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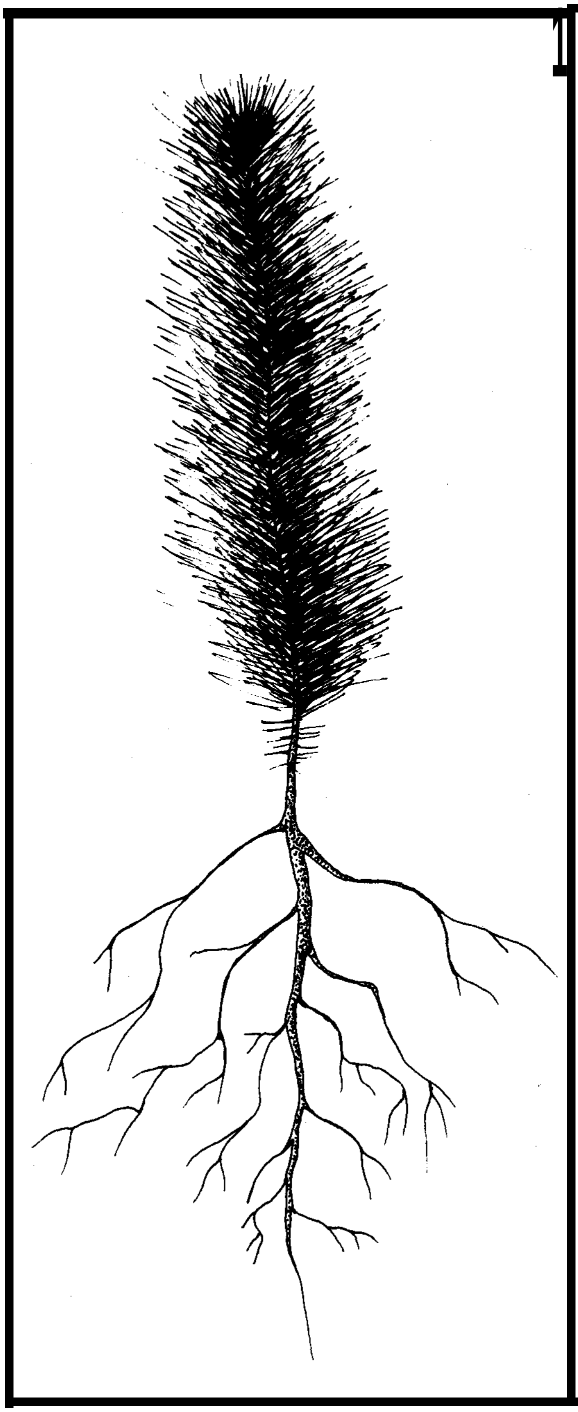
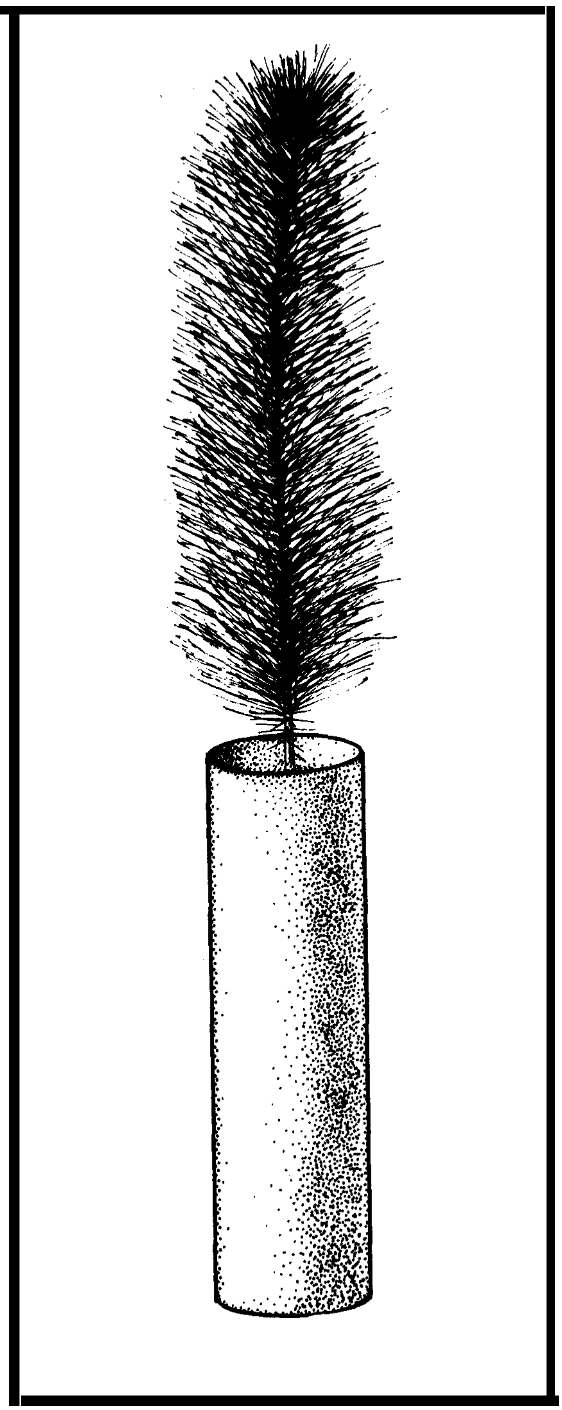
A Technical Guide for Forest Nursery Management in the Caribbean and Latin America

Leon H. Liegel and Charles R. Venator

An Institute of Tropical Forestry publication in cooperation with the University of Puerto Rico





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This manual is the product of 20 years of nursery, plant physiology, and plantation research programs at the Institute of Tropical Forestry, Southern Forest Experiment Station, Río Piedras, Puerto Rico. The research was conducted in cooperation with the University of Puerto Rico.

October 1987

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A Technical Guide for Forest Nursery Management in the Caribbean and Latin America

Leon H. Liege1 and Charles R. Venator

CHAPTER 1

I. INTRODUCTION

Forest nursery stock is produced by bare-root and container systems. Healthy seedlings are grown in either system if proper nursery management and techniques are used (fig. l-1). Each system has two levels of operation: 1) the *traditional way,* which is small-scale and usually hand-labor oriented, and 2) the more *modern way,* which is large-scale and highly mechanized. Level of mechanization in either system depends on available human and monetary resources and the actual number of seedlings that will be planted.

1.1 Purpose and Scope

This technical guide[1] is a comprehensive summary of forest nursery practices for the Caribbean, tropical Latin America, and, to a lesser degree, other tropical areas in the world. Included are actual and the authors' recommended practices, pointing out the advantages and disadvantages wherever possible with specific examples. Container and bare-root systems are discussed since both are used in the region, sometimes interchangeably within individual countries. However, guides for vegetative propagation techniques are excluded, except for passing reference in some sections.

The intent is to make the guide self-contained. Included are both traditional and modern approaches, with as many mechanical alternatives as possible. However, specific guides, such as fertilizer rates or herbicide rates, are difficult to prescribe because each country has its own problems with product availability and distribution.

1.2 Audience

The guide is *technical* because it is assumed that the readers are individual nursery managers or administrators who already have a graduate degree in forestry, agriculture, agronomy, crop science, or a related discipline and have practical nursery experience, at least in their own countries. Thus, all discussions are fairly detailed. More generalized guides are found in Chapter 7 of the Peace Corps Tropical America Reforestation Manual, now under editorial review. Definitions for pesticide (herbicide and insecticide) and other technical terminology are given in appropriate appendices or within individual chapters.

1.3 Subject Arrangement

This guide is divided into six major areas: 1) general stage setting for situations in the region, past and present, 2) overall nursery establishment and planning, 3) seed management, 4) small-scale (traditional) operations, 5) general management considerations, and 6) large-scale operations. Where subject overlap occurs within major sections, it is so indicated within parentheses.

Since each chapter is an individual unit, literature citations are placed after each chapter. For certain topics, more specific or "how-to-do-it" guides are given in various appendices. Rather than order these consecutively by numbering or lettering systems, a numbering system was chosen that refers to actual chapters where a topic is discussed in greatest detail or where it appeared first. For example, the first Appendix is number 4, because shading and nursery bed orientation are first discussed in Chapter 4.

Some subject matter overlap within chapters was intentional. For example, weeding and watering are critical concerns for early and later tending care of

[1]Funding for secretarial support was obtained from the U.S. Agency for International Development, project AID/SCI/E2/06: Growth and Site Relationships of Caribbean Pine. .in Costa Rica, Jamaica, Trinidad, and Venezuela, 1982–87.

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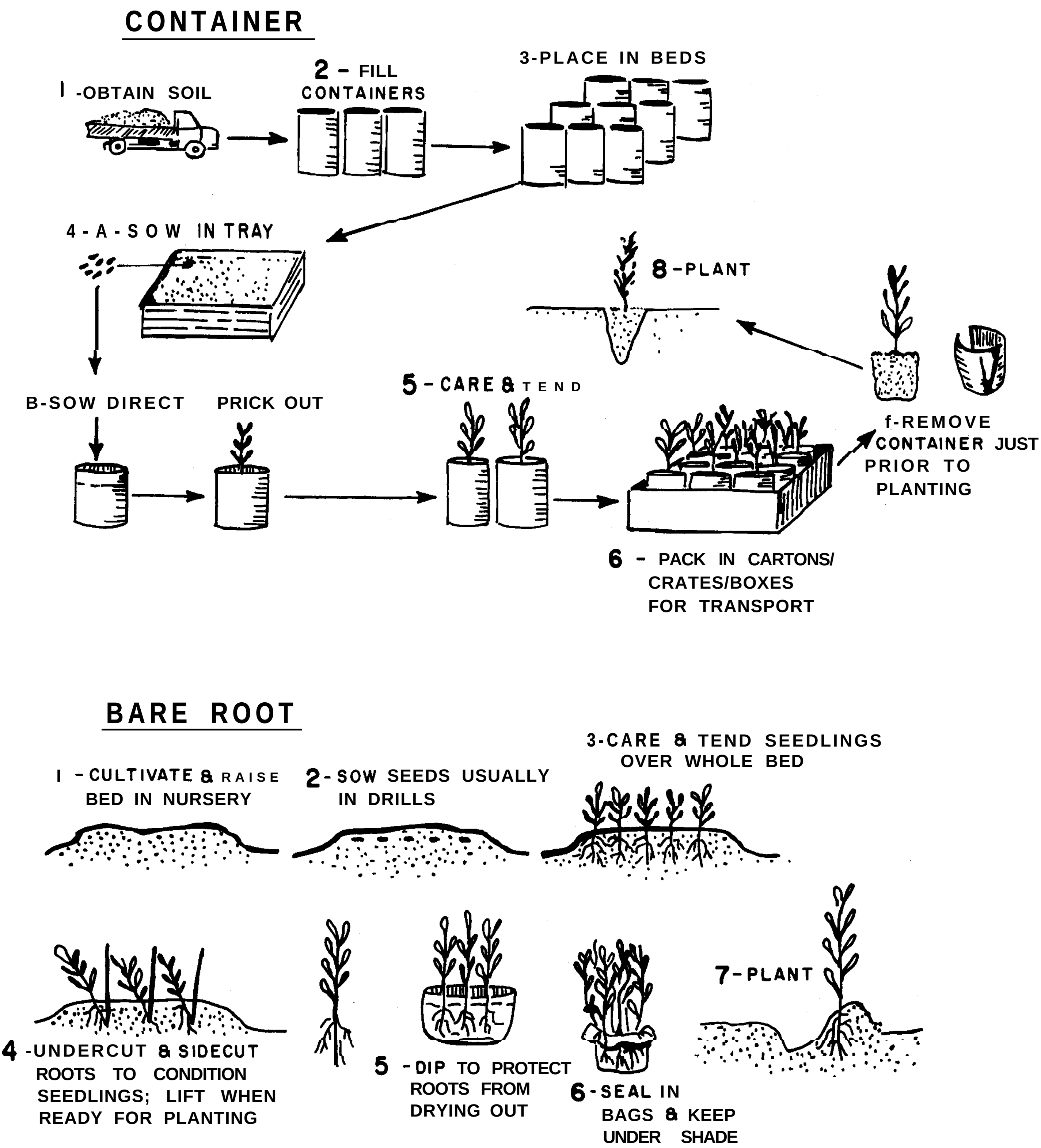

Figure *1-l.-Container and bare-root nursery procedures. Adapted from (1).*

bath mechanized container and bare-root systems. However, severity of the problem and effective controls are slightly different for each system; thus, these topics are discussed separately in each chapter.

1.4 Terminology

The terms "container" and "pot" are used interchangeably throughout the text. Both refer to individual or unitized entities containing some kind of growing material to support seedlings. Detailed breakdown of various pot or container types is given in Chapters 9 and 15 and Appendix 15.

The terms "pot mix" and "pot medium" ("container mix" and "container medium") are also used interchangeably, which may not suit the precise technical vocabulary of mechanized greenhouse operators. Yet both terms are used throughout the region, reflecting the usual practice of including more than one material in the growing medium.

"Plastic bag" is the shorter form of "polyethylene bag." The first form is retained throughout, except where another kind of material is used instead of polyethylene.

1.5 Source Materials

Most practical examples and illustrations are drawn from forest nursery experiences in Puerto Rico. Nursery research in Puerto Rico has been quite extensive because the United States has provided continual financial and personnel support for local reforestation efforts since the early 1900's.

Included, whenever possible, are examples and practices seen in the authors' travels in the Caribbean and Latin America or related by visitors and Peace Corps workers in this region. Because local nursery managers travel little outside the region, appropriate literature citations from nursery research done in the Asian and African tropics are included as well. Such references are not comprehensive but indicate the wide range of practices and problems existing elsewhere. Frequently, these citations will indicate other studies that may be of interest to some readers.

