interaction was found to be significant by ANOVA ($P<0.001$). The total root elongation from root zone 3 for the overwintered Multipot seedlings was again lower than that for the current crop. However, the total root elongation for the overwinter crop for both container types and all three root zones was generally lower than that for the current crop except for root zone 2 of the Multipot stock and root zone 3 for the Paperpot seedlings. Again all other 3rd order and higher interactions were not significant.

DISCUSSION

Container seedlings have the advantage over bare-root seedlings in that intimate contact between the roots and the soil is maintained throughout the growing and outplanting process (Tinus, 1974). Tinus also noted that container seedlings can have an external supply of food reserves and moisture in addition to its internal supplies. This may reduce the degree of moisture and nutrient stress experienced by the seedling after outplanting. However, it is still imperative that the container seedling extend new roots into the surrounding soil for successful establishment (Ritchie, 1985). New reserves of soil moisture and nutrients, which are essential for seedling growth, must be tapped quickly in order to ensure seedling survival. Seedlings, therefore, should have a high root growth potential (RGP) at the time of outplanting in order to ensure adequate survival and growth, especially if site conditions are poor, i.e inadequate moisture and nutrients (Burdett, 1987). Day *et al.* (1976) stated that RGP is one of the most critical indicators of the physiological condition of the stock.

From an establishment viewpoint root growth within the plug despite high RGP is inconsequential relative to the extension of new roots into the surrounding soil and according to Kinghorn (1974) containers that restrict root egress after outplanting and the seedlings contained therein are "useless". It is essential then, that seedlings not only have a high RGP at the time of outplanting, but that the roots must also penetrate the container wall into the surrounding soil. In other words, they must also have a high *effective* RGP after outplanting.

The point of root egress from the container is important. Seedlings must develop horizontal roots to ensure tree stability and to extract moisture and nutrients from the upper humic soil layers. According to Hulten and Jansson (1978) seedling stability increases with the number of lateral roots and the roots' cross-sectional area. These roots must also be evenly distributed radially for maximum tree stability. Seedlings also must develop vertical roots in order to exploit the soil for moisture and nutrients at greater depths. The method used to evaluate the effective RGP of container stock in this study takes into account both the amount and location of root growth.

MEASUREMENT OF RGP

The development of the methodology for measuring the RGP of seedlings over the past three decades has concentrated mainly on bare-root seedlings. To date no methodology has been published that specifically measures the RGP of container seedlings. It appears that container stock are treated as if they were bare-root seedlings by removing all the soil from the plug before testing. The method for measuring RGP used in this study allows for the determination of the amount and location of the initial root elongation of the container seedlings into the surrounding soil over a three week period. In this way the effects of container design on the inital root egress as measured by the *effective* RGP of the seedling can be examined. Seedlings with a high RGP at the time of outplanting may have a low effective RGP if the roots do not egress past the container wall.

A similar zonal method has also been used by Rischbieter (1978) to examine the effects of physical barriers of the soil. Ruehle (1985) also used root zones for both bare-root and container stock to study the lateral root development and spread of ectomycorrhizae on loblolly pine seedlings after outplanting.

In order to maintain continuity within this thesis the secondary objective dealing the production of the stock used in this study will be discussed first followed by the primary objectives dealing with the RGP of the seedlings after outplanting.

GREENHOUSE PRODUCTION PHASE

A secondary objective of this study was to monitor the height, root collar diameter, shoot and root dry weight growth of jack pine seedlings grown in FH-408 Paperpots and Can-Am #2 Multipots during the greenhouse production phase for both an Overwinter Crop and two Current Crops of seedlings in order to determine if any differences in seedling morphology existed between seedlings grown in the two container types or between seedlings grown under the two cropping schedules. Seedling size has, in several studies, been shown to influence seedling survival and growth after outplanting in the field (Arnot, 1974; Scarratt, 1974; Armson, 1975; McMinn, 1981 and Barnett, 1984).

Several cultural factors during the greenhouse production phase are known to affect the rate of seedling growth. These factors include greenhouse temperature, relative humidity, light conditions including light intensity and photoperiod, irrigation and fertilization schedules, CO^2 concentrations and biotic factors such as diseases and insects (Larson, 1974). All of these factors influence in one way or another the rate of seedling photosynthesis and ontogenetic development (Larson, 1974) which in turn influences the morphological and physiological condition of the seedlings at the end of the greenhouse production phase. Differences between the seedlings grown in the two container types and between the seedlings grown under the two crop schedules are a result of differences in these cultural factors. In this study, little information other than the basic irrigation and fertilization schedules was collected during the greenhouse production phase.

Comparison Between Crops

Comparisons were made between the 1986 and the 1987 Current crops and between the 1986/87 Overwinter Crop and the 1987 Current crop grown in this study. The crops were compared at a common time base of 14 weeks after germination as growth measurements were available for all three crops then.

1986 Current Crop vs 1987 Current Crop

Differences between the two current crops were found to exist at the common growth time of 14 weeks. Seedlings grown at Hill's greenhouses in 1986 were signifcantly taller and had a slightly higher root collar diameter and shoot dry weight than the seedlings grown at Hodwitz's greenhouses in 1987. The seedlings grown in 1987 were, however, significantly larger in root dry weight than those grown in 1986 (Appendix X). As similar peats were used in the two crops, the most probable explantation for these differences lies in the cultural techniques used by the two growers. Each grower regulates the irrigation and fertilization of their seedlings in order to achieve their desired crop objectives. Differences in root dry weight are quite possibly the result of different irrigation and fertilization schedules. According to the growing records of the crops and personal communication with the growers it appears that the seedlings grown in Hills' greenhouses were irrigated and fertilized more frequently than the seedlings grown in Hodwitz's greenhouses. This may have resulted in the soil in the containers at Hills' being slightly overmoist leading to poorer soil aeration and subsequent poorer root development. According to Sutton (1969) as excess soil moisture results in poor soil aeration and retards root development and also results in depressed photosynthesis (Jarvis and Jarvis, 1963).

The increased frequency of irrigation and fertilization is further exemplified by the significant difference in height ($P<0.001$) and the slight difference (non-significant by ANOVA) in shoot dry weight. Hills' seedlings were larger in both of these two attributes and this better shoot elongation and shoot biomass production could be related to the increased nutrient availabilty although the effect may have been offset somewhat by the lack of root production.

Differences between the two growing seasons in the other environmental factors, such as those mentioned earlier, could also have accounted for some of the differences in the morphology of the crops produced but, as these other factors were not monitored during the greenhouse production phase, any further discussion would be speculative.

1987 Current Crop vs 1986/87 Overwinter Crop

The overwinter crop of seedlings was generally smaller than the current crops of seedlings in all four of the morphological attributes measured. This is in agreement with the data obtained for other overwinter and current crops grown in the North Central region (Table 4).

Differences in the morphological attributes of the seedlings grown under the two cropping schedules could be due to differences in greenhouse temperature. Greenhouse temperature is much more difficult to maintain at optimal levels in the summer months and high greenhouse temperatures on sunny summer days, coupled with low relative humidites can result in stomatal closure and a reduction in net photosynthesis even if the seedlings are well watered (Tinus and MacDonald, 1979). This is turn will result in a reduction in seedling growth. Also, seedlings have been noted to die from heat stress caused by excessive greenhouse temperatures. Excessive greenhouse temperatures can also lead to over-watering in order to cool the greenhouse which can result in poor soil aeration and lead to poor root development.

The smaller size of the overwinter seedlings could also relate to the natural shortening of the photoperiod over the latter 3/4 of the greenhouse production phase. As usually no supplemental lighting is used (Day, 1988, pers. comm.) the shortening photoperiod results in the natural slow down in seedling growth and the setting of buds. Some growers also use 'black out' curtains to effect an eight hour day to cause bud set. A well developed bud results in good shoot elongation in the spring, which increases the size of the overwinter crop so that they are often larger than the current crop of seedlings when outplanted.

Different growers may be another factor that could account for some of the difference in size between the 1986/87 Overwinter crop and the 1987 Current crop. The 1986/87 Overwinter crop was grown at Hills' greenhouses while the 1987 Current crop was grown at Hodwitz's greenhouses. As was discussed earlier in the comparison between the two current crops, different growers often use different growing techniques which may result in differences in morphological attributes of the seedlings produced. However, both the 1986 Current crop and the 1986/87 Overwinter crop which were grown at Hills' greenhouses also exhibited morphological differences (Table 4).

The other environmental factors mentioned earlier could also account for some of the differences between the morphological attribute of the two crops but, as before, they were not monitored so any discussion of their effects would be speculative.

Comparison Between Containers

There were no significant differences in height and root collar diameter between seedlings grown in the two container types except in the 1987 Current crop in which the paperpot seedlings were significantly taller than the multipot seedlings. The multipot seedlings were larger in shoot dry weight than the paperpot seedlings in all three crops. This difference was significant in two of the three crops produced, the exception being the 1987 Current crop. The most consistant difference between seedlings grown in the two container types was the difference in root dry weight. In each of the three crops produced in this study seedlings grown in the Can-Am #2 Multipot had a significantly higher root dry weight than those grown in the FH-408 Paperpot.

Both container types have approximately the same volume, 67 ml for the Can-Am #2 Multipot and 70 ml for the FH-408 Paperpot, so container volume was not a likely causal factor. The paperpot trays do, however, have more cavities per unit area resulting in less growing space per seedling. Seedlings grown in the FH-408 Paperpot have a potential growing space of 9.79 cm^2 per seedling whereas those seedlings grown in the Can-Am #2 Multipot have a potential growing space of 11.49 cm^2 per seedling. Larson (1974) notes that the self-shading of the lower foliage by the upper foliage and other seedlings can be a limiting factor [to growth] in closely grown container stock. As more light of higher intensity reaches the lower foliage in less closely grown seedlings, the photosynthetic productivity increases resulting in increased growth rates. The same effect on seedling photosynthesis can be attained in closely grown seedlings by increasing the light intensity. Larson (1974) reports that shoot and root dry weights of several coniferous species increased with an increase in light intensity and that higher light intensities also resulted in increased lateral branching.

However, in a study by Tanaka and Timmis (1974) on the effects of container density on growth and cold hardiness of Douglas fir seedlings, no significant differences in root collar diameter and shoot and root dry weight were found between the two seedling densities, 75 and 100 seedlings per sq. ft. (12.39 cm^2 per seedling and 9.29 cm^2 per seedling respectively), most closely approximating the seedling densities of the containers used in this study. Differences in seedling height and shoot/root ratio did exist between these two densities. Significant differences between the lowest density (25 seedlings per sq. ft.) and the highest density (100 seedling per sq. ft.) also existed for all five of the measured morphological attributes. Adjustment of the morphological data in this study to compensate for the differences in growing space per seedling resulted in a reduction in the level of significance for shoot dry weight to non-significant but differences in the root dry weight between the seedlings grown in the two container types remained highly significant.

Differences in root dry weight between seedlings grown in the two container types could be a result of better moisture relations in the soil of the Can-Am #2 Mulitpots. The soil in the FH-408 Paperpot tends to remain moister during the periods between irrigation. This may result in the soil being 'overmoist' and lacking in proper soil aeration which has been shown to retard root development (Sutton, 1969) and result in depressed photosynthesis (Jarvis and Jarvis, 1963). Kantor (1988), however, found no significant differences in height, root collar diameter, shoot dry weight, root dry weight or shoot/root ratio between jack pine seedlings grown in FH-408 Paperpots watered every day, every other day or every fourth day. He concluded that no differences were found because "the soil in the paperpots was always moist regardless of which regime was used."

In contrast, seedlings grown in the Can-Am #2 Multipots under the same watering regimes showed significant differences in all five morphological attributes between seedlings watered every day and every other day and those watered every fourth day. The seedlings watered every fourth day were significantly smaller in height, root collar diameter, top dry weight and root dry weight and had a significantly larger shoot/root ratio than those seedlings watered under the other two regimes. The soil in the Multipot containers watered every fourth day was very dry and this may account for the smaller seedlings. However, in spite of this, the Multipot seedlings were still significantly larger in height, root collar diameter, shoot dry weight and root dry weight and had a significantly smaller shoot/root ratio than those seedlings grown in the FH-408 Paperpot.

The improved root development of seedlings grown in the Can-Am #2 Multipots could result in higher levels of root growth after outplanting which could result in better seedling survival and higher rates of seedling growth.

Other factors, such as better drainage or higher cavity temperature because of the air spaces between the seedling cavities leading to faster drying or the shape of the Can-Am #2 Multipot could all potentially lead to improved root development. But, these factors, as well as others that could explain the differences in morphology between the seedlings grown in the two container types, were not monitored and warrant further in-depth investigation.

