VEGETATIVE PROPAGATION OF PINE AND SPRUCE: PROBLEMS AND SOLUTIONS

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Abstract: Propagation of pine and spruce by stem cuttings is not a common nursery practice. The problems associated with propagation by stem cuttings are discussed and methods to overcome the problems are suggested. Also emphasized is the need for a breeding program to be coupled with a clonal forestry program. A breeding program would insure the continued development of genetically superior individuals for operational use.

With few exceptions, e.g. prostrate junipers and *Taxus* cultivars, vegetative propagation of coniferous species and cultivars by stem cuttings is not commonly used. Spruce, hemlock and pine cultivars are propagated almost exclusively by grafting. Propagation by rooted cuttings would be more advantageous because it requires less skill than grafting and is relatively inexpensive.

Vegetative propagation is beneficial for several reasons. Most importantly, all of the genetic superiority of the ortet[1] is transferred to the ramet. Sexual propagation transfers only a portion of the ortet's genetic superiority to the progeny. Compared to seedling production, rooted cuttings can produce a larger plant in a shorter period of time (29,30). For instance, eastern white pine cuttings averaged 21 cm in height 13 months from propagation (cuttings stuck January 1979, rooted by June and measured July, 1980). They were equivalent in size to 3-0 or 2-1 seedlings. Another benefit of vegetative propagation is increased unformity. Even with these benefits, propagation of spruce and pine by rooted cuttings is uncommon. This paper discusses problems innate to pine and spruce propagation by stem cuttings and offers methods by which these problems can be overcome.

Physiological juvenility and maturity in conifers. Probably the greatest single reason for the infrequent use of stem cutting propagation is the inability of physiologically mature stem cuttings to form adventitious roots (3,14). The transition from the easy-to-root juvenile phase to the difficult-to-root mature phase occurs from 4 to 12 years of age (2,5,11,13,15,23,24). Often the genetic worth of an individual cannot be assessed

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[1] The progenator of a vegetatively propagated clone is called the **ortet** (33). A **ramet** is an individual member of a clone.

before this transition. In the absence of juvenile-mature correlations, the forester's rule of thumb is that selection or assessment of genetic worth cannot be made before one-half rotation age. For instance, selection would have to be delayed until year 30 for eastern white pine grown for saw timber. Schemes to maintain juvenility until genetic worth can be assessed have been developed and are in operation (12). However, costly long term planting is required and generally beyond the resources of individual nurserymen.

Vegetative propagation of conifers for Christmas tree use has great potential. The short rotation time, about 10 years in Ohio (4), allows early assessment of genetic worth while the select tree is physiologically juvenile. High crop value and short rotation time justify the increased costs and risks associated with vegetative propagation.

How much gain can one expect? Gains of 50% can be realized by selecting the correct Scotch pine source (33). An additional 25 to 50% gain could be expected if the best phenotypes within the best provenances are vegetatively propagated. This amount of gain would make propagation via stem cuttings economically feasible.

Yearly-variation in clonal rooting response. However, even within the physiologically juvenile phase, great year-to-year variation exists in the rooting response (23,22,25,26,28). Ortet rooting response is independent of year. For instance, some eastern white pine ortets rooted well in years when average rooting response was poor, while other ortets rooted poorly in years when average rooting response was good (23).

In general, exposure to chilling temperatures has promoted rooting of north temperature conifer stem cuttings (10,15,19,25,28,32). The effect of pre- or post-severance chilling on rooting response depends on chilling temperature and duration (10,15,32) and whether it is administered at constant or fluctuating temperatures (28). Too little chilling as well as too much chilling will reduce rooting response.

To predict the time of cutting collection in which rooting is maximized and to reduce the yearly variation in rooting response, a chill unit accumulation model was developed for eastern white pine grown in North Carolina (28). The chill unit accumulation model accounted for 58% of the variation in rooting response. Alternatively, if calendar date was used to predict time of cutting collection, only 47% of the variation in rooting response could be accounted for. The model predicted optimum rooting after 1000 hours of chilling, (about mid-January in Raleigh). Cumulative chill units, rather than calendar date would be expected to be a more accurate predictor of rooting response as it measures a physiological condition.

