PRINCIPLES AND CONCEPTS IN CONTAINER PLANTING 1/

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Abstract.--Principles governing the acceptability of conventional and innovative artificial forestation techniques are discussed. Containerized seedling systems, like direct seeding and bare-root planting, are attempts to stock lands according to goal prescriptions at minimum overall cost. Useful principles of container methods are those that have a demonstrated, or potential capability of balancing adequate biological field performance against acceptable production costs. Container concepts are cited to illustrate guiding bio-economic principles.

SCOPE DEFINED

What I have to say today is not new; all has been said before in one way or another. But I do hope to re-emphasize a few important principles and to remove some of the trivia and the aura of mystery that surrounds containerization at present. Let me put some boundaries around the discussion. We must assume that foresters have already decided that it is important to revegetate lands with certain species, within certain time limits, and at specified levels of stocking and spacing. Furthermore, let us assume that the purpose of revegetation is to establish forests for wood production and that the site has been prepared for the trees. Containerized seedlings, or for that matter any other kind of forestation method, cannot overcome the problems created by land that is overgrown with competing vegetation, is poorly drained, unstable, or is nutritionally impoverished. All too often we hear foresters declare that container seedlings by some miracle will solve problem situations where all else has failed. What nonsense! Look first to the site, then decide how best to restock it.

I do not intend to give a lengthy review of container concepts and methods; these will be covered adequately later by many other speakers and have already been reported competently by several people in recent years. When I refer to a specific container planting method it is for the purpose of illustrating a principle that is either important or nonconsequential. Containers are only an aid to the planting of seedlings. Container techniques are no more than the extension of the principles governing bare-root and direct seeding forestation methods. With this in mind, let us try to identify the key factors that control the success and applicability of conventional and innovative forestation systems.

BASIC FORESTATION PRINCIPLES

The only valid reason for manipulating plants beyond the seed stage is to increase the probability of establishing a forest within a specified time and at a stocking level and spacing prescribed by the crop desired. Manipulating plants through nursery, transport, and planting phases incurs costs. Ideally, probability of establishment should be maximized and cost of establishment minimized. These two values are universally and incontrovertibly linked, except when society imposes a secondary objective such as a "make work" program. Therefore, every forestation method must be judged on its capability of reaching a satisfactory compromise between biological success and costs. Costs can be readily quantified and forecast. Probability of success is a much more elusive value, and where new methods are introduced, years or even decades of field experience are required to establish success probabilities. All forestation systems must balance the bio-economic equation. None of the alternatives is satisfactory if viability and vigor of the plant is subserviated to economic and mechanical considerations of transport and distribution.

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By contrast, any system will not survive if the biological requirements cannot be melded with the realities imposed by principles of efficient mass production and transport. Funds available for artificial forestation are not unlimited. In their enthusiasm for the controls that containerization promises, biologists sometimes appear to have overlooked this fact. By contrast, engineers or inventors of one sort or another often forget that we hope to take back to the forests a living organism, not simply a container. Minimal cost at any crop survival rate is just as senseless as biological success at any price. Compromise is the key word.

A fact of forestation frequently overlooked is that, like logging, it is basically a problem of mass transit only in the reverse direction. Unlike logging, reforestation has the additional problem of maintaining viability of the tree while in transit; the load is lighter, but the delicate product is more sensitive to mishandling. Overshadowing the whole process is the simple fact that costs cannot be gauged against a short-term return on the investment. Successful forestation is a cost that can only be justified against the probability of incurring a greater cost or an obscure loss at a future date.

In order to identify the principles of containerization useful and applicable to the forestation process, it will be helpful to examine several historic and contemporary concepts. Where, in our experience, can we find examples of successful forestation systems, and what lessons do they teach us today? Let's start with seed:

TRADITIONAL FORESTATION

The Seed Coat Container

In the beginning, God made man and amongst other things, the seed coat. In some cases he made the cone, a supplemental holder for protecting and transporting the individual containers. Each of these little containers may even be provided with its own wing for distributing the young plant to its new home. The seed coat container is biodegradable, and permits free egress of the root which will grow in a shape governed by the genetic characteristics of the individual and according to the physical and chemical make-up of the medium its root penetrates. Although the seed coat is permeable and biodegradable, rate of degradability is governed by the environment, so that on occasion, even this near-perfect container causes deformation of the plant. For example, a seed coat that dries too quickly will adhere to the cotyledons, constraining and deforming their growth. But we know that degree of deformity is not limiting, and that the future size and shape of the mature plant will be virtually unaffected.

Most certainly the size and weight of the seed is optimal from the viewpoint of economic handling and distribution. Then why not settle for the seed container? The answer is born of man's experience and ambitions. If uncertain stocking levels are acceptable, then seed will do. The naked seed minimizes cost, but yields minimal guarantees of success. The germinant emerging from the seed is akin to the new-born "Joey" of the Kangaroo, having life, but often needing the protection of another pouch or secondary womb where it can be protected and nourished until it has grown in size and hardiness until the time arrives when it can compete with the harsh external environment. To emulate this secondary phase we can coat the seed, wrap it, encapsulate it, or even germinate it in a protective sheath. With each added step, costs increase, and so does the probability of successful establishment. As we look at man-made containers, we will see an extension of the seeding principle. Protection of the plant requiring increasing inputs of materials, labor, and transport, can only be justified if probability of survival and precision of stocking levels increase correspondingly.

Before leaving the seed container, one further principle should be noted. Within the seed, the endosperm provides nourishment that sustains the germinant until it can gather its own water, light, and minerals for growth. The seed coat protects, but does not nourish the plant. Without the stored energy that enables the seedling to forage forth to exploit its new home, the container is useless. Indeed, if it impedes growth it is a liability.