ROOT GROWTH POTENTIAL

Growth Chamber Trials

In both 1986 and 1987 the seedlings' effective RGP increased over the three potting dates (Figures 19 and 22). This effect was more pronounced in 1987 at the third potting date. Seedlings potted in July showed a markedly higher effective RGP than seedlings potted in May or in June for both container types. This marked increase in effective RGP could be due to a natural surge in seedlings' RGP or, more probably, it could be related to the fact that, while all environmental factors were thought to be held constant, a fresh batch of peat-Vermiculite soil had to be used at the third potting date. At the two previous potting dates an older peat mix had been used as it was already moist. It was necessary to use a fresh peat mix as the supply of the older peat mix had been depleted. Samples of the two soil types used in the study were sent to the Glendon Hall Research Labaratory, Faculty of Forestry, University of Toronto for macro-nutrient analysis to see if a possible cause for the increase in RGP relating to the peat used could be found. However, no significant differences were found in the macro-nutrient content of the two peat mixes. It was thought that the differences in the expression of seedling RGP may be related to the differing structural properties and state of decompostion of the two peat mixes. As the peat breaks down it becomes more compacted and its water holding capacity increases. This can lead to excessive soil moisture retention and poor soil aeration for an extended period of time after irrigation which in turn has been shown to retard root development (Sutton, 1969).

This result clearly illustrates the importance of maintaining a homogeneous environment, including peat mixes, throughout RGP experiments.

In 1986 the same peat mix was used throughout the growth chamber trial. An increase in the RGP of the seedlings over the three potting dates was still evident although it was a more gradual increase. It can be assumed, therefore, that the seedlings tested in the 1987 growth chamber trial would have shown a similar pattern of RGP development had the same peat mix been used throughout the 1987 study.

According to Stupendick (1973) jack pine bareroot seedlings have a single pulse of RGP in the spring prior to bud break. RGP then declines over the summer months even when grown under ideal conditions in a growth chamber. Stupendick's findings are contrary to what was found in this experiment. A probable explanation for this discrepancy is that the experiments conducted by Stupendick used 2+0 bareroot seedlings grown under the natural climatic conditions in a nursery while the experiments done in this study were conducted using 14-26 week old container seedlings grown in the artificial climatic conditions of a greenhouse. It is possible that the younger container seedlings may not be developed enough physiologically to exhibit the periodicity in RGP expressed by older more developed seedlings. To date there is no published research studying the periodicity in RGP of jack pine container stock.

Seedling periodicity in RGP is thought to relate to the allocation of current photosynthate between the roots and shoots of the tree seedlings and that the reduction in root growth which is commonly associated with renewed shoot activity may be related to competition between the shoots and roots for carbohydrates or their relative sink strengths (Ritchie and Dunlap, 1980). However, Larson (1974) noted that if growth conditions are favourable and food supplies adequate, root growth may proceed more or less continuously despite the close ontogenetic link between the shoots and the roots.

The current crop of seedlings tested in controlled-environment cabinets in 1986 and 1987 had been hardened off prior to testing but still exhibited some shoot growth over the course of the RGP test periods. The overwinter crop tested in 1987 also exhibited some shoot growth over the test period but, because the height and root collar diameter measurements for both crops were made after each RGP test it is difficult to determine the exact period in which this growth occurred. However, in spite of this renewed shoot activity, the level of effective RGP continued to increase for both crops over the three test dates (Figure 25). The current crop showed a gradual increase in RGP over the three potting dates whereas the overwinter crop showed little increase in RGP between the first two potting dates but increased substantially at the third; almost 6 times as much.

The RGP results for the current crop tend to support the statement by Larson (1974) in that root growth can be continuous given favourable growing conditions in spite of active shoot growth. The RGP results of the overwinter crop also support the statement by Larson (1974) as root growth at the first two potting dates did occur even though active shoot elongation was also occurring. The surge of root growth at the third potting time also lends support to statement by Ritchie and Dunlap (1980) in that after shoot elongation ceases, which was the case at the third potting time, more photosynthate is available for root growth resulting in higher effective RGP values at that time. Part of this sudden increase could, as was discussed earlier, relate to the fresh peat-vermiculite mix used at the third test date.

The differences in response in seedling RGP between the two crop types can be expected. Overwinter crops are generally more aligned with the natural growth rythmns than are the current crops (K. McClain, 1989, pers. comm.) as they have already undergone a growth/dormancy cycle prior to planting whereas the current crops have not. Current crops are removed from the greenhouse, acclimatized or hardened off and then are outplanted and in essence, are still in the same growing season. In other words, there has been no real dormancy period so continued growth in both the roots and the shoots, as was exhibited by the current crops in the growth chamber trials in this study, can be expected.

The general increase in RGP that occurred over the three potting dates for both crops could also relate to an increase in seedling root mass. As the seedlings remain in the containers, root growth often still occurs and hence seedlings tested at the last potting date may have had more root mass than those seedlings tested at first potting date. An increase in root mass over the test period may result in an increase in RGP over the same period. Unfortunately, as was mentioned earlier, measurements on the seedlings tested for RGP were only made at the end of 21-day test period and only seedling height and root collar diameter were measured and thus this hypothesis could not be tested here.

The overwinter crop had a significantly higher RGP than the current crop of seedlings at all three potting test dates (Figure 25). This would tend to refute the importance of seedling size on RGP as it was found that although the overwinter crop was smaller in all four measured morphological attributes than the current crop at the end of the greenhouse production phase, the overwinter seedlings had a higher effective RGP. It was indicated, however, by height and root collar diameter measurments made after each RGP test that the overwinter seedlings were in fact slightly larger than the current seedlings at the end of each of the RGP tests. It can be assumed, therefore, that the overwinter seedlings grew vigourously in all morphological attributes between the time of spring measurement and time of RGP testing, a period of 6 weeks to the first test date. However, because no measurements were made prior to each RGP test this hypothesis cannot be tested. This further illustrates the need to measure samples of seedlings prior to testing for RGP.

The continued increase in the seedlings' effective RGP over the three potting dates for both crops in the growth chamber trials could also be attributed to the balance of plant growth regulators within the seedling and the effect of photoperiod on these balances. However, a discussion of the exact role of these plant growth regulators on the expression of seedling RGP is beyond the scope of this research. Ritchie and Dunlap (1980) list several studies involving different plant growth regulators and briefly discuss the effect of these substances on the expression of seedling RGP.

Both 1986 and 1987 seedlings grown in the Can-Am #2 Multipots had higher effective RGP than those seedlings grown in the FH-408 Paperpot at all three test dates (Figures 19 and 22). This difference in the effective RGP between seedlings grown in the two container types could be related to the higher root dry weight of the multipot seedlings at the end of the greenhouse production phase or it may be related to the barrier to root egress caused by the paper of the FH-408 Paperpot. Very few roots were able to penetrate the paper of the paperpot resulting in lower effective RGP values for the Paperpot seedlings. The effective RGP was also higher in the overwinter crop than in the current crop for both seedlings grown in Can-Am #2 Multipots and FH-408 Paperpots (Figure 26). It should be pointed out that for the current crop, the effective RGP of the multipot seedlings was higher than that of the paperpot seedlings, while in the overwinter crop the reverse was true. This is related to the length of time the seedlings are stored in the containers. The longer the time in the containers, as in the case of the overwinter crop, the more time the roots have to grow and hence more roots will reach the bottom of the plug and elongate from there after outplanting. This would be beneficial to the paperpot seedlings as there is no barrier to root egress at the bottom of the container and thus more roots could egress from this point resulting in higher effective RGP for the overwinter paperpot seedlings.

There was also no reduction in the effective RGP for the overwinter multipot seedlings. Moreover, a significant drop in root dry weight after overwinter storage did not occur suggesting that freezing damage to the root ball of the multipot seedlings during the overwinter storage period was inconsequential.

The expression of the seedlings' effective RGP was found to vary significantly between the three root zones in both the 1986 and 1987 growth chamber trials. Root growth was the highest from root zone 3, medial from root zone 2 and lowest from root zone 1. In the 1986 study the amount of root growth from root zone 1 and root zone 2 were not significantly different however. High effective RGP values from root zone 3 were expected as in the growing process in the greenhouse roots are directed downward by the container and hence the majority of roots have grown to the bottom of the container plug and elongate from there after outplanting. Also high RGP values could be expected from root zone 3 as there is no barrier to root egress at this zone in either of the two container types studied.

Root production from root zone 3 was also found to increase significantly over the three potting test dates whereas root production from root zones 1 and 2 remained relatively constant throughout the test period (Figures 20 and 23). An exception to this occurred at the third potting date in the 1987 trial in which the effective RGP increased dramatically in all three root zones. This is probably related to the different peat mix used as was discussed earlier. The increase in the effective RGP from root zone 3 over the test period may be caused by the fact that as the seedlings remain in the container for longer periods of time more roots grow to the bottom of the container and hence elongated from there after outplanting. This effect was especially pronounced for the Overwinter Crop where the seedlings remained in the container over the winter before being tested for RGP in the spring. The effect of the crop type on the effective RGP of seedlings was investigated in the 1987 study. It was found that the effective RGP of the Overwinter Crop was higher for all three root zones than that of the Current Crop and that this difference was most pronounced for root zone 3 (Figure 27). The effective RGP for the Overwinter Crop from root zone 3 was over twice as high as the effective RGP for the Current Crop.

Container type also influenced the expression of the seedlings' effective RGP values from the three root zones. Seedlings grown in the Can-Am #2 Multipot exhibited a gradual increase in root production over the three root zones with the most roots elongating from root zone 3 (Figures 21 and 24). The FH-408 Paperpot seedlings however had very low root production from root zones 1 and 2 while the effective RGP was very high from root zone 3. In the 1987 study the amount of root growth from root zone 3 for the paperpot seedlings was even greater than that for the multipot seedlings for the same root zone. The paperpot seedlings also exhibited a decrease in root production from root zone 2 over root zone 1. This decrease can be attributed to the fact that in root zone 1 roots can grow out of the top of the plug resulting in a higher effective RGP value for that zone. Conversely, roots in root zone 2 cannot do this and hence fewer roots were measured. The low root production from root zones 1 and 2 for the Paperpot seedlings and high effective RGP values from root zone 3 in both the 1986 and 1987 growth chamber trials clearly illustrates the restrictive nature of the FH-408 Paperpot to root egress. It forces the majority of the roots to grow out the bottom of the container plug whereas the Can-Am #2 Multipot allows a more even distribution of roots over the three root zones. This effect is also shown in the photographs of seedlings grown for 21 days in controlled-environment cabinets in the root study boxes. As can be seen in Figures 37 and 39 effective root growth from root zones 1 and 2 for the seedlings grown in the FH-408 Paperpot was minimal whereas effective root growth from root zone 3 was quite high. The roots seen egressing from the paperpot container in both photographs quite likely are egressing through the seam in the paper. The photographs of the effective root growth of seedlings grown in the Can-Am #2 Multipots are shown in Figures 38 and 40. Effective root production from root zones 1 and 2 is much higher for these seedlings than for the paperpot seedlings and the seedlings have a more even distribution of roots egressing from the three root zones.

Outplanting Trials

Results of seedling RGP tests obtained from the outplanting trials in 1986 and 1987 were also similar to those obtained from the growth chamber trial but for one notable exception, other than the difference in the scale of the RGP measurements. Root growth potential values for the growth chamber trials were higher than those obtained from the outplanting trials due to the more favourable growing conditons in the growth chambers.

The one notable difference between the growth chamber trials and the outplanting trials relates to the potting date factor. In the growth chamber trials the seedlings' effective RGP increased over the three test dates whereas in the outplanting trial the seedlings' effective RGP peaked at the second outplanting date and then decreased. This peak at the second outplanting date was evident in all interactions containing the time factor in both the 1986 and 1987 trials (Figures 28 and 31). This peak at the second outplanting date is most likely a function of the environment as it has been shown that, given ideal growing conditions, as in the growth chambers, the seedlings' effective RGP increased over the three test dates for seedlings grown in both container types (Figures 19 and 22). Several environmental factors or a combination of these factors could account for these trends, including, soil factors, moisture and temperature, and climatic factors, air temperature, light intensity and photoperiod.

