IMPROVING CONTAINERIZED REFORESTATION SYSTEMS 1/

William I. Stein 2/

Abstract.--A technical critique of containerized reforestation based primarily on papers presented at the North American Containerized Forest Tree Seedling Symposium held at Denver, Colorado, USA in August 1974. The critique outlines scope of the symposium, summarizes current status and reasons for container seedling use in North America, and discusses salient economic, engineering, and biological problems that should be solved to further development of containerized reforestation systems.

PROGRAM OVERVIEW

In their correspondence, organizers of the North American Forest Tree Seedling Symposium emphasized that containerized reforestation was a fast-moving and dramatic development in forestry. After benefiting from all the information presented, we surely must agree!

Certainly, the Symposium itself is evidence of dynamic events and widespread interest. This Symposium had its genesis among recommendations of an ad hoc task force which discussed the 'state of the art' and future possibilities of seedling production in controlled environments somewhat over 2 years ago. After some conditioning and dissemination, the idea found enthusiastic sponsors. Two planning meetings were held in the second half of 1973, followed by diligent committee work and the wholehearted cooperation of those in the forefront of container technology. A compressed, fact-filled Symposium has been the result of these singularly cooperative efforts.

Fact-filled has been a salient characteristic of the Symposium. In 2 1/2 days, including evenings, we have tried to absorb the philosophy, explanations, and facts contained in 43 summary-type papers and 33 volunteer papers on an array of container-related subjects. Let me assure you there is still more available! In the time allotted, speakers covered only the highlights of their subjects. In the Proceedings, their full papers provide more data and explanation worthy of your attention.

Container reforestation's potential role in forestry was highlighted by the challenging remarks made by the keynote speaker, Mr. Bingham. He spoke of the need to grow 2 cunits of wood where 1 grew before, the need to revise our national efforts to speed reforestation of current cuttings and rapidly reduce a huge backlog of nonstocked acres. Adequate reforestation effort looms as a large problem and the development of containers a great boost for its solution.

In a variety of excellent presentations that followed, the principles and concepts of container technology and the present status and outlook for containerization in most of North America were surveyed. Professor Hulten of Sweden and others provided insights into modern container use in distant parts of the world. This overlook was followed by half-day sessions on the biology and engineering applied in producing containerized seedlings in different regions of North America and for different purposes. We then heard about field

1/Paper presented at North American Containerized Forest Tree Seedling Symposium, Denver, Colorado, August 26-29, 1974.

2/ Principal Plant Ecologist, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Corvallis, Oregon.

performance of the seedlings produced, and gained some insight into costs involved in containerized reforestation systems. Volunteer papers added depth and detail to many of the technical summaries, and provided us with a stimulating description of unique reforestation problems and container applications.

A shift from the detailed look at facts, figures, tables, and slides to a wider view of containerized reforestation systems, their strengths and shortcomings, and their potential for helping meet reforestation goals is now in order.

CERTAINTIES OF TODAY

What are the certainties of today about containerized reforestation?

Growing and transporting trees in containers is really not a new and revolutionary idea. In fact, man has been doing this for a very long time. In a 1969 talk summarizing some early container trials in Oregon and Washington, Jim Dick of Weyerhaeuser Company alluded to an Egyptian mural dating back at least 4,500 years which depicted loading of containerized frankincense aboard ship (Dick 1970).

Containerized trees and woody ornamentals have been produced in modest quantities for years in the United States and Canada. Furthermore, the technical forestry literature contains hundreds of reports on the production of containerized stock for large-scale reforestation purposes in different parts of the world. During this program, there has been repeated reference to container experience elsewhere and to production in the hundreds of millions. Aside from the fact that we are participants, what makes recent container developments dramatic and noteworthy?