1.6 Physical Setting

The difficulty in prescribing specific nursery practices for individual countries is due in part to physical diversity in the countries themselves. The "tropics" is ordinarily delineated as areas between the Tropic of Cancer and Tropic of Capricorn. This area is large and includes geologically young, coastal plain soils; older dissected and eroded uplands; and steep mountain ranges having young volcanic soils. Climates may be very dry, almost desertic, to moist and very wet, all within relatively short distances (e.g., going from 700 to over 5,000 mm of rainfall annually within a horizontal distance of 185 km in Puerto Rico). Cultural values, traditions, and standards of living vary greatly as well.

As a result, the geological-soil-climatic-cultural mix of tropical countries is highly diverse and unique; generalizations are often difficult to make and support. For native workers and long-term residents of tropical regions, such diversity is normal and commonplace. When such diversity is overlooked, however, reforestation and nursery failures frequently occur because localized conditions do not meet idealized misconceptions of what tropical conditions really are. The authors have attempted to avoid overgeneralizations and misconceptions in this guide.

1.7 Dedication

This guide is dedicated to nursery managers and administrators throughout the Caribbean and Latin America. The authors hope that it offers them new ideas and alternatives for better utilization and more efficient use of their country's inherent natural, human, monetary, cultural, and social resources, both for short- and long-term planning.

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1. Evans, J. Plantation forestry in the tropics. Oxford: Clarendon Press; 1982. 472 p.

CHAPTER 2

2. REVIEW OF REGIONAL NURSERY PRACTICES

2.1 Puerto Rico

2.1 .l Traditional Approaches.- Designation of the Luquillo National Forest by President Theodore Roosevelt on January 17, 1903, signaled the beginning of a professional forestry program in Puerto Rico (*19*). In 1917, the U.S. Department of Agriculture (USDA) Forest Service was incorporated into the Puerto Rico Department of Agriculture and Works. In 1920, the University of Puerto Rico granted a small parcel of land in Rio Piedras for the first forest tree seedling nursery.

In its first year of operation, the nursery distributed 3,800 tree seedlings at no charge (*2*). Demand for seedlings increased so rapidly that by 1925 over

40,000 seedlings were distributed in 1 month alone. This total included 9,577 coffee seedlings. Shade tree seedlings for coffee plantations were also a significant part of the nursery's total production.

In 1926, a second forest nursery was constructed in Utuado; it produced coffee and shade tree seedlings. A third forestry nursery was established at the Polytechnical Institute campus in San German in 1927; it produced seedlings for private farms in western Puerto Rico. In 1928, the three nurseries distributed a total of 860,000 seedlings.

In 1934, tree distribution to private farms was put under control of the USDA Agriculture Extension Service. In 1936, a large model reforestation project was established on a private farm. This "Mercado project" marked a new direction for reforestation in Puerto Rico. Approximately 20 percent, of the 7 million trees distributed went to private farms. Of these, 60 percent were considered commercial species (*2*).

2.1.2 Nursery Consolidation.-Forest tree nursery construction continued at a rapid pace. By 1940, 25 small nurseries existed (2), primarily on state forests. Then, in 1945, two centralized nurseries were built, one in the Luquillo National Forest at Catalina (fig. 2-1) and the other at Toa Alta. All small nurseries were eliminated.

During the Civilian Conservation Corps era and afterwards, Federal funds helped plant some 10,000 ha between 1934 and 1954. However, between 1954 and 1963 only 720 ha were planted (*27*). The number of trees planted per hectare generally ranged from 1,700 to 2,950.

The decline in forest tree seedling production, beginning in the 1950's and continuing until the present, had its roots in two different areas. First, tree planting until 1954 was done on degraded and deforested land acquired by the Puerto Rican government and set aside as public forests. By the mid-1950's, about 50 percent of this total area had been reforested by direct. seeding with maria (*Callophyllum brasilensis*) and roble (*Tabebuia* sp.) seedlings or other species not suited for direct seeding. Second, private lands reforested in this period were usually large blocks abandoned from sugar cane plantations and coffee haciendas or lands acquired by consolidating small farms. By 1954, these areas were largely reforested to the extent desired by owners. The largest percentage of Puerto Rico remaining unforested in the 1950's belonged to small landowners who saw few economic rewards in reforestation.

In summary, the first quarter-century of nursery work in Puerto Rico was characterized by: 1) high dependence on hand labor techniques; 2) production of a very heterogeneous species mix of mostly hardwoods (e.g., about 75 species were used); 3) dependency upon U.S. Federal Government funds; 4) neglect of research; 5) exclusion of conifers except for a few Araucarias; 6) emphasis on producing coffee and coffee shade tree seedlings; and 7) emphasis on commercial species like mahogany (*Swietenia* sp.), eucalyptus, cordia (*Cordia* sp.), Spanish cedar (*Cedrela odorata*), teak (*Tectona grandis*), maria, and mahoe (*Hibiscus elatus*).

2.1.3 Nursery Centralization.-Seedling production took on a new dimension in Puerto Rico when nursery operations for the entire Island were consolidated at Monterrey, southwest of Dorado, in 1963 (fig. 2-2A). The nursery was located on a flat coastal plain site having ample room for expansion. Improvement for consolidating forest seedling production was paid in part with Federal funds.

Nursery production at Monterrey concentrated on those species showing superior growth and performance in the late 1950's and early 1960's: Honduras pine (*Pinus caribaea* var. *hondurensis),* kadam (*Anthocephalus chinensis),* hybrid mahogany *(Swietenia macrophylla* x *S. mahagoni*), and mahoe. Operations were labor intensive, with all seedlings produced in 10 by 25 cm vented plastic bags.

In 1975, to increase pine seedling production, a containerized nursery operation (see Chap. 15) for Honduras pine was established in Santa Ana, near Vega Alta. The intention was to separate forest tree seedling production from fruit tree production, which was also centered at Monterrey. Unfortunately, this project was abandoned in 1979. Annual production between 1976 and 1979 averaged about 300,000 seedlings that were grown in Styrofoam block containers.

Forest seedlings are now produced at Monterrey by the local Administration for Agricultural Promotion and Development (AFDA) for the Forestry Area of the Puerto Rico Department of Natural Resources (DNR). Plans were underway to increase pine seedling production to 2 million annually by 1984 (fig. 2-2B), using Styroblock and plastic bag stock. The DNR maintains its own small nursery on the Cambalache State Forest for mahogany, teak, and other hardwoods (fig. 2-3). During 1980-82, an average of 500,000 and 100,000 seedlings were distributed annually from the Monterrey and Cambalache nurseries, respectively.

2.1.4 The Catalina Nursery.- Bare-root mahogany seedlings are still produced at the Catalina nursery (fig. 2-1B). They are used in line plantings to upgrade understocked natural forest lands within the Caribbean National Forest. During 1982-85, production averaged 25,000 seedlings per year.

***2.1.5 The Experimental Nursery.*—**The Institute of Tropical Forestry (ITF) has maintained an experimental nursery in Rio Piedras for almost half a century (fig. 2-4A). Investigations from 1939 through the 1950's involved finding correct germination procedures and seed extraction and storage techniques (*10,*

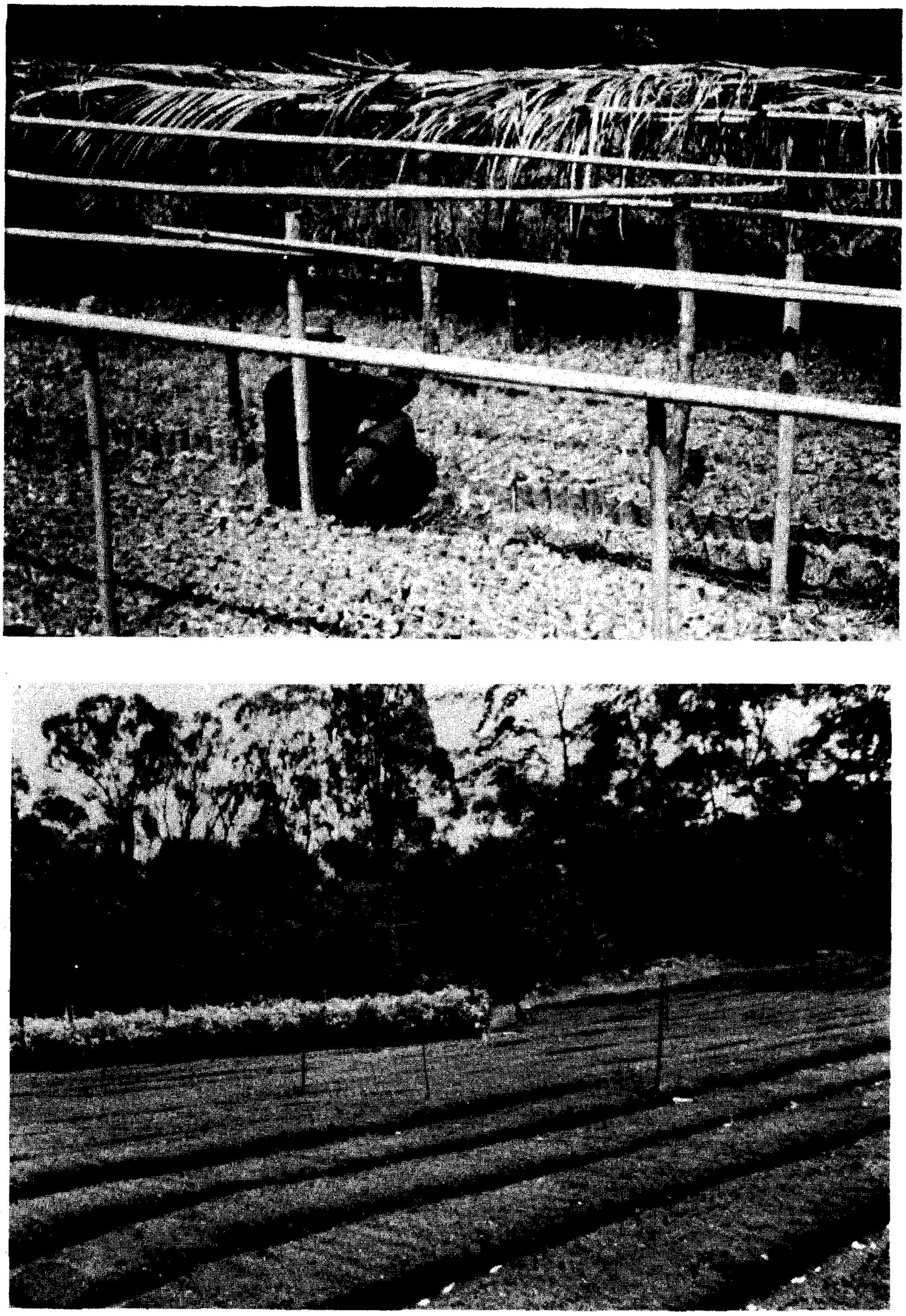

Figure 2-1.—*The Catalina Nursery. (A) From 1945 to 1963 [illegible] producing forest tree seedlings for the entire Island. (B) Today (1986) the nursery produces bare-root mahogany seedlings exclusively for line plantings to upgrade [illegible] lands within the Caribbean National Forest.*

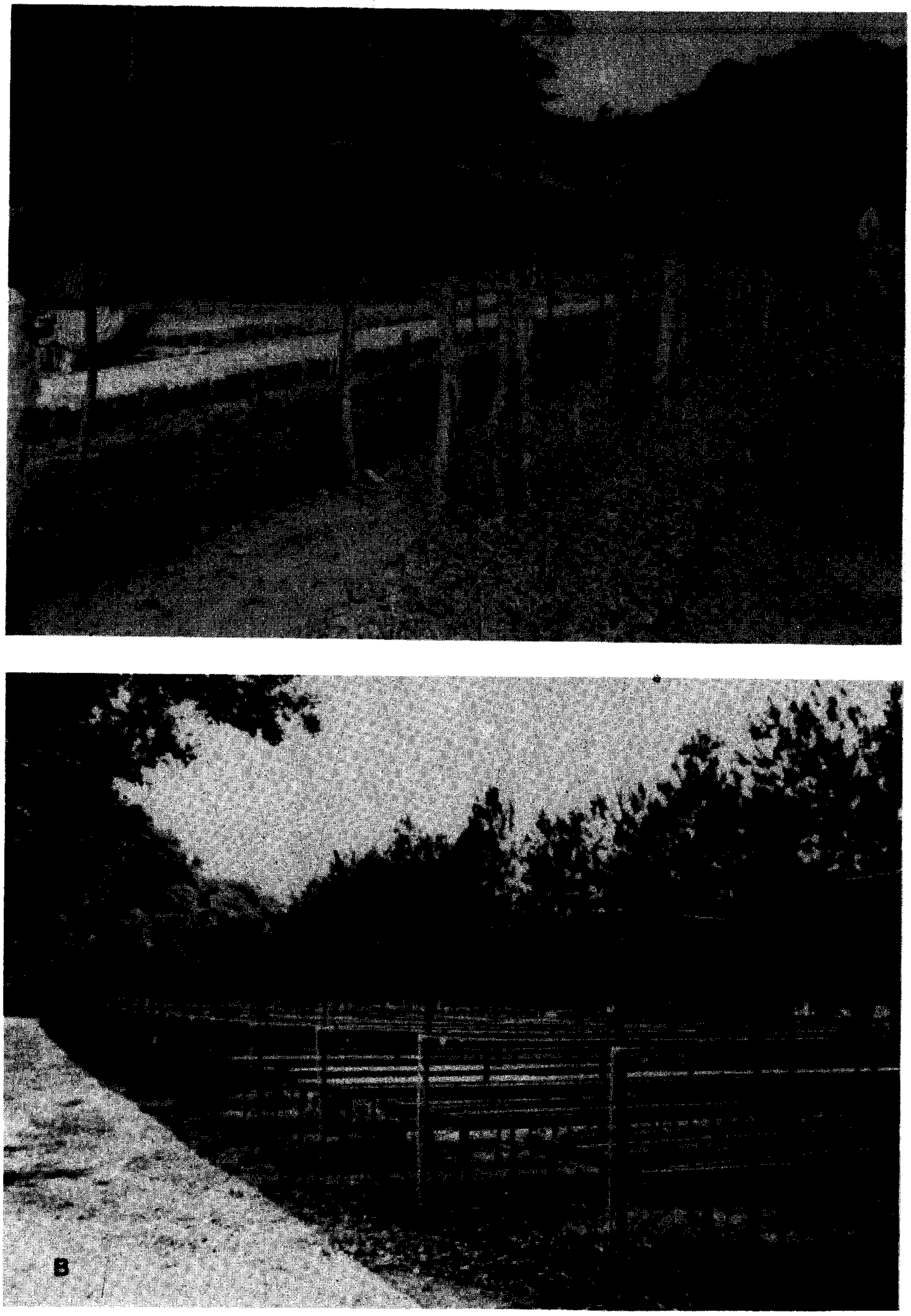

Figure 2-2.—*The Monterrey nursery in Puerto Rico. (A) As it appeared in the mid-1960's. (B) As it appeared in 1985.*