The Lessons of Bare-Root

Bare-root techniques have amply demonstrated that the growing of secondary or tertiary tissue improves the probability of survival. In general, and within limits, the larger and older the seedling, the greater will be its probability of surviving drought, rodents and vegetative competition. The size or age limit is dictated by costs of land, handling and implanting, and by the inherent decline of manual planting quality as the size of the seedlings increase. One-year nursery rotations have proven satisfactory only for fast-growing species in climates warm enough to produce ample secondary tissue within one growing season. For conifers, two-year-old seedlings frequently provide the best compromise between cost and performance.

Bare-root optimizes cost of transportation by reducing bulk and weight of the product to a minimum. Growing costs are also held to acceptable levels through efficient mechanization and use of selective herbicides. Growth rates are optimized within limits permitted by local climate, and by maintaining clean, fertile soil and controlled irrigation.

Throughout the nursery phase roots may be undercut, wrenched or laterally pruned, and when practiced correctly, these various manipulations yield enhanced survival by producing a compact, fibrous root structure. Vigor, or built-in energy of seedlings is often sufficient to overcome the stress and deformities imparted by roots cut and torn on lifting, or by roots dried and deformed during transit and planting.

Even under the best management conditions, bare-root systems are highly vulnerable to uncontrolled nursery environments. Seedling size and quality parameters indicated by field performance are such that the conventional nursery requires relatively high area/plant and soil volume/plant ratios. Thus attempts to control precisely the chemical and physical environment surrounding root and shoot are both difficult and costly. The best nurseryman is at the mercy of seasonal weather fluctuations. Periodic crop failures are accepted as being as unavoidable as the vagary of the elements.

By definition also, the system is subject to both human and environmental error because naked, disturbed, and frequently damaged roots of variable size and shape have to be handled and implanted. Manual planting of bare-root seedlings demands a heavy seasonal labor input, and in this age of affluence and social security, represents a labor pool that is becoming more difficult to obtain and even more costly to retain.

Notwithstanding these inherent disadvantages, the bare-root system, backed by good nursery practice, well-organized distribution, and high-quality planting, can be an exemplary forestation method. It fails, as will other methods fail, where lack of knowledge or indifference violates principles of good crop husbandry, where inadequate organization abuses seedlings in transit, or where poor planning and supervision results in low planting quality. Candidate forestation alternatives must emulate the advantages of bare-root technology, while striving to reduce or eliminate its deficiencies. New sets of compromises have to be evolved and demonstrated.

PRINCIPLES OF CONTAINERIZATION

The Pillars

To be successful, all forestation systems must be supported by four foundation pillars: seed, sound crop husbandry, sound management, and adequate site preparation (fig. 1). If one or more of these pillars is removed, the system fails. No amount of technical wizardry, "green-thumbing", or planting speed can overcome deficiencies of these fundamentals. So important are they to all of our subsequent discussions, that a reminder is important, even if each pillar is a subject in itself.

Seed is essential. We are at least twenty years before the time when clonal forestation through tissue culture may become a practical substitute. Not only must seed match the site, but it must be available in quantity and quality to allow forestation goals to be reached. Nothing is more costly to a forestation program, regardless of the system used, than poor seed. The problem of obtaining full stocking of all containers with seed of low viability is particularly difficult. Empty cavities cast just as much to buy and tend as those with plantable seedlings. The attractiveness of sophisticated nursery manipulations rapidly diminishes when confronted with the problems of poor seed.

Certain principles of growing plants are basic. What is the use of planting seedlings that have not been cultured to the maximum quality permitted within the constraints dictated by economics? For instance, why go to the expense of enriching CO_2, if adequate light for photosynthesis has not been provided, or if temperature has been sub-optimal? Why grow weeds, instead of seedlings? Why feed insects, pathogens, or birds, if it is within your capacity to take preventive action? Why starve seedlings, when balanced nutrition is so easy? Water is as essential to plant growth as is light and mineral nutrition. It is easy to make any planting system look absurd, if the basics are ignored. Apply the intricate techniques of light manipulation, micro-biological control and trace element optimization, only after the basic requirements of plants have been mastered!

Forestation is a complex process consisting of seed provision, nursery management, transportation, and planting. All of these phases have to be melded into a workable whole. Administrators have a responsibility to ensure that road-blocks do not interfere with any one of the key phases of the process. I have a particular dislike of purchasing and other organizational procedures that can ruin