Differences in yearly environmental conditions would affect the number of chill units accumulated on a given date, causing yearly variation in the rooting resonse. At Raleigh, the number of chill units accumulated by January 15 in the years 1977-1980 varied from 906 to 1176, about a 25% difference. Thus, the year-to-year variation in rooting response can be reduced by basing time of cutting collection on physiological condition (which can be predicted by cumulative chill units) rather than calendar date. The model needs refinement and its reliability determined by testing with different species in different geographical areas.

Root system quality. There are three measures of root system quality; number of roots per cutting, spacial relationship among roots (root symmetry) and development of tap or sinker roots.

For research purposes, a cutting is usually considered rooted if there is one root per cutting greater than one mm in length (19,29). However, for operational use, one short root per cutting is probably inadequate.

Observations of eastern white pine stem cutting root systems indicate that the number of major roots a cutting has is determined within a year from first root initiation (29). Similar fixing of the number of lateral roots within the first year has been found for seedlings (18). Further, within this same period, one root tends to dominate, having a larger diameter and length, and a greater number of secondary and tertiary roots (Fig. 1). It could be that long term performance is more closely

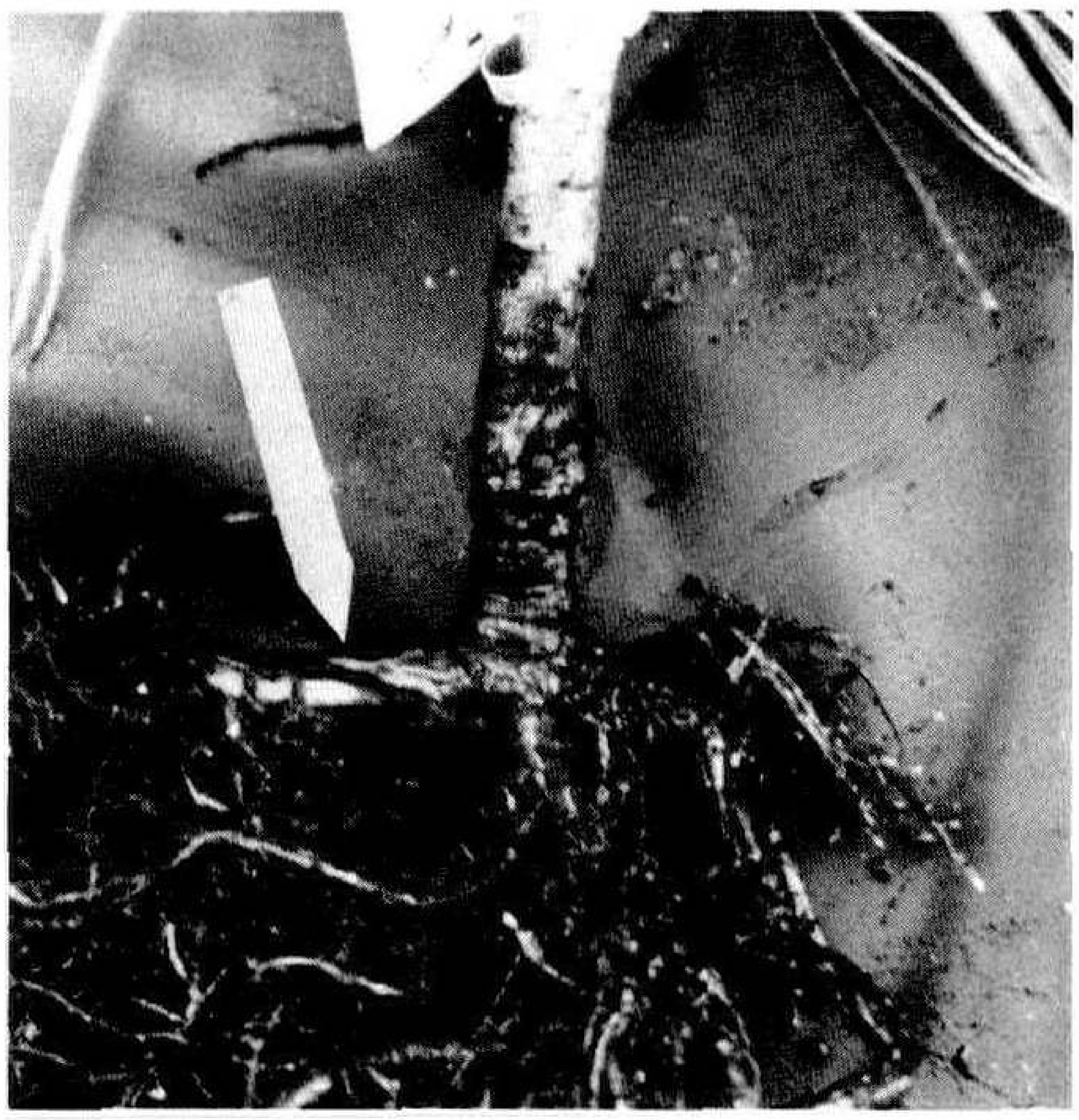

Figure 1. Root system of a 14 month old Eastern white pine rooted cutting. Within the first year one root will become dominant (see arrow), having a larger diameter and greater length than other roots.