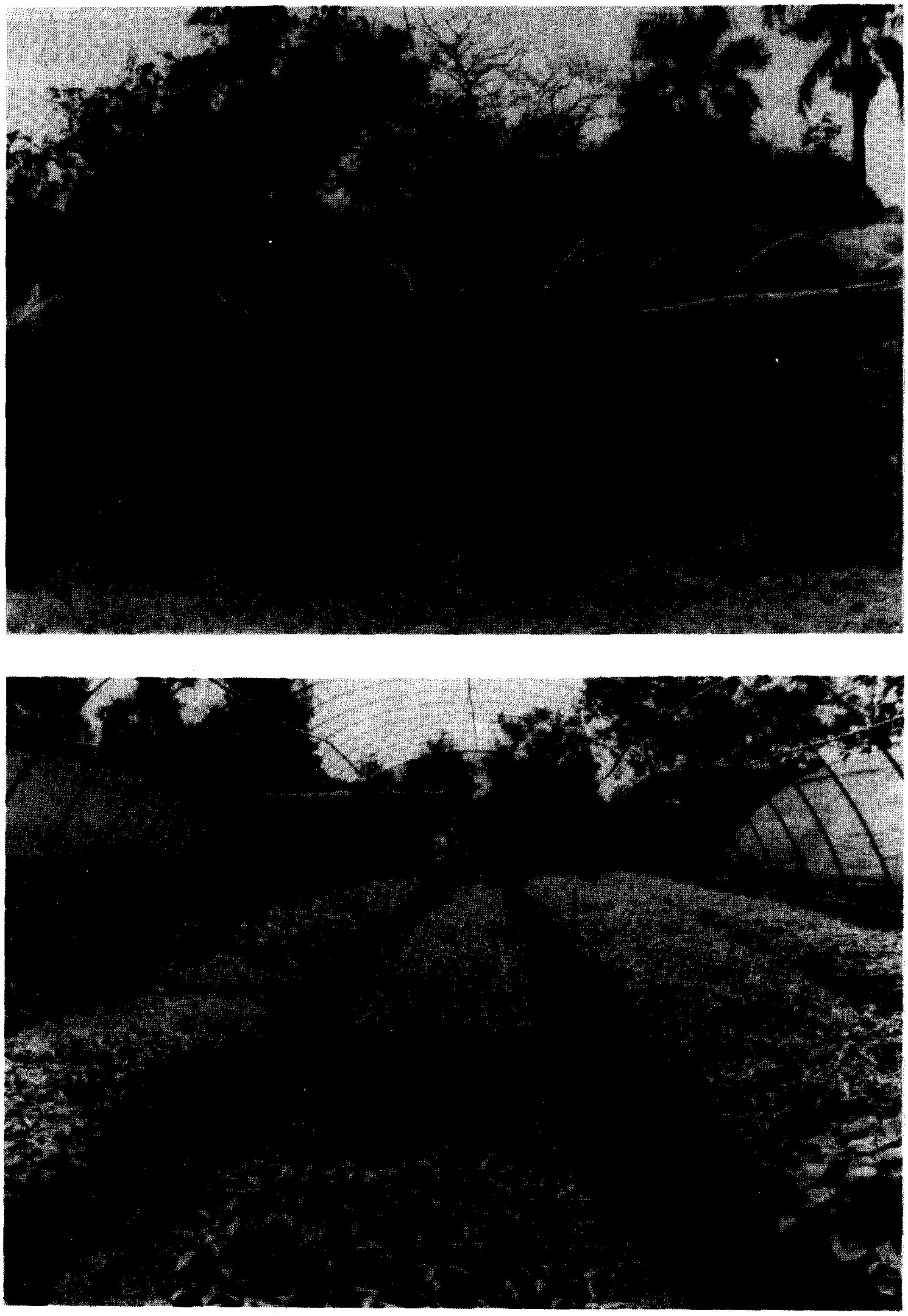

Figure 2-3.—*The Puerto Rico Department of Natural Resources Forest Division nursery at Cambalache State Forest. (A) Unshaded outdoor beds. (B) Beds where different shading intensities can be used.*

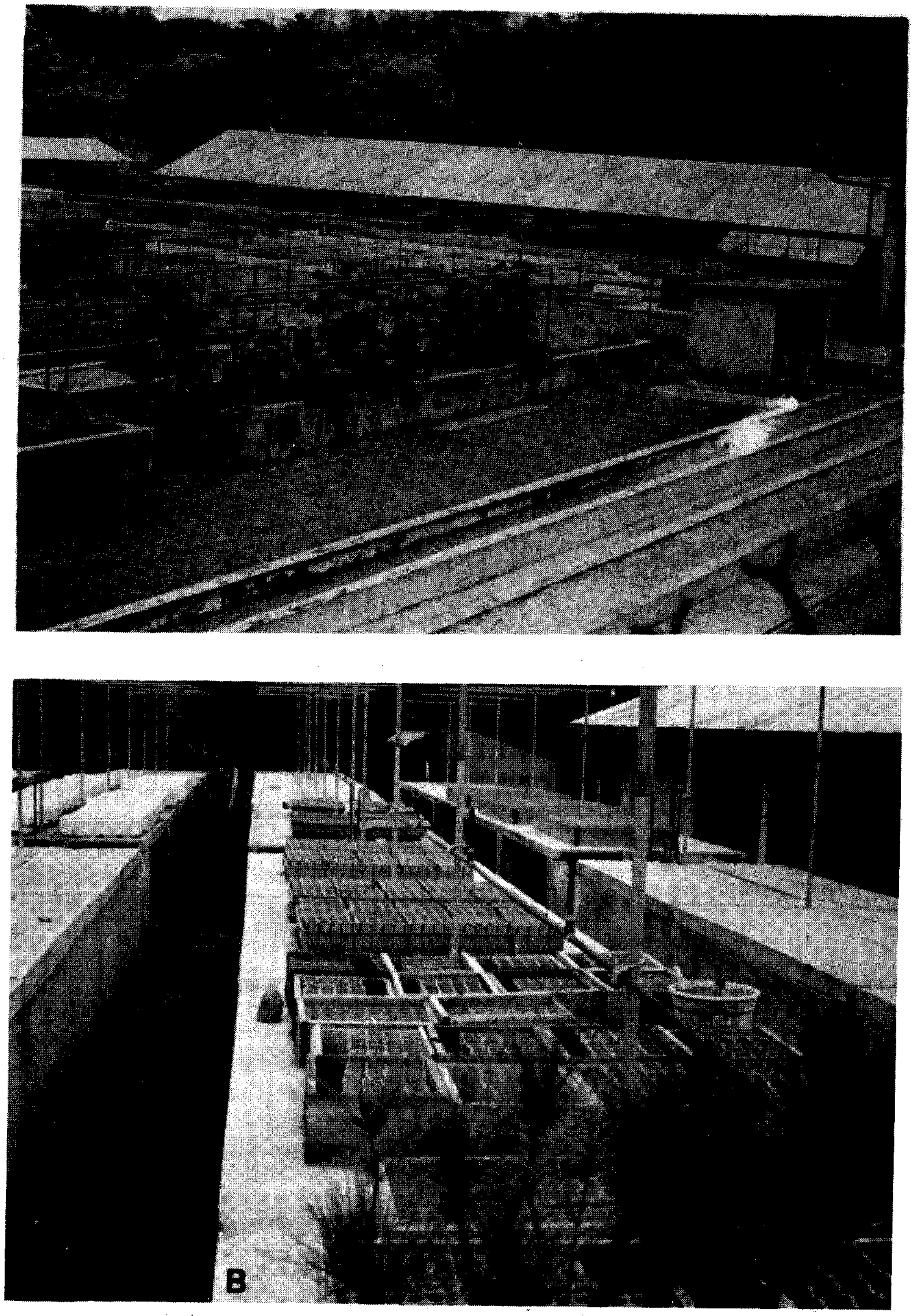

Figure 2-4.—*The institute of Tropical Forestry (ITF) experimental nursery, Rio Piedras, Puerto Rico. (A) Overall view of facilities, 1970's through 1984; bare-root and raised-bench container beds (center); open-sided, covered work* area *(top); small beds irrigated from below (bottom, right); and central irrigation pump house (center, right). (B) Several container systems that were tested in the mid-19705 for* Pinus caribaea *and* P. oocarpa *provenances: Styroblocks, book planters, and polypots, in addition to the traditional plastic bag.*

15, 16) for hardwoods and conifers tested in island-wide adaptability trials (*17, 18*). This early work successfully attributed poor pine growth across the Island to lack of native mycorrhizal fungi (*3*).

From the 1960's through 1978, ITF nursery research included germination tests and observations on seedlings used for small field trials of kadam and ***Gmelina*** provenances (C.R. Venator, unpublished materials at ITF); a local pine seed orchard (*7*); and international trials of mahogany (*22, 25*), teak (*4, 24*), and ***P. caribaea*** and ***P. oocarpa*** (*28, 29, 30*). Research on pines included suitability of bare-root (*2*) and container-grown stock (fig. 2-4B) (32). Survival implications of speed of germination, hypocotyl color and chlorophyll-a content, and emergence time of secondary needles were shown for ***P. caribaea*** varieties. (33) Albino or other "abnormal" seedlings were also reported (28).

Today, ITF has no ongoing nursery research program as it did from 1969 to 1978. Since 1979, only a few hundred to 1,000 or 2,000 seedlings have been produced annually. The facilities are used for summer student and thesis projects (6, 26) and short course training exercises (*11*). A small seed bank is still maintained for storing and distributing seeds to other governmental agencies for nursery research.

2.2 The Caribbean and Tropical Americas

2.2.1 Traditional Approaches.-Traditional nursery practices in Caribbean and Tropical nations are generally similar. Operations are labor intensive and small-scale. Forest Department or Forest Division staff manage the nurseries. The same staff provides technical assistance on where and how to plant seedlings that are usually provided at no cost (*1,* 27). Most seedlings are used to reforest blocks of land that, once cut over for agriculture, are now idle or abandoned. Small landowners clear and plant several acres each year on private lands, and government workers plant crownlands (21,231. Sometimes farmers receive cash incentives for tree planting.

Most countries have at least one small but permanent regional nursery that annually produces 10,000 to 30,000 seedlings of several species. In a large country like Jamaica, a regional nursery may produce 500,000 to 1 million or more seedlings per year. On small West Indies islands, temporary "flying" nurseries are established for special projects on local erosion control and improvement of understocked forests. Young seedlings are brought in from a regional nursery and grow to outplanting size under temporary shade, sometimes one large tree (fig. 9-3). Or, instead of using germinated seedlings, naturally regenerated seedlings (i.e., "wildings") located close to the flying nursery are dug up, transplanted into pots, and are left to grow to outplant size.

Agroforestry plantings are common when farmers interplant trees with food crops. When cultivation stops, the small tree crop remains. In Haiti, where population density is high, land is scarce, and fuelwood is even scarcer, seedlings are given to or bought by farmers who tend them in small parcels with food crops (*14*). After 2 or 3 years, the fast-growing trees are cut for fuelwood or charcoal; some trees may be left for post and pole production.

The most common problem in traditional reforestation practices is failure to plant seedlings immediately after obtaining them. If seedlings are not watered and protected from the sun or desiccating winds, they will all die before or shortly after planting. Nursery stock in large containers can withstand harsher conditions than stock in small containers when delivered seedlings are not planted immediately. However, when large containers are used, fewer seedlings are delivered to each landowner. Pines and eucalyptus are generally produced in containers.

Using bare-root and stump nursery stock eliminates cumbersome containers and allows easier distribution of larger numbers of seedlings to individual landowners (20). Not all species are plantable as bare-root or stump stock. Commonly planted bare-root stock are mahogany and ***Gmelina;*** teak and ***Gmelina*** are also planted as stumps (fig. 11-5B).

Two well-known traditional container production systems are those using tarpaper pots (34) and plastic bags (*31*). The somewhat mechanized tarpaper pot system was developed in Surinam and was adapted later by several countries. Major drawbacks of tarpaper plots now are cost and availability of tarpaper. For small and highly organized reforestation projects where tarpaper is readily available, the tarpaper pot system may work well.

The plastic bag system is widely used in American, Asian, and African countries. Clear and dark plastic are available, with small (400 cc) to large volume (>3,000 cc) capacities. Bags are usually filled with alluvial soil. In Puerto Rico, Trinidad, and Jamaica, sugarcane waste (bagasse), rice hulls, vermiculite, and peat moss are mixed with soil or compost without soil.

