United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report NC-142

Bareroot Nursery Production and Practices for White Spruce: A Literature Review

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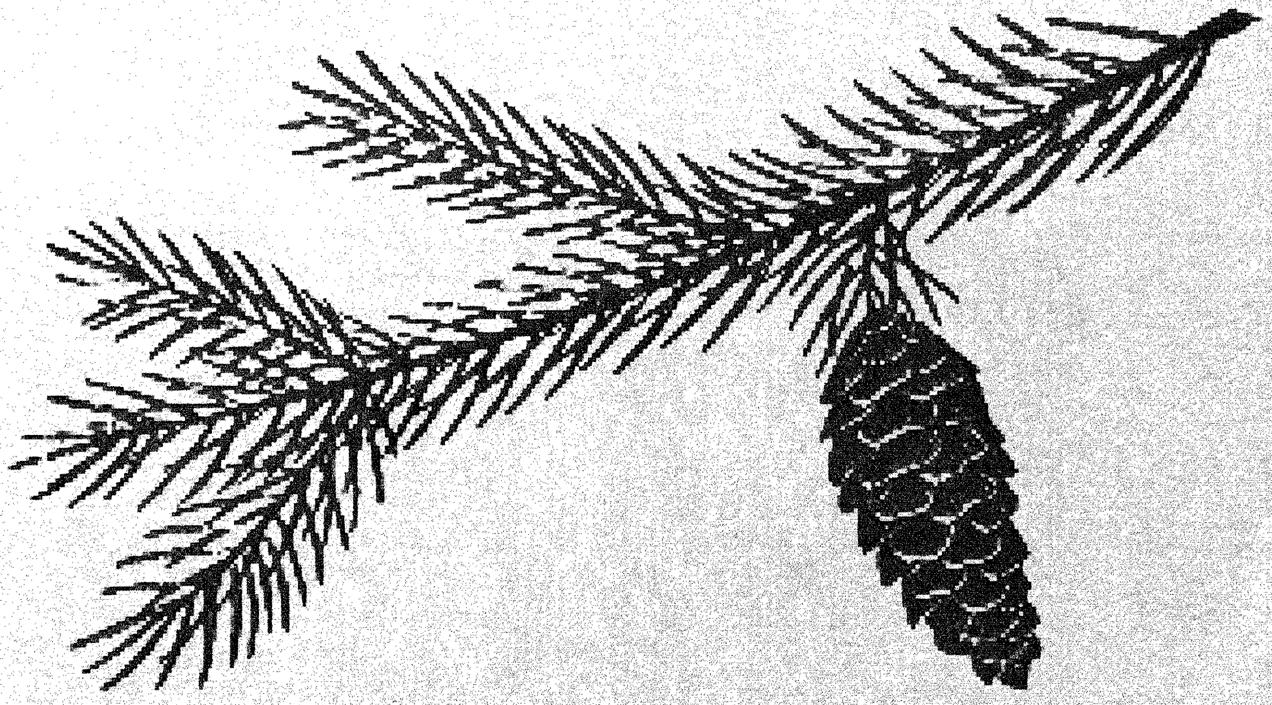

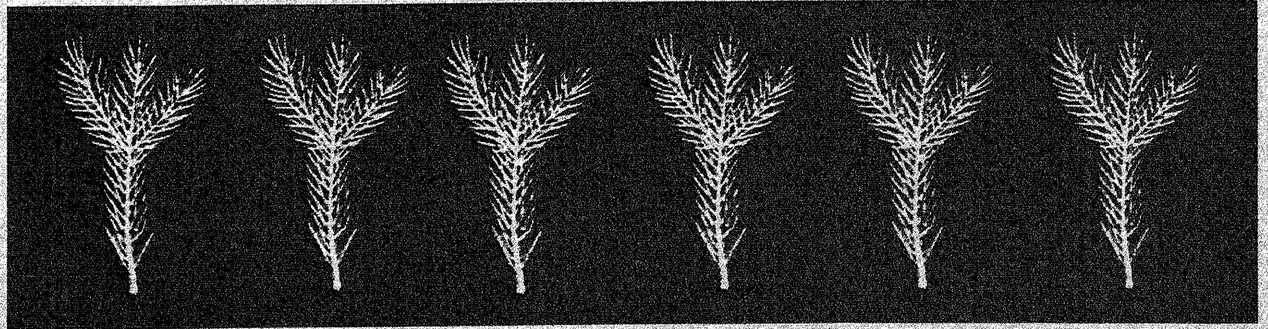

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Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication January 18, 1991
1991

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White spruce (*Picea glauca* [Moench] Voss) ranges across Canada into interior Alaska. This transcontinental species is also common in the northern Lake States, in upper New York, and in the northeastern United States (Fowells 1965, Rudolf and Andresen 1965).

White spruce has been planted in the upper Great Lakes Region since the late 1920's. Between 1975 and 1985, more than 21,000 acres of white spruce plantations were established in this region. Currently, an estimated 233,200 acres are classified as commercial white spruce forest cover type (Erickson and Rauscher 1985). About 76 percent of this is in plantations (Rauscher 1984). The demand for this species is expected to grow and may double by the year 2000 (Nienstaedt 1982).

Nursery seedling losses in the Lake States due to stunting and mortality from undefined causes have been as high as 80 percent in some years. At one Lake States nursery, production goals have been attained only three times in the past 20 years (Vaughn 1988).

This literature review discusses white spruce seed collection and treatment, seasonal seedling growth patterns, nursery cultural practices, and measurements of seedling quality. It includes only those references related to bareroot white spruce and does not deal with containerized seedlings. Information relating to containerized seedling production of white spruce can be found in manuals by Carlson (1983) and Tinus and McDonald (1979).

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SEED CHARACTERISTICS

Collection/Source

White spruce is a prolific seed producer with good crops every 2 to 6 years; the average yield is 226,000 seeds/lb (USDA 1974). Trees bear seed at least by age 30, often much earlier. Stiell (1976) noted seed production in white spruce at ages 12 and 20, and Sutton (1969a) observed cones on 4-year-old transplants one season after planting. Seed orchards have been developed in the Lake States (Nienstaedt 1982) and the Northeast (Carter 1985) to provide genetically improved seed.

White spruce seed differs in germination energy (Khalil 1986), needle initiation (Pollard 1973b), and height growth (King and Rudolf 1969; Nienstaedt 1969; Khalil 1975, 1978; Segaran 1978) among provenances. Nienstaedt and Teich (1972) have provided a complete discussion of white spruce genetics.

Time of cone collection influences seedling development. Winston and Haddon (1981) found that seed from cones collected 2 to 4 weeks before seed dispersal and artificially ripened through cold storage had higher germination success and produced significantly better seedlings than seed from cones collected when ripe. This suggests a period of maximum vigor may be exploited through early cone collection. Edwards (1978) also observed maximum seedling growth from early collection and prechilling of white spruce cones. Methods to determine white spruce cone and seed maturity are provided by Wang (1974), Stiell (1976), and Edwards (1978).