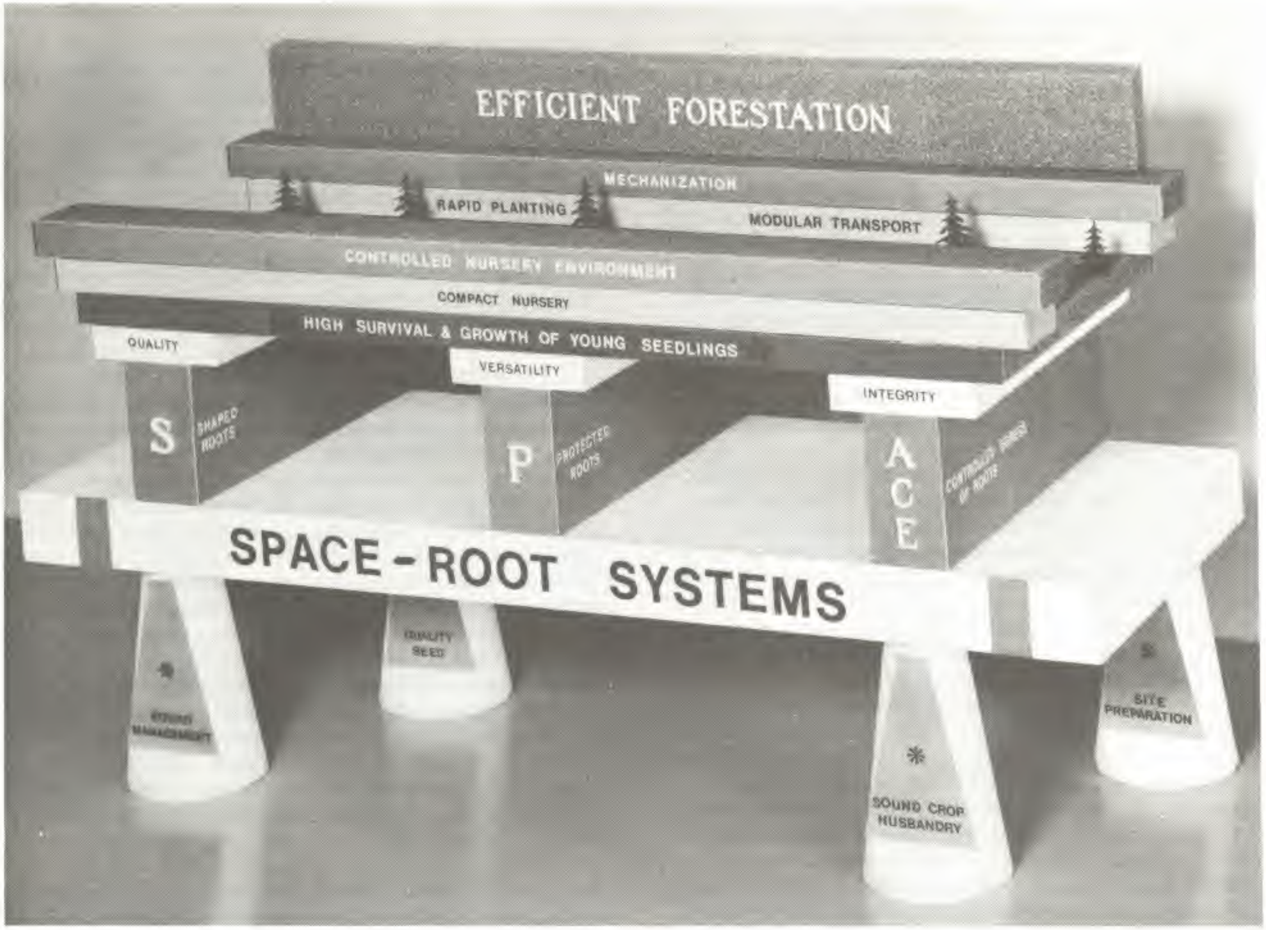

Figure 1.--Building blocks of forestation systems (see text). Bare-root, as well as containerized systems depend on the strength of the main supporting pillars. Container methods shape, protect and control root Egress (hence the acronym SPACE-root systems). Successful application of these foundation principles can lead to adequate field performance of relatively small, young seedlings. Where this premise holds, increased planting rates and relatively compact nurseries may economically support manipulations that will precisely control the physiological condition of seedlings produced. The composite structure may lead ultimately to maximum mechanization from seed to planted seedling.

a planting program because seed collection is denied at a time when it is optimal to collect cones, when a nurseryman cannot buy a fertilizer or pesticide immediately when it is needed, when a transport company can get away with leaving a truckload of seedlings in the sun on a weekend, or when a planting crew leaves seedlings to dry while they drink coffee. If a road-block exists, the administrator must destroy it! People must know what they are doing. Technology evolves. People change. Continued training must go hand-in-hand with changing technology. Prescription of procedures may be a potential advantage of containerization, but the prescription means nothing if technicians are not trained to follow the prescription, and trained and motivated to take corrective action when crises arise... which they will. Planning, organization, and training, are the responsibility of the forestation administrator.

Finally, we come to site preparation as the fourth pillar of successful forestation systems. Climate of a region will rule that land will eventually revegetate toward its climax potential. If man wants a crop of a certain kind, he can, within limits of soil and climate, place a crop in the ground that will satisfy his needs. Various forestation systems aid the forester in solving his particular problems, but not without help. Certainly containers will not overcome a problem site that has been allowed to degenerate beyond the point where a healthy seedling cannot surmount the deficiencies or competition of the site. As indicated previously, this problem is a subject in itself.

The SPACE-Root Principle

A container contains roots in the nursery where it is useful. If it contains roots after outplanting, it is useless! The very word "container" is ambivalent. We want to constrain a root at one stage, then let it go free at another. Our objective is to Shape roots, to Protect roots and to Control Egress of roots from the contained core. Container systems are better described as SPACE-root systems, contrasting with the traditional bare-root systems.

From the biological point-of-view, the constant size and shape that containers impart to a root leads to higher planting quality. Human errors in planting are reduced and there is a greater probability that roots will be placed in direct contact with moist sub-surface soil than with friable, dry organic litter that often falls into the hole when a mattock or planting bar is used for opening the ground.

Protecting roots while seedlings are in transit and while being planted confers significant biological advantages, particularly if the root is undisturbed in the process. An unprotected root can be handled and planted successfully provided that great care is exercised. A number of research trials have shown that bare-root seedlings can be planted with good results in a droughty "off" season. When translated to operational practice, less careful handling frequently fails to substantiate the usefulness the research trial implies. Protecting roots lends greater versatility to planting programs. Adequate or improved survival rates have been achieved before and after the planting season considered "normal" for bare-root seedlings. Protected root seedlings in full flush can often be handled and transplanted successfully. Bare-root describes traditional methods perfectly. Naked, man and seedlings are vulnerable to harsh environments. Clothe man, and he can survive and grow in desert and snow. Clothe seedling roots in moist peat and they can survive much more mishandling, and dry soil. Naked, we and seedlings may die, protected we can survive! The principle is that simple!