The most notable change I see is one of outlook. No longer are the reforestation methods of yesteryear good enough in North America. There is willingness and incentive to break out of the weather and seasonal constraints which provided the traditional sideboards to the use of bare-root stock. In a broad sense, we are witnessing a continuing trend--from reliance on natural regeneration, to nursery stock, to speedy aerial seeding, and now to further compression of the regeneration establishment period by means of containerized seedlings. Furthermore, the increasing need for prompt and more certain reforestation is now manifest by a willingness to commit substantial manpower and large investments to perfect advanced reforestation practices.

Container Stock Production

Let's take a quick look at relative production of containerized and bare-root nursery stock. The report on planting and seeding in the United States (USDA Forest Service 1973) shows that 963,105,000 trees were produced for forest and windbarrier purposes during fiscal year 1973. A rough tally of the production totals provided by speakers from different parts of the United States indicates that at least 26 million or roughly 3 percent of the total trees produced were containerized. Only in the Pacific Northwest did container production represent a sizeable percentage of total production, 22 million containerized, 159 million bare-root seedlings, or 12 percent (Ter Bush 1974). In that region, an estimated 42 million containerized seedlings will be produced in 1974, and installed container capacity is nearly one-fourth that of bare-root nurseries, 47 vs. 206 million.

In several provinces of Canada, container production represents an important part of total tree production:

	Containerized	Bare-root	Percent of total
	-- Millions of seedlings --		
Alberta	7.5	2.5	75
British Columbia	17	83	17
Ontario	8	80	9

Containerized seedling production totaled about 34 million in the provinces for which it was reported.

Containers are removed before planting from much of the stock grown in regions of high production. Obviously, containerized production must be considered fully operational when seedlings are grown by the millions and installed capacity is rapidly expanding.

Pros and Cons

Why have containerized seedlings drawn so much attention and their production expanded so rapidly? Nearly 40 objectives and reasons or variations of reasons have been mentioned by speakers during this Symposium, and I wouldn't be surprised to learn of several more! It is important to examine the objectives and reasons for use of containerized seedlings, for their potential and limitations need to be Judged in the context of reforestation problems that must be solved.

I've combined stated objectives and reasons a bit and will briefly cover six prominent ones.

1. To meet accelerated reforestation challenges.

   a. More stringent State Forest Practice laws and new forestry incentive programs have raised the demand for seedlings.

   b. Changing management goals have also raised demand--more acres to be reforested and reforestation is more intensive.

   c. Container seedlings are filling the void created by diminishing use of direct seeding.

   d. Nursery sites are expensive, scarce, and take much time to develop; container production requires less space and site is not so critical.

   e. Containerized production is a rapid, flexible means to meet increased demand for seedlings.

   f. Seedling production is easy to contract in commercial greenhouses.

   The time needed to produce plantable seedlings is shorter.

   h. Containerization provides one more important tool for use in meeting reforestation goals.

2. To improve survival and growth of seedlings.

   This objective is a broad umbrella. Achieving better survival and growth is the universal hope of everyone in reforestation. The desire to improve stimulates container work in regions where current success with bare-root stock tops 90 percent almost as much as in regions where bare-root results are marginal at best.

3. To produce species slow or difficult to grow in bare-root nurseries, or difficult to keep in good condition during handling, transporting, or outplanting.

   Every geographic region has one or more such species--western hemlock on the West Coast, true firs and spruces in several regions, eucalyptus in California, Florida and Hawaii, oaks in the Ozarks and South. Container production holds promise too, for all species that must be produced in the short growing seasons of high elevations or northern latitudes.

4. To extend the planting season in several respects.

   a. Make well-conditioned stock available at times it is often not available now from bare-root nurseries--western hemlock for midwinter planting on the West Coast; true firs, spruces, and other species for high elevations in late spring or early fall.

   b. Use protected stock to extend the planting season further into the growing season - in Alberta, British Columbia, and in the South.

   c. Stretch the usual season to permit planting with a smaller and more stable work force.