related with the vigor of this dominant root than with the total number of roots originally initiated. The important point is that the number of major roots a pine cutting has when it leaves the propagation bench will not increase after field planting.

Often, rooted cuttings have asymmetrical root systems. Commonly, roots are initiated on only one side of a cutting, resulting in planting stock with one-sided root systems. Asymmetrical root systems are undesirable for several reasons (8,16,18): they offer less stability to the planting stock; they increase susceptibility to wind throw; they promote compression wood formation; and, if the rooted cuttings are to be dug after lining out in transplant beds, a large proportion of the root system would be lost in the digging operation. Root system symmetry does affect shoot growth. Of all the root system characteristics studied, root system symmetry was found to account for the greatest proportion of variance in shoot growth (16).

Another problem with stem cutting root systems in this case is that adventitiously initiated roots tend to grow horizontally, just below the soil surface (Fig. 2 and Ref. 22). The shallow root systems of rooted cuttings offer less stability than seedling taproots. Adventitiously initiated roots sometimes turn downward only when deflected by a barrier.

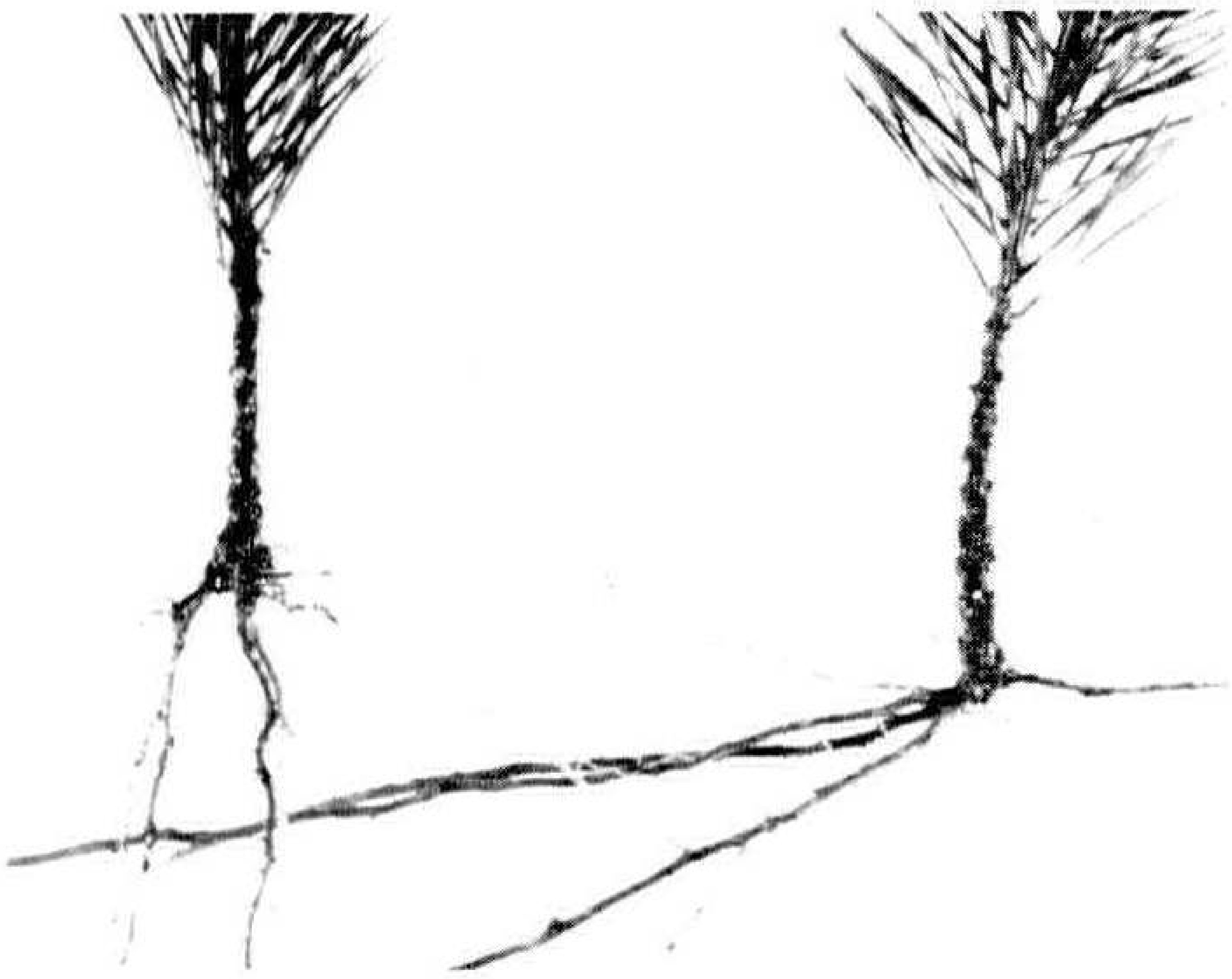

Figure 2. Rooted Scotch pine cuttings. The cutting on the left was rooted in a 4 cm diameter cylinder (a RL Super Cell). The cutting on the right was rooted in a flat. Adventitiously initiated roots tend to grow horizontally, unless deflected downard by a barrier.

The problems of lack of geotrophic response, asymmetrical root systems and few numbers of roots per cutting of vegetatively propagated pines and spruces can be solved by rooting cuttings in containers such as RL-Super Cell[1] or Spencer-Lamaire Books[2], rather than in flats. When the elongating root strikes the container wall it is deflected downward. Because of the small diameter of these containers, the root travels only a short distance before striking the container wall, resulting in a minor root defect. Even if only one root per cutting is initiated, that root appears similar to a tap root (Figure 3 left). It is anticipated that, in addition to looking like a taproot, the adventitious root will also function as a taproot, initiating many laterally growing mother (1,31) or pioneer roots (21). Unfortunately, this may not be the case (17). One year old tissue-cultured loblolly pine plantlets, rooted in RL-Super Cells, had a less fibrous root system, with little secondary root development near the medium surface, compared with seedling root systems. The plantlets' smaller size, compared to the seedlings, was attributed in part to inferior root system development.