The third attribute attainable by container methods is control of the seedling's root form and size. By limiting the growth of roots to a discrete soil volume during the nursery phase, shoots and roots can be kept in proportionate balance, and integrity of the root can be retained. All of the root supporting a top in the nursery can be transferred intact to the field. Once planted, roots can be permitted free egress. Methods of controlling roots at one stage and releasing roots at another are neither simple nor entirely proven, but they may be so critical to the continued success of container systems that they warrant further elaboration in a later section.

As many have pointed out, container planting is not new; what is new within only the last decade are numerous demonstrations of adequate survival and growth of seedlings grown in relatively small containers. SPACE-root seedlings grown in soil volumes of 50 cm^3 or less, and at spacings ranging from 600 to $1500/m^2$ have frequently survived well. Usually only one growing season or its equivalent in a controlled environment has been required to produce these seedlings. Equivalent performance of bare-root seedlings is generally not attainable. When a seedling's roots are protected, the old stock standards no longer hold.

Defining the minimum permissible limits of age, size, and spacing is contingent on results from many more carefully executed field trials, and I will not attempt to define these now. As we shall see, however, it is very important to define the min mum stock standards that can be tolerated and still reach reforestation objectives.

SPACE-root seedlings can satisfy forestation goals under many situations. Therefore, nurseries can be compressed, which in turn makes environmental control of the nursery economically feasible. And environmental control opens the way for a great variety of manipulations that can shorten the nursery rotation and condition seedlings so that they can be adapted physiologically to their destined planting site. Granted, much has to be learned about ways and means of controlling environment optimally, but at least the compact, controlled environment permits exploitation of many research findings that are not presently applicable in the extensive conventional nurseries. Biological manipulation now becomes feasible.

The decade's demonstration of the viability of relatively small and young nursery stock (coupled with the shaped root) is also the foundation for significantly increased manual planting rates. From many experimental and production work studies it has been shown that planting rates of 50 cm3 or smaller SPACE-root seedlings are at least double that of planting conventional nursery stock. Here is the enormous potential economic gain. Viewed from an international aspect, manual planting of a billion SPACE seedlings may represent a saving of at least 30 million dollars that could be put to use more productively in other endeavors.

Constant size and shape of the object (root) to be handled also means that containers can be blocked together in modular units. Once these dimensions are defined on the basis of biological trials, engineers can then design machines for semi-or fully automatic handling, including mechanical planting. One of the last strongholds of intensive human toil that has not yielded to extensive mechanization is tree planting. If societies wish to retain a significant element of labor-intensive chores they can do so with many tasks that will not be amenable to mechanization. Why penalize or jeopardize forest renewal for the sake of jobs that very few desire? SPACE-root principles lay the basis for efficient forestation, the up-grading of jobs, and release from dependency on seasonal labor that may not be obtainable or will be available only at an exorbitant price.

The temptation will be ever present to enlarge the spacing and volume of the container. Biologists will continue to prove that a larger, fatter seedling can be grown faster in a larger, wider-spaced soil volume. Administrators will be anxious to display the instant forest for the public and shareholders to admire. Before embarking on a forestation program based on a large container (e.g., rooting volume greater than 100 cm^3 and spacing less than $600/m^2$), recognize the economic consequences of such decisions. Nursery costs increase as the square of the container's side dimension or diameter, and transportation and planting costs increase proportionate to the volume of the object to be handled. In many instances, the relatively extensive nursery will no longer make environmental control economically feasible, and planting rates will drop to levels no greater, or even less than rates attainable with bare-root. Machines may not even be able to make up the deficit large containers dictate. Notwithstanding this observation, I hasten to point out that there will be biological and economic circumstances that will justify the use of a relatively large container. Just be sure that a small SPACE-root seedling will not serve. The only way this can be proven is through field trials of SPACE-root, not bare-root stock. Organizations that base their own decisions on the ground work of others are assuming risks that may be wholly unjustified under a new set of circumstances. Do not look for a panacea in containers if the basic pillars described earlier are lacking or weak, and do not expect containers to offer an economical solution to your problems if seedling stock prescriptions are based on experience of seedlings with naked roots.

Root Realities

Virtually all containers modify root structure. As soon as the radicle reaches the bottom of the container its downward plunge is altered. With some species in small pots this happens within days after germination. If it grows through a central hole, it is no longer controlled and if it penetrates a favorable substrate, it must be cut or torn off when the plant and container is moved. If it is dried off as it emerges, further root growth is transferred to the laterals. Lateral roots are similarly limited and modified by the walls of the container. If the walls are penetrable, the impact is lessened, although some directional modification invariably occurs. Once laterals have penetrated the walls, they too are no longer controllable, and may be shorn, damaged or deformed on implanting. The only conceivable way of guaranteeing a completely natural root form is to plant the seedling before any of the roots have grown to the limits of the rooting medium, and then the roots must be free to extend unimpeded in the new soil. This guarantee can be achieved by planting a germinant grown in an uncompartmented cohesive rooting medium such as American Can's BR8 or Agritec's Polyloam. The attendant penalty is that only juvenile tissue is produced and in many situations survival rates will be inadequate.

If field trials show that secondary tissue formation is required to achieve adequate survival and growth, then there is no container alternative that can leave root form unaltered. The objective should be to grow a root from that has the least risk of altering the root structure in a way that may cause death, reduced growth rate, or toppling of trees at a later date.