5. To achieve greater production and planting efficiencies; this objective has many facets.

   a. Use seed effectively, particularly genetically improved seed.

   b. Regulate application of fertilizers and fungicides more readily.

   c. Produce more uniform stock.

   d. Move crop easily when adversities arise or for other reasons.

   e. Mechanize more and thus reduce labor, both in production and planting.

   f. Make planting more attractive.

   g. Speed planting to reduce total time required.

   h. Improve quality of planting.

   i. Facilitate planting in rocky ground or among residues.

   j. Keep seedlings in good condition more easily if there are delays in planting. Anyone who has experienced unexpected snow or frozen ground with hundreds of thousands of lifted bare-root seedlings on hand truly appreciates the holding problem.

6. To keep 100 percent of the root system!

   This is the key biological basis for

use of containerized seedlings--a promising, reasonably economic means of getting the highest quality, fastest growing tree possible established on every reforestation site. In theory at least, the use of containerized seedlings avoids the setbacks bare-root nursery stock now sustains by losing part of its root system during lifting, by loss of vitality during protracted storage, by further loss of roots through dessication, and by other mistreatments it receives during handling, transport and planting. The containerized seedling goes to the field intact with an undisturbed or little-disturbed root system surrounded by its individual protective shield. Added to the biological benefits of packaging are some mechanical advantages in handling and planting a uniformly shaped, compact product. These theoretical advantages of containerized stock are clearly evident; the challenge is to get them in actual practice.

Disadvantages that may counterbalance or override the theoretical or realized advantages of containerized seedlings should also be recognized. Among these we might single out:

1. A better tree may cost more to produce--the benefits of shorter and more mechanized production, faster planting, and better results may not always offset the increased costs.

2. Successful container seedling production requires a higher level of technical knowledge and more demanding day-to-day attention than required for production of bare-root nursery stock. Seedlings are growing in a very limited amount of rooting medium which is much more subject to sudden changes than are the soil systems in nurseries. Conditions that accelerate tree growth also accelerate the incidence and effects of diseases, nutritional imbalances, and other ailments.

3. It now appears containerized seedlings will sometimes have to be overwintered or held in cold storage just like bare-root stock. When this must be done, the advantages of container stock may be diminished substantially.

4. Where performance of bare-root nursery stock is very adequate, any improvements gained from containerized seedlings may not be large enough to be worth the developmental effort required.

Known Facts

Now that we have scrutinized the apparent advantages and disadvantages of containerized seedlings, let's touch on some certainties about their production and use. I shall make only four or five observations about the detailed information now available.

Collectively, you have demonstrated ability to grow containerized seedlings in a variety of ways. The production totals and the procedures described by various speakers provide ample evidence on this capability. Techniques employed to raise containerized seedlings range from highly developed ones, the products of lengthy research and development programs, to those that represent but the first step in gaining perspective on seedling requirements and production mechanics. Notably, optimism is universal among practitioners that they can improve on present techniques. The principles involved and pitfalls to avoid in production of containerized seedlings are now well known. There is no longer a valid excuse for practicing brinkmanship with the biology of the seedling, though the tendency to do so for engineering or economic objectives or for simple expediency will continue to be with us.

As Dr. Larson pointed out so clearly, we do not know the upper limits of growth for a single species we are growing (Larson 1974). And I would predict that, in most instances, we will not be approaching the limit in the near future. I was struck, as you were perhaps, by the relatively small size of trees produced over many months under some greenhouse schedules. You may have noted also, that sizes for the same species varied substantially in different production facilities. Such differences can undoubtedly be rectified by easily determined changes in techniques. Though important, such size adjustments are really minor. More mind-stretching and important is the knowledge that a tremendous reservoir of growth potential is there to be harnessed and turned to our advantage. For example, containerized Douglas-firs now being produced range from 4 to 9 inches (9 to 23 cm) in average height (Van Eerden 1974, Owston 1974). Some grown in large containers and pushed at the Ed Wood Nursery, near Aurora, Oregon, reach 3 feet (91 cm) in 14 months. In two full seasons, seedlings up to 8 feet (244 cm) tall have been grown in a greenhouse at Corvallis, Oregon (Copes et al. 1969). Mind you, this height was attained without any manmade genetic improvements. I'm not suggesting that such tall seedlings should be a realistic goal, but they do illustrate, dramatically, the inherent growth potential available for manipulation.