Figure 3. (left). A Scotch pine cutting rooted in a 4 cm diameter cylinder (R L Super Cell). It is anticipated that the long root will function as a tap or mother root, giving rise to numerous, vigorous, laterally growing roots.

(right). Coiled root system of a 2-year-old tissue cultured loblolly pine. This coiled root resulted from rooting the plantlet in a smooth-walled test tube. (Photo courtesy of Steve McKeand, Tree Improvement Specialist, Department of Forestry Resources, North Carolina State University, Raleigh).

The rooting container must have ridges on the internal walls to prevent development of circular roots. Figure 3, right,

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[1] Ray Leach Container Nursery, 1500 North Maple Street, Canby, Oregon 97013.

[2] Spencer-Lamaire Industries, Ltd., Edmonton, Alberta, Canada T5K 1N1.

shows a circular root on a two-year-old loblolly pine tissue-cultured plantlet which was rooted in a smooth-walled test tube. This plant lacked stability, being blown about in moderate winds (Personal communication, Steve McKeand, Tree Improvement Specialist, Department of Forestry, North Carolina State University, Raleigh).

Whether or not the number of roots per cutting, root system symmetry, and lack of tap or sinker root development in adventitiously initiated root systems, affects growth can only be determined by field planting rooted cuttings.

The oldest eastern white pine study comparing performance of rooted cuttings with seedlings was field-planted in 1945 (22). The four planting sites each used a checker-board design, alternating seedling plots with rooted cutting plots. Unfortunately, rooted cutting clonal identity was not retained. The study was last measured in 1954. At that time survival was 83% (531 of 640) for the rooted cuttings and 89% (519 of 584) for the seedlings. There were no differences in height growth or diameter at breast height.

Two plantations, Wood County and Dane County, were remeasured in 1982 (Table 1). Survival at both locations was higher for rooted cuttings than seedlings. At the Wood County location, cuttings were taller and had greater diameter at breast height (DBH). The reverse was true at the Dane County location. If equal numbers of cuttings and seedlings are compared at the Dane County location (by deleting the smallest sized cuttings from the analysis) rooted cuttings have similar height and DBH as seedlings. A more detailed analysis, includ-

Table 1. Survival, height and diameter at breast height (DBH) of eastern white pine rooted cuttings and seedlings after 37 years[1].

