Designing Propagation Environments in Forest and Native Plant Nurseries

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Abstract: Propagation environments are areas that have been modified for plant growth, and can be designed using the law of limiting factors. Identifying critical factors that are most limiting to optimal plant growth is helpful when developing both bareroot and container nurseries. Propagation environments can be categorized into minimally-controlled, semi-controlled, and fully-controlled. The defining characteristics of each are discussed. When planning a nursery, three things should be considered: the type of crop, local soil and climate conditions, and available budget.

Keywords: limiting factors, nursery design, seedling, greenhouse, bareroot

Using Limiting Factors to Design Propagation Environments

A propagation environment can be defined as any area that has been modified to promote faster and better plant growth. Although most people immediately think of a greenhouse, a propagation environment may or may not involve a structure of some sort. When designing or managing a nursery, I like to think in terms of limiting factors. Liebig originally developed the concept of limiting factors and his law of the minimum for mineral nutrients (Wikipedia 2012). It was often depicted as a wooden barrel where the amount of water that the barrel could contain is limited by the shortest stave (Figure 1A). In actual practice, limiting factors are not independent but act sequentially (Figure 1B). Water is almost always the most limiting factor to plant growth and development, but when that factor has been culturally resolved, another will become limiting - such as nitrogen. Once that limitation has been managed another factor such as the absence of beneficial microorganisms will become limiting, and so on. The ideal environment where all potentially limiting factors have been resolved is a growth chamber, but the energy costs are prohibitive except for specific functions such as seed germination chambers. Once all the growth limiting factors have been resolved, this demonstrates the true genetic growth potential of the plants (Figure 1B).

