Using "Limiting Factors" to Design and Manage Propagation Environments

Thomas D. Landis
USDA-Forest Service, P O Box 3623, Portland, Oregon 97208

THE PRINCIPLE OF LIMITING FACTORS

One of the basic concepts of ecology is called the principle of limiting factors which states that, when a process is governed by several factors, its rate is limited by the factor that is closest to the minimum requirement (Odum, 1971). Conceptually, the idea of limiting factors can be visualized with the wooden barrel analogy which Whitcomb (1988) used to explain mineral nutrient deficiencies. Plant growth is represented by the water in the barrel which is constructed of wooden staves, each representing a different limiting factor (Fig. 1). The water level (plant growth rate) at any one time or location is limited by the height of the shortest stave (limiting factor) in the barrel.

If we expand this concept to nursery design and management, we can identify those environmental factors that are potentially limiting to plant growth. The main factors of the atmospheric environment are light, temperature, humidity, and carbon dioxide and the two principal factors of the edaphic environment are water and mineral nutrients (Fig. 2). The atmospheric factors are primarily determined by geographic location and type of nursery facility and so must be carefully considered during nursery site selection and construction of propagation

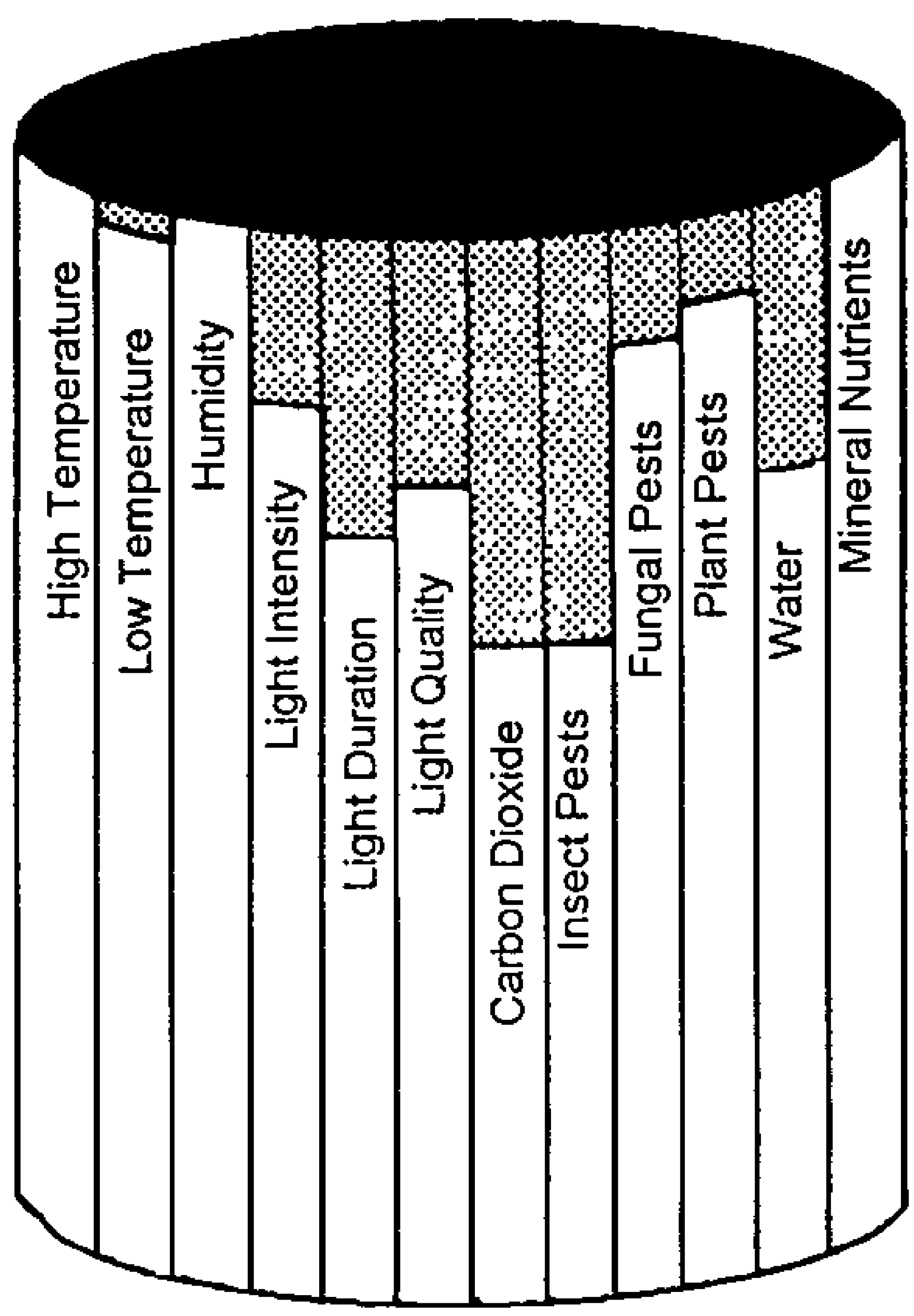

Figure 1. The concept of limiting factors can be visualized as a wooden barrel in which the height of each stave controls the amount of water (plant growth rate) in the barrel (modified from Whitcomb, 1988).

structures. In container nurseries, the two edaphic factors are independent of nursery location and can be completely controlled by the type of growing medium and cultural practices.

In addition to the physical and chemical factors listed above, the propagation environment also contains a biological component—other organisms that often limit plant growth (Fig. 2). 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 a propagation environment that excludes pests.

DESIGNING A PROPAGATION ENVIRONMENT—ATMOSPHERIC FACTORS

A good container nursery design will reflect both the environmental conditions on the site and the biological requirements of the specific crop. So, the first step is to determine crop requirements—a propagation environment that is ideal for one group of plants may be biologically or economically unsuitable for another. Nursery crops can have radically different environmental requirements which nursery developers must factor into the nursery design process. Most forest and conservation nurseries produce a number of different species; therefore, different propagation environments must often be designed to meet the needs of the various crops. On a practical basis, however, most nursery developers must compromise for some sort of average environment in which they can grow the entire range of crop species.