It is almost trite to mention that we know production techniques affect later seedling field performance. Every nurseryman and reforestation specialist realizes there is a relationship. Yet there is need to comment. In my experience, it has proved difficult to adequately evaluate the field performance of bare-root nursery stock. By the time field results were in, nursery techniques had either been subtly bent or drastically changed, so the field evaluation no longer applied to stock currently being produced. With shortened time schedules and fast-changing techniques, it will be even more difficult to get relevant results on field performance of containerized stock. I cannot overemphasize that the effects on field performance must be carefully considered for every proposed change in production technique. We need to avoid the failing so common to production of bare-root nursery stock--that major changes in production, handling, or storage are never evaluated sufficiently for their effects on field performance. We cannot formally test the effects of every change, but benchmark trials are sorely needed to indicate likely consequences.

It is evident that coordinated production and performance information should be developed for individual species. Numerous factors are involved and the possible test combinations overwhelming for each of the 50 or more species that might be produced in containers. Thus, there should be ample incentive to screen, narrow, and standardize at every opportunity, so that proven production techniques and related seedling performance data will be as broadly applicable as possible.

Satisfactory field performance has been reported for containerized seedlings produced by a variety of systems. Universally, the larger the seedling, the better its field performance. The preliminary results certainly warrant the continued development of containerization.

In judging field performance, we should recognize that containerized seedlings are being used to reach reforestation objectives by dissimilar routes. There are those who seek to extend the planting season, gain flexibility, and reduce costs by use of small containerized seedlings. These purposes can be achieved reasonably satisfactorily by raising seedlings on short production schedules using substantial, but low cost mechanization. There are others who seek to produce a containerized seedling which will equal or better the size and performance of bare-root stock. Such seedlings may cost more than bare-root stock, but the gains in field performance, speed of reforestation, and management flexibility are expected to make the efforts worthwhile. Presently, growth comparisons of containerized and bare-root seedling performance are not sufficient for soundly evaluating our progress along either of these routes.

Quite a few more comments could be made about what we know, but let's spend the rest of the time on what we need to know and the job ahead.

SALIENT NEEDS

Repeatedly, speakers have pointed out the need for more biological, engineering, and economic information. Typically, as we intensify efforts, we need to know more about every aspect of containerized reforestation. Yet, we can't study everything at once. Thus, we must concentrate efforts on those key problems which must be solved to insure continual progress.

If we really knew as much as we ought to about the basic biology of tree seedlings, we could provide the specifications needed by engineers for equipment design and the performance data needed by economists for cost analyses. For genuine progress, I believe one key input is needed from economists, one from engineers, and half dozen or more from tree physiologists and foresters.

Economic

I ask economists--what is prompt reforestation worth today? Tomorrow? How are we to judge the true meaning of seedling production or planting costs revealed by your computer analyses? Are those costs excessive or entirely reasonable in terms of the financial and social values inherent in forestry?

Least cost has been a continuing goal and constraint in producing and planting both bare-root and containerized seedlings. A least-cost effort may put small, live trees on the ground, but is that sufficient? There are those who argue that least-cost efforts are short-sighted. What is it worth to reduce the stand rotation by 1, 2, 3, or more years? One large industrial company has stated their reforestation goal is to have a 4-foot-high seedling by the end of the third year. They will use the size of container seedling required to reach this biologically attainable goal. From an economic and social viewpoint, where should such instant reforestation be our goal?

There are many things foresters can do to grow bigger bare-root or containerized seedlings and speed their field growth by departing a bit from the constraints of least cost. In recent years, economic concepts not based on reforesting a single piece of bare ground have been recognized and discussed (Briegleb 1964; Flora 1970, 1971; Zivnuska 1964). But economists must do much more to realistically define the economic limits within which foresters and engineers should strive to develop adequate reforestation systems.