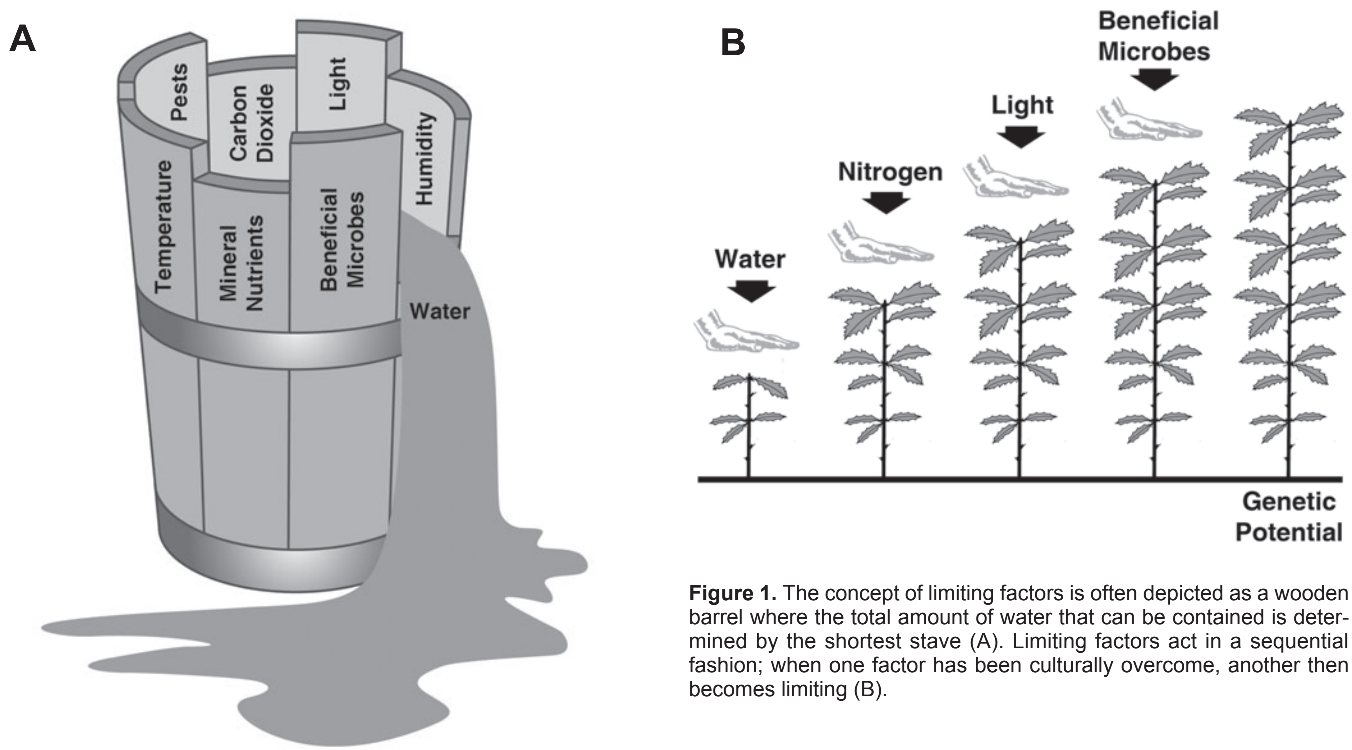

Figure 1. The concept of limiting factors is often depicted as a wooden barrel where the total amount of water that can be contained is determined by the shortest stave (A). Limiting factors act in a sequential fashion; when one factor has been culturally overcome, another then becomes limiting (B).

So, for our purposes, an ideal propagation environment is one where all environmental factors that are potentially limiting to plant growth (Table 1) are kept at optimum levels. Although water is almost always limiting to plant growth (Figure 1), this factor is relatively easy and cheap to control with irrigation in a propagation environment. Some factors, such as light intensity, cannot be economically supplied because photosynthetic lighting requires large amounts of electricity.

In addition to physical and chemical factors, the propagation environment also contains a biological component - other organisms that often limit plant growth. Pathogenic fungi and insect pests can injure or even kill succulent nursery plants and, because of the lack of natural biological controls in nurseries, pests can build up to damaging levels very quickly. One of the primary attractions of container nursery culture is that growers have more control over these biological factors and can design propagation environments to exclude most pests. On the other hand, beneficial microorganisms such as nitrogen-fixing bacteria and mycorrhizal fungi can greatly affect plant growth and development so their absence can be considered a limiting factor (Figure 1; Table 1).

Types of Propagation Environments

The limiting factors concept can be applied to design and management of both bareroot and container nurseries; although, greenhouses and other specialized propagation structures offer many more options for managing limiting factors.

Minimally Controlled

All bareroot nurseries fall into this category because they can only manage two potentially limiting environment factors: water and mineral nutrients. All bareroot facilities feature some sort of irrigation system to supply water during dry periods. Even nurseries in the mild climates, where rain occurs at regular intervals throughout the growing season, have to supply irrigation at some point to prevent moisture stress. Irrigation can also be used to cool seedbeds during germination or to provide some degree of frost protection during periods of freezing weather in the fall or spring.

Smaller scale nurseries can use raised beds filled with special growing media to overcome cool soil temperatures in the spring. The wooden frames can also be fitted with hoops of wire or plastic pipes,

Table 1. Potentially limiting factors that can be controlled in a propagation environment.

Environmental Factors	Supplied in Nurseries By:
1. Water	Irrigation
2. Mineral nutrients	Fertilization
3. Light	Type of covering, photoperiod lighting, photosynthetic lighting, blackout curtains
4. Temperature	Heaters, ventilation, shadecloth
5. Humidity	Irrigation, ventilation
6. Carbon dioxide	Ventilation, carbon dioxide generators
7. Beneficial microorganisms	Inoculation with nitrogen-fixing bacteria or mycorrhizal fungi
8. Pests	Exclusion screens, pesticides, biocontrol agents

Table 2. Amount of Control of Limiting Factors in 3 Types of Propagation Environments.