Each country, and regional nursery within a country, follows different practices for tending seedlings, including shading and applying fertilizers. Specific examples are given in appropriate chapters of this guide.

The biggest difference between traditional nursery practices in Caribbean and Tropical American countries is the type of container used to propagate seedlings. Common methods in any country depend on past traditions and customs as well as local organization of seedling distribution and planting efforts. The major goal is to produce seedlings that can survive rigors of small scale operations, Highly efficient and

Figure 2-5.—*Large-scale, bare-root seedling production of Caribbean pine* (P. caribaea *var.* hondurensis) *by CONARE (Compañia Nacional de Reforestacion) in Venezuela's eastern savannas.*

cost saving techniques are available to nursery managers, but sometimes these conflict with other overriding community goals of providing employment.

2.2.2 Nontraditional Approaches-Large countries with rising demands for wood products cannot obtain adequate numbers of seedlings for reforestation projects from small traditional nurseries. Instead, large-scale, semi- and fully-mechanized operations at large central nurseries produce millions of seedlings annually. Examples are Carton de Colombia's hardwood and pine plantings in Colombia's highlands (*12, 13*), CONARE's (*5*) operations in the eastern savannas of Venezuela with ***P. caribaea*** var. ***hondurensis*** and eucalyptus (fig. 2-5), and the JAR1 project's work (8, 9) in the Brazilian Amazon Basin with ***P. caribaea*** var. ***hondurensis, Gmelina arborea,*** and eucalyptus. In 1983, production was 30 million seedlings at three CONARE nurseries, each producing 10 million.

In large-scale operations, seeding, tending, lifting, and outplanting activities are highly organized. High outplant survivals require same-day planting of seedlings after lifting and transporting them to the field. Large-scale seedling production is suitable for both bare-root (CONARE-Venezuela) and containerized (Carton de Colombia-Colombia) nursery stock. Stump plantings were initially used for ***Gmelina*** at JAR1 in Brazil; yearly production once approached 1,000 ha and 1.3 million stumps. Before takeover by local Brazilian businesses in 1982, JAR1 field operations for ***Gmelina*** had changed to operational direct seeding on 500 ha.

Nontraditional, large-scale nursery operations for seeding, tending, and fertilizing are quite variable from country to country. Practices used depend on species planted (hardwoods versus conifers), soils (sands versus volcanic ash), local climate (dry versus moist or wet), and outplanting technique (machines or by hand). Some of these large-scale practices are explained in detail in Chapters 15 and 16.

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CHAPTER 3

3. NURSERY SITE SELECTION

Nursery site selection is done with considerable care and caution. Many ecological and economic factors influence the success or failure of a nursery. As minimum requirements, each nursery site must have sufficient area, suitable climate and soils, adequate energy and transportation facilities, water of adequate quantity and quality, and available labor to produce healthy seedlings. Some factors discussed for site selection may not be important if a nontraditional mechanized system (Chap. 16), rather than either a traditional container or bare-root system, is chosen for operational use.

3.1 Climate and Environment

Preferred sites are those with favorable climatic and environmental conditions that are neither too wet nor too dry. Long-term rainfall and temperature data will indicate whether normal rainfall is adequate for growing seedlings. Windy areas should be avoided to minimize windburn and desiccation effects on seedlings. Constant whipping of seedlings by wind is detrimental to growth. In the dry season, plants are often watered daily to avoid desiccation, particularly young seedlings or those recently transplanted. Experience in Puerto Rico shows that dry, gusty, February and March winds will desiccate young pine seedlings less than 4 weeks old if they are not watered sufficiently. Locating nurseries in the Caribbean between 90 and 300 m above sea level and well away from coastal areas will avoid wind-laden salt contamination.

On islands like Puerto Rico where predominant trade winds move from east/southeast to west/northwest, nurseries are best located on west or northwest slopes if flat protected valleys are unavailable. A west or northwest aspect provides greatest protection from wind, lowers evapotranspiration and creates more humidity among seedbeds.

When environmental alternatives exist for establishing forest nurseries, extremely dry areas, such as the southwestern coast of Puerto Rico, should be avoided. Dry climates are unfavorable for fast-growing species like pine, eucalyptus, kadam, cedar, mahogany, and *Gmelina.* The number of shade-free days in dry, semi-desert areas is also high, increasing transpirational water loss from seedbeds. The best nursery location in Puerto Rico is in the interior mountain range, which has the greatest number of days in which rainfall exceeds 2.5 mm (8). Major selection criteria for nursery managers in countries with predominantly dry climates (Haiti, Dominican Republic) are adequate sources of irrigation water and soils of low salt content.

3.2 Location and Essential Facilities

Locating nurseries close to major reforestation areas assures timely transportation of seedlings from nursery to field. Costs are reduced and fewer trucks are needed if seedling delivery trips are short. Thus, nurseries are usually located on major road systems connecting with planting areas. In Puerto Rico, the ideal central nursery location is in the western part of the Island where the largest tracts of reforestable land are found. For large operations, staff personnel housing on nursery grounds deters vandalism, creates strong job identification, and facilitates watering plants on long weekends or holidays.

Large, mechanized nurseries must have electrical power sources to operate equipment such as irrigation pumps, refrigerators, potting machines, typewriters, and lighting systems. Heavy machinery, including soil mixers, potting or packing machines, and saws, may require three-phase electrical lines. These are costly to install if no lines exist close to the nursery site. For areas without power or where power outages are frequent, a diesel-powered generator may be necessary.

Good communications are essential. If possible, nurseries should be located close to existing telephone lines or have radiotelephone communications between nursery and central forestry administrative offices. Such systems help coordinate field deliveries from the nursery headquarters. Regular mail service is needed to transmit seedling requests to the nursery and to inform interested landowners of the availability of the nursery's current stock and prices.

3.3 Soils and Topography

For drainage control, nursery beds should have a 0.2 to 1.0 percent slope; crossbed slope for the entire nursery area can be 0 to 2.0 percent. Sites subject to flooding and having rocky soils should be avoided (fig. 3-l). Soil scientists should be consulted throughout the entire site selection phase.

3.3.1 Physical Conditions.-For a containerized nursery, soil type may not be an important site factor. However, soil is very crucial in selecting bare-root nursery sites because all drainage and trafficability problems, as well as ease in lifting seedlings, are directly or indirectly related to soil texture (*1*). Selection of a good nursery site must be based on soil survey data and actual field visits, not on easy access or

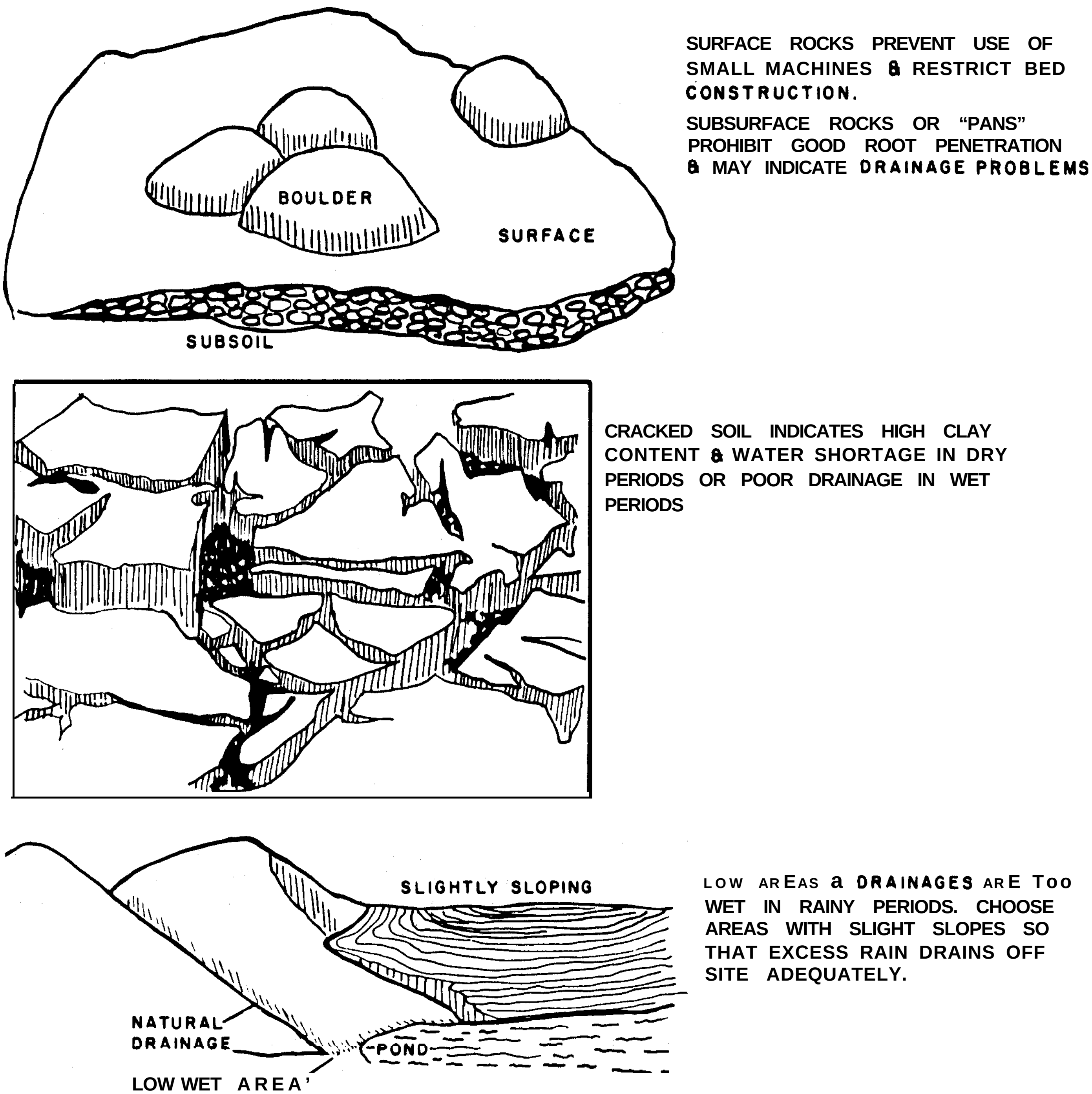

Figure 3-1.—*Poor nursery sites. Adapted from (9).*

economic advantage. In fact, because nurseries are long-term commitments, "sacrificing" the good physical and chemical properties of soils for other site factors such as closeness to paved roads or power lines *is not* recommended. These factors can be added later, whereas it is impossible to move a nursery once beds are contoured, water facilities are installed, and nursery buildings are finished.

In all cases, clay soils with high shrink-swell capacity must be avoided (fig. 3-l). Clay soils are also undesirable for raising bare-root seedlings because both large and small roots are broken during lifting (*4, 6*). Aeration is also poor in heavy clay soils, inhibiting seedling root development.

Soils that range between fine sand and sandy loam have the fewest problems related to soil texture. They do not readily compact as do clay soils. Other advantages of sandy soils are excellent drainage, fewer root rot problems, water more readily available to plant roots, easy tillage and no crusting-over following rains or irrigation, and suitability for heavy mechanical equipment used in constructing beds and maintaining healthy seedlings via various cultural activities.

When the nursery is contoured, all topsoil should be removed first and then replaced after grading is completed. Lifting properties of nursery beds are quickly altered if A and B horizons are mixed during plowing and grading operations. All physcial and mechanical analyses of soils at a potential nursery site should be done by a soil scientist on a well replicated basis (Chap. 14).

3.32 Chemical Conditions.-Soil acidity or reaction (pH) is probably the single most important chemical property of nursery soils. It directly affects other chemical reactions in the soil, the behavior of seedling roots, and soil micro-organisms around roots. Optimum **pH** varies according to the species grown. For tropical pines, the range is usually **pH** 5.5 to 6.0; when acidity drops below **pH** 5.0 or rises above **pH** 6.5, corrective action must be taken (21.

When soil becomes too acidic (below pH 5.0), lime ($CaCO_3$+$MgCO_3$) is added at rates usually ranging from 1 to 6 metric tons per ha. Actual amounts applied to any site depend on change in acidity desired, soil texture, and organic matter content. The kind of lime applied depends on the amount of available calcium and magnesium in the soil. Dolomitic lime is added to soils lacking both calcium and magnesium; calcitic lime is added when only calcium is needed. Soils too high in calcium and magnesium can induce trace element deficiencies in woody species. Acid-forming fertilizers such as ammonium sulfate or ammonium nitrate are added to lower high pH values (Chap. 13).

3.4 Water Supply

The lifeline of any nursery is the water supply. To produce seedlings that are ready for planting by beginning of the wet season, seedling culture must begin at the end of the wet season and extend through the dry season. Unless sufficient water is available, a serious problem can develop. Even small islands can have a wide variation in rainfall. For example, a nursery located on the dry, south coast of Puerto Rico usually has 260 to 300 rainless days or days with less than 0.25 mm of rain and only 30 to 40 days of 2.5 mm of rainfall (*8*). Also important are the number of wet versus dry months in each locality. A month is considered dry if it receives less than 50.0 mm of rainfall. Generally, artificial watering systems must be able to provide a minimum of 100 mm per month for conifers and 200 mm for hardwoods.

The water supply must be monitored on a regular basis to determine whether it contains excess salts or pollutants. If neither can be removed or lowered to acceptable levels, a new water supply is needed. Well water may be used, but in coastal areas excessive withdrawal may result in salt water intrusion to the aquifer. The ideal water source is a large pond or pollution free river from which water is pumped to an elevated tank and distributed under pressure through a sprinkling system. If a natural water source is unavailable, then treated water from a public waterworks can be used. However, proper authorities should be consulted first to determine whether sufficient water is available. Also, the waterworks authority has the technical expertise to determine whether sufficient water pressure exists at the selected site for high-pressure irrigation systems.