Seed Handling

Seed may be coated with a fumigant during processing to prevent loss due to damping off. Belcher and Carlson (1968) tested 69 compounds for seed coating and found none effectively controlled preemergent damping off. Thirteen of the chemicals controlled postemergent damping off but all inhibited germination to some extent. Lock *et al.* (1975) and Lamontagne and Wang (1976) reported reduced germination and first-year survival for seed treated with Polyram and Vitavax. Waldron and Cayford (1967) found Captan controlled damping off but it also produced more abnormal germinants than untreated seed. Carlson and Belcher (1969) listed Captan as effective in controlling damping off on white spruce, but Bamford (1970) reported the opposite. Arasan, Endrin and Benlate seed treatments have also been reported to have some negative effects on white spruce (Carlson and Belcher 1969, Cayford and Waldron 1966, Lock *et al.* 1975). Compounds recommended as stickers for fungicide seed treatment include latex and methyl cellulose (Cayford and Waldron 1966, 1967). Seed may also be pelleted with rodent repellents. Radvanyi (1975) found no reduction in white spruce germination due to coating with R-55.

Sutherland *et al.* (1978) found that dusting white spruce seed with aluminum powder to act as a lubricant decreased germination and first-year height growth. Cayford and Waldron (1966), however, reported no difference in total germination nor in number of abnormal germinants when seed was treated with aluminum flakes. Pelleting with baby powder actually improved germination (Waldron and Cayford 1967), possibly due to better moisture absorption by the seed. Storage of seed does not appear to be affected by chemical seed coating (Cayford and Waldron 1966, Radvanyi 1975). Wang (1974) provided a complete review of seed storage.

Seed Sizing

Studies examining the correlations between seed size and seedling growth parameters have produced conflicting results. Bunting (1969) and Khalil (1986) found a positive correlation between germination capacity and seed weight; however, other studies have found germination to be unaffected by seed size (Burgar 1964a, Reese 1967, Ackerman and Gorman 1969). Part of this discrepancy may be due to the method by which germination was measured, or differences in how seed size classes were determined. Reese (1967), for example, grouped several seed sizes into two categories at either extreme and noted this may have led to his inconclusive results.

Positive correlations have been demonstrated between seed weight and white spruce seedling height at 4 months (Khalil 1986) and also at 1 year (Burgar 1964a). Seedlings produced from the largest seed showed height advantages of 44 percent in 1-0 (Reese 1967) and 31 percent in 2-0 stock (Bunting 1969) over seedlings produced from the smallest seed. Hellum (1966) found seed weight to have a positive influence on hypocotyl length, but noted adverse site conditions may obliterate this influence. However, Meagher and Armson (1963) observed no height difference attributable to seed weight.

Khalil (1981) tested 10 seed characteristics for correlation with seedling height and found only seed weight to be significantly correlated. He concluded that endosperm seedcoat, which makes up most of the weight of a seed, was not the sole factor responsible for this positive correlation. While it may have accounted for taller trees the first year, increased annual height growth up to 4 years was not a mere carryover of initial effect the first year.

Genetic variation and germination rate of individual seedlings may also affect height (Sweet and Wareing 1966, Ackerman and Gorman 1969). Khalil (1986) determined provenances with high germination energy had high germination capacity and fast juvenile growth.

Burgar (1964a) and Ackerman and Gorman (1969) found a positive correlation between seed weight and seedling dry weight during the first year of growth, but this influence may decrease with seedling age. Reese (1967) found an 87 percent increase in seedling weight due to seed sizing the first year, but no weight advantage at the end of the second year.

Other growth parameters positively correlated with seed weight include the number of cotyledons

(Ackerman and Gorman 1969) and, possibly, seedling survival. Bunting (1969) found seedlings from the largest seed had 25 percent better survival at 1-0 and 15 percent at 2-0 than those from the smallest seed; Burgar (1964a), however, reported no significant difference in survival among seed size classes at the end of the first growing season. Parameters that appear to be unaffected by seed size include time of bud set (Reese 1967), shoot:root ratio (Ackerman and Gorman 1969), and seedling "vitality" (Canada: Toronto University 1967).

In examining the source of seed size variation, Hellum (1971) found no correlation between seed weight and any of several climatic conditions tested except latitude of parent tree. He concluded that seed weights may change from year to year within stands, trees, and crown locations in the tree. Hellum (1976) also found no correlation between seed weight and size of cone crop; seed weight within a tree, however, is distinct and rarely covers the full range of weights found within a stand. He cautioned that sorting seed by size may lead to genetic bias and recommended avoiding the procedure until more is known about the genetic implications.

NURSERY SEEDBED ESTABLISHMENT

Soil Fumigation and Mycorrhizae

Several species of nematodes and root pathogens damage white spruce seedling roots in the nursery, resulting in reduced vigor and winterkill (Nienstaedt 1982, Hepting 1971). Sutherland (1967a,b) listed species of nematodes known to be associated with white spruce and described interactions between nematodes and species of damping-off fungi. Methyl bromide-chloropicrin formulations are the most effective soil fumigants for controlling both types of pests (Abrahamson 1980) and are frequently used in white spruce nurseries. Vapam (sodium N-metham dicarbomate) is also a commonly used biocide.

In addition to effects on unwanted organisms, soil fumigants may influence seedling growth. Henderson and Stone (1970), Vaartaja (1964), Griffin (1965), and Danielson and Davey (1969) reported a marked growth increase in seedlings grown in fumigated beds that could not be attributed solely to control of root-rotting fungi and nematodes. One explanation is soil sterilization disrupts the equilibrium in number and activity of microorganisms (Wall 1978, Sinha *et al.* 1979), allowing nonspecialized microflora to recolonize and exhibit less inhibitive effects (Ingestad and Molin 1960). A change in microbial activity may also affect soil biochemistry, which can ultimately influence soil fertility and plant growth (Wall 1978, Abrahamson 1980). Fumigation has also been shown to influence trace element solubility in the soil, especially manganese (Wainwright 1978).

However, stimulation of seedling growth may not be a benefit. Iyer *et al.* (1969) reported that while 3-0 seedlings grown in mylone-treated beds were almost 60 percent taller than seedlings in control beds, they also displayed extreme succulence, abnormally high shoot-root ratios, reduced absorptive surface in the root system, and fewer mycorrhizae. They suggested treatments to acidify fumigated soils to reduce available nitrogen and therefore reduce excess foliar growth.