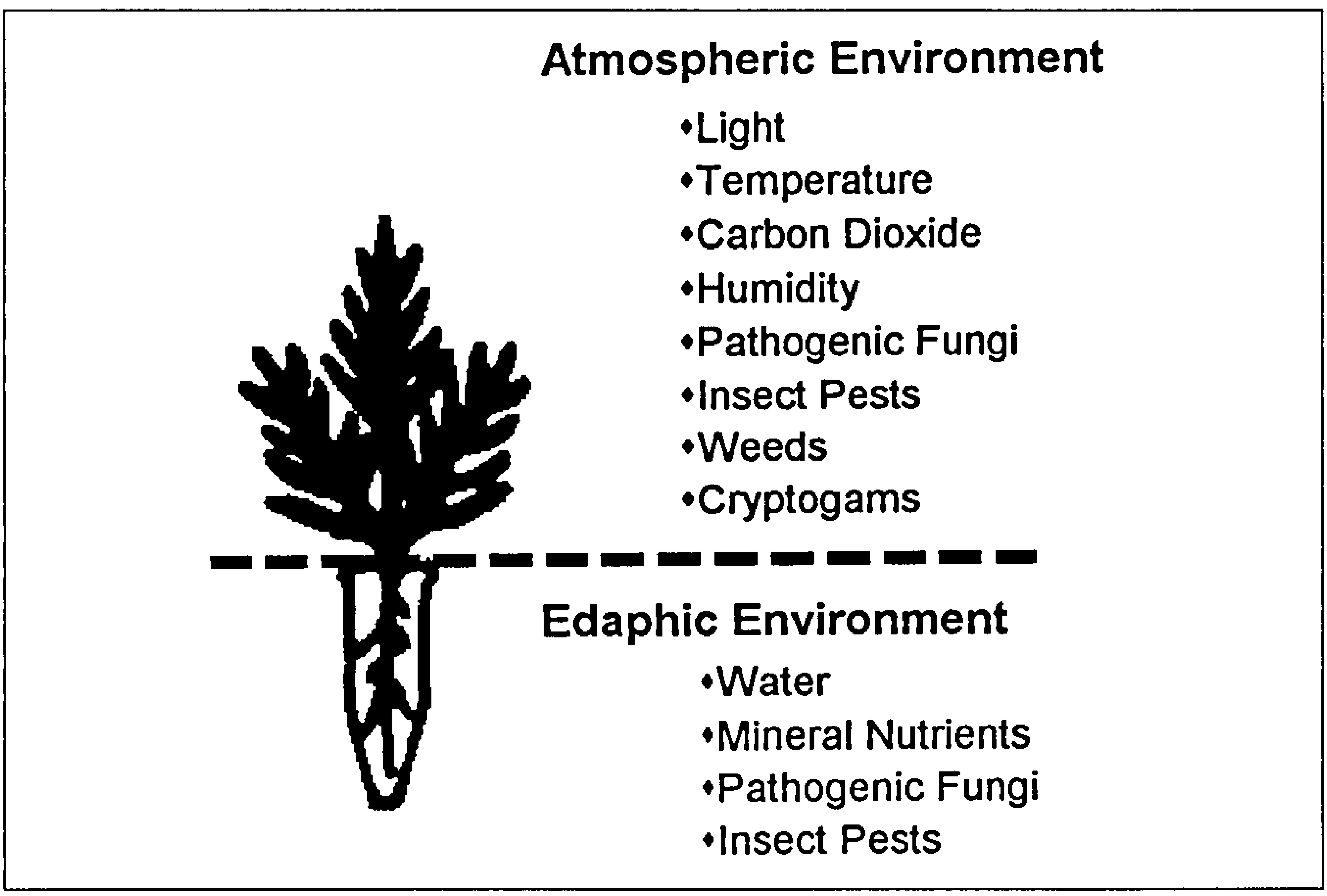

Figure 2. Environmental factors that can potentially limit growth in the container nursery environment.

Next, the nursery developer must determine the amount of environmental modification that will be necessary on the selected site. Of course, the costs of nursery development and operation increase with the amount of environmental modification that will be required. The nursery that matches the biological requirements of the crop to environmental conditions of the site will also be the most economical, and so nursery developers should devote ample time to site analysis before the type of propagation environment is selected.

Container nursery facilities can be categorized by their relative amount of environmental modification: fully-controlled environments, semi-controlled environments, and minimally-controlled environments.

FULLY-CONTROLLED ENVIRONMENTS

A fully-controlled growing environment requires a propagation structure that contains all the environmental control equipment necessary to keep all the potentially limiting factors at optimum levels (Table 1). Greenhouses are suitable for almost any type of climate due to the high degree of environmental control, reducing the risk of losing a crop to severe weather. The favorable growth conditions permit forest and conservation nursery crops to be grown year round with a rotation of 3 to 9 months, making multiple crops a distinct possibility. However, fully-controlled environments are the most expensive to build and operate, primarily due to high energy requirements.

Table 1. Potential to control limiting factors in different propagation environments.

	Type of propagation environment		
Limiting factors	Minimally controlled	Semi-controlled	Fully controlled
Atmospheric			
Temperature- high	No	Partially	Yes
Temperature-low	No	Yes	Yes
Humidity	No	Partially	Yes
Light-photoperiod	Yes	Yes	Yes
Light-photosynthesis	No	Yes	Yes
Light-quality	No	Yes	Yes
Carbon dioxide	No	Partially	Yes
Pests	No	Partially	Yes
Edaphic			