Salts and calcium must be monitored in natural water sources. Increases in both may raise soil alkalinity that in turn favors growth of root rot organisms. Conifers are more sensitive to excess calcium than broadleaf tree species. When the potting medium exceeds **pH** 7.0, conifers usually exhibit chlorosis because soil iron becomes less available. Under alkaline conditions, young leaves often emerge yellow. The problem is intensified if a sodium or potassium nitrate fertilizer is applied because potting medium alkalinity will increase even more. Soil or soil mixtures above **pH** 6.5 are less favorable for mycorrhizal fungi growth and tend to favor pathogenic fungi that cause damping-off.

3.5 Air

Air pollution is a potential problem for nurseries located close to highly industrialized areas or even in rural areas. Phytotoxic pollutants, including sulfur dioxide (SO_2), hydrogen fluoride (HF), and ozone (O_3), can be carried downwind from their source onto a nursery and settle out directly on seedlings (*3*). Pollutants may also be carried great distances by wind and then be deposited on seedling foliage and possibly cause seedling death.

3.6 Labor

Because nurseries require skilled and unskilled labor, they must be located close to cheap and available labor sources. If laborers must be brought in from far away cities, housed, and fed in work camps, expenses will be very high. Therefore, it is better to locate nurseries near towns or villages from which laborers can commute. Much nursery work is seasonal. Workers living nearby can supplement their nursery income from other jobs in their villages or on their own small farms (*7*).

Where project funds are limited, contracting for some production operations may be better than maintaining a permanent or seasonal labor force, particularly for traditional hand operations. Nurseries also employ several kinds of skilled labor. Employees are needed for applying pesticides or fertilizers, maintaining seed storage and germinating operations, and operating heavy machines and tractors.

3.7 Nursery Equipment and Tools

Organization and layout of a nursery require space for storage and maintenance of equipment and tools (*5*). An adequate inventory system must be implemented from the very beginning of nursery operations. If an inventory is not made and equipment not accounted for, many tools will be either lost or stolen and purchased in duplicate when they cannot be located. Time and money are wasted when tools or equipment are not readily available. One person should be given responsibility for equipment issue, retrieval, operation, maintenance, and repair.

A bimonthly maintenance and preventive maintenance schedule for major equipment should be implemented. For example, compost shredders, soil mixers, mechanical bag fillers, etc., should be greased regularly and covered to avoid dust accumulation during storage. When rust appears, equipment should be sanded and repainted with rust-inhibiting paint. In the moist and wet tropics where deterioration of mechanical devices is rapid, repainting schedules are frequent. In all climates, preventive maintenance is the only way to prolong the life and use of nursery equipment.

An equipment inventory should be taken immediately after the planting season has ended or at the earliest appropriate time thereafter. Thus, the nursery manager will know well ahead of time when to purchase equipment or supplies for the next season.

Some of the basic tools and equipment needed for a tropical nursery are listed below. The list may not be exhaustive for certain specialty nurseries; however, smaller traditional nurseries in developing countries can accomplish much with only a few of the items listed.

Adding machine
Adze
Anemometer
Apron, cloth
Apron, rubber
Auger, soil type
Autoclave, pressure cooker type, wooden and rubber
Balance, analytical
Balance, bar
Balance, spring type
Baskets, metal
Baskets, woven
Bench, sitting
Binoculars
Blackboard
Boots, rubber
Boxes, wooden bottom
Boxes, wire mesh bottom
Buckets, galvanized
Buckets, plastic
Burlap, bags and rolls
Cans, gasoline
Cans, watering
Carpenter supplies and tools
Chain saw
Cloth bags
Containers, large capacity measuring
Containers, polyethylene
Containers, tin
Crowbar
Cutters, wire
Desk lamps
Drafting supplies
Drilling, electric, plus bits
Drums, 208-liter, several
Electronic calculator
Electric bag sealer
Electric fan
Electric grinder
Files
Filter paper, for seed germination
Fire extinguisher
First aid cabinet
Flats, galvanized
Forklift
Freezer, for seed storage
Funnels
Germinator
Gloves, cloth
Gloves, rubber
Goggles, industrial type
Graduated cylinders
Grafting tape
Hacksaw and blades
Hammers
Hammer mill, large capacity
Hand cart
Hand lens, 10×
Hormone for vegetative propagation
Hygrothermograph, recording
Knives, grafting
Knives, pruning
Labels, dagger type
Labels, plastic slip-on
Laboratory chemicals and glassware
Machetes
Mallets
Masks, respiratory
Metalworking equipment
Microscope
Mirror
Mixer, soil
Nails, galvanized
Nozzles, fogg-it type
Office supplies and equipment
Petri dishes
pH meter, electronic and portable
Pickaxe
Pitchforks
Plastic trays, for seed germination
Pliers
Polyethylene bags
Polyethylene sheeting, black
Rakes, garden
Rain guage station
Rasps, wood

Refrigerators
Rulers, metric
Saran shade, 20, 30, and 50 percent
Saw, electric
Screwdrivers
Seed blower
Seed divider
Seed moisture tester
Seed separator
Seed sieve
Shovels
Shredder, for compost
Side cutters
Soil moisture tester
Soil sieves, large capacity
Soil sterilizer
Soil thermometer
Soldering equipment
Spray tanks, 11-liter, for fertilizer and pesticides
Stakes, wooden, treated
Storage bins
Tables, wooden or metal
Tape measures
Test tubes
Thermometers, recording
Tractors
Vise
Wagons
Welding equipment
Wheel barrows
Wire, galvanized
Wire mesh, 6-mm & 13-mm sizes
Wrenches, plumbing type

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CHAPTER 4

4. DESIGN AND LAYOUT

A permanent nursery is a long-term commitment and investment. As much care and caution should be used in designing a nursery as in choosing a site. Foresight in design and layout will increase efficiency in growing seedlings and in minimizing lost time for personnel.

Actual design and layout depend on whether a nursery produces bare-root or containerized seedlings, uses mechanized or nonmechanized techniques, and has a large or small capacity. Anticipated operation as a commercial ornamental (*2*) or commercial greenhouse (*6*) is also a concern.

4.1 Production Areas

Nursery production areas are dedicated to actual growing of seedlings, whether in mounded or ground-level bare-root beds, raised or ground-level container yards, or germination and propagation plant shelters. In small traditional nurseries, production areas make up 90 percent or more of the total nursery area (fig. 4-l). In large bare-root nurseries, as much as 50 percent of the production area may be left fallow each year (Sec. 16.1.2).

Production efficiency is achieved by locating each major operation in a specific area of the nursery. Within each area, fallow or unused beds may exist from year to year. In large operations, areas should include space for expansion. Bare-root beds are always located in those areas having the best soil chemical and physical properties.

Production area size depends on several factors. General considerations are size of entire complex, expected yearly production rates for species grown, seedling density in beds, kind of equipment used, and whether bed orientation is square, or rectangular and parallel, or diagonal to major buildings (2, 3). For bare-root beds, specific considerations include the number of rows in each bed, seedling spacing in each row, and minimum aisle width needed to accommodate equipment or hand labor. For container beds,

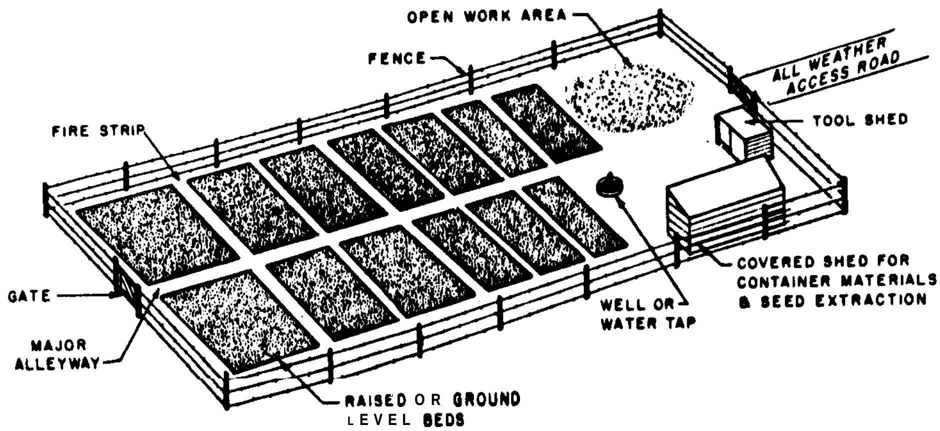

Figure 4-1.—*Generalized design and layout of a small traditional nursery. Most of the area is production oriented because operational, storage, utility, and communication areas are minimal. Adapted from (7).*

specific considerations are whether beds are raised or ground-level type, have hard or soft surfaces, have wide or narrow benches, and whether containers used are unitized or individual cells (figs. 15-1 and 15-6).

4.2 Administrative/Employee Areas

These areas should be located close to major access roads. Routine movement of personnel and vehicles should not disrupt other operations (5). For example, separate internal access roads for employee, delivery, and machine traffic are possible, as are separate facility entrances for field workers and visitors. Separation of administrative and nursery worker facilities (change areas, rest rooms, etc.) is another alternative. Certain common areas for parking, recreation, and meals provide opportunity for interaction between nursery workers and administrative personnel about mutual interests and problems.

Scale of operation dictates need for special facilities. Large nurseries have residence areas and an infirmary; a part-time nurse or doctor may be on call certain days or daily. Such facilities should be close to, but separate from, other buildings to ensure the privacy and well-being of persons needing them.

4.3 Storage-Shipping-Receiving Areas

These areas are the hub of most nurseries because they receive all raw materials for producing nursery stock. Access roads should be wide, all-weather type, and free of curves (fig. 4-2). Turn-around areas are needed for trucks entering and leaving the facilities.

Storage facilities must be large enough to accommodate daily raw material needs as well as spare parts for small equipment (grinders, power saws, mowers, etc.). Machine sheds and work areas for servicing heavy equipment are best located away from main facilities.

4.4 Operational Areas

Other areas are required for extracting, drying, and processing seed; preparing germination trays and pot mix; screening compost; filling pots; and washing, grading, and packaging seedlings (7). The key concern for these areas is maintaining flexibility and integrated flow of activities (1).

Flexibility' means the willingness to incorporate new machinery and procedures as needed to increase production or to change kinds of seedlings grown. It is best to overbuild new facilities to accommodate future activity shifts.

Integrated flow means arranging buildings, walkways, roadways, alleys, etc., to complement each other. For example, compost pits should be close to compost screening and mixing areas. Space is saved by *intentionally* designing certain areas to accommodate several activities. Open-air seed drying areas also serve for filling pots in good weather; covered, open-sided buildings double as lunchrooms and places where small construction jobs (e.g., making germination tray shade boxes) are possible in bad weather (fig. 4-3).

4.5 Herbicide and Insecticide Storage

Chemical storage areas are specialized operational areas because materials stored in them have toxic or caustic properties. All chemicals, including insecticides, fungicides, and herbicides must be protected from environmental elements. Suitable storage areas must be:

- located in separate buildings away from other areas used by humans and animals;
- constructed of fire-proof materials and hard-surfaced shelves and floors;
- accessed only by authorized personnel;
- kept dry, cool, and well-ventilated; and
- posted with proper signs advising of dangerous area (fig. 4-4).

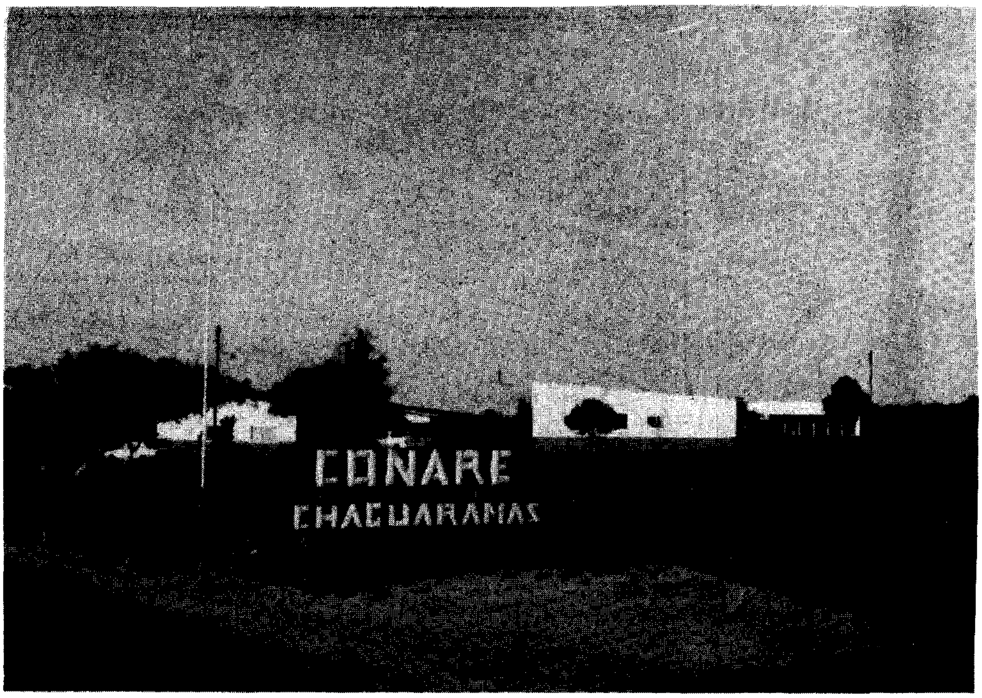

Figure 4-2.—*Hard-surfaced, split-access road to nursery facilities of CONARE (Compañia Nacional de Reforestacion), Estado Monagas, in Venezuela's eastern savannas, Right fork goes to laboratory and administration area; left fork goes to employee residence, meal, and recreation facilities. Not seen is* a *dirt road off left fork that leads to machine shop and storage area.*