Adverse responses have also been reported following soil fumigation. Mitchell *et al.* (1937) and Stone (1950) reported failure of seedlings to grow much beyond the cotyledon stage, purple foliage, and increased winter mortality. Affected seedlings also lacked mycorrhizae and had low shoot phophorous content. Henderson and Stone (1970) found that white spruce seedlings grown on soil treated with Trizone (methyl bromide compound) or Vapam had significantly lower shoot dry weights and phosphorous contents at 14 months than control seedlings. When the fumigated seedbeds were inoculated with forest soil or fertilized with phosphorous, seedling growth improved and often surpassed growth of control trees. The two treatments together resulted in significantly larger trees than either alone. In a similar study, Campagna and White (1973) tested the effects of adding forest soil, phosphorous, or mycorrhizal cultures to soils sterilized with Vapam. The addition of phosphorous improved seedling shoot and root dry weight over the control, but adding mycorrhizae inoculum alone did not improve growth. The two treatments together gave results similar to adding phosphorous alone. Shaw *et al.* (1982) worked with unfumigated soil and noted no difference in any measure of seedling growth between white spruce inoculated with *Cenococcum geophilum* and uninoculated seedlings.

Enebak *et al.* (1989) found an increase in stunted seedlings resulting from fumigation. They tested Dazomet, Captan, Thiram, Captan-Thiram, and silica sand in white spruce nursery beds in Wisconsin. Soil fumigated with Dazomet resulted in about 50 percent stunted seedlings but produced the highest stand density. Beds treated with the other chemicals had about the same degree of stunting but lower seedling density. The silica sand (nontreated) beds had the lowest seedling density of all treatments but the least stunting.

Species of mycorrhizae associated with white spruce have been described by Hepting (1971), Vaartaja (1968), and Moore (1922). Trappe *et al.* (1984) reviewed the literature regarding eradication and reintroduction of mycorrhizae. Iyer *et al.* (1980a) described the use of catalytic analysis (Wilson *et al.* 1975) to rapidly quantify mycorrhizal short roots on 2-0 and 3-0 nursery stock in Lake States nurseries and discussed the use of this method to measure impact of soil fumigation treatments. Iyer (1978b) and Iyer *et al.* (1980b) indicated that climatic conditions, time of year, and seedbed seedling density all may affect the production of enzymatic substances measured through catalytic analysis. They cautioned these factors should be considered when using the process to determine effect of fumigation on mycorrhizal development.

Seed Sowing

White spruce is commonly drill-sown in nursery beds in six to eight rows, with the rows 6 inches apart (Stiell 1976, van den Driessche 1984). Canadian nurseries sow white spruce seed at depths of 1/8 to 1/4 inch (van den Driessche 1969).

Fall sowing of white spruce is most common in Canadian nurseries; it eliminates the need for seed stratification and provides a longer first growing season due to earlier germination, resulting in larger trees than spring-sown seed (van den Driessche 1969, Stiell 1976). This early germination may also affect seedling survival. Waldron (1966) reported June and July germinants suffered the highest mortality during the first growing season, but August germinants suffered more mortality over winter. At the beginning of the second growing season the June and July group had the highest overall survival. Fourth-year survival for June germinants was slightly greater than July and four times that of August germinants.

Burgar (1964a) concluded that spring-sown white spruce had more consistent and higher germination than fall-sown based on a comparison of inventory records.

Stratification

To ensure fast and even germination, seed sown in the spring must be stratified (Armson and Sadreika 1979). The most common method is cold stratification, in which seed is soaked in tap water for up to 24 hours, superficially dried, and then stored moist at temperatures just above freezing for a few weeks to 2 months (Burgar 1964b, van den Driessche 1969, Santon 1970).

Hellum (1968) indicated cold stratification of an Alberta variety of white spruce led to irregularities in germination rate and, as length of the stratification period increased, percent germination decreased. Hocking (1972) conducted a paired test with stratified and nonstratified Alberta seed from several sources but found no trends in response to stratification. He concluded other factors such as seed maturity, handling, and storage were affecting germination and did not recommend stratification unless these factors could be controlled. Winston and Haddon (1981) found cold storage of white spruce cones at 5° C for as little as 4 weeks eliminated the need for seed stratification after extraction.

Several other methods of stratification have been tested on white spruce. Seeds soaked in hydrogen peroxide had higher germination than cold-stratified seeds but seedling growth was adversely affected (Canada: Toronto University 1967). Fraser (1971) soaked seeds in dilute acid for 36 hours and found none of the seeds germinated at temperatures below 45° or above 95° F; the optimum temperature range for germination varied significantly by provenance. Phipps (1969) reported no difference in germination between seed placed in moist perlite for 31 days and seed subjected to incandescent or fluorescent light for varying lengths of time following 2 hours of soaking. Both treatments gave significantly better germination than the controls but the positive effects of the light treatments decreased with increasing storage time. Germination of seeds soaked in cold water for 14 days was significantly reduced. Timonin (1966) tested exposure to ultrasound as a stratification method. While 6 minutes of treatment proved lethal, a 2-minute treatment increased germination at 15 days almost nineteenfold; dry weight at 30 days was twice that of the controls.

Use of Mulch

Mulch is often applied to seedbeds after sowing, especially in fall to reduce overwinter loss of seed (van den Driessche 1969). Clifford and Massello (1965) described the performance of several mulching materials. Mullin (1965) concluded 3-0 white spruce trees grown on plots with sawdust mulch were shorter and weighed less. In testing the effects of varying levels of fibramulch (a wood-fiber product) applied after spring sowing, Racey and Raitanen (1985) determined that germination was unaffected but stem diameter and seedling dry weight were significantly reduced with increasing levels of mulch. They recommended 0.1 kg/lineal foot as the maximum mulch for good seedling growth. In a laboratory study, Carlson and Belcher (1970) determined that while sawdust had no effect on white spruce germination, it appeared to help control damping-off fungi.

Seedbed Density

Several authors reported that as seedbed seedling density decreases, seedling dry weight and root collar diameter increase (Armson 1968, Bell 1968, McClain and Armson 1976, Mullin and Bowdery 1977, van den Driessche 1984). This inverse relationship was determined to be valid regardless of whether seedlings were drill or broadcast sown (van den Driessche 1969). Bunting (1973) showed the weight and diameter increase of 2-0 seedlings to be greater at densities below 15 trees/ft^2 than at those above. Nova Scotia Department of Lands and Forests (1983) reported the heaviest 2-0 seedlings were produced at a density of 215/m^2 (20/ft^2).

Root growth also appears to benefit from seedbed seedling density control. Decreased density has been shown to increase root length (Mullin and Bowdery 1977), volume (Bell 1968, Bunting 1973), biomass (Richards *et al.* 1973), and root area index (RAI) (McClain and Armson 1976, McClain 1977). McClain and Armson (1976) suggested it may be more practical to increase root growth through density control than through fertilizers.

McClain (1977) found increased uniformity in terms of seedling weight, RAI, and height with decreasing density, but Richards *et al.* (1973) found no effect of density on seedling height. Mullin and Bowdery (1977) reported significantly taller trees in plots with 15 trees/ft^2 than in plots with twice that density. Increases in white spruce seedling height in response to increased fertility levels has been shown to be magnified by lower densities (Bell 1968, McClain and Armson 1976, Phipps 1977).