Soil moisture was monitored over the 1987 outplanting trial using static tensiometers. The tensiometers were also used in the 1986 trial but unfortunately a late spring frost damaged them and the repairs took the rest of the 1986 outplanting season to complete. However, from Ministry of Natural Resources fire weather records collected at Great Lakes Forest Products' (Canadian Pacific Forest Products) Camp 45,

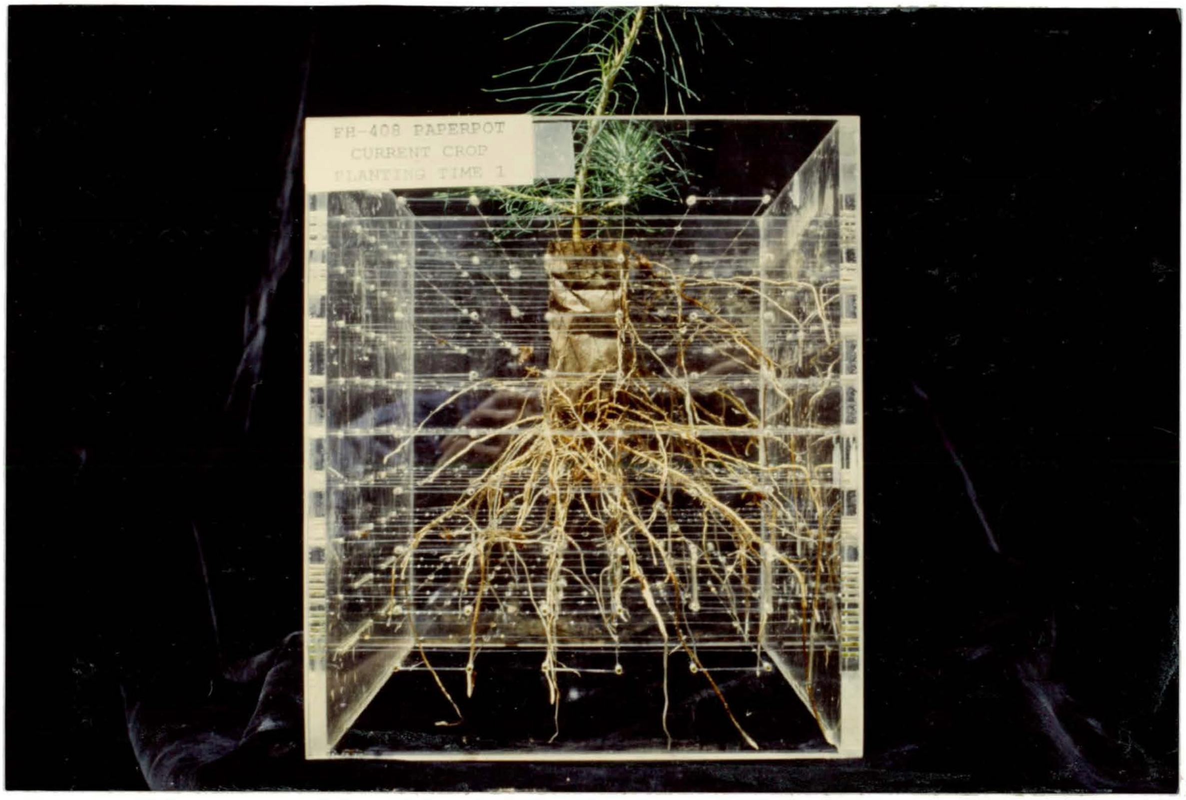


Figure 37. Root egress of a current crop FH-408 Paperpot seedling placed in the root study box at the first RGP test date in 1987 and grown for 21 days.

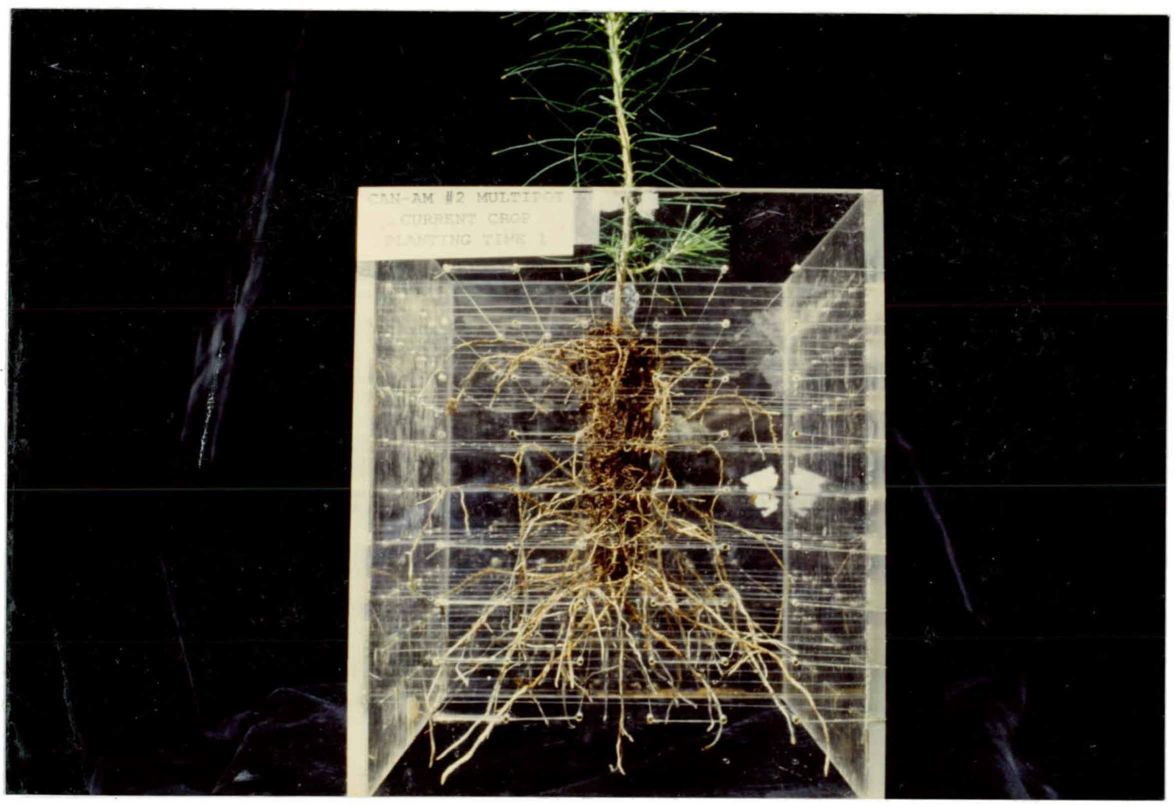


Figure 38. Root egress of a current crop Can-Am #2 Multipot seedling grown in placed in the root study box at the first RGP test date in 1987 and grown for 21 days.

Figure 39. Root egress of an overwinter crop FH-408 Paperpot seedling placed in the root study box at the second RGP test date in 1987 and grown for 21 days.

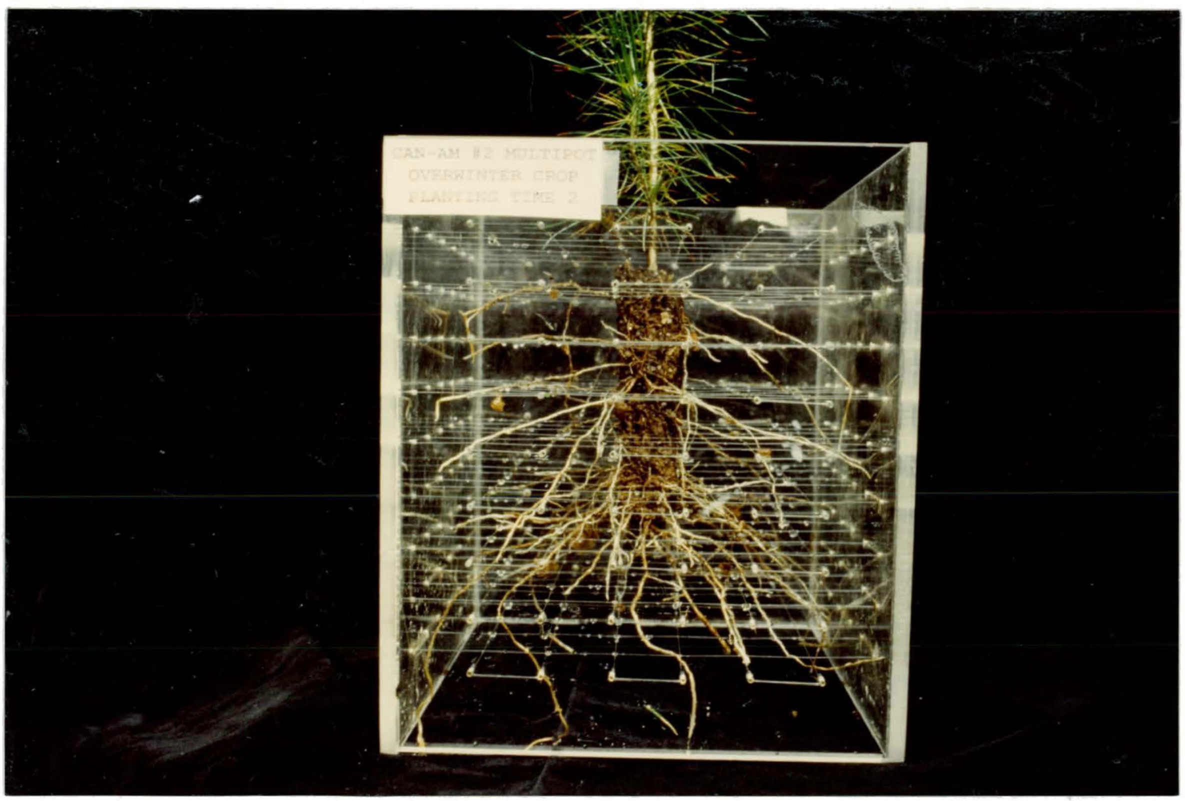


Figure 40. Root egress of an overwinter crop Can-Am #2 Mulipot seedling placed in the root study box at the second RGP test date in 1987 and grown for 21 days.

precipitation was found to be adequate throughout the 1986 growing season. There was, however, a dry spell at the beginning of the first outplanting period. This dry spell resulted in the Ministry of Natural Resources implementing a restricted fire zone in the planting area which lasted until day five of the first outplanting test period. This may have affected the expression of seedling RGP at the first outplanting date as low levels of soil moisture retard the growth and maturation of roots (Sutton, 1969). Without soil moisture readings though, it is difficult to assess the effects of this dry period on the expression of the seedlings' effective RGP. In 1987 soil tensiometer readings showed that soil moisture was adequate, above -0.3 MPa, throughout the three RGP test periods. This is further supplemented by Environment Canada weather data which indicated only slightly below normal precipitation (83.05%) over the three months of May, June and July, 1987.

Soil temperature was not measured over the test dates, but it can be assumed to be reflected by the air temperature during the test period. From Ministry of Natural Resources data for 1986 collected at Canadian Pacific Forest Products' Camp 45 and Environment Canada data for 1987 collected at Thunder Bay airport, it was found that maximum air temperature was relatively constant over the three outplanting test periods. In 1986 there was an abnormally warm period of weather corresponding to the dry spell discussed earlier.

Light intensity was not monitored during these tests so its affect on seedling RGP cannot be evaluated.

Ritchie and Dunlap (1980) stated that photoperiod may also affect the RGP of seedlings, but that there is no published information relating this factor to the RGP of outplanted seedlings. It is interesting to note, however, that the peak in seedling RGP in both 1986 and 1987 corresponded to the peak in the natural photoperiod during the summer soltice (June 21-22). During the second outplanting period the natural photoperiod is the longest (16.3 hrs in Thunder Bay). At the 1986 site which was north of Thunder Bay this would be even longer. This means longer days which in turn would lead to increased photosynthesis, provided that no other environmental factors, such as soil moisture or temperature are limiting. An increase in the amount of photsynthesis would mean that more photosynthate would be available for seedling growth. This could, therefore, lead to a higher levels of root growth at the second outplanting date. Larson (1974), in a paper about factors influencing seedling growth in greenhouses, states that photoperiod is one of the most critical controllable factors affecting seedling growth. It would stand to reason that photoperiod is also a critical factor influencing seedling growth, both shoots and roots, after outplanting.

At the third outplanting time day length had decreased somewhat resulting in reduced photosynthesis and therefore reduced levels of photosynthate available for shoot and root growth. This is supported by the fact that in the growth chamber trials, in which photoperiod was kept constant, RGP continued to increase from the second to the third test date.

Photoperiod may also have an effect on seedling growth by influencing hormonal levels within the seedling and its effect on the induction of seedling dormancy. Endogenous factors may also play a role in the expression of seedling RGP during the outplanting trials, but as was mentioned in the growth chamber trial section the discussion of these factors is beyond the scope of this study.

Similar results in the other RGP interactions were found between the outplanting trials and the growth chamber trials in both 1986 and 1987 trials. As in the growth chamber trials container type influenced the expression of the seedlings' effective RGP values from the three root zones in both the 1986 and 1987 outplanting trials. Effective root production increased gradually over the three root zones for seedlings grown in the Can-Am #2 Multipot (Figures 30 and 33). Effective root production for the FH-408 Paperpot was, on the other hand, very low from root zones 1 and 2 and increased substantially from the third root zone. Effective root production of the paperpot seedlings from root zone 2 was again lower than that from root zone 1 for the same reason as was discussed in the growth chamber trial section. The low effective root production from root zones 1 and 2 and the high effective root production from root zone 3 after outplanting reinforces the point that the paper of the FH-408 Paperpot is a barrier to root egress. The Can-Am #2 Multipot has no such barrier to root egress which results in well distributed pattern of effective root production over the three root zones which will theoretically result in better initial seedling survival and growth and will lead to a more stable tree as the tree matures.