Limiting Factors	Minimally-Controlled	Semi-Controlled	Fully-Controlled
1. Water	All High – Irrigation can be performed any number of ways for each		
2. Mineral Nutrients	All High - fertigation or incorporation of controlled-release fertilizers into growing media		
3. Light	Generally none, some use of photoperiod lights & blackout curtains	Generally none, some use of photoperiod lights & blackout curtains	Medium - coverings, photoperiod lights, blackout curtains
4. Temperature	Generally none, some use of irrigation & fabric covering for frost protection	Portable heaters, and some use of irrigation & fabric covering for frost protection	High - heaters, fans & vents
5. Humidity	No	Low	High - irrigation, heat & vents
6. Carbon Dioxide	No	No	Medium - CO2 generators
7. Beneficial microorganisms	All High - apply inoculum as seed coating, top dressing, or incorporate into growing media		
8. Pests	Low – fencing to exclude deer	Moveable sidewalls prevent bird predation of seed	High - permanent walls exclude insects and birds

which are then covered with clear plastic sheeting. These minimal structures capture the heat of the sun to allow earlier sowing during the spring or prevent frost damage during the fall (Table 2). Some larger bareroot nurseries have also used hoop structures over their seedbeds to support coverings with frost fabric to prevent cold injury (Moench 1994).

Minimally-controlled container nurseries are known as open growing compounds, and were developed to produce an inexpensive container seedling that was well acclimated to the environment. Although they have been most popular for growing southern pines in the southeastern US (Barnett and others 2002), open compounds have been the standard propagation environment in tropical and subtropical nurseries. In the Maritime provinces of Canada and coastal British Columbia, open compounds are used to produce a 2-year container stocktype. Typical compounds are graded for good drainage and either covered with weed barrier fabric and gravel or paved with asphalt. Semipermanent irrigation lines supply water and can also be used to supply mineral nutrients through fertigation (Table 2). Some open growing compounds are equipped with photoperiodic lighting to extend the growing season, and blackout curtains to induce dormancy and cold hardiness. Although open growing compounds are the least expensive way to produce container stock, growth rates are slow and, depending on the climate, it may take 1 to 2 years to produce a shippable seedling. Weather damage, such as a killing frost or torrential rain, is also a constant concern and so the risk of crop loss is the highest of all types of propagation environments (Landis and others 1995).

Semi-controlled

The only instance of semi-controlled propagation environments being used in bareroot nurseries were the bedhouses used at Wind River Nursery in the early 1980's (Hansen 1983). These bedhouses consisted of moveable high tunnels that protected the seedbeds early in the growing season and then were physically removed when ambient growing conditions became favorable. Although these bedhouses did improve seedling growth rates, and shorten the growing season for some conifer species, their use was eventually discontinued. Bedhouses of clear poly sheeting over metal hoops (Figure 2) were also tested in northern British Columbia for growing white spruce and lodgepole pine bareroot stock (Simpson 1990). These trials demonstrated increases in seed germination due to warmer soil temperatures and increased growth rates that produced larger 1+0 seedlings that were less prone to frost heaving. Although the bedhouse technology showed some advantages, it has not been widely adopted.

A wide variety of semi-controlled propagation environments have been used in container nurseries (Landis and others 1995). Crops can be grown in semicontrolled structures in all but the most severe climates. Some types of semicontrolled structures, especially shadehouses and tunnels, are also used for hardening and intermittent seedling storage. From an economic standpoint, semi-controlled environments are cheaper to build and operate than fully controlled environments, although there are considerable variations between the different types of structures.

Shelterhouses are a modification of the traditional greenhouse with a permanent transparent roof with movable walls that can be rolled up after the danger of frost has past (Hahn 1982). These structures can be outfitted with environmental control equipment that allow control of many of the potentially growth-limiting factors (Table 2). In the spring or in unusually cold weather at any time during the growing season, the sidewalls are kept down and portable heaters can used to raise temperatures. As soon as ambient temperatures become favorable, the sides can be raised to permit natural ventilation, eliminating the need for forced air cooling.

Semi-controlled environments also include hoop houses and tunnels that are used much more for ornamental or food crops than for

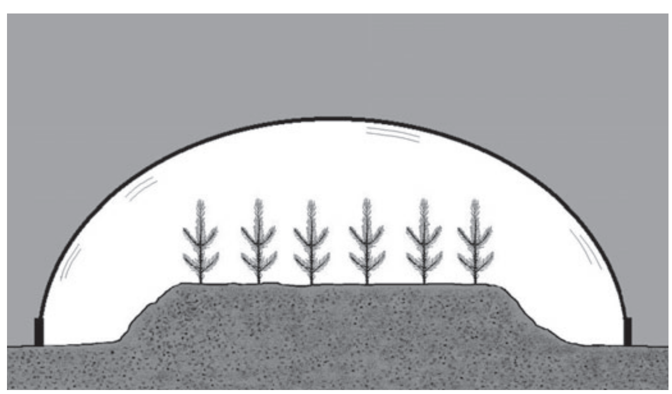

Figure 2. Bedhouses of clear poly sheeting over metal hoops are a type of semi-controlled propagation environment.