Other documented effects of decreasing density include an increase in survival from the first to third growing season (Bunting 1973), and an increase in mean foliage concentration of phosphorous and calcium and a decrease in potassium (McClain and Armson 1976). Iyer (1978b) determined the incidence of mycorrhizal short roots was inversely related to seedling age when trees were grown in dense, shaded beds. Germination energy of white spruce was found to be unrelated to seedbed density, as was seedling root growth potential (RGP) (van den Driessche 1984).

Whitney (1959) reported that in densely stocked seedbeds, soil packing facilitated infection of white spruce foliage by soil fungi, leading to substantial mortality. In seedbeds with lower densities this was not observed.

The beneficial effects of density control in the nursery on outplanting performance were still apparent at the end of the first field growing season (Bell 1968). Van den Driessche (1984) reported greater shoot growth and survival during the first year after outplanting for trees thinned to a density of one every 5 cm in nursery drill rows than for trees grown at 0.6 cm spacing. In a study examining performance 5 years after outplanting, trees produced at lower densities were significantly taller on five out of eight sites (Mullin and Bowdery 1977).

Morphological quality of trees may increase with decreasing density, but thinning increases production costs. Bunting (1973) found this cost increase may be offset somewhat by a decrease in the number of culled trees at lifting time. However, van den Driessche (1984) concluded wider spacing does not result in a significant increase in yield of shippable trees regardless of the culling standards employed. Recommended stocking levels are 30-35 trees/ft^2 for 2-0 stock (Bell 1968, Stiell 1976), 45-150 trees/ft^2 for 2-0 stock that will be transplanted (Stiell 1976), and 25-30 trees/ft^2 for 3-0 stock (Bunting 1980). Transplants are generally spaced at 2- to 3-inch intervals (Stiell 1976). Bell (1968) showed that reduction in growth at higher densities can be compensated for, up to a point, through fertilization.

SEEDLING GROWTH IN SEEDBEDS

Shoot Growth

Jablanczy (1964) described three stages in the early morphogenesis of white spruce seedlings, but seedling growth in the first year is generally indeterminate from the time of germination until growth ceases due to declining day length or a stess-induced dormancy (Pollard 1974). An overwintering bud may or may not be formed at this time (Armson and Sadreika 1979).

There is evidence that seedling growth patterns in white spruce vary by population and year (Armson 1966). The relationship of seedling dry weight with time has been demonstrated to be both curvilinear (Armson and Sadreika 1979) and linear-curvilinear (Canada: Toronto University 1969) during the first season, although dry weight growth often continues into late fall with no indication of flattening out. During the second growing season, this relationship tends to be linear (Armson 1960). Relative dry weight or rate of dry weight accumulation is initially high and decreases as the season progresses (Armson and Sadreika 1970). While the rate generally decreases after the first year (Armson and Sadreika 1979), approximately 65 to 75 percent of the total weight of a 2-year-old spruce accumulates during the second growing season (Richards *et al.* 1973).

When water and soil nutrients are not limiting, seedling dry weight increases over the growing season and is a function of temperature (Armson 1960, Arnott 1982). Armson (1962, 1966) demonstrated an exponential relationship between total seedling weight and cumulative degree days for the first 2 years of seedling growth. The best fit was obtained when 34° or 36° F was used as a base for calculating degree days.

Toronto University researchers observed diameter growth during the first year to continue until late summer, although at a low rate from late July to early August; during the second year, diameter growth increased linearly from late June to late July (Canada: Toronto University 1969). They also noted three patterns of height growth in first-year white spruce seedlings: some seedlings completed shoot growth by early July, others stopped or slowed growth later in July but resumed height extension after 2 to 4 weeks, and a third group continued growth throughout the summer but at a progressively decreasing rate. These same three patterns of height growth were more apparent in second-year seedlings, although the bulk of the activity was in June rather than July.

Shoot growth potential for the following year is largely determined by needle primordia formed during the current year (Pollard 1974, Pollard and Logan 1977, Hellum 1967). Needle primordia are formed in white spruce between mid-July and mid-September during a period Nienstaedt (1966) referred to as the transitional phase of dormancy development. The commencement of this period depends on the sensitivity of the seedling to dormancy-inducing mechanisms, a sensitivity which increases with age during the first season (Winton 1964, Pollard 1973a). Pollard (1973b) observed genetic differences among seedlings in duration of the period as well as rate of needle initiation. Seedling height was also shown to be directly related to size of the bud formed (Hellum 1967). Pollard (1974) determined this relationship was dependent on seedling age, with the influence of height on bud size decreasing with age. The number of primordia formed are also influenced by site factors such as nutrient supply, light intensity, and temperature (Hellum 1967). Pollard and Logan (1977) found the rate of bud morphogenesis was optimal at 25° C. If the period of initiation is interrupted by chilling, no more primordia will form (Nienstaedt 1966).

After seedlings enter dormancy, chilling is required before growth can resume. Length of the chilling requirement depends on physiological age of the plant when chilling began. Chilling must be continuous—the effects of many short chilling periods are not cumulative. A period of 4 to 8 weeks of 36° to 40° F temperatures has been shown to fulfill the requirement of 2-year-old spruce (Nienstaedt 1966, 1974).

Khalil (1981) determined that the superior juvenile height growth displayed by some seed sources is genetically controlled. No significant differences were noticed in height until the trees were 2 years old, however, and it has been suggested that part of the superiority may be due to a greater degree of outbreeding (Khalil 1978). In a study of growth differences between self- and wind-pollinated white spruce, Mergen *et al.* (1965) found self-pollinated trees to be smaller at 6 weeks of age; after 1 year, however, there was no height difference and after 3 years self-pollinated trees showed a significant height advantage.

Sweet and Wareing (1966) cautioned that studies of seedling height growth should first establish how much of the observed difference is due to time of seed germination. This difference may also interact with genetic differences in growth rate. Segaran (1978) determined seedling growth rate in the nursery was directly related to seedling height. He noted that tall seedlings had a higher growth increment and more lateral branches than smaller seedlings and concluded this will enable them to maintain or increase their height advantage.

Bunting (1980) described a method of constructing nursery-specific growth curves to predict stock size at the end of a given year. He suggested using these curves to plan practices to achieve desired size of stock since cultural treatments can have a large impact on seedling growth patterns.

Multiple-leadered seedlings can also result in reduced height growth. Hofstra *et al.* (1988) reported multiple-leadered white spruce in Canadian nurseries to be 20 to 30 percent shorter than single-leadered seedlings of comparable age. However, there was no weight difference. Low temperatures resulting in terminal bud injury were cited as the cause of multiple-leadering in northern Ontario, but in southern Ontario nurseries the cause was more likely to be abnormal bud formation. The causes of abnormal bud formation were not known at the time of investigation.

Seedling Stunting

Uneven height growth or stunting of white spruce in the nursery has been studied for a number of years. Affected seedlings sometimes display almost no growth (Berbee *et al.* 1980), or growth is arrested mid-season during the first year (Croghan 1985). Foliage often becomes purple late in summer (Croghan and LaMadeleine 1982) but returns to green after seedlings resume growth the following spring (Croghan 1985). Croghan and LaMadeleine (1982) indicated the height differences become more apparent as seedlings grow older, and by the time they are lifted as 3-0 stock the stunted trees are considerably shorter than normal.