Spencer (1974) stated that the basic design of the container system should include container walls that are either a) unrestrictive to root growth or b) removed completely at the time of outplanting. The Fh-408 Paperpot container seems to fit into neither category as the barrier to root egress caused by the wall of the Paperpot, as shown by the low RGP values from root zones 1 and 2, has been found to persist for many years in the field after the seedlings are outplanted (Carlson and Nairn, 1977; Ben Salem, 1978; Segarin *et al.*, 1978). Not only does the Paperpot container restrict the RGP and initial root egress of the seedlings, which in turn affects initial survival and outplanting performance, but they also lead to stability problems in the plantations later on. Bergman and Haggstrom (1976) stated that the presence of the paper of the paperpot container for an extended period of time after outplanting has led to severe root deformities which may inhibit root development and cause instability, early windfall or even kill the seedling. The lack of RGP from root zones 1 and 2 for the Paperpot seedlings can lead to the type of stability and root form problems found by the J.D. Irving Company of St. John, New Brunswick in their jack pine plantations.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The results of this research show that jack pine seedlings grown in the Can-Am #2 Multipot are superior morphologically to those grown in the FH-408 Paperpot especially in root dry weight. The higher root dry weight of the seedlings grown in the multipot results in a better balanced seedling, which in turn may lead to higher survival and better growth after outplanting.

The jack pine seedlings grown in Can-Am #2 Multipots also exhibited higher levels of effective root growth potential after outplanting than seedlings grown in FH-408 Paperpots, especially in the upper two root zones where the paper wall of the paperpot container still remained around the container plug. Similar results were also obtained in the growth chamber trials and the restrictive nature of the paper wall of the paperpot container to root egress was also clearly evident in the photographs of the seedlings grown in the root study boxes. These results support the hypothesis that seedlings grown in container-free plugs such as the Can-Am #2 Multipot, which are planted with an unrestricted rootball, will exhibit a higher level of root egress as expressed by higher effective RGP values than those seedlings grown in the FH-408 Paperpots which are planted with the paper barrier of the container still surrounding the rootball.

The implications for management based on these results and others dealing with the long term effects of the paperpot on seedling survival and root-form (Bergman and Haggstrom, 1976, Carlson and Nairn, 1977 and others) are clear. It is recommended that serious consideration be placed on converting existing greenhouses from the production of seedlings in the FH-408 Paperpot to the production of seedlings in a container-free plug, be it the Can-Am #2 Multipot or some other container-free system and that newly constructed greenhouses be set up to produce seedlings using a container-free plug system.

There were also differences in the morphology and RGP of seedlings grown under the two cropping schedules. The overwinter crop is generally favoured by forest companies as it exhibits rapid post-planting shoot elongation which allows it to compete with existing vegetation on the site. However, it is imperative that the overwinter crop have sufficient root growth in order to support the renewed shoot activity. If there is insufficient effective RGP soon after outplanting to support renewed shoot activity and if environmental conditions, such as soil moisture, are limiting, the seedling will be subjected to moisture stress which will, if environmental conditions are severe enough, result in the death of the seedling. A current crop of seedlings, on the other hand, may exhibit some shoot growth after outplanting but only if environmental condtions are favourable. The current crop, although having less effective RGP, as found in this study, does not have the extra shoot growth to support and may be better able to survive unfavourable environmental conditions.

RECOMMENDATIONS FOR FUTURE RESEARCH

This research deals with the morphological development of jack pine seedlings in a greenhouse environment and the effective root growth potential of these seedlings after outplanting in the field. It is necessary, however, to further our understanding of the physiology of container produced seedlings to ensure the establishment of vigorous plantations. Areas in which further research is required are:

1) The periodicity in root growth potential of container produced seedlings and the factors that relate to or affect periodicity,

2) growth rhythms of container produced stock under greenhouse conditions,

3) the relationship of the components of seedling morphology such as seedling height, root collar diameter and shoot and root dry weight on root growth potential and field establishment,

4) the ecophysiology of container produced seedlings, and

5) the effect of the container system on long term plantation performance.

LITERATURE CITED

Abod, S.A. 1978. Effect of air and soil temperatures on root regeneration of tropical pine seedlings. pp. 124-134 *in* A. Riedacher and J. Gagnaire (eds.) Proc. IUFRO Symposium on Root Physiology and Symbiosis, Vol. 1., Sept. 11-15, 1978, Nancy, France. 317 pp.

Abod, S.A., K.R. Shepherd and E.P. Bachelard. 1979. Effects of light intensity, air and soil temperatures on root regeneration potential of *Pinus caribaea* var. Hondurensis and *P. kesiya* seedlings. Aust. For. Res. 9:173-184.

Armson, K.A. and V. Sadreika. 1979. Forest tree nursery soil management and related prcatices (Metric Edition). Ont. Min. Nat. Res. Pub. 179 pp.

Arnott, J.T. 1974. Performance in British Columbia. pp. 283-289 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium, Denver, Colorado, Aug. 26-29, 1974. Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Aubez, M. 1971. Croissance des racines du pin laricio de corse (*Pinus nigra* Arn. var. *laricio*) au stade juvenile. Ann. Sci. For. 28:259-288.[Root growth of Corsican pine in the juvenile stage: relation to growth of above ground parts and to environmental factors.] (Summary in English).

Barney, C.W. 1951. Effects of soil temperature and light intensity on root growth of loblolly pine seedlings. Pl. Physiol. 26:146-163.

Barnett, J.P. 1984. Relating seedling physiology to survival and growth in container-grown southern pines. pp. 157-176 *in* Duryea, M.L. and G.N. Brown (eds.) Seedling Physiology and Reforestation Success. Proc. of the Physiology Working Group Technical Session. Soc. of Amer. Foresters Nat. Conv. Portland, Oregon. Oct 16-20, 1983. Martinus Nijohff/ Dr. W. Junk Publishers. Dordrecht/Boston/ London. 326 pp.

Bell, T.I.W. 1978. The effect of seedling container restrictions on the development of *Pinus caribaea* roots. pp. 91-95 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Ben Salem, B. 1978. Root form of *Pinus pinea* seedlings grown in paper pot containers. pp. 96-99 *in* Van Eerden, E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Bergman, F. and B. Haggstrom. 1976. Some important facts concerning planting with rooted forest plants. (Trans. by R.A. Hellenius). For Chron. 52:266-273.

Bilan, M.V. 1964 Acrylic resin tubes for studying root growth in tree seedlings. For. Sci. 10:461-462.

Bloomberg, W.J. 1963. A translucent rooting medium for the observation of Douglas fir seedling roots. Pl. Dis. Reporter 47:455-458.

Burdett, A.N. 1978. Root form and mechanical stability of planted lodgepole pine in British Columbia. pp. 162-165 *in* Van Eerden, E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Burdett, A.N. 1979a. New methods of measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Burdett, A.N. 1987. Understanding root growth capacity: Theoretical considerations in assessing planting stock quality by means of root growth tests. Can. J. For. Res. 17:768-775.

Burdett, A.N., D.G. Simpson and C.F. Thompson. 1983. Root development and plantation establishment success. Pl. and Soil 71:103-110.

Burdett, A.N., L.J. Herring and C.F. Thompson. 1984. Early growth of planted spruce. Can. J. For. Res. 14:644-651.

Carlson, L.W. 1972. V. Mortality in 1969 spring-planted jack pine plantations in jack pine in Southeastern Manitoba: A compendium of Research, 1967-1970. C.F.S., Nth. For. Res. Cen. Inf. Rep. NOR-X-50E. 26 pp.

Carlson, L.W. and L.D. Nairn. 1977. Root deformities in some container-grown jack pine in southeastern Manitoba. For. Chron. 53:147-149.

Chavasse, C.G.R. 1977. The significance of planting height as an indicator of subsequent seedling growth. N.Z.J. For. 22:283-296.

Columbo, S.J., D.P. Webb and C. Glerum. 1984. Frost hardiness testing: An operational manual for use with extended greenhouse culture. Ont. Min. Nat. Res., For. Res. Rep. No. 110. 14 pp.

Day, R.J. 1981. Evaluating the root regeneration potential of bare-root nursery stock. Lakehead University, School of Forestry Rep., Aug. 1981. 19 pp.

Day, R.J. 1985. Basic seedling physiology. Essential information for producing and planting nursery stock. In Proc. Northern Silviculture Committee Meeting, Prince George, B.C., Feb. 5 and 6, 1985. 29 pp.

Day, R.J. and J.T. Stupendick. 1974 Root regenerating potential of black and white spruce nursery stock in 1972 and 1973. Lakehead University, School of Forestry Rep. 14 pp.

Day, R.J. and J.M. Butler. 1975. Root regeneration of spring- and summer-lifted black spruce and jack pine nursery stock in relation to soil moisture content. Lakehead Univ., School of For., Unpub. Rep. 13 pp.

Day, R.J. and G.R. MacGillivray. 1975. Root regeneration of fall-lifted white spruce nursery stock in relation to soil moisture content. For. Chron. 51:196-199.

Day, R.J., J.T. Stupendick and J.M. Butler. 1976. Root periodicity and root regeneration potential are keys to successful plantation establishment. pp. 19-21 *in* Proc. Plantation Establishment Symposium, Kirkland Lake, Ont. Ont-Can. For. Serv. Pub. O-P-5.

Day, R.J. and E. Breunig, 1977. Root regeneration of 3+0 white spruce varies with root system size, post planting soil moisture and climate. Lakehead Univ., School of For., Unpub. Rep. 38 pp.

Day, R.J. and E.M. Harvey, 1984. Morphological and physiological stock quality in relation to field outplanting performance. (Second report, 1982-83 results). Lakehead Univ., School of For. Rep. 217 pp.

Day, R.J., D.C. Sutherland and J. Conner. 1984. Silviculture laboratory manual. Lakehead Univ., School of For., Thunder Bay, Ont. 344 pp.

Day, R.J., W.R. Bunting, C. Glerum, E.M. Harvey, B. Polhill, K.H. Reese and A. Wynia. (ed. P.H. Aird). 1985. Evaluating the qualtiy of bareroot forest nursery stock. Ont. Min. Nat. Res. Pub., Toronto, Ont. 140 pp.

Environment Canada, 1986. Monthly Meteorologcal Summary, At Thunder Bay "A" Ont. January - December, 1986. Atmospheric Environment Service.

Environment Canada, 1987. Monthly Meteorologcal Summary, At Thunder Bay "A" Ont. January - December, 1987. Atmospheric Environment Service.

Farrar, J.L. and G.D. Huntley, 1969. The effect of root pruning on extension growth of *Pinus banksiana* (Lamb.) and *Picea glauca* ((Moench) Voss.) seedlings. Univ. of Toronto. Fac. For. Glendon Hall Rep. 1968/69 pp 5-6.

Fraser, P.J. 1976. The influence of prelifting cold treatment on the root regeneration potential of overwinter stored red pine seedlings. B.Sc. F. thesis. Lakehead Univ., Thunder Bay. 30pp.

Green, P.E. 1978. Analyzing Multivariate Data. The Dryden Press. USA. 519 pp.

Grene, S. 1978. Root deformities reduce root growth and stability. pp. 150-155 *in* Van Eerden, E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Hagner, S. 1978. Observations on the importance of root development in the planting of containerized tree seedlings. pp. 109-113 *in* Van Eerden, E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Hahn, P. and S. Hutchinson. 1978. Root form of planted trees and their performance. pp. 235-240 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symp. Victoria, B.C., May 16-19, 1978. 357 pp.

Hallett, R.D. 1981. Contrasting approaches to containerized seedling production 3. The Maritime provinces. pp. 129-138 in Scarratt, J.B., C. Glerum and C.A. Plexum (eds.) Proc. of the Canadian Containerized Tree Seedling Symposium, Toronto, Ont., Sept. 14-16, 1981. 460 pp.

Harvey, E.M. 1987. Methods of stock quality monitoring for the prairie provinces. pp. 1-7 *in* Harvey, E.M. (compiler) Proc. of the 1986 Prairie Federal-Provincial Nurseryman's Meeting., C.F.S., Nth. For. Cen., Inf. Rept. NOR-X-287. 54 pp.

Harvey, E.M. and R.J. Day. 1972. A method of estimating the root regeneration potential of coniferous seedlings by pot bioassay. Lakehead Univ., School of For. Rep. 15 pp.

Hauranek, W.M. and V. Benecke. 1978. The influence of soil mositure on water potential, transpiration and photosynthesis of conifer seedlings. Pl. and Soil 49:91-103.

Hiatt, H.A. and R.W. Tinus. 1974. Container shape controls root system configuration of Ponderosa pine. pp. 194-196 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium, Denver, Colorado, Aug. 26-29, 1974. Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Hilton, R.J. 1978. Root growth in the Guelph rhizotron. pp. 135-142 *in* A. Riedacher and J. Gagnaire (eds.) Proc. IUFRO Symposium on Root Physiology and Symbiosis, Vol. 1., Sept. 11-15, 1978, Nancy, France. 317 pp.