There are enough world-wide examples of container plantation failures to warrant serious concern about the long term effects root aberrations may impart. These examples may be manifestations of ignoring SPACE-root principles or of atypical site effects, but they are warnings that should not be disregarded. Continuing studies of root systems of container-planted trees are essential. The counter evidence that is encouraging emanates from bare-root exper- ience. It is almost a certainty that most bare-root seedlings have been planted with roots twisted, snarled and in slit-like holes, yet millions of trees have grown to rotation age without problems attributable to root form.

Fortunately, there are ways of reducing the effect of the container on root form. Roots can be guided into a predetermined shape with minimal spiralling or cross-over of lateral roots. The square corners of the Todd "Speedling" container is an example. Flutes or ribs on the walls of containers such as the Spencer-Lemaire book planters and the BC/CFS Styroblocks accomplish the same effect of keeping laterals vertically oriented. Even restricting diameter of the container limits the plant from growing meandering roots that must ultimately self-graft into a ball that will act as a fulcrum on which the top can rock into a recumbent position. If present designs do not continue to yield thrifty, stable trees, there are still many design options open.

A common misconception of container attributes is that they take a miniature nursery to the field with the plant. On the contrary, roots must leave the mini-nursery as soon as possible. Upon implanting, a seedling, to survive, must extend roots quickly (a matter of days, not months) to exploit moisture and nutrients in the soil. Like electrical conductors, the relationship governing this capability is proportional to the surface area of the container (or wire) rather than to its volume. The current container system that exploits this principle to greatest advantage is that devised by Nisula. Nisula rolls produce seedlings with a two-planer root system that maximizes surface area relative to rooting volume. If you question this principle, consider that a solid having dimensions of 1 x 10 x 10 cm has a surface area of 230 cm2, whereas a cylinder of equivalent volume (100 cm3) has a surface area of only 122 cm2, or only about one-half of the plate form.

When seedlings have grown until the formation of secondary tissue in a limited rooting volume (e.g., 40 cm3) we know that they must be watered every two or three days to prevent drought stress. The moisture requirement for these seedlings will be the same when they are outplanted, unless moisture regime of the site is at field capacity, or unless roots extend to tap a greater soil volume. Consider the two sample shapes given above. If roots grow one cm outside of the 1 x 10 x 10 plate, they tap the moisture and nutrient in 296 cm3 of new soil. With the cylindrical plug, roots that grow one cm tap only 168 cm3 of new soil. The plate-like root shape will have the better chance of survival under conditions of moisture deficit.

One final point is worth mentioning before leaving the subject of roots. Regardless of the size or design of the container, there is a time limit beyond which plants cannot be confined without undue risk of "pot-binding" This may yield adequate survival, but they will be Bonsai that may not grow according to expectation, or may not be root firm. More precise definition of these limitations will only be learned from field trial experience.

SPACE-ROOT CONCEPTS

There is not one planting concept today that can justifiably claim superiority over every other system. All compromise either a technical, economical or biological principle. Several however, appear to have reached a bio-economic balance that is giving acceptable results. They can be classified according to the economic or SPACE-root principles they either follow or compromise

Penetrable-walled Concepts

The Fish

One of the earliest containers that has useful principles for us is the fish. I am indebted to Mr. Blomberg, Ahlstrom's proponent of the "Finnpot" system, for drawing to my attention the fact that the Aztecs3/ or early Americans of similar vintage used the carcass of a fish as a container for growing seedlings. The method must have looked something like the primitive nursery shown in figure 2. The fish illustrates a number of principles we seek in the design of an optimal seedling container. The form of the container is maintained by an endoskeleton, yet the outer wall can be penetrated by roots and is shaped for easy implanting. Even built-in appendages provide hangers for supporting them to permit application of the air-root pruning principle, and for increasing spacing as the plants grow. The substance of the fish's body provides a ready-made slow-release fertilizer for plant nutrition during the nursery phase and after outplanting. Examination of the shape of the fish's visceral cavity shows that roots will be channelled towards a simple fundamental orifice. The odor of the fish container might limit the availability of nurserymen and planters, but even here we have the potential of an inherent deer repellent that has absorbed many research dollars for rediscovery. Contemplate this ancient container, then dare to claim novelty for container design! I am quite ready to admit that I do not know how to grow seedlings in a fishy substrate, but it does illustrate the versatility of substrates that may be used, provided techniques are learned, mastered and applied.

3/Excuse the inexact reference, but the chances are that the idea was borrowed from an earlier, wiser generation.

Figure 2.--The fish container. One of the oldest plant containers illustrating several principles emulated by contempory SPACE-root concepts.

Peat Pots

Of all contemporary container methods, peat pots have the longest record of acceptable performance. Most, however, have been used in sizes far exceeding volumes and spacings permissible for economical mass forestation. Lack of blocking into modular multi-units for processing and handling was ignored earlier and was limiting, but "Finnpots" molded in modular units at least partly overcome this shortcoming. Peat can be blended with wood-pulp or other materials to control the rate of penetrability.

Paperpots

Japanese Paperpots are presently finding the greatest degree of acceptance today. Rate of root egress can be controlled through selective blending of wood pulp and synthetic fibre. Modularity of the pot units satisfies many of the technical processing problems container culture presents. If paperpot sets are raised to ensure root-pruning, integrity of seedling roots can be maintained; if they are placed on soil or sand, some roots are destroyed in the transfer from nursery to the field. Again, performance is the principal criterion on which to judge a system. If an acceptable probability of success is being achieved economically, then there is no valid reason for denigrating real or hypothetical shortcomings of a system.