forest or native plant propagation. Hoop houses, also known as row tunnels or low tunnels, are low-profile metal bow-arch structures covered with poly sheeting that only retrain solar heat early in the growing season (Wells 1996). High tunnels can be equipped with portable heaters to prevent frost damage and accelerate seed germination (Kleinhenz 2011). During warm weather, the ends or even the sides of the tunnels can be rolled up to provide ventilation. They can also be covered with shadecloth. Hoop houses and tunnels are also equipped with ground-based irrigation lines to provide water and mineral nutrients through fertilizer injection (Table 2).

Shadehouses or lathhouses are semi-controlled propagation environments that have been widely used for growing forest seedlings and other native plants (Landis and others 1995). Traditionally, shadehouses were constructed of a wood frame covered with snowfence or wooden slats, but metal frames covered with shadecloth are also common. Shadehouses are usually equipped with basal or overhead irrigation so fertigation is also possible. Although traditionally used as hardening or holding areas, shadehouses can also be used to propagate many forest and native plants. In colder climates, shadehouses are also used for overwinter storage. Shadehouses with a permanent roof and open mesh sides have found considerable acceptance in the Tropics and the Subtropics, where sunlight can be too intense for young seedlings and torrential rains and wind can damage crops.

Fully Controlled

Greenhouses are the traditional propagation structure for producing container plants, and they can be equipped to fully control the propagation environment (Table 2). Greenhouses use natural sunlight that is trapped inside the transparent structure and converted to heat (the "greenhouse effect"). The drawback of the transparent covering is that greenhouses are inherently poorly insulated and require both high-capacity heating and cooling equipment for good temperature control. Depending on whether the climate is arid or humid, the greenhouse environment may need humidification or dehumidification. Many forest and native plant conservation species are sensitive to changes in daylength, and so photoperiodic lighting is often installed to prevent dormancy. Blackout curtains can be used to shorten the daylength and induced hardiness. Although carbon dioxide generators can be used to promote faster growth rates, they can only be run when the structure is completely closed. Irrigation systems with fertilizer injectors supply ideal levels of water and all the essential mineral nutrients. Computer-controlled equipment can keep potentially growth-limiting factors at optimal levels as well as provide a permanent computer record for growth comparisons and trouble shooting.

Greenhouses with retractable roofs and sides are the most recent innovation, and have useful applications for forest and native plant crops (Svenson 1996). Early in the growing season, the roof and sides are closed and the structure functions like a traditional greenhouse. Later, when ambient conditions improve, the roof and/or sides can be opened to allow for full air exchange. Retractable roof greenhouses are equipped with sophisticated computer controls that can open and close as needed to minimize the use of energy intensive heating and cooling equipment. The roofs and sides can be left closed early in the season and during cool weather, but opened later to allow natural hardening to under ambient conditions. This feature is ideal for forest and native plant crops which can be gradually hardened yet still be protected from climatic extremes (Landis and others 1995).

Things to Consider When Planning a Nursery

As you can see, there are a wide variety of possible propagation environments; the trick is to design one that is appropriate for your own situation. Here are three things to consider (Figure 3):