Hobbs, S.D. 1984. The influence of species and stock type selection in stand esatblishment: An ecophysiological perspective. pp. 179-224 *in* Duryea, M.L. and G.N. Brown (eds.) Seedling Physiology and Reforestation Success. Proc. of the Physiology Working Group Technical Session. Soc. of Amer. Foresters Nat. Conv. Portland, Oregon. Oct 16-20, 1983. Martinus Nijohff/ Dr. W. Junk Publishers. Dordrecht/Boston/ London. 326 pp.

Hoffman, G. 1971. The growth rhythm of roots of forest trees. Sozial Forstw. 22 (1):18-19, 26, 31-32. (*cited in* Tinus, 1974).

Hsiao, T.C. 1973. Plant responses to water stress. Rep. Pl. Physiol. 24:519-570.

Hulten, H. and K. Jansson. 1978. Stability and root deformation of pine plants (*Pinus sylvestris*). pp. 145-149 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Iyer, J.G. and S.A. Wilde. 1982. A quick way to appraise the performance potential of tree planting stock. Tree Planters Notes 32(4):26-27.

Jarvis, P.G. and M.S. Jarvis. 1963. The water relations of tree seedlings. Physiol. Plant 16:215-235.

Johnson, H.J. 1974. Canadian Forestry Service Container Planting Trials in Alberta, Saskatchewan, and Manitoba. pp. 298-305 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of North American Containerized Forest Tree Seedling Symposium, Gt. Plains Agricultural Coun. Publ. 68, 458 pp.

Johnson, H.J. and N.R. Walker. 1976. Five year field performance of pine and spruce styroplugs in Alberta. For. Chron. 52:197-198.

Johnson-Flanagan, A.M. and J.N. Owens. 1985a. Development of white spruce (*Picea glauca* (Moench) Voss.) seedling roots. Can. J. Bot. 63:456-462.

Johnson-Flanagan, A.M. and J.N. Owens. 1985b. Root growth and root growth capacity of white spruce (*Picea glauca* (Moench) Voss.) seedlings. Can. J. For. Res. 15:625-630.

Jones, E.W. 1968. A note on the dimensions of shoots and roots. For. 41:199-206.

Kaufman, C.M. 1945. Root growth of jack pine on several sites in the Cloquet Forest, Minnesota. Ecology 26:10-23.

Kinghorn, J.M. 1974. Principles and concepts in container planting. pp. 8-18 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium, Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Kinghorn, J.M. 1978. Minimizing potential root problems through container design. pp. 311-318 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Kreuger, K.W. and J.M. Trappe. 1967. Food reserves and seasonal growth of Douglas-Fir seedlings. For. Sci. 13:192-202.

Krugman, S.L., E.C. Stone and R.V. Bega. 1965. The effects of soil fumigation and lifting date on the root regenerating potential of Monterey Pine planting stock. J. For. 63:114-119.

Krugman, S.L. and E.C. Stone. 1966. The effects of cold nights on the root regeneration potential of ponderosa pine seedlings. For. Sci. 12:451-459.

Larcher, W. 1980. Physiological Plant Ecology. 2nd edition. Springer-Verlag. New York. 303 pp. (translated by M.A. Biederman-Thorson).

Larson, M.M. 1962. Construction and use of glass-faced boxes to study root development of tree seedlings. U.S.D.A. For. Serv. Res. Note No 73. 4 pp.

Larson, P.R. 1974. The upper limit of seedling growth. pp. 62-76 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium, Gt, Plains Agricultural Coun. Publ. No. 68. 458 pp.

Larson, H.S., D.B. South, J.M. Boyer. 1986. Root growth potential, seedling morphology and bud dormancy correlate with survival of loblolly pine seedlings planted in December in Alabama. Tree Physiol. 1:253-263.

Lavin, F. 1961. A glass-faced planter box for field observations on roots. Agron. J. 53:265-268.

Lee, C.I. and W.P. Hackett. 1976. Root regeneration of transplanted *Pistacia chinensis* Bunge. seedlings at different growth stages. J. Amer. Soc. Hort. Sci. 101:236-240.

Lindgren, O. and G. Orlander. 1978. A study of root development and stability of 6 to 7 year old container plants. pp. 142-144 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Long, J.N. 1978. Root system form and its relationship to growth in young planted conifers. pp. 222-234 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

MacDonell, M.B. 1980. Development of a soil-less method to test seedling root growth capacity. pp. 9-12 *in* Day, R.J. (ed.) Proc. the Eigth Annual Silviculture Seminar. Lakehead Univ., School of For., Thunder Bay, Ont., Apr. 3,1980. 56 pp.

Mahon, D.D. 1976. Methods of measuring the plant moisture stress of white spruce nursery stock and relating it to root regeneration after transplanting. H.B.Sc.F. thesis, Lakehead Univ., Thunder Bay. 18 pp.

Mattice, C.R. 1981. Comparative field performance of paperpot and bare-root planting stock in Northeastern Ontario. pp. 321-330 *in* Scarratt, J.B., C. Glerum and C.A. Plexum (eds.) Proc. of the Canadian Containerized Tree Seedling Symposium. Toronto, Ont., Sept. 14-16, 1981. 460 pp.

McClain, K.M. 1981. Growth, nutrition and root development of Ontario tublings, plugs and 3+0 bare-root black spruce. pp. 331-341 *in* Scarratt, J.B., C. Glerum and C.A. Plexum (eds.) Proc. of the Canadian Containerized Tree Seedling Symposium. Toronto, Ont., Sept. 14-16, 1981. 460 pp.

McCraken, I.J. 1971. Periodicity of root regeneration potential in *Alnus viridis* and *Pinus mugo*. N.Z. For. Serv., For. Res. Inst. Rep. for 1970. 1p. [A note].

McDonald, S.E., R.W. Tinus and C.P.P. Reid. 1980. Root morphology control in forest tree seedling containers. pp. 40-45 *in* Proc. of Intermountain Nurseryman's Association and Western Forest Nursery Association Combined Meeting. U.S.D.A. For. Serv., Boise, Idaho. Aug. 12-14, 1980.

McMinn, R.G. 1981. Size of container-grown seedlings should be matched to site conditions. pp. 307-312 *in* Scarratt, J.B., C. Glerum and C.A. Plexman (eds.) Proc. of the Canadian Containerized Tree Seedling Symposium. Toronto, Ont., Sept. 14-16, 1981. 460 pp.

Merritt, C. 1967. Effect of environment and heredity on the root growth pattern of red pine. Ecology 49:34-40.

Morrison, I.K. and K.A. Armson. 1968. The rhizometer- a device for measuring roots of tree seedlings. For. Chron. 44(5):21-23.

Mullin, R.E. 1963. Growth of white spruce in the nursery. For. Sci. 9:68-72.

Mullin, R.E. 1974. Effects of root exposure on establishment and growth of outplanted trees. pp. 229-242 *in* Proc. II International Symposium Ecology and Physiology of Root Growth. 438 pp.

Muzik, T.J. and J.W. Whitworth. 1962. A technique for the periodic observation of roots in situ. Agri. J. 54:56-57.

Nambiar, E.K.S. 1980. Root configuration and root regeneration in *Pinus radiata* seedlings. N.Z.J. For. Sci. 10:249-263.

Nambiar, E.K.S., G.D. Brown and R. Sands. 1979. Root regeneration and plant water status of *PInus radiata* D.Don. seedlings transplanted to different soil temperatures. J. Exp. Bot. 30:1119-1131.

Navratil, S., L.G. Brace and I.K. Edwards. 1986. Planting stock quality monitoring. C.F.S., Nth. For. Cen., Inf. Rep. NOR-X-279. 21 pp.

Neil, B. 1978. Thunder Bay Forest Station: Analysis of root regeneration potential. Thunder Bay Forest Station Unpub. Rep. 5 pp.

Polhill, B. 1975. Root regeneration of spring-, summer- and fall-lifted white spruce nursery stock in relation to soil mositure supply. Lakehead Univ., School of For., Unpub. Rep. 8 pp.

Rischbieter, N.O. 1978. Root egress from dibble planted containerized Douglas fir seedlings. pp. 241-252 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: It's development and expression in forest tree seedlings. N.Z.J. For. Sci. 10:218-248.

Ritchie, G.A. 1985. Root growth potential: principles, procedures and predictive ability. pp. 93 to 106 *in* Duryea, M.L. (ed.) Proc. Evaluating Seedling Quality: Principles, Procedures and Predictive Abilities of Major Tests. Oregon State Univ., Corvallis. 143 pp.

Rowe, J.S. 1972. Forest regions of Canada. C.F.S. Pub. No. 1300. 172 pp.

Ruehle, J.L. 1985. Lateral root development and spread of *Pisolithus tinctorius* ectomycorrhizae on bare-root and container grown loblolly pine seedlings after planting. For. Sci. 31:220-225.

Schubert, G.H. and R.S. Adams. 1971. Reforestation practices for conifers in California. State of California, The Resources Agency, Dept. of Conservation, Div of For., Sacramento California. 359 pp.

Segaran, S., J.C. Dojack and R.K. Rathwell. 1978. Assessment of root deformities of jack pine (*Pinus banksiana* Lamb.) planted in Southeastern Manitoba. pp. 197-200 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Simpson, D.G. n.d. British Columbia Ministry of Forests root growth capacity test., B.C. For. Serv. Rep. 3 pp.

Smyth, J.H. and A.J. Brownright. 1983. Forest tree production centers in Canada, 1983. C.F.S. Inf. Rep. 0-X-357. 50 pp.

Spencer, H.A. 1974. To 'engineer' the container. pp. 229-232 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium. Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

SPSS Inc., 1986. SPSS-X™ User's guide. 2nd ed. Printed in USA. 988 pp.

Steel, R.G.P. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach. McGraw Hill Inc. 633 pp.

Stefanson, 1978. Root quality of pine plantations established with seedlings grown in Multipots. pp. 114-118 *in* Van Eerden, E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. For Sci. 1:90-94.

Stone, E.C. and G.H. Schubert. 1959a. Root regeneration by ponderosa pine seedlings lifted at different times of the year. For. Sci. 5: 322-332.

Stone, E.C., J.L. Jenkinson and S.L. Krugman. 1962. Root regenerating potential of Douglas fir seedlings lifted at different times of the year. For. Sci. 8:288-297.

Stone, E.C., G.H. Schubert, R.W. Benseler, F.J. Baron and S.L. Krugman. 1963. Variation in the root regenerating potentials of ponderosa pine from four California nurseries. For. Sci. 9:217-225.

Stone, E.C. and J.L. Jenkinson. 1970. Influence of soil water on root growth capacity of Ponderosa pine transplants. For. Sci. 16:230-239.

Stone, E.C. and J.L. Jenkinson. 1971. Physiological grading of Ponderosa pine nursery stock. J. For. 69:31-33.

Stone, E.C. and E.A. Norberg. 1971. Modification of Nursery climate to improve root growth capacity of ponderosa pine transplants. *in* Proc. Amer. Soc. Agri. Eng., Pullman, Wash. June 27-30. 7 pp.

Stone, E.C. and E.A. Norberg. 1978. Container-induced root malformation and its elimination prior to planting. pp. 65-72 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium, Victoria, B.C., May 16-19, 1978. 357 pp.

Stupendick, J.T. 1973. Root regeneration potential of three species of coniferous nursery stock on the Thunder Bay Forest Station. B.Sc.F. thesis. Lakehead Univ., Thunder Bay. 9 pp.

Stupendick, J.T. and K.R. Shepherd. 1979. Root regeneration of root-pruned *Pinus radiata* seedlings. 1. Effects of air and soil temperature. Aust. For. 42:142-149.

Stupendick, J.T. and K.R. Shepherd. 1980. Root regeneration of root-pruned *Pinus radiata* D.Don. seedlings. 2. Effect of root pruning on photosynthesis and translocation. N.Z.J. For. Sci. 10:148-158.

Sutherland, D.C. 1984. Effects of container volume and shape on the growth of black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings. M.Sc.F. thesis, Lakehead Univ., Thunder Bay, 138 pp.

Sutton, R.F. 1969. Form and development of conifer root systems. Commonw. For. Bur., Oxford, England. Tech. Commun. No. 7. 131 pp.

Sutton, R.F. 1978. Root system development on young outplants particularly white spruce. pp 172-185 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Sutton, R.F. 1980. Planting stock quality, root growth capacity and field performance of three boreal conifers. N.Z.J. For. Sci. 10:54-71.

Sutton, R.F. 1982. Plantation establishment in the boreal forest: Planting season extension. C.F.S. Inf. Rep. 0-X-344. 129 pp.

Sutton, R.F. 1983. Root growth capacity: relationship with field root growth and performance in outplanted jack pine and black spruce. Pl. and Soil 71:111-122.

Sutton, R.F. 1987. Root growth capacity and field performance of jack pine and black spruce in boreal stand establishment in Ontario. Can. J. For. Res. 17:794-804.