Stunted trees have also been reported to have lower shoot:root ratios and to weigh less than half as much as unaffected stock (Berbee *et al.* 1980). Croghan and LaMadeleine (1982) reported stem diameters to be 61 percent of normal. They also determined stunted seedlings had 25 percent less nitrogen and 72 percent less phosphorous than normal, even though soil tests revealed no deficiencies.

Croghan and LaMadeleine (1982) found stunted trees in nursery beds adjacent to healthy seedlings, although portions of beds where stunting occurred were poorly stocked. They reported 28 percent of first-year spruce at the USDA Forest Service nursery in Eveleth, Minnesota were stunted in 1979. Berbee *et al.* (1980) estimated between 15 and 30 percent of the stock in Lake States nurseries in 1977 was stunted.

Berbee *et al.* (1980) reported an increase in fall mortality of stunted stock during drought years, but the major impact of this condition appeared to be an increase in cull rate at time of lifting. Croghan (1985) reported 57 percent cull in stunted stock compared with 7 percent in nonstunted stock. When both types of stock were outplanted there were no significant differences in shoot and diameter growth or growth rate after 2 years in the field.

The absence of ectomycorrhizae on white spruce seedlings has been investigated as a cause of stunting. Berbee *et al.* (1980) found mycorrhizal infection "adequate" on both stunted and normal stock and noted that stunted seedlings had generally well developed root systems for their size. Croghan *et al.* (1987), however, determined only 2-7 percent of stunted stock was infected with mycorrhizae, compared with 44-79 percent for normal seedlings. They hypothesized that soil fumigation eliminates mycorrhizae and the lack of natural reinfection in roots of stunted stock is related to the poor growth displayed by these seedlings. Iyer *et al.* (1969), however, found 3-0 white spruce from beds treated with Mylone were 60 percent taller than trees from untreated soil and concluded the tall trees were abnormal due to their high shoot:root ratio and extreme succulence. Berbee *et al.* (1980) also noted stunting in Wisconsin DNR nursery beds was significantly reduced by spraying with Benomyl and Captan even though no fungi could be isolated.

In a study comparing spruce (species not given) seedlings grown on Vapam-treated soil with those grown on untreated soil, (Laiho and Mikola 1964) found little difference between the groups in mycorrhizal infection at the end of the first year and no difference in height at the end of the second season. Hellum (1966) speculated that stunting is not a fungal problem but rather a cultural one influenced by soil moisture and shade.

Seedling Roots

There is extreme variability in root form in white spruce (Wagg 1967), perhaps partially due to variation in soil texture and moisture content (Anderson 1932, Anderson and Cheyney 1934, Schultz 1969). As seedlings age, variability in root form increases (Sutton 1978).

Early root system development in white spruce seedlings is generally characterized by elongation of a taproot (Sutton 1969b). Taproot form is frequently transitory and may become dominated by the two or three large laterals that usually develop just below the root collar and serve to extend the root system (Mullin 1963). Initial growth is most rapid in these large primaries (Tryon and Chapin 1983), but production and elongation of fine absorbing roots distributed throughout the upper 4 inches of soil continues later into the first season (Armson 1972). Several methods are used to assess seedling root development, including dry weight measurement, volume determination (Burdett 1979, Ritchie and Dunlap 1980), and root area or root area index (RAI) (Morrison and Armson 1968). In a comparison of dry weight, RAI, and volume measurements, Racey (1985) recommended the volume method for white spruce as it is highly correlated with the other two and faster for operational use.

Results of root growth potential (RGP) tests have revealed a seasonal periodicity in root growth of white spruce (Farrar and Huntley 1969). This pattern seems to be related to the bud dormancy cycle (Ritchie and Dunlap 1980), but there are conflicting reports. Day *et al.* (1977) reported root regeneration in white spruce was good from May 25-June 5, erratic to poor between July 21 and August 21, very poor from late August through mid-September, but improved after mid-September. They concluded white spruce has a well-developed inherent root periodicity, but differences in pattern exist due to nursery location.

Hambly (1973) also noted a peak in growth early in the season, but it was followed by a brief period of decline rising to an extended period of major root activity after mid-summer. Van den Driessche (1978) found a growth peak during August followed by an immediate decline, a gradual increase during winter, and a very low level in April.

Field studies on development of white spruce roots showed no periodicity during the growing season (Armson 1960). Root surface area increase was linear-curvilinear for the first growing season, but during the second year there was a pronounced peak in late July, and the increase was minimal after August (Canada: Toronto University 1969). Mullin (1963) reported that root dry weight increased and growth rate tended to be linear in 3-0 spruce. Part of the discrepancy between RGP tests and field results may be due to alteration of natural endogenous controls of root growth in spruce when determined under RGP conditions (Johnson-Flanagan and Owens 1985). Soil moisture content was also shown to affect both root regeneration and elongation (Day and MacGillivray 1975).

Soil temperature also affects root growth (Sutton 1969b). Tryon and Chapin (1983) found growth higher at a soil temperature of 20° C than at 10° C. Ritchie and Dunlap (1980) determined 19° C was optimum for root development. Effects of soil temperature on cold-hardiness were discussed by Johnson and Havis (1977).

SOIL FERTILITY

Soil fertility can have a dramatic effect on seedling growth. Armson (1966) reported unfertilized seedlings in the nursery grew for only two-thirds of the available season, had a lower rate of growth, and attained only half the final height of fertilized trees. High fertility in the rooting medium favors shoot growth over root growth after the resources in the seedcoat have been depleted (Sutton 1969b, Etter 1971), but response to supply of a limiting nutrient was demonstrated to be much more pronounced in white spruce at 26 weeks than at 16 (Swan 1971).

Stiell (1976) and Duryea and McClain (1984) described negative effects on seedling growth from an oversupply of nutrients. Excessive nitrogen supplies have been demonstrated to result in reduced potassium availability (Armson and Sadreika 1979) and a delay in dormancy that may increase frost damage (van den Driessche 1980).

Nitrogen

The rate of nitrogen uptake parallels the growth curve of white spruce—i.e., it is not absorbed with periodicity (Armson 1960, 1965; Canada: Toronto University 1963) and the rate can be increased through fertilization (Armson 1966). Increased soil nitrogen levels have been shown to increase white spruce shoot height and weight (Talli 1967; Armson 1968; Etter 1971, 1972), shoot:root ratio (Armson 1963), root-collar diameter (Mullin and Bowdery 1977, Brown and Myland 1978), RAI (McClain and Armson 1976, Bunting 1984), and root branching (Mueller-Dombois 1964, Sutton 1969b, McClain and Armson 1976). Foliar concentrations of potassium and calcium have also been reported to decrease with an increase in nitrogen supply, but magnesium concentration was unaffected (McClain and Armson 1976).