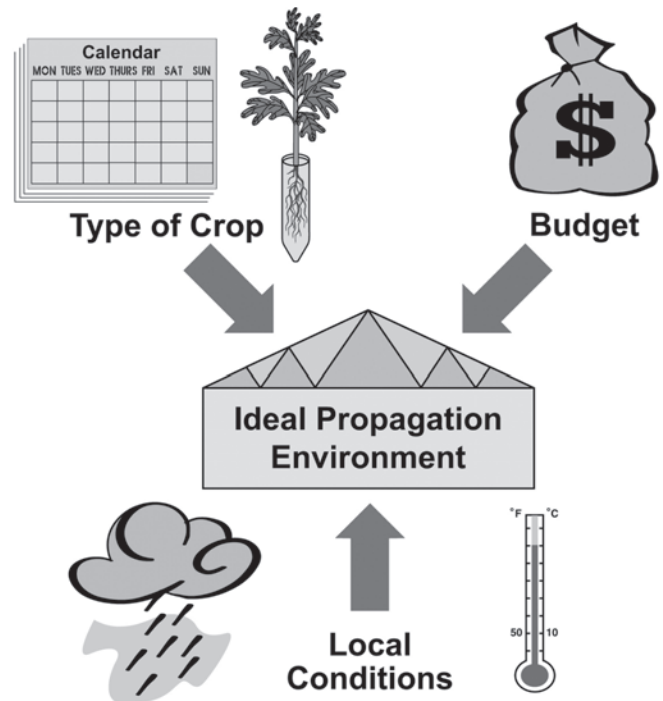

Figure 3. Several varied factors must be considered when designing a propagation environment, but one of the most important is to make certain that structures are appropriate for local conditions.

1. Type of Crop

Although this may seem obvious, all too often people wanting to start a nursery just assume "plants are plants" and can be grown in some average propagation environment. So, they spend most of their time on the economics of the situation or get caught up in design specifics. There's no such thing as an average propagation environment. The type of crop that you want to grow will have an enormous impact on your choice. The first decision is whether to grow crops as bareroot or container plants (Landis and others 1995).

Bareroot seedlings are grown in open fields in native soil, and consequently, the soil, water supply, and climate of the nursery site must be suitable for tree growing. The rate of seedling growth and length of the growing season are largely controlled by the climate at the nursery site. Quality sites are often difficult to find in convenient locations, and good agricultural land is almost always expensive. A considerable capital investment is usually required to develop a bareroot nursery of any size. Bareroot nurseries are also sensitive to the economies of scale. Once a nursery is established and operations have begun, it is important to function at near-capacity levels to have reasonable unit production costs. Compared to container nurseries, energy requirements and associated expenses are relatively low.

Container nurseries can be constructed on land with low agricultural value that would be unsuitable for bareroot seedling production. The amount of capital investment varies with the type of facility. Fully controlled greenhouses require expensive structures and en-