Engineering

I challenge engineers to perfect the ideal container! That container should be adequately supportive of seedling biological requirements, have all the characteristics necessary for full automation of production and field planting, and cease its containing function moments after the seedling is in the ground. In the several plug systems used today, the container primarily helps speed nursery production. It also shapes seedlings for field planting, but doesn't facilitate that final labor-saving step, automatic planting. The prime containerization concept of delivering an intact, undisturbed tree to the planting site is violated because we don't have a good mechanical removal system in the field or a long-enduring, yet quickly biodegradable container.

Let me emphasize that container degradation over weeks or months is not enough. In most planting situations, transpiration starts as soon as seedlings are in the ground. The moisture brought to the field in the container will last for only a short time, so roots must establish contact with soil as quickly as possible. And, for speedy growth, many roots need to make contact with surrounding soil, not just the few that egress from a limited number of openings in the container.

Biological

I confront biologists with the greatest challenge. Prescribe environmental conditions and optimum schedules for growing containerized seedlings of desired size and other proven field performance characteristics. Develop such information for about 50 individual species and subspecies, applicable to the important geographic provinces where each is to be planted. We can choose to produce containerized seedlings and muddle along with the same paucity of information about seedling response as done with bare-root production, but the slipups are likely to be more often and severe, and seedling performance will be less than potentially possible through containerization.

Much needed information about seedling biology will be developed piecemeal as seedlings are produced. But there are key areas which require intensive fundamental investigation. I shall comment on a few.

Seed

High quality seed is needed for efficient production of containerized seedlings. Seed quality also has substantial influence on subsequent seedling growth. There are many facets of seed quality, storage, pretreatment, and use that could be improved to insure the best possible start for containerized seedlings.

Seedling Nutrition

I'm confused, as are many others, by the diversity of fertilization schedules reported for growing and conditioning seedlings. Perhaps you noticed the rather divergent prescriptions used to harden Douglas-fir (Van Eerden 1974, Timmis 1974). Guidelines for desirable nutrient levels in foliage are skimpy or nonexistent for most species. Certainly, the nutrition levels required at different stages of a seedling's growth and the desirable balance among elements need substantial study.

Seedling Morphology

Time and time again, I have read or heard mention of top-root ratio and the need for a balanced seedling. Really now, what is a balanced seedling?

Our knowledge about the significance of top-root ratio and other morphological attributes of seedlings is skimpy indeed. Every nurseryman will readily show you seedlings which have a good top-root ratio. But, how many of you have seen quantitative data which relate various top-root ratios to actual field performance under specific conditions? I would submit that we hardly know what the term means or how to measure it. In fact, we might start by using the term consistently--should it be root-shoot or shoot-root ratio?

It takes a functioning top to grow roots and functioning roots to sustain a working top. Which parameter of seedling size should we really be looking at for balance--length, fresh weigh or dry weight of top and root; photosynthetic area vs. root absorbing surface, or what? In length, the shoot-root ratio of natural 1-year--old seedlings I have measured was generally about 1 or 2 to 10 and varied by species (Stein 1963). In dry weight, the shoot-root ratio was between 0.9 and 1.6 to 1 and again varied by species. I believe shoot-root ratio is important for both containerized and bare-root seedlings, and we need to be able to prescribe with certainty what height, shoot-root ratio, stockiness, sidebranching, etc., are needed for specific reforestation conditions.

Seedling Physiological Condition

Insuring that seedlings are in the proper physiological condition is another vague admonition we often hear. What does this mean, and how do we recognize it? Physiological condition has been expressed in terms of root regeneration potential, frost-hardiness, setting of buds, food reserves, electrical conductivity, mycorrhizal formation, and other attributes. These all indicate something about the state the seedling is in, but what level of which attribute bears a direct and well establised relationship to field performance? We had better calibrate one or two of these indicators sufficiently to put them to intelligent use.