Water	Yes	Yes	Yes
Mineral nutrients	Yes	Yes	Yes
Pests	Yes	Yes	Yes

The traditional way of growing forest and conservation nursery crops was to start the seedlings in a greenhouse and then move them to a shadehouse for hardening. In fact, growers soon learned that the hardening phase was the most challenging and began to look at ways of modifying the crop schedule. Many began removing the greenhouse covering so they could harden their crops in place without the additional labor expense of moving the seedlings. Others began looking at structural modifications to the traditional fully-controlled greenhouse.

SEMI-CONTROLLED ENVIRONMENTS

This category includes a wide variety of growing structures which, as their name infers, are designed to control only certain aspects of the ambient environment (Table 1). Crops can be propagated in semi-controlled structures in all but the most severe climates. Depending on the type of structure, crops can be grown from spring to fall with generally one crop produced per year; winter crops are not economical in harsh climates. From an economic standpoint, semi-controlled environments are cheaper to build and operate, although there is considerable variation between the different types of structures.

To better suit the conditions in the western Oregon environment, a modified greenhouse was developed with a permanent transparent roof and flexible walls that can be rolled up (Hahn, 1982). This "shelterhouse" design permits considerable flexibility in environmental control. In the spring, or in unusually cold weather at any time during the growing season, the sidewalls can be lowered and heat turned on to maintain ideal temperatures. When ambient temperatures become favorable, the sides can be raised to permit natural ventilation, eliminating the need for forced air cooling. Other than these structural modifications, shelterhouses can be outfitted with any or all of the standard greenhouse environmental control equipment to modify most growth-limiting factors (Table 1).