The form of nitrogen fertilizer applied may affect seedling response. Nitrogen can be absorbed by white spruce in either the ammonium (NH_4^+) or nitrate (NO_3^-) form (Armson and Sadreika 1979), but growth has been reported to be improved by the ammonium form (Edwards 1981, Etter 1972). White spruce seedlings supplied with ammonium had significantly higher dry weights and nitrogen content after 5 weeks (McFee and Stone 1968) and after 109 days (Swan 1960) than those supplied with nitrate. After the second season, however, fresh weight was shown to be greatest for those supplied with nitrate (Durzan and Steward 1967). They also concluded that without nitrate, spruce failed to utilize ammonia to promote rapid growth. This response may be due to seasonal variations in metabolism.

Van den Driessche (1969) reported there was no significant advantage of urea, urea formaldehyde, ammonia, and ammonia phosphate over ammonia sulphate or ammonium nitrate, but the sulphate form of ammonia frequently produced a greater seedling response than the nitrate form.

Timing of nitrogen applications did not significantly affect seedling dry weight, but late-season applications increased foliar nitrogen concentration (Armson 1963) and content (Canada: Toronto University 1962b). Guidelines for nitrogen fertilizer application rates and schedules have been provided by van den Driessche (1969), Armson and Sadreika (1979), and Bunting (1984).

Phosphorous

The addition of nitrogen fertilizers has been demonstrated to impact phosphorous nutrition in white spruce. An increase in nitrogen fertilizer supply has been associated with a decrease in foliar phosphorous concentration in 1-0 (van den Driessche 1969) and 2-0 seedlings (McClain and Armson 1976). But Armson (1963) found no indication that phosphorous concentration of 2-0 seedlings was affected by either quantity or time of fertilizer application when phosphorous and nitrogen were added together. The concentration of phosphorous in white spruce, however, has been shown to be much more variable over time than nitrogen (Armson 1960).

Bunting (1984) reported no significant improvement in seedling growth by the addition of both phosphorous and nitrogen fertilizers over the addition of nitrogen alone. A synergistic effect from mixing phosphorous and nitrogen was demonstrated by Armson and Sadreika (1979) in 2-0 white spruce. Bunting (1980) observed that this interaction becomes less noticeable as soil phosphorous levels approach "recommended" values.

Seedling dry weight has been shown to increase with increasing levels of phosphorous (Meagher and Armson 1963), but Chapin *et al.* (1983) observed no significant difference in white spruce weight at 10 weeks due to level of phosphorous fertilizer. As phosphorous is not mobile in the soil, the difference in results may be due to fertilizer placement. In tests comparing surface-incorporated and banded phosphorous applications, the latter significantly increased seedling dry weight and also stimulated root development in the banding zone (Canada: Toronto University 1962a, Meagher and Armson 1963). Although Etter (1972) concluded phosphorous fertilizer could not be used to stimulate early root growth, a study conducted by Canada: Toronto University (1964) researchers demonstrated an increase in both root length and surface area 35 days after germination due to banded phosphorous fertilizer.

Potassium

The potassium absorption rate in white spruce roughly parallels the seedling relative growth rate except late in the season when potassium is lost from the plant (Armson 1965). According to Armson (1966), there is no well-defined relationship between seedling potassium content and seedling size. A slight increase in height has been reported with increasing potassium levels (Swan 1960), but the range of potassium content associated with good growth is wide (Ingestad 1962).

Excessive applications of other fertilizers, particularly ammonium, have resulted in reduced availability of soil potassium (Krause 1971, Armson and Sadreika 1979). Ingestad (1967) recommended a potassium:nitrogen ratio of 0.65 for optimum nutrition. Youngberg (1980) reported low survival among white spruce seedlings with low foliar potassium concentrations accompanied by high phosphorous contents. The mortality was due to the fact seedlings did not harden off properly.

Because the rate of uptake is usually very low during the first year and high during the second, a single presown application of potassium fertilizer may not be enough for an entire rotation of white spruce. Potassium loss from the soil increases with acidity, therefore the frequency and level of fertilizer treatment should be based on soil pH and base saturation (Krause 1965, 1971). Potassium addition schedules have been provided by van den Driessche (1969) and Armson and Sadreika (1979).

Micronutrients

Swan (1960) discussed the effects of calcium and magnesium levels in the soil on white spruce seedling growth. The addition of chelated micronutrient fertilizers has been shown to substantially increase growth of 2-0 and 3-0 white spruce in a Wisconsin nursery (Iyer and Wilde 1974, Iyer 1977). The effects of micronutrient additions included an increase in the volume and absorbing capacity of the root system, a decrease in shoot:root ratio, and significant increases in both major and micronutrient concentrations in the foliage. When 3-0 seedlings received an additional treatment of iron, manganese, copper, and zinc and were allowed to grow one more year, the uptake of all nutrients more than doubled, foliar concentrations of all elements except potassium increased, and dry weight was significantly increased over the controls (Iyer 1978a).

Chemical Properties

Soil chemical properties can have a large impact on nutrient availability and seedling growth, but studies with white spruce have produced conflicting results. Stoeckeler and Jones (1957) reported a sharp reduction in availability of potassium, phosphorous, calcium, and magnesium at pH levels between 4.0 and 4.5, while pH levels greater than 6.8 resulted in reductions in phosphorous assimilation, seedling vigor, height, weight, needle length, and bud development. Rawinski *et al.* (1980) determined height growth was negatively correlated with pH between 5.0 and 6.1. Armson and Sadreika (1979), however, concluded that white spruce is more tolerant of pH levels above 6.0 than other conifer species. Van den Driessche (1969) indicated white spruce grows best on soils with pH between 4.0 and 5.0.

Rawinski *et al.* (1980) determined height growth was unaffected by organic matter content between 0.5 and 4.0 percent, but Brown and Myland (1978) recorded increases of 38, 58, and 157 percent for height, diameter, and weight, respectively, when peat addition to white spruce nursery beds was raised from 200 to 800 yd^3. Wilde *et al.* (1964) showed cation exchange capacity to be significantly and linearly related to white spruce height growth.

Recommended soil properties and nutrient levels for white spruce seedlings grown in bareroot nurseries are provided in table 1. General recommendations for conifers, including white spruce have also been provided by van den Driessche (1980) and Edwards (1981). Several factors influence determination of these levels, including the testing procedures employed. Soil phosphorous extracted with an acid solution of ammonia fluoride correlated well with the amount available to white spruce in Ontario (Armson and Sadreika 1979).

Table 1.—*Recommended soil nutrient levels for the production of white spruce seedlings*

	%		ppm				
pH	OM	CEC	P	K	Ca	Mg	
5.5-6.5		5.0	26	63	240	85	(1)
5.5	4.5		75	117	300	35-40	(2)
5.5-6.5	3-5		300	117	600	61	(3)
5.5-6.5	2.5-3		200	117	600	61	(4)
5.5	5		20-40	126			(5)

(1) Wilde *et al.* (1979); seedbed..
(2) Hallett (1980); 2-0 stock.
(3) Bunting (1980); seedbed.
(4) Bunting (1980); transplants.
(5) Edwards (1981); seedbed.