Wall-less Concepts

Reference has already been made to the attributes of a cohesive rooting medium. Their application is to the planting of seedlings having only juvenile tissue and as such, spacing and rotation length can be compressed to an absolute minimum. Economically the techniques have potential; biologically they are subject to the vulnerability of the "Joey" referred to earlier. As noted in figure 5, these materials might be invaluable for transferring germinants to larger containers or bare-root transplant fields.

Plug Concepts

I am gratified to know that the "plug" has, in only five years, become a term recognizable in International lexicons. It is no different than the ball planting term approved by the Society of American Foresters, but it does not imply the spherical shape which is inimitable to SPACE-root principles. Plug systems use the container to shape and protect the root, but require removal from the container so that roots can egress freely upon implanting. Numerous variations of plug concepts exist, of which the standard plant pot is the oldest example. With its flat bottom, the standard plant pot completely ignores the extreme aberration of roots that containers may cause. A large top can be grown (fig. 3a),

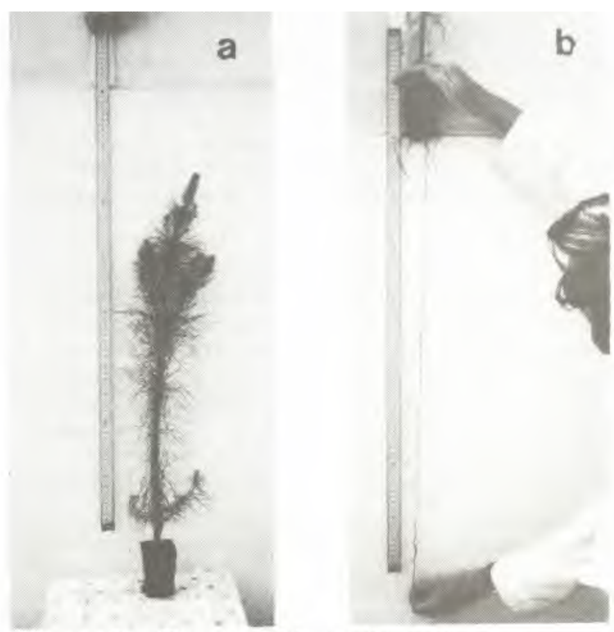

Figure 3.--The age-old standard plant pot showing that a magnificent top can be grown in a tiny soil volume (a), but that the great lengths of root coiled into the pot (b) will not be proportionately functional in supporting the top after outplanting.

but the root may be so coiled in the bottom of the pot that great lengths of non-functional root may be produced (fig. 3b). Balanced top/root principles are entirely overlooked. Plastic bags, whether perforated or not, whether removed or not, fall into the same category of systems that pretend that no problems with ultimate root form exist. Swedish Multipots must be similarly classified because each cavity of the modular unit is only a miniature replica of the standard plant pot.

A number of modular units have been designed which attempt to minimize root aberrations by channelling roots towards a central bottom hole. By supporting the units clear of the ground emerging roots automatically dry, thus encouraging growth of numerous laterals into a tapered, relatively untangled root form. I hesitate to name all of the modular units of this class that are being manufactured, but I think it is not unjust to suggest that most are modifications of Todd Speedling trays and BC/CFS Styroblocks which in turn were patterned from experience gained with Walters' bullet design. Spencer's book planters (or "Rootrainers" as they are now being called) add some unique design refinements.

Methods of packaging bare-root seedlings in protected and shaped coverings can hardly be classed as plug concepts unless the seedlings are grown on to redevelop a balanced and intact root. The Nisula roll method of growing on bare-root transplants is worth mentioning because it is capable of producing plants in modular packages that have several plug attributes. Root integrity can be maintained by separating the peat band in the rolls into discrete pockets. A recent Norwegian variation seals peat pads into completely separated tapered pockets of a double layered film roll.

Generally, plug concepts compromise the precise shaping of roots for subsequent automatic handling, and they require that plants be grown to a size when roots are sufficient to hold the protective cover of peat intact. These concepts do, however, ensure that roots can egress without impediment. They represent another set of compromises that lend versatility to forestation without assuming serious risks.

Solid-Walled Concepts

Tubes

Although solid walled containers have long been used for growing plants (bamboo, tin cans, etc.) the concept receiving the most attention in recent years is the Province of Ontario's plastic tube. One might describe the last decade as the rise and fall of the Ontario tube. Like all glib phrases it is only partly true. Ontario tubes are still being used with apparent success in Ontario, Britain, and Carolina in the forestation of pines on certain sites. The system was predicated on factory-like production of juvenile seedlings, with minor matching of the area of free roots to the new mother soil. The concept compromises seedling vigor dictated by age, and maximized free root egress. If the same tube system, through modified techniques, permits planting of seedlings with secondary tissue, area for root egress may be enough to ensure adequate survival and growth. If the Ontario tube experiment has served no other purpose, it has demonstrated how important it is to launch production-scale forestation alternatives only after large-scale field trials have thoroughly demonstrated biological and economic potentials and limitations of a system.

Bullets

Amongst the proliferation of container ideas Walters' bullet concept stands alone. It envisages complete rationalization of planting from seed to established seedling. It maximizes efficient mechanical handling and planting with a rigid container that can be thrust into the ground with a one-step implanting action. Early designs of the bullet limit free root egress and impart a one-sided, unbalanced root form, but improved designs could overcome these shortcomings. Although cost of the basic container is relatively high, planting rates on a production basis are yet to be exceeded by any other system.

The rigid casing surrounding the root is a biological compromise that many find difficult to accept. The bullet idea has certainly stimulated more interest - and controversy - in containerization than any other innovation. If bullet planted seedlings survive at a somewhat lower rate than their root-free equivalents, their use may be wholly justified by significantly reduced planting costs. Time and continued field testing of modified designs will ultimately show the way.