Root Configuration

The roots of seedlings that establish naturally differ somewhat in their configuration from those of planted seedlings. Millions of acres of fast-growing plantations bear testimony that the levels of root deformity sustained in wanting bare-root trees must generally not be too serious. However, the survival problems of bare-root stock following incorrect planting that causes "J" roots, and the occasional toppling of older plantations because of insufficient root support are also well-known. Massive crowding of roots in the container and the known occurrence of pot binding should be sufficient warning that we need to check root development of containerized stock in the field. Preliminary evidence seems reassuring, but root deformity problems severe enough to reduce growth may first become evident long after containerized reforestation programs are in high gear.

The effect of planting technique on subsequent seedling survival and growth is another under-evaluated aspect of containerized and bare-root reforestation.

CONCLUSION

I am firmly convinced that containerized reforestation is here to stay. There are a lot of growing pains ahead in developing the basic biological knowledge, refining systems and techniques, and defining the limits of use for containerized seedlings. I believe we will see substantial development of techniques intermediate between nursery and greenhouse production--covered nursery beds, seedlings started indoors in containers and then grown or hardened outdoors, and so forth.

Ironically, more intensive and sustained work is being done today in seedling physiology to further container production than was over allotted to bare-root stock. How good might bare-root stock performance be now if we had applied the same level of nutrient monitoring, water regulation, dormancy control, and protection to bare-root seedlings? Fortunately, the basic information developed for containerized seedlings will also be applicable to bare-root nursery stock. We can anticipate that a very vigorously growing container tail will soon be wagging the whole tree production dog.

LITERATURE CITATIONS

Briegleb, Philip A.
1964. Is economic analysis alone the appropriate yardstick for reforestation? West. For. Conserv. Assoc. West. Refor. Coord. Comm. Proc. 1963: 1-2.

Copes, Donald, Frank Sorensen, and Roy Silen
1969. Douglas-fir seedling grows 8 feet tall in two seasons. J. For. 67: 174-175, illus.

Dick, James.
1970. Container planting in Oregon and Washington. West. For. Conserv. Assoc. West. Refor. Coord. Comm. Proc. 1969: 41-43.

Flora, Donald F.
1970. Economics and policy environments for forest regeneration. p. 62-63. In Regeneration of Ponderosa Pine Symp. Proc. 1969. R. K. Hermann, ed.

1971. Is reforestation economically possible? West. For. Conserv. Assoc. West. Refor. Coord. Comm. Proc. 1970: 42-44.

Larson, Philip R.
1974. The upper limit of seedling growth. p. 62-76. In North Am. Containerized For. Tree Seedling Symp. Proc. Great Plains Agric. Counc. Publ. 68.

Owston, Peyton W.
1974. Two-crop production of western conifers. p. 104-111, illus. In North Am. Containerized For. Tree Seedling Symp. Proc. Great Plains Agric. Counc. Publ. 68.

Stein, William I.
1963. Comparative juvenile growth of five western conifers. Ph.D. thesis, Yale Univ., 194 p., illus.

Ter Bush, Frank A.
1974. Seedling production and capacity. In USDA For. Serv. Pac. Northwest Reg. Refor. Notes 23, p. 1-5.

Timmis, Roger.
1974. Effect of nutrient stress on growth, but set and hardiness in Douglas-fir seedlings. p. 187-193, illus. In North Am. Containerized For. Tree Seedling Symp. Proc. Great Plains Agric. Count. Publ. 68.

USDA Forest Service.
1973. Report of forest and windbarrier planting and seeding in the United States (July 1, 1972 - June 30, 1973). 13 p.

Van Eerden, E.
1974. Growing season production of western conifers. p. 93-103, illus. In North Am. Containerized For. Tree Seedling Symp. Proc. Great Plains kgric. Counc. Publ. 68.

Zivnuska, John A.
1964. What is the impact of taxation on reforestation? West. For. Conserv. Assoc. West. Refor. Coord. Comm. Proc. 1963: 5-7.