Tanaka, Y. and R. Timmis. 1974. Effects of container density on growth and cold hardiness of Douglas fir seedlings. pp. 181-186 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium. Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Tinus, R.W. 1974. Characteristics of seedlings with high survival potential. pp. 276-281 *in* Tinus, R.W., W.I. Stein and W.E. Balmer, (eds.) Proc. of the North American Containerized Tree Seedling Symposium. Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Tinus, R.W. and S.E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Gen. Tech. Rep. RM-60. 256 pp.

Todd, G. 1964. Douglas fir seedlings have roots? J. For. 62: 561-563.

Togoni, F. and R. Lorenzi. 1972. Acidic root-promoting growth inhibitor(s) found in *Picea* and *Chamaecyparis*. J. Amer. Hort. Sci. 95:574-578.

Van den Driessche, R. 1969. Forest Nursery Handbook. British Columbia For. Serv., Res. Note No. 48. 43 pp.

Van den Driessche, R. 1978. Seasonal changes in root growth capacity and carbohydrates in red pine and white spruce nursery seedlings. pp. 6-19 in A. Riedacher and J. Gagnaire (eds.) Proc. IUFRO Sympsoium on Root Physiology and Symbiosis, Vol. 1., Sept. 11-15, 1978, Nancy, France. 317 pp.

Van den Driessche, R. 1987. Importance of current photosynthate to new root growth in planted conifer seedlings. Can. J. For. Res. 17:776-782.

Van Eerden, E. and J.T. Arnott. 1974. Root growth of container grown stock after planting. pp. 393-397 *in* Tinus, R.W., W.I. Stein and W.E. Balmer (eds.) Proc. of the North American Containerized Tree Seedling Symposium, Gt. Plains Agricultural Coun. Publ. No. 68. 458 pp.

Van Eerden, E. 1978. Roots of planted trees in Central British Columbia. pp. 201-208 *in* Van Eerden E. and J.M. Kinghorn (eds.) Proc. of the Root Form of Planted Trees Symposium. Victoria, B.C., May 16-19, 1978. 357 pp.

Villee, C.A. 1977. Biology. 7th edition. W.B. Saunders Company. Toronto. 870 pp.

Webb, D.P. 1977. Root regeneration and bud dormancy of sugar maple, silver maple and wash ash seedlings. Effects of chilling. For. Sci. 23:474-483.

Webb, D.P. and E.B. Dumbroff. 1978. Root growth in seedlings of *Acer saccharum*. pp. 57-70 *in* A. Riedacher and J. Gagnaire (eds.) Proc. IUFRO Symposium on Root Physiology and Symbiosis, Vol. 1., Sept. 11-15, 1978, Nancy, France. 317 pp.

Whitcomb, C.E. and J.D. Williams. 1985. Stair-step container for improved root growth. Hort. Sci. 20:66-67.

Wood, J.E. 1983. Five year comparison of jack pine bare-root, Ontario tube and paperpot seedlings. C.F.S., Gt. Lakes For. Res. Cen. Inf. Rep. 0-X-355. 13 pp.

Zaerr, J.B. 1967. Auxin and root regeneration potential in Ponderosa pine seedlings. For. Sci. 13:258-264.

Zavitkovski, J. and H.M. Phipps. n.d. Survival and growth of two intensively cultured jack pine provenances raised in tubepak and Jiffy 7 containers. N. Cent. For. Expt. Sta. Rep. 5 pp.

APPENDICES

APPENDIX I

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE MORPHOLOGICAL ATTRIBUTES FOR EACH CROP TYPE AT THE END OF THE GREENHOUSE PRODUCTION PHASE

Statistical Model and Expected Mean Squares Table used for the analysis of the measured attributes for each crop type at the end of the Greenhouse Production Phase.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + Co_k + \varepsilon_{(ijk)l} + \rho_{(ijkl)m}{}^{*}$$

Y = Height, Root Collar Diameter, Shoot Dry Weight <u>or</u> Root Dry Weight.
i = 1...6 Blocks
j = 1 restriction error
k = 1...2 Container Types
l = 1
m = 1...5 Subsamples
$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$
$\varepsilon_{(ijk)l}$ = NID $(0, \sigma_\varepsilon^2)$
$\rho_{(ijkl)m}$ = NID $(0, \sigma_\rho^2)$

Source	df	R 6 i	R 1 j	F 2 k	R 1 l	R 5 m	
Block i	5	1	1	2	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 10\sigma_\delta^2 + 10\sigma_\beta^2$
Restriction error (i)j	0	1	1	2	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 10\sigma_\delta^2$
Container k	1	6	1	0	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 30\phi_{(Co)}$
Error (ijk)l	5	1	1	1	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2$
Subsample (ijkl)m	48	1	1	1	1	1	σ_ρ^2
Total	59						

* <u>Note</u>: The statistical model and Expected Mean Squares Table is the same for each measured attribute (Height, Root Collar Diameter, Shoot Dry Weight and Root Dry Weight) for each of the three crops (1986 Current, 1986/87 Overwinter and 1987 Current) used in this study.

APPENDIX II

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE BETWEEN CROP COMPARISONS AT THE END OF THE GREENHOUSE PRODUCTION PHASE

Statistical Model and Expected Mean Squares table used for the analysis of the between crop comparisons at the end of the Greenhouse Production Phase.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + Cr_k + Co_l + CrxCo_{kl} + \varepsilon_{(ijkl)m} + \rho_{(ijklm)n}^{*}$$

Y = Height, Root Collar Diameter, Shoot Dry Weight <u>or</u> Root Dry Weight.
i = 1...6 Blocks
j = 1 restriction error
k = 1...2 Crop Types
l = 1...2 Container Types
m = 1
n = 1...5 Subsamples
$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$
$\varepsilon_{(ijkl)m}$ = NID $(0, \sigma_\varepsilon^2)$
$\rho_{(ijklm)n}$ = NID $(0, \sigma_\rho^2)$

		R	R	F	F	R	R	
		6	1	2	2	1	5	
Source	df	i	j	k	l	m	n	
Block i	5	1	1	2	2	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 20\sigma_\delta^2 + 20\sigma_\beta^2$
Restriction error (i)j	0	1	1	2	2	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 20\sigma_\delta^2$
Crop k	1	6	1	0	2	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 60\phi_{(Cr)}$
Container l	1	6	1	2	0	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 60\phi_{(Co)}$
Crop X Container kl	1	6	1	0	0	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2 + 30\phi_{(Cr\ X\ Co)}$
Error (ijkl)m	5	1	1	1	1	1	5	$\sigma_\rho^2 + 5\sigma_\varepsilon^2$
Subsample (ijklm)n	96	1	1	1	1	1	1	σ_ρ^2
Total	119							

* <u>Note</u>: The statistical model and expected mean squares table is the same for each of the measured attributes (Height, Root Collar Diameter, Shoot Dry Weight and Root Dry Weight) for both of the crop comparisons (1986 Current vs 1987 Current and 1986/87 Overwinter vs 1987 Current) in this study.

APPENDIX III

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE 1986 GROWTH CHAMBER TRIAL DATA

The Statistical Model and Expected Mean Squares table used for the analysis of the 1986 Growth Chamber Trial data.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + T_k + Co_l + T \times Co_{kl} + Z_m + T \times Z_{km} + Co \times Z_{lm} + T \times Co \times Z_{klm} + \varepsilon_{(ijklm)n} + \rho_{(ijklmn)p}$$

Y = Total Root Elongation (cm)
i = 1...6 Blocks
j = 1 restriction error
k = 1...3 Potting Dates
l = 1...2 Container Types
m = 1...3 Root Zones
n = 1
p = 1...12 Subsamples*
$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$
$\varepsilon_{(ijkl)m}$ = NID $(0, \sigma_\varepsilon^2)$
$\rho_{(ijklm)n}$ = NID $(0, \sigma_\rho^2)$

Source	df	R 6 i	R 1 j	F 3 k	F 2 l	F 3 m	R 1 n	R 12 p	
Block i	5	1	1	3	2	3	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 216\sigma_\delta^2 + 216\sigma_\beta^2$
Restriction error (i)j	0	1	1	3	2	3	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 216\sigma_\delta^2$
Potting Date k	2	6	1	0	2	3	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 432\phi_{(T)}$
Container l	1	6	1	3	0	3	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 648\phi_{(Co)}$
Potting Date X Container kl	2	6	1	0	0	3	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 144\phi_{(TxCo)}$
Zone m	2	6	1	3	2	0	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 432\phi_{(Z)}$
Potting Date X Zone km	4	6	1	0	2	0	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 144\phi_{(TxZ)}$
Container X Zone lm	2	6	1	3	0	0	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 216\phi_{(CoxZ)}$
Potting Date X Container X Zone klm	4	6	1	0	0	0	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2 + 72\phi_{(TxCoxZ)}$
Error (ijklm)n	85	1	1	1	1	1	1	12	$\sigma_\rho^2 + 12\sigma_\varepsilon^2$
Subsample (ijklmn)p	1188	1	1	1	1	1	1	1	σ_ρ^2
Total	1295								

*Note: Subsample seedlings were selected at random and placed in pots at random. The pots were placed at random within the growth chamber. Therefore any pot effect is confounded within the subsampling error.

APPENDIX IV

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE 1987 GROWTH CHAMBER TRIAL DATA

The Statistical Model and Expected Mean Squares Table used for the analysis of the 1987 Growth Chamber Trial Data.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + T_k + Cr_l + T \times Cr_{kl} + Co_m + T \times Co_{km} + Cr \times Co_{lm} + T \times Cr \times Co_{klm} + Z_n + T \times Z_{kn} + Cr \times Z_{ln} + T \times Cr \times Z_{kln} + Co \times Z_{mn} + T \times Co \times Z_{kmn} + Cr \times Co \times Z_{lmn} + T \times Cr \times Co \times Z_{klmn} + \varepsilon_{(ijklmn)p} + \rho_{(ijklmnp)q}$$

Y = Total Root Elongation (cm)

i = 1...6 Blocks

j = 1 restriction error

k = 1...3 Potting Dates

l = 1...2 Crop Types

m = 1...2 Container Types

n = 1...3 Root Zones

p = 1

q = 1...8 Subsamples*

$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$

$\varepsilon_{(ijklmn)p}$ = NID $(0, \sigma_\varepsilon^2)$

$\rho_{(ijklmnp)q}$ = NID $(0, \sigma_\rho^2)$

Source	df	R 6 i	R 1 j	F 3 k	F 2 l	F 2 m	F 3 n	R 1 p	R 8 q	
Block i	5	1	1	3	2	2	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\sigma_\delta^2 + 288\sigma_\beta^2$
Restriction error (i)j	0	1	1	3	2	2	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\sigma_\delta^2$
Potting Date k	2	6	1	0	2	3	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 576\phi_{(T)}$
Crop Type l	1	6	1	3	0	2	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 864\phi_{(Cr)}$
Potting Date X Crop Type kl	2	6	1	0	0	2	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\phi_{(TxCr)}$
Container l	1	6	1	3	2	0	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 864\phi_{(Co)}$
Potting Date X Container Type kl	2	6	1	0	2	0	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\phi_{(TxCo)}$
Crop Type X Container Type lm	1	6	1	3	0	0	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 432\phi_{(CrxCo)}$
Potting Date X Crop Type X Container Type klm	2	6	1	0	0	0	3	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 144\phi_{(TxCrxCo)}$
Root Zone m	2	6	1	3	2	2	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 576\phi_{(Z)}$
Potting Date X Root Zone km	4	6	1	0	2	2	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 192\phi_{(TxZ)}$
Crop Type X Root Zone ln	2	6	1	3	0	2	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\phi_{(CrxZ)}$
Potting Date X Crop Type X Root Zone kln	4	6	1	0	0	2	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 96\phi_{(TxCrxZ)}$
Container Type X Root Zone mn	2	6	1	3	2	0	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 288\phi_{(CoxZ)}$
Potting Date X Container Type X Root Zone klm	4	6	1	0	2	0	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 96\phi_{(TxCoxZ)}$
Crop Type X Container Type X Root Zone lmn	2	6	1	3	0	0	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 144\phi_{(CrxCoxZ)}$
Potting Date X Crop Type X Container Type X Root Zone klmn	4	6	1	0	0	0	0	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2 + 48\phi_{(TxCrxCoxZ)}$
Error (ijklm)n	175	1	1	1	1	1	1	1	8	$\sigma_\rho^2 + 8\sigma_\varepsilon^2$
Subsample (ijklmn)p	1512	1	1	1	1	1	1	1	1	σ_ρ^2
Total	1727									

*Note: Subsample seedlings were selected at random and placed in pots at random. The pots were placed at random within the growth chamber. Therefore any pot effect is confounded within the subsampling error.