Tissue Analysis

Soil nutrient deficiencies can be detected to a certain degree by characteristic morphological symptoms in affected seedlings. Swan (1960) provided color photographs of white spruce seedlings grown at varying levels of imposed nutrient deficiency. Nutrient deficiencies not manifested in visual symptoms may be detected through tissue analysis. Table 2 provides a summary of the recommended optimum nutrient concentrations in white spruce foliage.

Table 2.—*Foliar nutrient concentrations association with optimum growth of white spruce seedlings*

% Oven dry weight					
N	P	K	Ca	Mg	
2.03	0.39	0.92	0.62	0.12	(1)
2.22	.45	1.12	.55	.11	(1)
2.07	.28	1.19	.49	.17	(2)
1.50	.18	.40-.56	.15	.10	(3)
1.8	.10-.30	.70-1.1	.09-.60	.09-.16	(4)
1.5 -2.5	.18-.32	.45-.80	.15-.40	.10-.20	(5)
2.28-2.91	.30-.35	.83-.98	.39-.59	.14-.17	(6)
2.00-2.40	.25-.35	.60-1.0			(7)
2.00-2.40	.20-.30	.50-.80			(8)
1.90-2.40	.18-.24	.45-.60			(9)

(1) Berbee *et al.* (1980); 1-0 stock.
(2) Croghan and LaMadeleine (1982); 1-0 stock.
(3) Morrison (1974).
(4) Ingestad (1962); 160-day-old seedlings grown in nutrient solution.
(5) Swan (1971); 26-week-old seedlings.
(6) Duryea and Landis (1984); 1-0 stock.
(7) Armson and Carman (1961); 1+0 stock.
(8) Armson and Carman (1961); 2+0 stock.
(9) Armson and Carman (1961); 2+1 stock.

CULTURAL TREATMENTS

Shading

Shading of white spruce nursery beds for all or part of the first growing season is generally considered beneficial to seedling growth (Stiell 1976). Iyer (1978b) found the number of mycorrhizal short roots on seedlings to be directly related to the use of shade.

Based on inventory records, Burgar (1963) found the number of seedlings in shaded beds was greater than that in unshaded beds at the end of the first summer. Day (1963) also recorded significantly lower seedling mortality during the first few months after germination in beds with 40 percent shade than in beds exposed to full insolation. He cited the cause of mortality as stem girdling due to adverse heating and drying of the soil surface. Root development, as measured by root length, was unaffected.

Sutton's (1969b) literature review indicates shading can reduce the amount of radiation available for photosynthesis, which decreases the fraction of photosynthate that is produced and translocated to the roots. This can alter hormone production and result in abnormal root growth. Net uptake of nutrients per unit root area has also been shown to be reduced in shaded white spruce (Morrison 1970).

Due to the high cost of shading nursery beds, Stiell (1976) indicates a trend away from this practice with a corresponding increase in seedling loss. Many nurserymen feel the cooling effects of irrigation can partly compensate for shade.

Irrigation

Day (1963) reported surface temperatures of 45° to 50° C resulted in stem girdling of white spruce seedlings, but the severity of girdling was dependent on soil moisture. Temperatures above 50° C, however, resulted in severe mortality even when soil was moist to a 1-inch depth. Soil temperature was also shown to affect white spruce seedling weight (Heninger and White 1974) and root morphology (Chalupa and Fraser 1968), as well as nutrient and water uptake (Sutton 1969b).

The impact of irrigation on soil moisture content and its effects on white spruce seedling growth have been examined. Stiell (1976) indicated soil must be kept moist continuously during germination. Hellum (1972) determined that seeds from dry sites germinated better than seeds from wet sites when alternating periods of soaking and drying were employed. If irrigation is adequate, there is no beneficial effect on spruce growth from seedbed sideboards (van den Driessche 1969).

It has been observed that white spruce in Ontario suffers less growth reduction under moisture stress (as measured by seedling dry weight) than other conifers (Glerum and Pierpoint 1968, McClain 1973). Brix (1979) determined the threshold of water stress above which the rate of net photosynthesis declined from 100 percent to be -10.7 bars for 4-month-old white spruce. While the rate of net photosynthesis became 0 at -28.6 bars, seedlings survived upon rewetting after being stressed up to -100 bars. No significant reduction in terminal leader or diameter growth was noted in 3-0 white spruce subjected to soil moisture tensions up to 15 atmospheres (Glerum and Pierpoint 1968).

Soil moisture appears to affect root growth. In an RRP (root regeneration potential) study, Day and MacGillivray (1975) recorded a significant reduction in RAI (root area index) for 2-0 white spruce planted in soil maintained at 8 to 10 percent moisture content compared with seedlings in soil with a moisture content of 15 percent. McClain and Armson (1976) also found that foliar concentrations of potassium and calcium in 2-0 white spruce were directly related to moisture supply. The concentrations of both phosphorous and magnesium were unaffected, however.

Methods to determine irrigation needs and monitor soil moisture are discussed in Stiell (1976), Armson and Sadreika (1979), McDonald and Running (1979), and Day (1980a).

Herbicides

Of several triazine herbicides tested in the nursery, Prometryne was the only one that significantly increased survival and dry weight of 1-0 white spruce seedlings (Kozlowski 1963). It has been recommended for application the day after sowing (van den Driessche and Balderston 1974). These authors also recommended the application of Propazine the day after sowing, but Kozlowski (1963) found this chemical decreased the dry weight of 1-0 seedlings. Hallett (1983) recommended application of Propazine be delayed until white spruce is well established. Simazine is generally not recommended but may be applied at the end of the first growing season or later (Stiell 1976, Hallett 1983). Due to the negative impact on seedling growth, Atrazine is not recommended for use in white spruce beds (Kozlowski 1963, Hallett 1983).

Au (1985) recorded significant increases in height and dry weight over controls for 2-0 white spruce grown in beds treated with Devrino, Modown, and Dacthal as preemergent herbicides. Kozlowski (1963) noted similar results for Dacthal in 1-0, 3-0, and 2+2 beds and also recommended Eptam and Vegadex. Other herbicides recommended for use in white spruce beds include Aminotriazole (Armson and Sadreika 1979), "Shell" Agricultural Weed Killer (AWK) if applied before the seedcoat falls off (van den Driessche 1969), and Prometone applied 28 days after germination (van den Driessche and Balderston 1974). Due to negative effects on seedlings, Mylone (Iyer 1963) and Pronamide (Au 1985) are not advised. Symptoms of herbicide injury have been described by Gross (1983) and Hallett (1983).