Origin	Plantation Location	Percent Survival[2]	Height	DBH
seedling	Dane Co., Wisconsin	45	15.8 m.	25.9 cm.
cutting		64	13.9 (15.6)[3]	22.7 (27.7)[3]
seedling	Wood Co., Wisconsin	40	14.5	20.8
cutting		57	15.6 (17.3)[3]	22.2 (23.9)[3]

[1] Plantations were established with 2-2 seedlings and two-year-old cuttings in 1945 by Drs. R.F. Patton and A.J. Riker, Department of Pathology, University of Wisconsin, Madison.

[2] Seventy-five seedlings and rooted cuttings (150 total) were planted at the Dane Co. site, 89 seedlings and rooted cuttings (178 total) were planted at the Wood Co. site.

[3] The bracketed values were calculated for equal numbers of rooted cuttings and seedlings, eliminating the smallest rooted cuttings from the analysis.

ing wood specific gravity, will be forthcoming. On the basis of these data, rooted cuttings perform as well as seedlings. These are similar to results obtained for rooted cuttings of *Pinus radiata* (6).

Because clonal identity was not noted, the Patton and Riker study (22) could not answer such questions as: "How many roots per cutting are enough?"; "Is shoot growth affected by an asymmetrical root system?"; "How great is the within-clone variation in shoot growth?"; and "How much within-clone variation in shoot growth can be attributed to differences in root system morphology?".

In March, 1981, an eastern white pine rooted cutting-seedling study was field planted in Virginia to help answer these questions. For all ramets within a clone, the number of roots per cutting and the site of adventitious root initiation was noted prior to planting for each of the 168 rooted cuttings. Each one-year-old rooted cutting was paired with a 2-0 seedling. Two year growth data will be reported in 1983. The study is a cooperative effort between Ohio State University and two North Carolina State University Tree Improvement Cooperative members (Department of Forestry Resources, North Carolina State University and Virginia Department of Forestry).

Increasing rooting response. If rooting response of physiologically mature ortets can be increased, then clonal forestry for long rotation coniferous crops, such as saw timber, would be possible. To date, no means of increasing rooting response of physiologically mature conifers has been developed (20). Therefore, ortets need to be hedged to retain the juvenile, easy-to-root condition, until genetic worth can be assessed (12,14). However, only "good rooters" (ortets with high rooting response) can be used for clonal forestry. Thus, many otherwise superior ortets are eliminated.

Further, if rooting response of initially poor rooting, physiologically juvenile ortets could be increased, then the rapid narrowing of the genetic base associated with clonal forestry would be slowed. Too narrow a genetic base is disastrous in any breeding program. As planting stock becomes increasingly genetically homogenous, the susceptability to disease, insect and environmental factors is increased.

The genetic base in any breeding program narrows with each generation's breeding. Commonly, only the best 10% of each generation is used as the breeding population in the next generation. Therefore, if a breeding program begins with 1000 families or individuals and only the best 10% within each generation are retained for the next generation's breeding population, the breeding program would be terminated after four generations; there would be no unrelated individuals to mate and little genetic variability to exploit.

This rapid narrowing of the genetic base would be accelerated if high rooting potential was included as an additional selection criteria. If 10% of the 1000 member base population had high rooting potential (not an unreasonable assumption) then the breeding program would be terminated in three generations.[1]

Serial propagation. A method is needed whereby rooting response of initially poor rooting ortets can be increased. Serial propagation, where cuttings are taken only from rooted ramets, might be such a method (27). If serial propagation increases rooting response, then initially poor rooting, but otherwise superior ortets, need not be excluded from the breeding program.

The possibility of increasing rooting response through serial propagation has been under study for 18 months at The Ohio State University. One hundred one-year-old *Picea pungens* seedlings were received from Evergreen Nursery, Sturgeon Bay, Wisconsin, in April, 1981. Twelve ortets were selected for superior blue needle color and placed under a 20 hour photoperiod in a heated greenhouse. The extended photoperiod induced multiple growth flushes. Terminal and lateral shoots of each flush were used to make softwood cuttings. The cuttings were treated with Hormodin #3 (8000 ppm indolebutyric acid — talc powder) and placed under intermittent mist. A 1:1 peat:perlite rooting medium was used. Rooting was evaluated 8 weeks after sticking.