APPENDIX V

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE 1986 OUTPLANTING TRIAL DATA

The Statistical Model and Expected Mean Squares table used for the analysis of the 1986 Outplanting Trial data.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + T_k + Co_l + T \times Co_{kl} + Z_m + T \times Z_{km} + Co \times Z_{lm} + T \times Co \times Z_{klm} + \varepsilon_{(ijklm)n} + \rho_{(ijklmn)p}$$

Y = Total Root Elongation (cm)

i = 1...6 Blocks

j = 1 restriction error

k = 1...3 Outplanting Dates

l = 1...2 Container Types

m = 1...3 Root Zones

n = 1

p = 1...15 Subsamples

$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$

$\varepsilon_{(ijkl)m}$ = NID $(0, \sigma_\varepsilon^2)$

$\rho_{(ijklm)n}$ = NID $(0, \sigma_\rho^2)$

		R	R	F	F	F	R	R	
		6	1	3	2	3	1	15	
Source	df	i	j	k	l	m	n	p	
Block i	5	1	1	3	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\sigma_\delta^2 + 270\sigma_\beta^2$
Restriction error (i)j	0	1	1	3	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\sigma_\delta^2$
Outplanting Date k	2	6	1	0	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(T)}$
Container l	1	6	1	3	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 810\phi_{(Co)}$
Outplanting Date X Container kl	2	6	1	0	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\phi_{(TxCo)}$
Zone m	2	6	1	3	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(Z)}$
Outplanting Date X Zone km	4	6	1	0	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 180\phi_{(TxZ)}$
Container X Zone lm	2	6	1	3	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\phi_{(CoxZ)}$
Ouplanting Date X Container X Zone klm	4	6	1	0	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 90\phi_{(TxCoxZ)}$
Error (ijklm)n	85	1	1	1	1	1	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2$
Subsample (ijklmn)p	1512	1	1	1	1	1	1	1	σ_ρ^2
Total	1619								

APPENDIX VI

STATISTICAL MODEL AND EXPECTED MEAN SQUARES TABLE USED FOR ANALYSIS OF THE 1987 OUTPLANTING TRIAL DATA

The Statistical Model and Expected Mean Squares Table used for the analysis of the 1987 Outplanting Trial Data.

$$Y_{ijklm} = \upsilon + \beta_i + \delta_{(i)j} + T_k + Cr_l + T \times Cr_{kl} + Co_m + T \times Co_{km} + Cr \times Co_{lm} + T \times Cr \times Co_{klm} + Z_n + T \times Z_{kn} + Cr \times Z_{ln} + T \times Cr \times Z_{kln} + Co \times Z_{mn} + T \times Co \times Z_{kmn} + Cr \times Co \times Z_{lmn} + T \times Cr \times Co \times Z_{klmn} + \varepsilon_{(ijklmn)p} + \rho_{(ijklmnp)q}$$

Y = Total Root Elongation (cm)
i = 1...6 Blocks
j = 1 restriction error
k = 1...3 Outplanting Dates
l = 1...2 Crop Types
m = 1...2 Container Types
n = 1...3 Root Zones
p = 1
q = 1...15 Subsamples
$\delta_{(i)j}$ = NID $(0, \sigma_\delta^2)$
$\varepsilon_{(ijklmn)p}$ = NID $(0, \sigma_\varepsilon^2)$
$\rho_{(ijklmnp)q}$ = NID $(0, \sigma_\rho^2)$

Source	df	R 6 i	R 1 j	F 3 k	F 2 l	F 2 m	F 3 n	R 1 p	R 15 q	
Block i	5	1	1	3	2	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\sigma_\delta^2 + 540\sigma_\beta^2$
Restriction error (i)j	0	1	1	3	2	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\sigma_\delta^2$
Outplanting Date k	2	6	1	0	2	3	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 1080\phi_{(T)}$
Crop Type l	1	6	1	3	0	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 1620\phi_{(Cr)}$
Outplanting Date X Crop Type kl	2	6	1	0	0	2	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(TxCr)}$
Container l	1	6	1	3	2	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 1620\phi_{(Co)}$
Outplanting Date X Container Type kl	2	6	1	0	2	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(TxCo)}$
Crop Type X Container Type lm	1	6	1	3	0	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 810\phi_{(CrxCo)}$
Outplanting Date X Crop Type X Container Type klm	2	6	1	0	0	0	3	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\phi_{(TxCrxCo)}$
Root Zone m	2	6	1	3	2	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 1080\phi_{(Z)}$
Outplanting Date X Root Zone km	4	6	1	0	2	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 360\phi_{(TxZ)}$
Crop Type X Root Zone ln	2	6	1	3	0	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(CrxZ)}$
Outplanting Date X Crop Type X Root Zone kln	4	6	1	0	0	2	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 180\phi_{(TxCrxZ)}$
Container Type X Root Zone mn	2	6	1	3	2	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 540\phi_{(CoxZ)}$
Ouplanting Date X Container Type X Root Zone klm	4	6	1	0	2	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 180\phi_{(TxCoxZ)}$
Crop Type X Container Type X Root Zone lmn	2	6	1	3	0	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 270\phi_{(CrxCoxZ)}$
Outplanting Date X Crop Type X Container Type X Root Zone klmn	4	6	1	0	0	0	0	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2 + 90\phi_{(TxCrxCoxZ)}$
Error (ijklm)n	175	1	1	1	1	1	1	1	15	$\sigma_\rho^2 + 15\sigma_\varepsilon^2$
Subsample (ijklmn)p	3024	1	1	1	1	1	1	1	1	σ_ρ^2
Total	3239									

APPENDIX VII

ANOVA TABLES FOR THE 1986 CURRENT CROP

Anova Table for Height for the 1986 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	435.68	48	9.08		
Blocks	25.80	5	5.16	0.57	0.724 N.S.
Residual	138.36	5	27.67		
Container Type	62.42	1	62.42	2.26	0.193 N.S.

Anova Table for Root Collar Diameter for the 1986 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	5.40	48	0.11		
Blocks	0.74	5	0.15	1.32	0.271 N.S.
Residual	0.76	5	0.15		
Container Type	0.52	1	0.52	3.37	0.126 N.S.

Anova Table for Shoot Dry Weight (mg) for the 1986 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	4475398.42	48	93237.47		
Blocks	206825.56	5	41365.11	0.44	0.816 N.S.
Residual	491692.39	5	98338.48		
Container Type	692235.97	1	692235.97	7.04	0.045 *

Anova Table for Root Dry Weight (mg) for the 1986 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	368051.25	48	7667.73		
Blocks	39349.38	5	7869.88	1.03	0.413 N.S.
Residual	17603.33	5	3520.67		
Container Type	306935.23	1	306935.23	87.18	0.000 ***

APPENDIX VIII

ANOVA TABLES FOR THE 1986/87 OVERWINTER CROP

Anova Table for Height (cm) for the 1986/87 Overwinter Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	348.36	48	7.26		
Blocks	61.07	5	12.21	1.68	0.157 N.S.
Residual	22.71	5	4.54		
Container Type	0.00	1	0.00	0.00	0.986 N.S.

Anova Table for Root Collar Diameter (mm) for the 1986/87 Overwinter Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	4.72	48	0.10		
Blocks	0.56	5	0.11	1.14	0.351 N.S.
Residual	0.62	5	0.12		
Container Type	0.00	1	0.00	0.02	0.897 N.S.

Anova Table for Shoot Dry Weight (mg) for the 1986/87 Overwinter Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	1087660.08	48	22659.58		
Blocks	109470.51	5	21894.10	0.97	0.448 N.S.
Residual	98145.58	5	19629.12		
Container Type	233139.13	1	233139.13	11.88	0.018 *

Anova Table for Root Dry Weight (mg) for the 1986/87 Overwinter Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	108735.88	48	2265.33		
Blocks	11309.16	5	2261.83	1.00	0.429 N.S.
Residual	8879.26	5	1775.85		
Container Type	99853.92	1	99853.92	56.23	0.001 **

APPENDIX IX

ANOVA TABLES FOR THE 1987 CURRENT CROP

Anova Table for Height (cm) for the 1987 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	226.82	48	4.73		
Blocks	36.36	5	7.27	1.54	0.196 N.S.
Residual	9.43	5	1.89		
Container Type	236.02	1	236.02	125.20	0.000 ***

Anova Table for Root Collar Diameter (mm) for the 1987 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	2.79	48	0.06		
Blocks	0.47	5	0.09	1.62	0.173 N.S.
Residual	0.76	5	0.15		
Container Type	0.02	1	0.02	0.15	0.719 N.S.

Anova Table for Shoot Dry Weight (mg) for the 1987 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	1315725.16	48	27410.94		
Blocks	156310.27	5	31262.05	1.14	0.352 N.S.
Residual	217520.91	5	43504.18		
Container Type	224787.60	1	224787.60	5.17	0.072 N.S.

Anova Table for Root Dry Weight (mg) for the 1987 Current Crop.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	151057.04	48	3147.02		
Blocks	24079.58	5	4815.94	1.53	0.198 N.S.
Residual	14122.25	5	2824.45		
Container Type	276787.58	1	276787.58	98.00	0.000 ***

APPENDIX X

ANOVA TABLES FOR THE 1986 VS 1987 CURRENT CROP

Anova Table comparing the 1986 Current Crop with the 1987 Current Crop for Height (cm).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	893.46	96	9.31		
Blocks	34.23	5	6.85	0.74	0.599 N.S.
Residual	123.93	15	8.26		
Crop Type	924.63	1	924.63	111.92	0.000 ***
Container Type	228.25	1	228.25	27.63	0.000 ***
Crop Type X Container Type	43.80	1	43.80	5.30	0.036 *

Anova Table comparing the 1986 Current Crop with the 1987 Current Crop for Root Collar Diameter (mm).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	10.96	96	0.11		
Blocks	0.97	5	0.19	1.70	0.142 N.S.
Residual	2.18	15	0.15		
Crop Type	0.14	1	0.14	0.94	0.348 N.S.
Container Type	0.77	1	0.77	5.27	0.037 *
Crop Type X Container Type	0.44	1	0.44	3.05	0.101 N.S.

Anova Table comparing the 1986 Current Crop with the 1987 Current Crop for Shoot Dry Weight (mg).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	3990250.73	96	41565.11		
Blocks	256806.15	5	51361.23	1.24	0.298 N.S.
Residual	627983.06	15	41865.54		
Crop Type	32239.13	1	32239.13	0.77	0.394 N.S.
Container Type	563796.33	1	563796.33	13.47	0.002 *
Crop Type X Container Type	6457.73	1	6457.73	0.15	0.700 N.S.

Anova Table comparing the 1986 Current Crop with the 1987 Current Crop for Root Dry Weight (mg).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	355720.59	96	3705.42		
Blocks	51353.73	5	10270.75	2.77	0.022 *
Residual	53053.88	15	3536.93		
Crop Type	50069.85	1	50069.85	14.16	0.002 *
Container Type	525707.46	1	525707.46	148.63	0.000 ***
Crop Type X Container Type	359.84	1	359.84	0.10	0.754 N.S.

APPENDIX XI

ANOVA TABLES FOR THE 1986/87 OVERWINTER CROP VS THE 1987 CURRENT CROP

Anova Table comparing the 1986/87 Overwinter Crop with the 1987 Current Crop for Height (cm).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	575.18	96	5.99		
Blocks	13.63	5	2.73	0.45	0.809 N.S.
Residual	115.94	15	7.73		
Crop Type	25.30	1	25.30	3.27	0.091 N.S.
Container Type	118.60	1	118.60	15.34	0.001 **
Crop Type X Container Type	117.41	1	117.41	15.19	0.001**

Anova Table comparing the 1986/87 Overwinter Crop with the 1987 Current Crop for Root Collar Diameter (mm).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	7.52	96	0.08		
Blocks	0.44	5	0.09	1.13	0.349 N.S.
Residual	1.97	15	0.13		
Crop Type	5.02	1	5.02	38.31	0.000 ***
Container Type	0.02	1	0.02	0.15	0.707 N.S.
Crop Type X Container Type	0.01	1	0.01	0.04	0.847 N.S.

Anova Table comparing the 1986/87 Overwinter Crop with the 1987 Current Crop for Shoot Dry Weight (mg).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	2403385.24	96	25035.26		
Blocks	156729.59	5	31345.92	1.25	0.291 N.S.
Residual	424717.68	15	28314.51		
Crop Type	380092.61	1	380092.61	13.42	0.002 *
Container Type	457888.66	1	457888.66	16.17	0.001 **
Crop Type X Container Type	38.08	1	38.08	0.00	0.971 N.S.

Anova Table comparing the 1986/87 Overwinter Crop with the 1987 Current Crop for Root Dry Weight (mg).