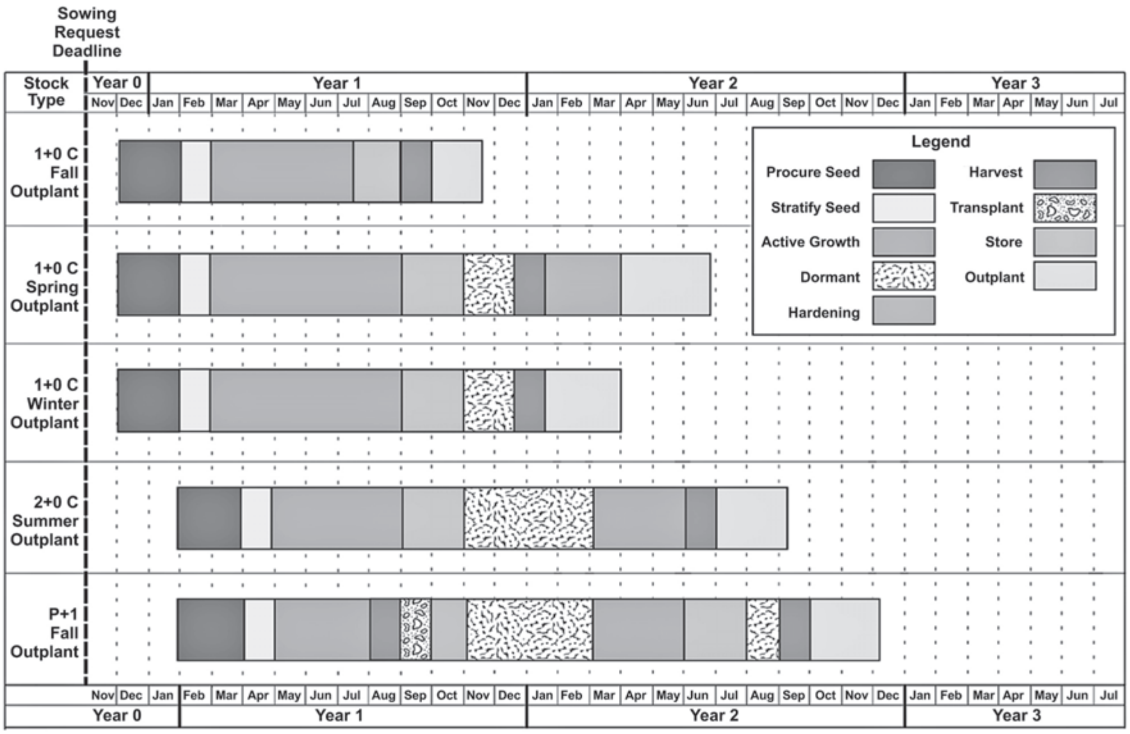

Figure 4. Growing schedules are useful during nursery planning to illustrate the time required for each phase of the nursery cycle from seed procurement to outplanting (Landis 2008).

vironmental controls, but open growing compounds are much less costly. Because container seedlings are grown at high densities, less land is required compared to a bareroot nursery. Container nurseries are less sensitive to economies of scale and, in extreme situations, part or all of the nursery can be shut down to reduce operating costs. Container seedlings have high growth rates, especially in fully controlled environments, and so crops can be produced in one growing season. From a business standpoint, this means that container nursery managers can respond quickly to changes in the market.

Once you've decided on either a bareroot or container nursery, the next things to consider are what plants you want to grow and how best to grow them. Let's say that you want to grow woody native shrubs in containers. Do you really have an idea of how long it will take to grow a saleable plant? Luckily, a source of "recipes" is available. In addition to information on seed collection and processing, the Woody Plant Seed Manual (Bonner and Karrfalt 2008) contains a section on Nursery and Field Practices for each plant genera. This book also has a chapter on the basics of plant propagation including growing schedules which show how long typical native plant crops take to produce (Figure 4). More detailed information can be found online at the native plant network (www.nativeplantnetwork.org) where several thousand propagation protocols can be found (Landis and Dumroese 2000).

2. Local Conditions

As we've already discussed, there is no ideal propagation environment; instead, each must be appropriate for the local situation. Irrigation water quality is of paramount importance for both container and bareroot nurseries, and there is no economical treatment for poor water quality. For bareroot nurseries, the next most important site quality factor is the soil. The ideal soil for a bareroot nursery is a sandy loam, primarily due to the ease of root culture and harvesting during the wet winter weather (Landis 1995). An excellent discussion of all the factors that must be considered during bareroot nursery site selection can be found in Morby (1984).

Container nurseries can be located on sites that would be totally inappropriate for a bareroot nursery because seedlings are grown in artificial growing media and with structures and equipment to modify the physical environment. Container nursery developers should allow adequate time to analyze potential sites because many biological and operational problems that develop later in nurseries can be traced back to site problems. The things to look for in a potential container nursery site can be divided into essential factors and desirable factors (Table 3). Essential site selection criteria consist of factors that are essential to a successful nursery operation. By comparison, desirable site factors are not absolutely necessary but will increase the economy and efficiency of the nursery operation. More detailed discussion on container nursery site selection is provided in Landis and others (1995).

3. Budget

Of course, economic considerations will always be paramount when planning a nursery operation. Unfortunately, it is impossible to provide detailed economic data because the size and objectives of for-

Table 3. Site selection criteria for container nurseries (Landis and others 1995).

Essential Factors	Desirable Factors
Good solar access	Protected microclimate
High quality water	Gentle topography
Inexpensive and reliable energy	Seasonal labor supply
Adequate land area including room for expansion	Year round accessibility
Ecopolitical concerns, especially zoning	Distance to markets

est and native plant nurseries is so varied. The economic constraints for a small mom-and-pop native plant nursery have little in common with that of a large commercial forest nursery. Still, nursery developers must give careful consideration to the economic aspects of starting and operating a nursery through a comprehensive business plan.

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