For clones 10, 20, 40, 41, 46 and 55, rooting response was clearly increased with each propagation series (Table 2). For clones 27, 44 and 53, no definite pattern was evident. In these clones the decrease in rooting response for a particular propagation series was due to high cutting mortality. The cuttings, when collected, were too soft and decayed within a month after sticking. If rooting percentages for these ortets are calculated excluding decayed cuttings, then rooting response increases with each propagation series (see footnote 2 in Table 2). Serial propagation did not increase rooting response in clone 8, whereas in clone 25 rooting response decreased.

The results are preliminary and therefore need to be interpreted with caution. First, only 12 ortets were studied. Second, limited numbers of cuttings within each propagation series have been stuck. Third, rooting response was confounded with different rooting environments, and fourth — rooting response

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[1] Assuming that crossing individuals with high rooting potential results exclusively in progeny with high rooting potential. If this is not the case, then the genetic base would be narrowed even more rapidly.

was increased in physiologically juvenile stock. As mentioned previously, attempts to increase rooting response in physiologically mature ortets has not been successful. However, if the preliminary results are confirmed in additional studies then high initial rooting response need not be a selection criteria in a breeding program for clonal forestry and rapid narrowing of the genetic base need not be innate to a breeding program for clonal forestry.

Table 2. The effect of serial propagation on rooting response of twelve *Picea pungens* 'Glauca' clones.

	Propagation Series		
	Number cuttings rooted/Number cuttings stuck		
Clone Number	Ortet	Ramet I[1]	Ramet II
8	2/15 (13%)	2/12 (17%)	—
10	7/21 (33%)	2/3 (66%)	—
16	1/10 (10%)	—	—
20	9/32 (28%)	40/80 (50%)	—
25	17/28 (60%)	14/45 (31%)	—
27	9/19 (47%)	11/20[2] (55%)	1/2[2] (50%)
40	10/23 (46%)	8/25[2] (32%)	2/3 (66%)
41	7/15 (46%)	3/5 (60%)	—
44	9/27 (33%)	55/62 (89%)	20/43[2] (41%)
46	8/18 (44%)	4/7 (57%)	—
53	8/10 (80%)	43/67[2] (64%)	1/1 (100%)
55	10/18 (56%)	34/39 (85%)	6/7 (86%)

[1] Ramet I in the propagation series refers to rooting response of cuttings collected from previous rooted cuttings; i.e., cuttings from cuttings. Similarly, Ramet II refers to rooting response of cuttings collected from rooted cuttings collected from rooted cuttings.

[2] In these cases, a large proportion of the cuttings were collected prematurely, when shoot growth was very soft. These softwood cuttings rotted in the mist bed. Losses due to rot in subsequent collections of semi-hardwood cuttings were negligible. The losses due to rot are as follows: Ortet 27, Ramet I-7, Ramet II-1; Ortet 40, Ramet I-5; Ortet 44, Ramet II-20; Ortet 53, Ramet I-12. If the number of rooted cuttings are excluded, the respective rooting percents are as follows: 85, 100, 40, 87 and 78%.

The mechanism by which serial propagation increased rooting response is unknown. Possibly, by collecting cuttings from rooted ramets, cuttings are selected in which the genetic information for adventitious root initiation is being transcribed and translated. Why, in these ramets the genetic information for adventitious root initiation is being transcribed and translated is unknown.

One additional benefit of serial propagation is the formation of morphological leaders. Repeated removal of terminal shoots for stem cuttings allows lateral shoots to develop orthotropic (upright) growth (7). These lateral shoots become morphological leaders which, if rooted, continue growing orthotropically.

Necessity for coupling a breeding program with clonal forestry. Asexual propagation transfers all of the genetic superiority of the ortet to the ramet, resulting in significant gains over sexual propagation. However, continued gains can only be realized when selections are made from a constantly improved genetic base. Without an improved genetic base from which to select, one is forced to look harder and harder in natural populations for superior individuals. A point will soon be reached where no great improvement can be made. Therefore, it is absolutely essential that a clonal forestry program be coupled with a breeding program. This is the only means of assuring the continued introduction of genetically superior selections. Also, a well designed breeding program can minimize and control inbreeding, thus reducing the risks associated with clonal forestry.

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