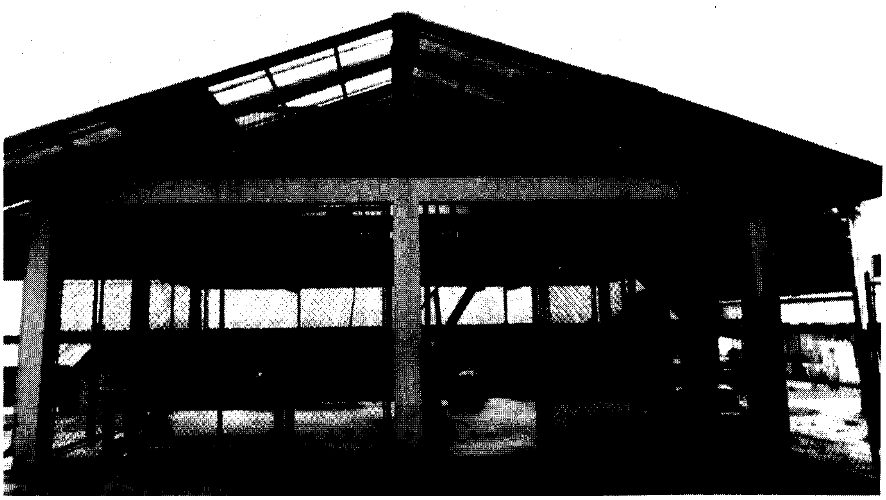

Figure 4-3.—*Covered, open-sided nursery building that also doubles as lunchroom, seed extraction and drying* area, *and carpentry area for making small items such as shade frames for germination trays.*

Figure 4-4.—*Pesticide and herbicide storage* areas *should be clearly marked, left dry, and kept locked when not in use.*

Insecticides and herbicides are always stored *separately.* All chemicals are stored in their original containers to avoid confusion with other products. Container lids or caps are tightly closed to prevent volatilization of liquids and escape of toxic fumes. If leaks are found, cleanup of remaining material and waste is done by following indicated label and standard safety instructions, using safety equipment (masks, gloves, respirators) when needed. For certain hazardous materials, local authorities may have to authorize final disposal. An up-to-date inventory should be kept of all chemicals, showing remaining amounts of liquid, solid, granular, and gaseous materials. At least one supervisor and one worker should be trained in all aspects of chemical use, storage, and handling so that routine and emergency procedures are understood and practiced.

4.6 Laboratory Facilities

Laboratory space is only essential for large nurseries. It provides a separate area to conduct pretreatment germination and storage experiments on seed, to test for soil pH and dissolved salts, and to monitor seedling nutrition at different stages of growth.

When many tests are planned, laboratory space may require two or more rooms. Soil screening and seed extraction procedures are "dirty" activities assigned to one room; "clean" chemical tests and procedures are performed in another. Clean and dirty labs are best located in separate buildings or different areas of the same building. Sensitive equipment (pH meters, spectrophotometers, atomic absorption units, etc.) requires continuous air conditioning to avoid corrosion of instrument parts in humid tropical climates. Other special needs for nursery labs are:

- apparatus for making distilled water for chemical tests;
- fluorescent lighting;
- voltage regulators to reduce power surges where electrical power interruptions are common;
- corrosion-resistant pipes in sinks where acid or alkaline chemical wastes are dumped;
- scrubbers to clean'toxic elements from fumes vented to outside areas;
- corrosion-resistant exhaust fans to direct harmful fumes away from seedlings, parking lots, and communal work or recreation areas; and
- cold storage to preserve chemical reagents, extractions, and materials needed in soil and seed testing experiments.

4.7 Utility Lines

Good design and placement of irrigation and electrical lines keep production efficiency high by reducing maintenance and repair costs. For example, locating irrigation pipes and pumps near production areas reduces both original and replacement piping costs (fig. 2-4A). Shutoff valve locations should be shown on maps of the nursery complex to help control emergency situations when leaks occur. Placing supports of overhead pipes away from roads and tractor alleyways reduces accidental breakage of water lines.

Corrosion-resistant fittings are essential for water lines and pumps, If irrigation water has high dissolved salts; large aperture nozzle fittings are required. A large supply of nozzles is needed where corrosion is a big problem.

Power and telephone lines are best placed underground to avoid potential damage from vehicles and storms. If overhead lines are used, they should be kept away from production areas and alleyways. When feeder power and telephone lines are placed in production areas, trenches must be deep and well marked, particularly in bare-root beds where tractor-drawn machinery is used. All water, power, and communication line locations should be clearly marked on overlays of the nursery complex blueprints.

4.8 Protection

4.8.1 Windbreaks. -Windbreaks are planted on windward sides of production areas and germination beds to reduce drying, eroding, and abusive effects of winds on growing seedlings. Ameliorating effects of windbreaks extend several times the height of mature trees (*4*). Large nurseries need several lines of windbreaks to adequately protect seedbeds. Usually, species different from those produced in the nursery are used because their seeds germinate like weeds and reduce effects of using improved seeds.

Species with large spreading root systems and crowns are not suitable. Shade from them reduces sunlight on nearby seedbeds; spreading root systems compete with bare-root seedlings for water and nutrients. Any insect or disease outbreak in windbreaks should be controlled quickly to reduce risk of spread to nearby nursery seedlings.

4.8.2 Shade and Nursery Bed Orientation.-An east/west orientation may be better than traditional north/south bed orientation in the tropics if individual, small covered beds are used rather than widespan shade houses. Justification for east/west orientation is based on: 1) need for some shade during the hottest part of the day and 2) minimizing the amount of shading material needed to provide shade protection for seedlings. Modern nursery management concepts also emphasize fostering as much environmental control as practical to reduce dependence upon nature's whims.

Puerto Rico lies at approximately 18" N. latitude from the equator. For maximum interception of the sun's rays, the shade roof should be tilted about 18" towards the sun. In other words, the north side of the east/west oriented shade roof should be higher than the south side (see Appendix 4 for a schematic view of inclination direction).

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CHAPTER 5

5. PRODUCTION SCHEDULING

5.1 General Principles

The key to a successful nursery program is planning and developing realistic timetables for all phases of seedling production; this is called production scheduling. Schedules are based on knowledge of nursery physical plant limitations and managerial experience. A detailed production and planning schedule like that described in Appendix 5 can be developed for large, mechanized operations. For smaller nurseries, a simple flowchart shows essential elements of seedling production (fig. 5-l).

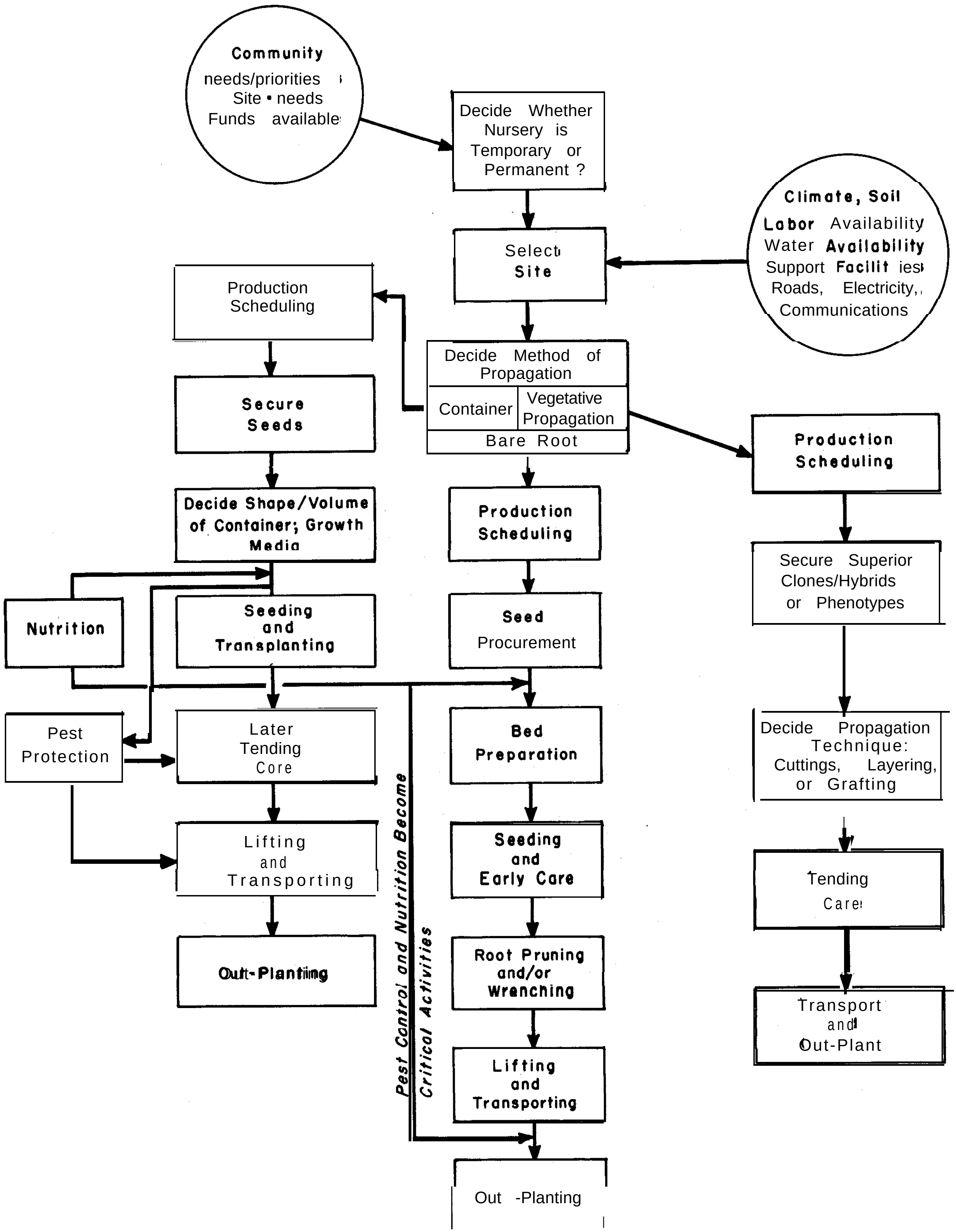

Figure 5-1 .—*Flowchart of procedures for successful nursery establishment and seedling production.*

Before initiating production schedules, a manager must obtain all equipment, materials, and supplies needed to produce the desired number of seedlings (3, *4*, *8*). Managers work closely with all groups requesting seedlings, including private industries, government agencies, and individuals. Maintaining good working relationships with nursery personnel is essential to smooth and efficient execution of production schedules.

Each step in a production schedule is identified, then listed in sequential order. Major production steps are then divided into minor ones. Breaking down the operational process into individual steps allows a manager to prepare lists for needed equipment, materials, and supplies. A good diagram will reveal potential problems in the production process, or it might indicate that more than one piece of equipment (e.g., two soil mixers) are more efficient than one piece for a particular operation. Individual steps in the production process can be translated to a standard work unit, for example 1,000 seedlings per man/hour. All nursery operations should be constantly under review for potential improvement (*1*, *2*).

To make realistic production schedules, nursery managers must know how and where to use each piece of equipment or procedure. They must be able to make adjustments and repairs or know where and how soon repairs can be made. Usually, they introduce new techniques and ideas and train supervisors to use them. Also, managers must 1) make sure laborers use equipment properly, efficiently, and safely and 2) stay abreast of new techniques and developments by reading nursery publications, visiting other nurseries, and attending nursery conventions on a regular basis.

Innovative nursery managers must not be content to let local traditions and labor habits dictate seedling production methods. If this happens, an entire program may be adversely affected. Periodic changes are often required that might upset work habits and traditions (*7*). To minimize conflicts with personnel and traditions, managers must educate their employees about the reason for and benefits of any changes.

Managers should also be cognizant of special community needs and realities. For example, although a semi-mechanized container operation may produce more seedlings in a shorter time than a less automated, more labor intensive operation, the latter may eventually be chosen. Such a decision would reflect long-term reforestation as well as socioeconomic program needs to utilize unemployed local labor (*5*). Employing local laborers promotes community self-help and fosters grass roots acceptance of nursery and reforestation objectives (*9*, IO).

5.2 Some Specific Principles

5.2.1 Overall Planning and Coordination. -Coordination is required so that managers do not produce seedlings at the wrong time of the year. For example, if normal planting lasts from the beginning of the rainy season until 1 month before the rainy season ends, seeds must be sown to produce seedlings throughout the entire planting season. If a forester in charge of planting needs 1 million seedlings of a specific species, height, and age between August 1 and December 1, the nursery manager must translate this information to a production basis. A certain percentage of each nursery crop contains cull seedlings that do not meet **outplant** specifications. Generally, at least 10 percent more seedlings are produced than are requested to allow for cull seedlings. The actual cull factor is determined by careful observation over several years.

5.2.2 Disease.-Disease may also eliminate some seedlings, requiring an even greater margin of safety. The possibility of diseases killing a high percentage of all seedlings is a constant threat in any nursery. If seedlings are produced on a staggered basis, the threat of total crop loss from a single disease is minimized. Reducing losses from disease is crucial in areas where entomologists and pathologists are locally unavailable.

5.2.3 Seedling Growth Rates. -Managers rely primarily on experience to determine how fast seedlings grow. For example, in some nurseries it may be possible to produce *P. caribaea* seedlings 25-30 cm tall between November 1 and May 1 (i.e., in only 5 to 6 months). However, if seeds are sown in December, it may take 6 to 7 months to produce the same-size seedlings. This time difference is caused by slower seedling growth from February 1 to April 30, the normal dry season in that nursery area. Production scheduling is therefore based on expected growth rates determined by personal knowledge and previous growth records.