PUTTING IT ALL TOGETHER

Any forestation system can be likened to a cycle rider attempting to negotiate a tight wire (fig. 4). In order to span the distance between two poles she must maintain balance. She relies on a counterweight that helps defy gravity, and she carries a balancing pole that, with her strength and skill, enables her to

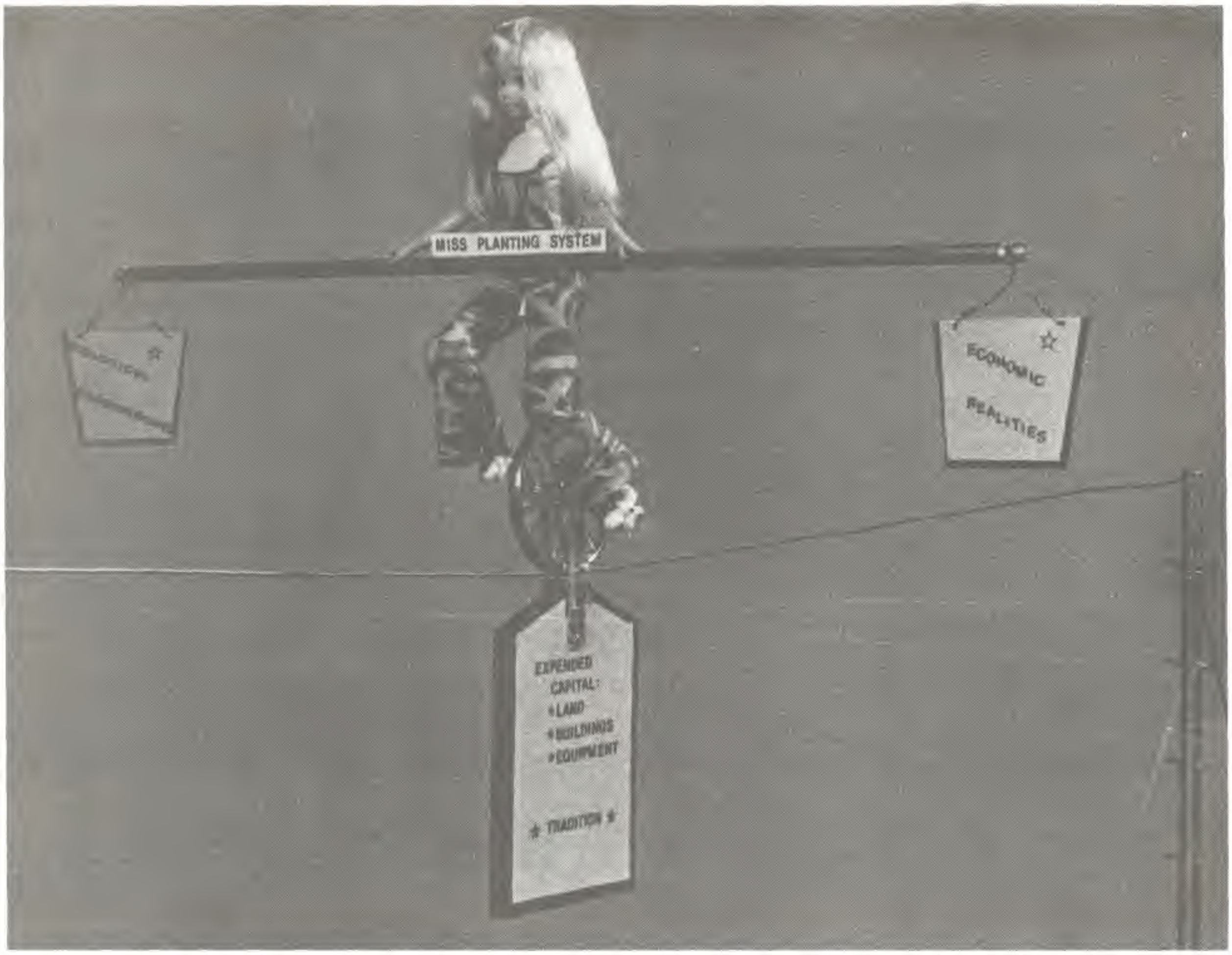

Figure 4.--The wire-rider illustrating the forces impinging on the successful progress of a planting system. Economic realities include funds available, labor supply, and skills and knowledge of managers and technicians. Balance of the system may be upset if biological factors become too demanding or complex. Similarly, progress will be slowed or halted even with a surfeit of resources if biological principles are compromised. The under-wire counterbalance is an asset to stability during the development period of a system, but may prove to be a liability if it continues to support a system that is no longer in bio-economic equilibrium.

stay upright on the wire. If for some reason her balance pole becomes too heavy she may not be strong enough to negotiate the course; if a weight is added to one end of the pole, she topples. Blocks may also be placed along the wire to further try her skill. If she is a novice, a safety net is placed beneath so that she will be saved for another attempt. If she is an old-timer, there is no safety net and she may tumble to her doom; there may even be a few hungry tigers awaiting below to finish the job.

Imagine a forestation system as the rider. Before a start can be made, seed must be procured, funds must be provided and a viable organization setup. Once started, the system has counterbalance to keep it stable; capital expended, tradition, and resistance to change help prevent failure, even if failure is deserved. To keep on a productive course, the system must balance economics, technology, and labor requirements against biological necessities. If the system requires an exacting biological input (e.g., large container, or controlled environment), cost may become too high, and the system will fail. If technical considerations (mechanization) become overweighted relative to the biological results achieved, the system fails. A more precise and expensive system will be needed if probability of success must be very high, or if exact spacing and stocking levels are demanded.