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	259792.92	96	2706.18		
Blocks	14732.87	5	2946.57	1.09	0.372 N.S.
Residual	43657.50	15	2910.50		
Crop Type	165013.42	1	165013.42	56.70	0.000 ***
Container Type	354568.54	1	354568.54	121.82	0.000 ***
Crop Type X Container Type	22072.97	1	22072.97	7.58	0.015 *

APPENDIX XII

ANOVA TABLE FOR THE SQUARE ROOT OF TOTAL ROOT ELONGATION FOR THE 1986 GROWTH CHAMBER TRIAL DATA

Anova Table for the Square Root of Total Root Elongation for the 1986 Growth Chamber Trial data.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	11256.59	1188	9.47		
Blocks	338.42	5	67.68	7.14	0.000 ***
Residual	1966.70	85	23.14		
Potting Date	2579.05	2	1289.52	55.73	0.000 ***
Container Type	5304.82	1	5304.82	229.27	0.000 ***
Potting Date X Container Type	174.59	2	87.29	3.77	0.027 *
Root Zone	15577.56	2	7788.78	336.63	0.000 ***
Potting Date X Root Zone	1123.39	4	280.85	12.14	0.000 ***
Container Type X Root Zone	2722.66	2	1361.33	58.84	0.000 ***
Potting Date X Container Type X Root Zone	504.24	4	126.06	5.45	0.001 **

APPENDIX XIII

ANOVA TABLE FOR THE LN OF TOTAL ROOT ELONGATION FOR THE 1987 GROWTH CHAMBER TRIAL DATA

Anova Table for the Ln of Total Root Elongation for the 1987 Growth Chamber Trial data.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	1568.63	1509	1.04		
Blocks	15.08	5	3.02	2.90	0.013 *
Residual	505.80	175	2.89		
Potting Date	1734.07	2	867.04	299.98	0.000 ***
Crop Type	141.06	1	141.06	48.80	0.000 ***
Potting Date X Crop Type	78.17	2	39.08	13.52	0.000 ***
Container Type	53.92	1	53.92	18.65	0.000 ***
Potting Date X Container Type	11.61	2	5.81	2.01	0.137 N.S.
Crop Type X Container Type	7.76	1	7.76	2.69	0.103 N.S.
Potting Date X Crop Type X Container Type	14.64	2	7.32	2.53	0.082 N.S.
Root Zone	322.42	2	161.21	55.78	0.000 ***
Potting Date X Root Zone	93.95	4	23.49	8.13	0.000 ***
Crop Type X Root Zone	9.12	2	4.56	1.58	0.209 N.S.
Potting Date X Crop Type X Root Zone	15.20	4	3.80	1.31	0.266 N.S.
Container Type X Root Zone	328.45	2	164.23	56.82	0.000 ***
Potting Date X Container Type X Root Zone	29.25	4	7.31	2.53	0.082 N.S.
Crop Type X Container Type X Root Zone	39.31	2	19.66	6.80	0.001 **
Potting Date X Crop Type X Container Type X Root Zone	9.26	4	2.32	0.80	0.526 N.S.

APPENDIX XIV

ANOVA TABLE FOR THE LN OF TOTAL ROOT ELONGATION FOR THE 1986 OUTPLANTING TRIAL DATA

Anova Table for the Ln of Total Root Elongation for the 1986 Outplanting Trial data.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	1184.72	1499	0.79		
Blocks	57.75	5	11.55	14.61	0.000 ***
Residual	205.79	85	2.42		
Outplanting Date	194.64	2	97.32	40.20	0.000 ***
Container Type	1098.96	1	1098.96	453.92	0.000 ***
Outplanting Date X Container Type	4.64	2	2.32	0.96	0.388 N.S.
Root Zone	214.55	2	107.28	44.31	0.000 ***
Outplanting Date X Root Zone	27.52	4	6.88	2.84	0.029 *
Container Type X Root Zone	202.77	2	101.39	41.88	0.000 ***
Outplanting Date X Container Type X Root Zone	9.28	4	2.32	0.96	0.434 N.S.

APPENDIX XV

ANOVA TABLE FOR THE LN OF TOTAL ROOT ELONGATION FOR THE 1987 OUTPLANTING TRIAL DATA

Anova Table for the Ln of Total Root Elongation for the 1987 Outplanting Trial data.

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F ratio	Probability
Within Cells	3205.83	2907	1.10		
Blocks	111.81	5	22.36	20.28	0.000 ***
Residual	464.67	175	2.66		
Outplanting Date	39.28	2	19.64	7.40	0.001 **
Crop Type	1.99	1	1.99	0.75	0.338 N.S.
Outplanting Date X Crop Type	1.51	2	0.75	0.28	0.753 N.S.
Container Type	816.21	1	816.21	307.39	0.000 ***
Outplanting Date X Container Type	11.60	2	5.80	2.18	0.116 N.S.
Crop Type X Container Type	3.17	1	3.17	1.19	0.276 N.S.
Outplanting Date X Crop Type X Container Type	1.47	2	0.73	0.28	0.759 N.S.
Root Zone	635.15	2	317.57	119.60	0.000 ***
Outplanting Date X Root Zone	101.42	4	25.35	9.55	0.000 ***
Crop Type X Root Zone	22.09	2	11.05	4.16	0.017 *
Outplanting Date X Crop Type X Root Zone	6.99	4	1.75	0.66	0.622 N.S.
Container Type X Root Zone	280.82	2	140.41	52.88	0.000 ***
Outplanting Date X Container Type X Root Zone	7.21	4	1.80	0.68	0.608 N.S.
Crop Type X Container Type X Root Zone	39.26	2	19.63	7.39	0.001 **
Outplanting Date X Crop Type X Container Type X Root Zone	10.96	4	2.74	1.83	0.392 N.S.

APPENDIX XVI

IRRIGATION AND FERTILIZATION SCHEDULES FOR THE 1986 CURRENT CROP GROWN AT HILLS' GREENHOUSES

HILL'S GREENHOUSES LTD.

GREENHOUSE TEMPERATURE RECORD

HOUSE # 11 CROP [illegible] 85 SEEDLOT

Jack Pine GERMINATION DATE Feb 26, 1985

MAXIMUM	MINIMUM	REMARKS
		BEGAN WETTING 4 CYCLES. Temp 9°C
14.0	4.0	1C 9:00 / 1C 11:00 / 1C [illegible] / 1C 3:15 / 1C [illegible]
27.0	3.0	1C 8:30 / 1C 10:30 / 1C 1:00 / 1P 3:30 / Temp P 27
30.0	21.0	1C 9:00 / 1C 11:00 / 1P 2:00 / 1C 4:45
34.0	19.0	1C 9:00 / 1P 11:00 / 1P 3:00 / 1D 5:00
36.0	20.0	1P [illegible] / 1P 11:00 / 1P [illegible] / 1P 4:30 /
30.0	20.0	1P [illegible] / 1P 11:30 / 1P [illegible] / 1C [illegible]
32.0	20.0	[illegible] / 1P [illegible] / 1P 2:00 /
33.0	17.0	P [illegible] / 1P 1:00 /
35.0	20.0	

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 9-11 CROP # [illegible] /86 SEEDLOT 86-01-01

SPECIES Pj GERMINATION DATE Feb 26

DATE	TREATMENT	RATE	REMARKS
March			
1			
2			
3			
4			
5			
6			
7	10-52-10	100 ppm	3 cycles (except 1 cycle to front)
8			
9			
10			
11			
12			
13	10-52-10	100 ppm	3 cycles
14			
15			
16			
17	20-20-20	100 PPM	[illegible] cycles
18			
19	20-20-20	100 ppm	1 C to [illegible]
20		"	
21	20-20-20	100 ppm	6 Cycles / 130ppm 20-20-20
22			
23			
24			
25			
26			
27			
28			
29	20-20-20	130 PPM	1 HOUR.
30			
31			

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 9/10/11 CROP # 10 [illegible] 86 SEEDLOT ______

SPECIES Jack pine GERMINATION DATE Feb 26

DATE	TREATMENT	RATE	REMARKS
[illegible]			
1			
2	20-20-20	130 ppm	9/10/11 1 hour
3			
4			
5			
6			
7			
8	20-20-20	200 ppm	1 hour
9			
10			
11	20³	200 ppm	45 min
12			
13			
14	20³	200 ppm	= 9/10 1 hour; #11 45 min fertilizer - 15 min. clear H2O
15			
16	20-20-20	400 PPM	2 HOURS + RINSE
17			
18			
19			
20			
21			
22	20³	400 PPM	1½ hours - front 8 rows ½ hour only
23			
24			
25	20³	400 PPM	2 hours - North side 1½ hours only + soft water
26			
27			
28			
29			
30			
31			

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 9.10.11 CROP # 10 Abitibi '86 SEEDLOT 86-01-01

SPECIES Jack pine GERMINATION DATE Feb 26

DATE	TREATMENT	RATE	REMARKS
MAY	—	—	
1			
2			
3			
4			
5			
6			
7	20^3	200 PPM	3 Hours
8			
9			
10			
11			
12			
13			
14	20-20-20	200 PPM	2 HOURS
15			
16			
17			
18	20-20-20	150 PPM	1½ Hours
19			
20	20-20-20/[illegible]	200 PPM	2½ Hours.
21			
22			
23	CLEAR WATER	—	2 HOURS
24			
25			
26			
27	CLEAR WATER		2 HOURS
28			
29			
30			
31			

APPENDIX XVII

IRRIGATION AND FERTILIZATION SCHEDULES FOR THE 1986/87 OVERWINTER CROP GROWN AT HILLS' GREENHOUSES

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 1-4 CROP # 11 MNR 86 SEEDLOT 34-2500

SPECIES JACK PINE GERMINATION DATE JUNE 16/86

DATE	TREATMENT	RATE	REMARKS
JUNE			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24	20-20-20	100 PPM	1 HOUR.
25			
26	20-20-20	100 PPM	1 HOUR
27			
28	20-20-20	100 PPM	1 HOUR
29			
30	20-20-20	100 PPM	1 HOUR
31			

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 1-4 CROP # 11 HNR 86 SEEDLOT 3425000

SPECIES Pj GERMINATION DATE June 16 /86

DATE	TREATMENT	RATE	REMARKS
JULY			
1			
2	20-20-20	100 PPM	1 HOUR
3	20-20-20	100 PPM	1 P
4	20-20-20	100 PPM	1 C
5			
6	20-20-20	100 PPM	2 C.
7	20-20-20	150 PPM	1 HOUR
8	20-20-20	150 PPM	3 C
9	20-20-20	150 PPM	1 HOUR
10	20-20-20	150 PPM.	1 HOUR
11	20-20-20	150 PPM	2 C
12			
13			
14	20-20-20	150 PPM	3 C
15	20-20-20	150 PPM	2 C
16			
17			
18	20-20-20	400 PPM	1½ HOURS NORTH 1½ HOURS SOUTH
19			
20			
21			
22	20-20-20	400 PPM	1½ HOURS
23			
24			
25	20-20-20	400 PPM	1½ HOURS
26			
27			
28			
29	20-20-20	400 PPM	1½ HOURS. THIODAN/CEC
30			
31			
AUG 1	20-20-20	400 PPM	1½ HOURS / #3 1½ HR.
			/

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 1-4 CROP # 11 MNR '86 SEEDLOT 34 25000

SPECIES Pj GERMINATION DATE June 16

DATE	TREATMENT	RATE	REMARKS
Aug			
1	20-20-20	400 PPM	1½ HR / # 3 1¼ HR.
2			
3			
4			
5			
6			
7			
8	20-20-20	400 PPM	1½ HOURS
9			
10			
11	20-20-20	400 PPM	2 HOURS
12			THIODAN (1 PASS ONLY)
13			
14			
15	20-20-20	200 PPM	1½ HOURS
16			
17			
18	20-20-20	200 PPM	1½ HOURS
19			
20			
21	20-20-20	200 PPM	2 HOURS
22			
23			
24			
25			
26			
27			
28			
29	CLEAR		2 HOURS W/ AKRBA
30			
31			

HILL'S GREENHOUSES LTD.

IRRIGATION AND FERTILIZATION SCHEDULE

HOUSE # 1-4 CROP # [illegible] 86 SEEDLOT 34 25 000

SPECIES Pj GERMINATION DATE June 16

DATE	TREATMENT	RATE	REMARKS
SEPT	—	—	
1			
2			
3			
4			
5	CLEAR H_2O	—	2 HOURS S-SIDE / 1½ HOURS N-SIDE
6			
7			
8			
9			
10	Clear		2 HOURS S / 1½ HRS N.
11			
12			
13			
14			
15			
16			
17			
18			
19	clear		1½ HOURS S / 1 HOUR N
20			
21			
22			
23	clear		1 HOUR BOTH SIDES
24			#3 Removed to Shade Area
25			
26			Removed to Shade area
27			
28			
29			
30			
31			

APPENDIX XVIII

IRRIGATION AND FERTILIZATION SCHEDULES FOR THE 1987 CURRENT CROP GROWN AT HODWITZ'S GREENHOUSES

Irrigation and Fertilization schedule for the 1987 Current Crop grown at Hodwitz's greenhouses. (based on personal communication with D. Hodwitz, 1987)

Time	Fertilization	Concentration	Frequency
0 - 6 weeks	water		every 5-7 days
6 - 8 weeks	10-52-10	25 ppm	every 5-7 days
8 - 14 weeks	20-20-20	150-175 ppm	every 5-7 days