5.3 A Case Example

In this section a nursery production system is described in detail, with special emphasis on major operational steps. Basic arithmetic calculations for determining amounts of potting medium, seeds, and other materials needed are given in Appendix 9. The example is limited to production of *P. caribaea* seedlings using soil, plastic bags, and hand labor.

This concept can be applied to other species, and the system described can be established in almost any area having adequate water supply and level terrain. The system is easily modified to accommodate temporary nurseries. In contrast, a highly mechanized container production system is discussed in Chapter 15.

For the plastic bag production system described here, assume that a nursery manager must produce 1 million pine seedlings and that the seedlings are needed between August 1 and December 1, the most favorable planting dates in his area. For adequate lead time to order new supplies, actual seedling requests should be submitted at least 1 year before the projected planting date. Under usual growing conditions, *P. caribaea* seedlings are ready to outplant 7 months after germination, when they are 25 to 30 cm tall and have a root collar diameter of 5 mm. If seedlings are grown in large bags (>400 cc) with soil, they can usually be held in a nursery for 2 to 3 additional months without seriously affecting their outplant survival and growth. When held longer than 7 months, potted seedlings must be root-pruned before outplanting to remove balled or entwined roots. Root pruning avoids potential problems of greater windthrow and disease incidence, which are associated with poor root form.

An experienced nursery manager knows that a minimum of 7 months is required to produce plantable seedlings; this factor is taken into account when making a production schedule. Ideally, the production process is split into several manageable phases, with subgoals of producing 200,000 healthy seedlings for outplanting on five dates the following year: August 1, September 1, October 1, November 1, and December 1. Staggered production avoids having all seedlings ready to outplant on the same date. Furthermore, when seedling production is separated into distinct phases, there is less risk of seedling loss to a disease like damping-off.

The manager's objective is to produce the quality and quantity of seedlings ordered on dates specified. As stated in Sections 5.2.1 and 5.2.2, extra seedlings are grown to replace cull seedlings and those killed by disease. It is generally unwise to hold small or slow-growing seedings for long periods. Accumulated evidence shows that small, unhealthy seedlings are genetically inferior to normal, vigorous seedlings and grow more slowly after outplanting. To obtain vigorous seedlings, use quality seeds selected from superior tree seed sources whenever possible or ordered from reputable seed suppliers.

A real problem with tree species in great demand is purchasing adequate quantities of seeds. One example is ***P. caribaea*** var. ***hondurensis,*** for which 1 kilogram of seed in 1986 cost up to $300, with improved seeds costing even more. Managers must make personal contacts with seed dealers to arrange for supplies well in advance of anticipated.sowing and production runs. Once seeds arrive, managers must decide if and how they should be stored, when they are to be planted, and in what proportions (6). Sowing rates for a production run are estimated from replicated trials showing germination percentage for seed lots that will be sown. Remaining seeds are stored as described in Chapter 6.

The most difficult part of any production run remains after sowing: growing seedlings to term. Constant monitoring is needed to determine moisture and nutrition needs. Vigilance is required to prevent insects and diseases from destroying seedlings. Weeds must be controlled. Additional concerns are abnormal short-term climatic influences (droughts or abnormally rainy periods) that might affect seedling growth and disasters like fires or hurricanes. Against fires, the precautions mentioned in Chapter 12 should be followed regarding facility security. If a hurricane is imminent, containers should be moved to protected areas (fig. 5-2). If bare-root beds are sloped properly

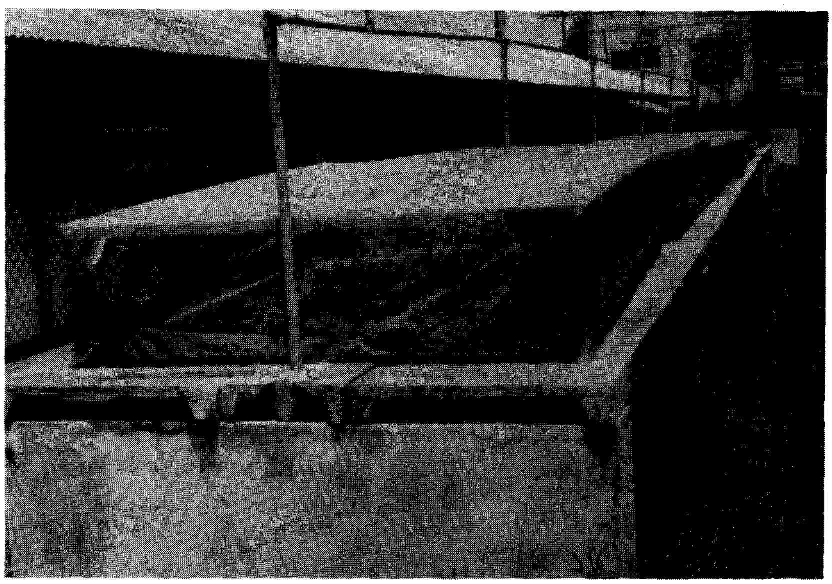

Figure 5-2.—*Storage space under raised cement benches can be used to temporarily store containerized seedlings during severe storms. Saran-covered box frames on benches protect newly-sown seed in germination trays from birds;* **using** *close-mesh metal screening instead of saran will protect trays against rats and mice.*

and soils are well drained, bare-root stock will survive all but the severest storms.

Once seedlings make it to term, they must still be lifted, packed, and transported to the field. Improper procedures in any of these later stages can cause undue mortality and reduce seedling vigor or health, As with all preceding production stages, only foresight and careful planning will avoid potential problems such as lack of packing materials and pallets, transport vehicles, or proposed vacation schedules for drivers and workers who must be present for the packing and transporting phases.

Skilled managers review all production phases carefully, well in advance of each production run. If planning is executed rigorously and if nursery managers are observant of daily changes in natural and work environments, each production run, large or small, should be successful.

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CHAPTER 6

6. SEED PROCESSING AND STORAGE

Seeds bought on consignment are already extracted and cleaned but must be stored properly. However, when fresh seeds are collected from local sources, they must by properly cleaned and prepared for either short- or long-term storage. This chapter reviews the fundamentals of seed processing and seed storage. More detailed information on these topics and on seed harvesting and transporting techniques is found in USDA Forest Service Agricultural Handbook 450 (*17*).

6.1 Fruit Types and Processing Practices

Seed processing includes drying and initial extraction, cleaning, culling damaged or empty seeds, reducing and maintaining proper moisture content, and, if needed, applying protective treatments like fungicides (2, *16*). Processing techniques vary slightly for the major fruit types: cones (pines), fleshy fruits (kadam and teak), and dry fruits (mahogany and *Cordia* sp.) The goal in processing each of these fruit types is maximum production of clean, viable seeds.

Of these seed processing practices, the most important is obtaining proper moisture content. Excess moisture can cause mold on seeds in storage. Mold is the most serious threat to seed viability. Therefore, several seed drying techniques are discussed. Other practices also important when processing seeds include cleaning, maintenance, and adjustment of extraction equipment; preventing accumulation of flammable dust, resin, or debris; following safety guidelines; and using approved safety devices whenever required (e.g., use of dust masks when separating seeds from dirt and chaff).

6.2 Cones and Dry Fruits

6.2.1 Initial Inspection and Handling. -Newly collected seeds must be carefully checked for disease, insects, mold, and external moisture or dampness (which could cause mold at a later stage). Using plastic bags for seed storage and transportation is unsatisfactory because impermeable plastic traps condense moisture inside bags. Green cones, pods, and dry fruits usually contain lots of moisture (14). Consequently, heat buildup will occur inside the bags through cellular respiration, and mold can then develop because of the humid, warm, and dark conditions in tightly packed bags. Thus, excess moisture must be removed immediately after seeds arrive in the nursery. Permeable paper, cloth bags, and cleaned burlap bags are best for collecting seeds; they are cheap and avoid moisture buildup, particularly when seeds are packed loosely in them.

6.2.2 Air-Drying.-Most damp seeds, cones, or pods can be air-dried. They are placed on protected drying screens or trays that allow sunlight and air to pass through but keep out rain. Cheap and effective driers use elevated racks, allowing air circulation from below (fig. 6-l). The same design principle is used for simple, portable seed drying racks or large drying sheds.

Drying screens and racks are basic seed processing equipment. Because most seeds lose germination vigor in processing, drying of external or surface moisture is done as quickly as possible. Seeds should never be left for long periods in drying racks. Even at ambient temperature, drying seeds will lose viability. Seeds are normally exposed to full sunlight for only 2 or 3 days. For uniform drying, seeds are evenly spread over the screens. A thin layer of seeds dries more

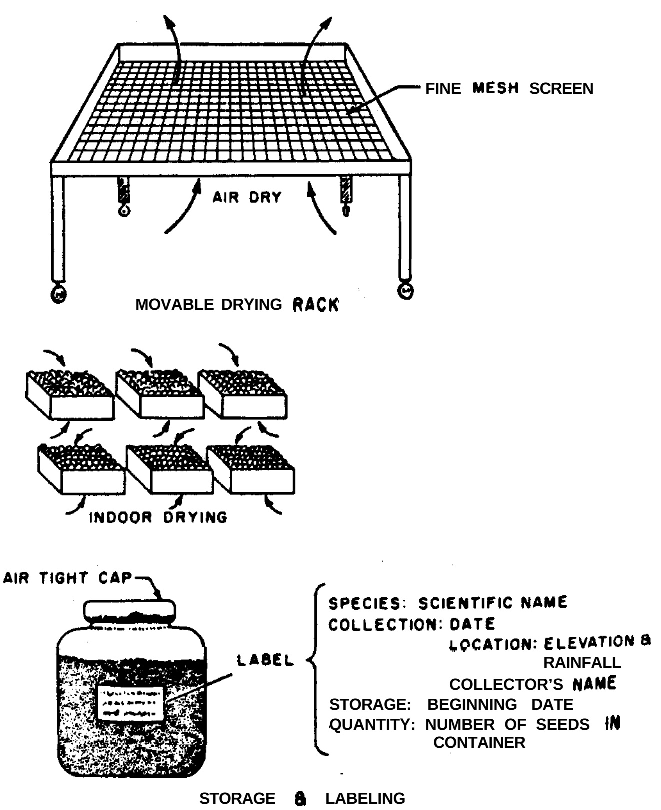


Figure 6-1.—*Seed drying and storage procedures. Adapted from (21).*

quickly than a thick layer. Seeds are stirred or turned over 2 to 3 times each day, allowing exposure of the entire seedcoat to the sun's rays. Air-drying is basically a quick way to remove external seed moisture; it prepares seeds for sizing, dewinging, cleaning, and separating filled from empty seeds (Appendix 6).

Processing large cone crops requires similar drying precautions. Sacked cones bundled too tightly cannot open fully and will obtain a "set" that precludes seed extraction (3). Packing sacks too close together stops adequate ventilation, causing heating and molding.

When small quantities of seeds are dried outside, on the ground or on paved driveways, one must be able to cover them quickly or move them inside when it rains. Similarly, seeds must be covered during the evening hours to avoid dewfall accumulation. A drying rack with wheels is easily moved to sheltered areas (fig. 6-l). All seeds must be screened from rodents and birds during drying.

6.2.3 Kiln-Drying. -Large quantities of seeds, cones, or pods are usually kiln-dried. Kilns have many sizes and shapes. Two general types are the rotating-drum kiln and the large conveyor-belt, progressive-type kiln. Drum kilns are fairly efficient because their rotating or tumbling action also separates seeds from pods or cones. For small seed batches, a small rotating-drum kiln is probably the best purchase. Seeds are removed from inside the drum as soon as possible because excessive tumbling is harmful.

Most large kilns are heated by natural gas or electricity. The kind of fuel used has no influence on drying; the least expensive or most readily available fuel is used. Large kilns have automatic controls that graduate and maintain specific heat and humidity levels. If kilns have sensitive controls, cones are opened and seed moisture content is lowered sufficiently for long-term cold storage. When kiln-drying cannot reduce seed moisture content sufficiently, seeds are dried further in convection ovens.

Kiln temperatures should not exceed 54°C for pines. Mahogany and cedar pods are forced open by kiln drying at 43°C. Kilns are readily constructed from local materials. The major task is providing adequate air circulation and maintaining an even flow of uniformly distributed heated air throughout the chamber. Drawings of custom made kilns are available upon request (8).

6.2.4 Solar Dryers. -Solar dryers are used for extracting seeds in the tropics, where the number of days with full sunlight is high. An experimental solar dryer at ITF (fig. 6-2) is rountinely used to open mahogany pods, cedar pods, and pine cones and to dry seeds of various species. Under normal sunlight conditions, pods and cones open within 3 to 4 days. Failure to stagger cone collecting over normal field maturation results in an accumulation of large quantities of cones that cannot be dried immediately because of a

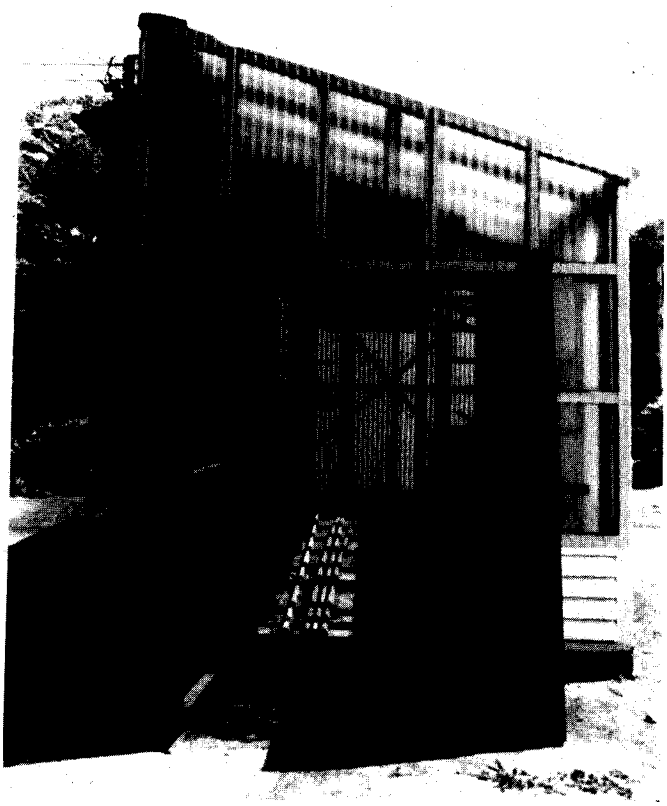


Figure 6-2.—*Solar* ***dryers are effective for drying seeds as well as lumber. Many designs exist; they are easy to construct and require little maintenance. The one shown here has fiberglass side and roof panels covering a treated wood frame.***

lack of space. If cones are improperly stored while awaiting drying, they may mold.