Until sufficient field testing has accumulated on a pilot production scale, an innovative forestation system is embarking on a hazardous journey. It may be more sound in the long run to meld innovative systems with the traditional while in the process of learning (fig. 5) If they have no other value, SPACE-root techniques can be a significant adjunct to traditional forestation. Excellent bare-root transplants can be grown from container-started seedlings. Very small containers or tiny blocks of cohesive rooting medium could be used for establishing crops in both bare-root and container nurseries. Traditional and innovative methods should complement one another, rather than be viewed as competing systems.

If a traditional nursery and planting method is achieving satisfactory results at reasonable cost, there are few valid reasons for a major change to another system just because it is new. Where traditional systems are in a state of costly chaos because of neglect of the fundamentals of forestation, then it is highly probable that a container program will only add to complexity, confusion and costs, rather than lead to more efficient operations.

Sydney Harris, the newspaper columnist, recently observed: "People who want simple answers to complicated questions are not seeking solutions as much as they are praying for panaceas." Prayers might help the young lady attempting to ride the wire, but she will never become a star performer without skill, perseverance and experience. Put yourself in her place. Can you see your goal? Are you strong enough, skillful enough and determined enough to overcome obstacles along the course? And, above all, are you retaining your balance?

I hope my little analogy will lend perspective to our efforts and will save some from falling to the mouths of the ever-hungry tigers!

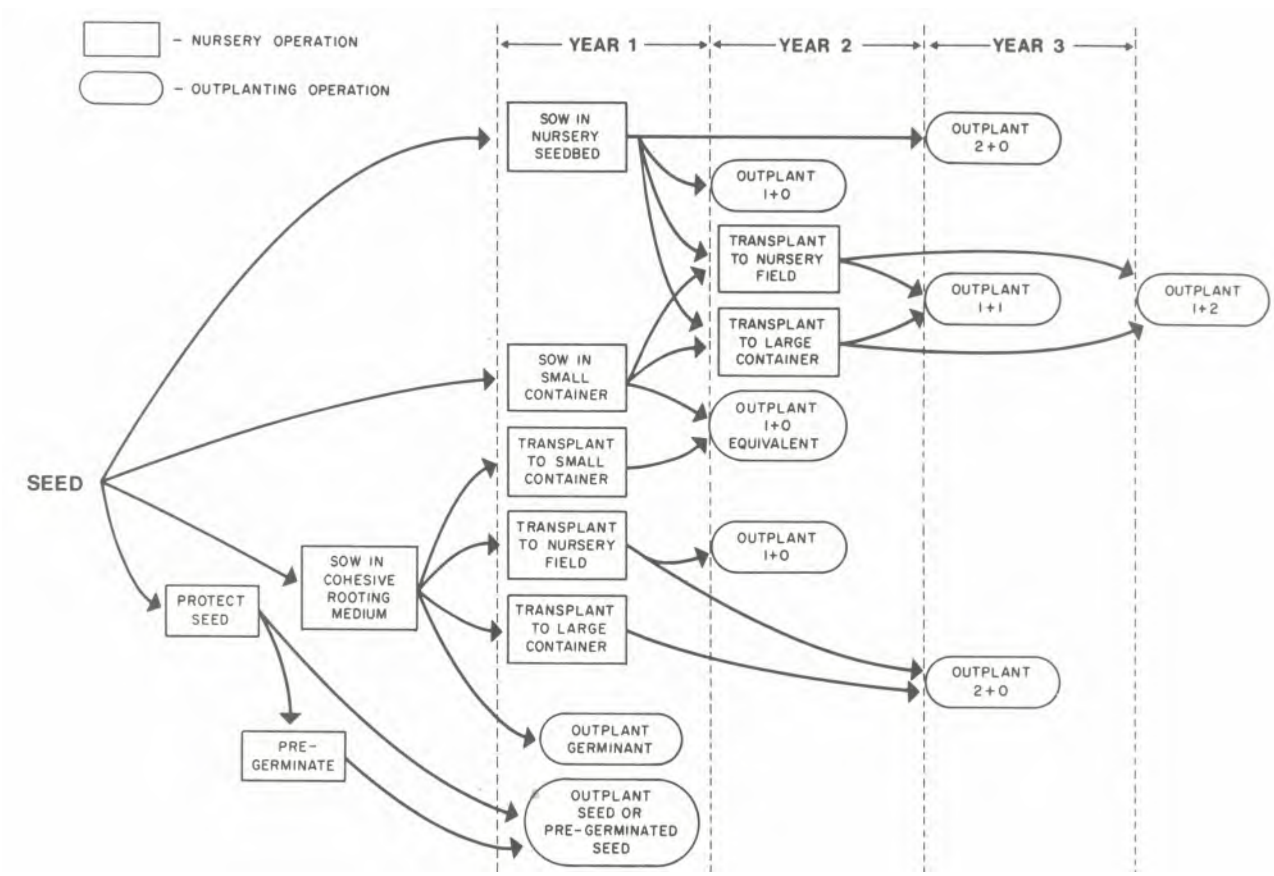

Figure 5.--Diagrammatic representation of potential forestation pathways. Containers may be used in several ways to complement bare-root production during a development period. Time spans indicated are only approximate. Containers of around 50 cm3 volume are here considered small; container capacities exceeding 100 cm3 are considered large. Germinants of some species grown in a "cohesive rooting medium" could be sown at densities as high as 10,000/m2. Rapid, economically feasible transfer of germinants to another unit is still an undeveloped pathway.