Recently, computer technology and a variety of new shading materials have made many different types of semi-controlled propagation environments possible. Cravo Equipment Ltd. of Brantford, Ontario has developed an innovative new design which features a retractable roof which can modify sunlight and crop temperature as weather conditions change. The roof material can be constructed of transparent fabric or a variety of different shadeclothes. These retractable systems can open or close automatically in only 3 to 6 minutes allowing the crops to receive more light early in the morning and late in the day or throughout the day under partly cloudy conditions. Retractable-roof propagation structures are particularly suitable for crops that need to be fully hardened before shipping because they can be gradually exposed to outside conditions while being protected from climatic extremes.

MINIMALLY-CONTROLLED ENVIRONMENTS

Although open growing compounds are the least expensive way to produce forest and conservation crops, seedling 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. Cold injury to overwintered seedlings has also been a serious problem at some nurseries, and so open growing compounds are only used in relatively mild environments.

MANAGING THE PROPAGATION ENVIRONMENT—EDAPHIC FACTORS

Many growers focus on the atmospheric environment and forget they can also control the edaphic environment. Actually, due to the use of artificial growing media and the fact that irrigation and fertilization are easier in container nurseries, growers have relatively more control over edaphic factors. Container characteristics, especially container volume and spacing, control the availability of water and mineral nutrients. And, new developments in container technology, such as chemical root pruning with copper compounds, will change the way in which growers manage the edaphic environment.

The composition of the growing medium offers many opportunities to culturally control this potentially limiting component in the edaphic environment. A wide variety of commercial growing media offer different physical, chemical, and lately, biological properties. Exciting new options for managing the biological characteristics of growing media will alter the management of the edaphic environment. Specially prepared composts can be used to make growing media suppressive to root pathogens (Hoitink et al., 1991), and forest and conservation nursery managers are inoculating their media with beneficial microorganisms such as mycorrhizal fungi and rhizobacteria (Linderman and Hoefnagels, 1992).

THE IDEAL PROPAGATION ENVIRONMENT

Nursery managers have numerous opportunities to control the propagation environment both in the design of their nursery facilities and through their cultural practices. However, there is not one propagation environment that is ideal for every crop - what works well for one crop may be entirely inappropriate for another. By consulting the scientific literature and talking with other nurseries, growers can determine crop response to each of the potentially growth-limiting factors.

Nursery developers must carefully analyze the climate at their site to determine which potentially limiting factors need to be modified to produce optimum plant growth. Several new innovations in the design of propagation structures are now available and existing structures may be easily modified. Growers should also periodically analyze their propagation environments to determine if some aspect of their cultural regime may be limiting to the growth of their crops. Container growers should pay particular attention to the edaphic environment and consider the influence of their containers and growing medium. Fertilization and irrigation practices should be re-examined, and new growing medium components and amendments should also be tested.

Although the propagation environment is complicated and dynamic, the concept of limiting factors can help growers to design better nurseries and identify and correct problems in their cultural programs.

LITERATURE CITED

Hahn, P.F. 1982. Practical guidelines for developing containerized nursery programs. p. 97-100. In: Proceedings of the southern containerized forest tree seedling conference; 25-27 August 1981; Savannah, Georgia. General technical report SO-37. New Orleans, Louisiana: USDA-Forest Service, Southern Forest Experiment Station.

Hoitink, H.A.J., Y. Inbar, and **M.J. Boehm.** 1991. Status of compost-amended potting mixes naturally suppressive to soil-borne disease of floricultural crops. Plant Disease 75(9): 869-873.

Linderman, R.G. and **M. Hoefnagels.** 1993. Controlling root pathogens with mycorrhizal fungi and beneficial bacteria. p. 132-135. In: T.D. Landis, tech. coord. Proceedings, Western Forest Nursery Association; 14-18 September 1992; Fallen Leaf Lake, California. Gen. Tech. Rep. RM-221. Ft. Collins, Colorado: USDA-Forest Service, Rocky Mountain Forest and Range Experiment Station.

Odum, E.P. 1971. Fundamentals of ecology. Third Ed. Philadelphia: W.B. Saunders Company.

Whitcomb, C.E. 1988. Plant production in containers. Stillwater, Oklahoma. Lacebark Publications.