Frost-heaving Protection

Frost heaving of soil, which can reduce seedling growth and cause mortality, is a problem in northern nurseries. It can occur whenever air temperature falls below 0° C, but it is most prevalent in late winter and early spring (Sutherland 1970) especially when there is little or no snow cover (Stiell 1976). The extent of frost heaving depends on climatic and soil conditions, and the severity of seedling damage may vary from year to year. Loss is especially apparent in overwintering first-year white spruce (Burgar 1964c, Mullin 1965, Stiell 1976, Nova Scotia Department of Lands and Forests 1983); factors that reduce root growth or damage seedling root systems may increase susceptibility (Sutton 1969b). Sutherland (1970) illustrated this point in a study with white spruce grown in soil inoculated with the nematode *Xiphinema bakeri*.

Many nurserymen cover the seedbeds with mulch to reduce frost-heaving losses. Burgar (1964c) reported 70-80 percent overwinter survival in 1-0 spruce beds that were mulched, and only 50 percent survival in nonmulched beds.

A Nova Scotia Department of Lands and Forests (1983) study concluded that increasing 1-0 seedbed density to 1,000-1,500 seedlings/m^2, in addition to mulching, reduced frost-heaving loss. However, beds must be thinned at the beginning of the second season. Mullin (1965) noted no difference in frost heaving related to seedbed density, but this conclusion was based on visual estimates. He also found no improvement in overwinter survival by leaving shading material on the beds until the second season, but he did record a significant reduction in seedling dry weight and an increase in height. Day (1963) also observed no reduction in frost heaving due to overwinter shading. Another method of reducing frost heaving is raising the nursery beds to improve drainage (van den Driessche 1969).

Root Pruning

Mullin (1957) tested several methods of pruning white spruce roots, including V cuts meeting at 1.5 or 3 inches below the surface. There was heavy mortality among seedlings subjected to the shallowest V cut, but the differences between other treatments and the controls were insignificant. In a later study of horizontal pruning depth, Mullin (1966) found no differences in seedling survival, but time of pruning did have a significant effect. Pruning on April 30 reduced shoot height, but it did not affect seedling survival, root length, stem diameter, or dry weight. Outplanting survival was increased when roots were pruned on June 25 as compared with pruning at other times.

Ritchie and Dunlap (1980) also concluded time of root pruning may alter the timing and perhaps strength of expression of root growth potential. Sutton (1967) and Mullin (1973) reported the effects of root pruning at the time of lifting on seedling outplanting performance.

SEEDLING QUALITY

The characterization of nursery stock is important as a means of quality control in providing suitable seedlings for outplanting (Racey *et al.* 1984), and most standards have been developed with this in mind. The assessment of trees at the end of a nursery rotation also reflects on nursery practices (Armson and Sadreika 1979). Dickson *et al.* (1960) developed an integrated seedling quality index to provide an "objective basis for comparing the results of nursery management practices". This index was based on the more common morphological parameters used to predict outplanting success, including shoot height, root-collar diameter, total seedling weight, and shoot:root ratio.

Seedling shoot height is one of the easiest parameters to measure at the time of lifting and is frequently used to grade nursery stock. Phillion *et al.* (1982) determined that while the tallest 3-0 and 2+2 stock at lifting time maintained its height advantage 9 years after outplanting, the growth curves of all the seedlings were similar. Pollard (1978) found that taller seedlings had a greater annual height increment than smaller seedlings. Seven years after outplanting, white spruce 2+2 seedlings that had heights greater than 17 inches at planting time maintained their height growth advantage over the control stock which had averaged 7.7 inches at planting time (King *et al.* 1965). After 18 years, they continued to have a 30 percent height growth advantage over the controls (Nienstaedt 1981). Mullin and Svaton (1972) recommended 6 inches as the minimum height standard for 2+2 white spruce planting stock.

Mullin and Christl (1981) showed stem diameter to be significantly correlated with outplanting success of 2+2 white spruce, and Bunting (1975) recorded significantly higher survival percentages for 3-0 stock with a minimum stem diameter of 3.6 mm. Burdett *et al.* (1984) suggested early postplanting height growth is fastest in stock with a low height:diameter ratio. Fifth-year height was determined to be correlated with seedling height, root volume, stem diameter, crown volume, and root volume (Racey *et al.* 1983). Mullin and Svaton (1972) found only height and stem diameter were correlated with growth 10 years after planting and recommended a minimum stem diameter of 6/32 inch as standard.

Dobbs (1976) separated 2-0 and 2+1 stock into weight classes and found that 2-0 white spruce seedlings originally weighing more than 4.5 g had significantly better survival percentages and height increments 3 years after outplanting than seedlings weighing less than 4.5 g. Mullin and Christl (1981) found a significant correlation between root volume and outplanting success and provided minimum standards for 2+2 stock. The use of root volume as a measure of seedling quality has also been recommended by Burdett (1979), Glerum and Boufford (1979), and Racey *et al.* (1984). Day and Walsh (1980) described the measurement of plant moisture stress and its use in evaluating stock. Shoot:root ratio has been determined to be an unreliable predictor (Mullin and Svaton 1972, Racey *et al.* 1983).

Ritchie (1985) concluded root growth potential was one of the most reliable predictors of outplanting performance due to its direct relationship with seedling cold hardiness and stress resistance, both attributes that impact outplanting performance. Sutton (1980) found both outplanting survival and height increment to be correlated to RGP, but the degree of these correlations was unclear. Burdett *et al.* (1983) determined that survival increased asymptotically and shoot extension increased linearly with RGP. They attributed most of the variation in first-year extension to variations in RGP. Standards have not been developed for RGP test results due to the lack of standardization in testing procedures and parameters measured (Johnson-Flanagan and Owens 1985). Bunting (1980) expressed the problem of determining minimum standards for any measured growth parameter as follows: "Each person responsible for tree planting is relating the size of stock he likes to his particular site, type of site prep, stock handling methods, type of planting (method) and his past success with planting stock which most likely ran the full range of sizes from too small to too large."

Minimum standards for measured seedling quality parameters have been developed by Armson and Carman (1961), Reese and Sadreika (1979), and Day (1980b).

SUMMARY

Nursery practices are continually being modified and improved. The literature is contradictory in some areas, and no attempt has been made to reconcile differences in research results. These existing contradictions indicate a need for additional work. For example, cause and seriousness of white spruce stunting is still not well documented, illustrating the need for further trials and studies. Based on current interest in production of white spruce in nurseries, research efforts will continue.

This paper complements Rauscher's (1984) review of growth and yield of white spruce in the Lake States, and helps to provide a complete digest of the available literature on white spruce silviculture.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 555-685/20100

Alm, A.A.; Vaughn, V.M.; Rauscher, H.M.
1991. **Bareroot nursery production and practices for white spruce: a literature review.** Gen. Tech. Rep. NC-142. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 25 p.

This summary of white spruce literature covers seed collection and treatment, nursery cultural practices, seedling growth patterns and measurements of seedling quality. It includes information relevant to bareroot white spruce but does not cover containerized seedlings. It is intended for forest land managers, researchers and bareroot forest nursery managers.

KEY WORDS: White spruce, forest tree nursery production, bareroot forest planting stock, forest nursery cultural practices, seedling growth, seedling quality.