Extraction may be done with a power-driven tumbler inside a solar dryer. Because solar dryers operate mostly on radiant energy, the only cost involved, besides labor, is the small amount of electricity used by a small motor that turns the tumbler and runs an extractor fan that blows moist air from the dryer. Solar dryers are simple to build; a wide variety of designs exists (13, 15). A clever carpenter can easily build a solar dryer, making special design adaptations for local conditions.

Because of design constraints, sensitivity control of humidity and temperature on solar dryers is not as precise as that on manufactured kilns or ovens. Moreover, heat buildup inside a solar dryer can fluctuate more than what normally occurs in ovens or kilns. Thus, solar dryers are not routinely used for lowering seed moisture content.

Another problem that might occur is rupture of the solar dryer. This is caused by expanding cones that occupy greater physical volume when expanded than when closed. There have been cases where walls of drying buildings have been pushed out or roofs lifted off as pine cones dried and expanded. Thus, one should always leave sufficient room in large or small solar dryers (about 50 percent of structure volume) for cone expansion.

6.3 Fleshy Fruits

Seeds with fleshy coverings require different processing than that required by cones and dry fruits (22). The kind of processing depends on whether seeds are covered by thin or thick flesh. If fleshy fruits are not processed soon after they are collected, fermentation and spoilage occur because high moisture and sugar content of the flesh favor bacterial and yeast growth.

Flesh is removed by hand or machine methods. Kind, quality, and value of the fruit determine which method is used. Small seed lots are usually macerated by hand: by squeezing, mashing, or rubbing fruits against wooden blocks or screens. Using nested sieves held under running water allows pulp to be washed away while retaining seeds.

Heavier seeds of fleshy fruits are separated by flotation. Macerated debris and seeds are placed in a slightly tilted bucket. A strong stream of running water from a garden hose is then directed against the container side, creating a swirling and lifting effect. Empty seeds, pulp, and other debris float to the surface and exit in overflow water. Good seeds are heavier; they sink and are trapped in the container.

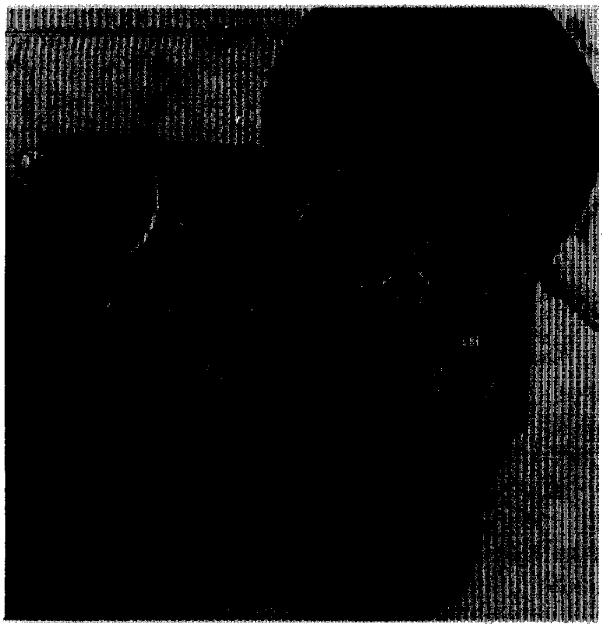
Large seed lots are best processed using feed grinders, concrete mixers, or commercial macerators and separators (fig. **6-3**). Some machines free only flesh from the seed, leaving seeds and residues that are separated in a later cleaning. Other equipment separates pulp from seeds and cleans seeds in a single operation. A flotation procedure is used to separate seeds from pulp and debris, as explained above. **Thin**-fleshed seeds like teak require no macerating, only drying after initial cleaning and washing.

After fruits are macerated and seeds are separated and washed, seed surfaces must be dried. This can be done indoors or outdoors on any clean surface that is sheltered. In moist climates where air-drying is not sufficient, kilns or ovens are used. Final cleaning and separating is done using air-screens or air-columns (fig. 6-4) to remove chaff and light debris (18,191.

6.4 Moisture Content Considerations

Kind of seeds, maturity, presence of fungi or bacteria, and prestorage treatment all influence longevity and viability of stored seeds. In general, optimum conditions for maintaining high seed viability over long periods are a combination of low seed moisture content and low ambient temperature during storage (***10, 11, 12***).

High seed moisture content causes several problems. At **30-percent** moisture content or above, seeds may germinate if the storage temperature is too high. If moisture content of stored seeds is between 15 and 30 percent, germination is improbable, but cellular respiration of stored nutrients in the endosperm lowers seed viability. Reducing seed moisture content to between 10 and 12 percent effectively eliminates most



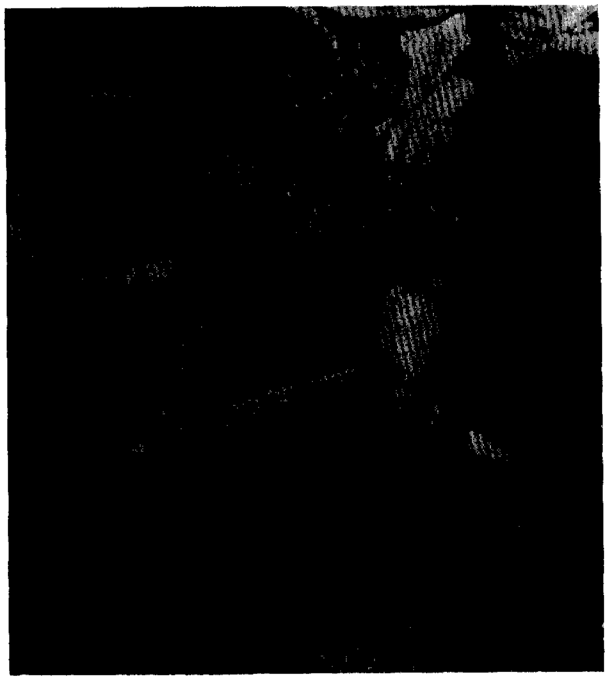


Figure 6-3.—*Separating large seeds from fleshy fruits.*

of these problems. However, fungi can still survive in this moisture content range, and molds can develop. Insects will even attack seeds when moisture contents are as low as 8 to 9 percent if they are stored above freezing temperatures.

In areas without refrigerated storage, seeds are often stored at ambient temperatures of 20” to 35°C. When seeds stored at higher temperatures are chemically treated to avoid insect and disease attack, internal moisture content will equilibrate at 8 percent if storage room relative humidity is maintained at 40 percent and room temperature is <13°C. If relative humidity is 60 percent and storage room temperature is 7°C, seed moisture content will eventually equilibrate to 12 percent. Wakeley (*20*) developed a chart for determining equilibrium of seed moisture content of longleaf pine in relation to temperature and relative humidity of a seed storage area (fig. 6-5).

The most accurate way to determine seed moisture is the oven-drying method of the International Seed Testing Association (*7*). Oven-drying measurement of moisture content is explained in Chapter 7. If moisture content is too high (≥ 12 percent), seeds should be dried at 55°C, following instructions and precautions outlined in Chapter 7. Electronic moisture detectors determine seed moisture content with sufficient accuracy to permit their use in seed laboratories.

6.5 Cleaning and Storage

Because cold storage is costly and uses space, separating empty from full seeds before storage is essential in seed processing. Several methods exist that separate seeds by endosperm content. Mechanical separation, involving a vibrating table held at a slant, is the most common method. Another method uses an air stream in baffled tubes (fig. 6-4). Percentage of full and empty seeds is estimated by sampling techniques using a low number of seeds. Flotation can be used to separate empty seeds (*12*), but moistened full seeds must be dried to stop mold development. In one instance, fire was used to separate balsa seeds from surrounding down-like material (*5*).

If seeds are sown shortly after collection, they can be stored temporarily at normal refrigerator temperatures of 2” to 3°C. Seeds of *P. caribaea* store fairly well in refrigerators if moisture content is less than 12 percent. Refrigerated seeds lose approximately 1.5 to 2.5 percent germination capacity per month. If storage is longer than 4 months, moisture content should be lowered to < 10 percent and the seeds should be frozen. Seeds of kadam and *Eucalyptus deglupta* store slightly better, with a germination loss of less than 1 percent per month. Because mahogany seeds lose viability quickly, even if refrigerated, they should be sown within 1 month of collection.

Seeds refrigerator-stored in sealed containers should not be removed unnecessarily. Condensation of moisture on inside container walls helps mold development. If seed subsamples must be removed from time to time, seeds should be stored in smaller packages, allowing minimal exposure to moisture.

Routine long-term storage of 5 to 10 years for many tree and shrub species, especially pines, is obtained by

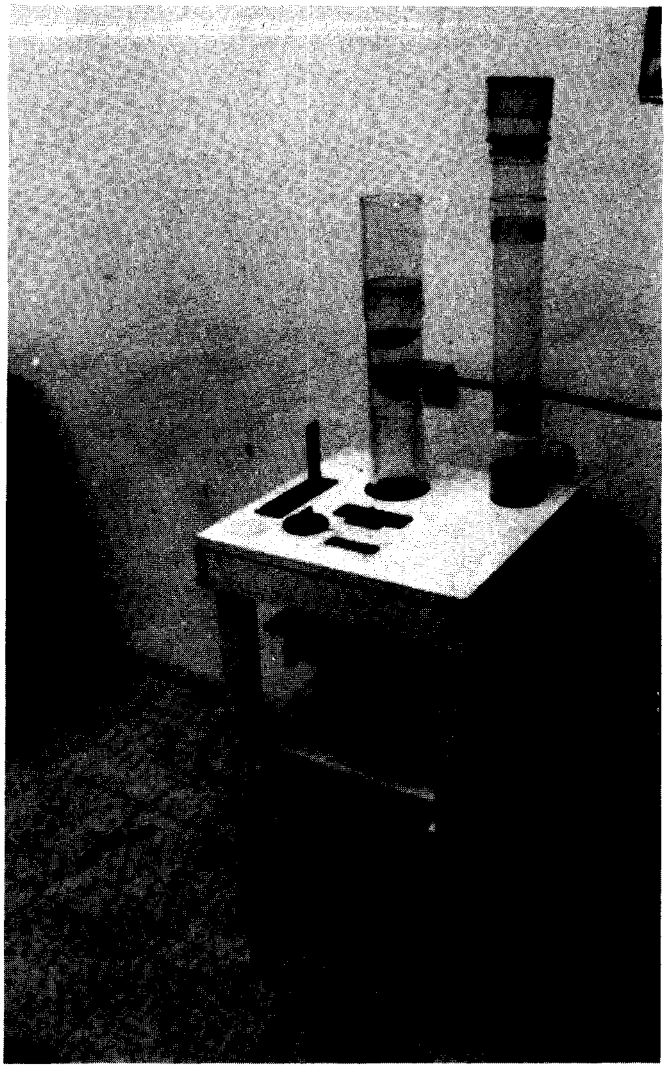


Figure 6-4.—*Mechanical separation of full and empty seeds by baffle-tube, air-column technique.*

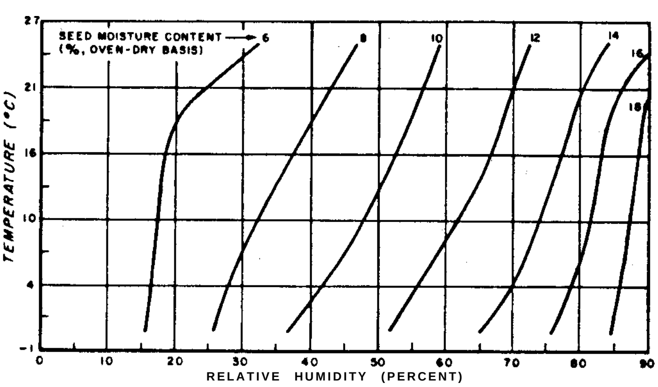


Figure 6-5.—*Chart for determining equilibrium of seed moisture content of longleafpine when temperature and relative humidity of seed storage area are known. Taken from (20).*

freezing at 0°C or lower temperatures, with seed moisture content between 5 and 10 percent. Long-term storage is important for storing genetically superior, scarce pine provenance seeds and for storing bumper seed crops. Dry tree seeds have tolerated extremely cold temperatures of -200°C (*4*); however, such low temperatures are not practical for long-term storage. More specialized methods, including storage under partial vacuum (*1*), storage in an inert gas such as nitrogen (*9*), and replacing oxygen with carbon dioxide in storage containers (*6*), have had various degrees of success with certain species. Such methods are not practical for most seed storage operations, particularly in most developing countries.

Choice of containers for seed storage depends on whether storage is short or long-term. For the latter, rigid-walled containers (e.g., glass) that restrict air and moisture entry are preferred. These, designated as "tightly closed," are seldom completely airtight or sealed, i.e., completely impermeable to entry of air and moisture (fig. 6-l).

When needed, internal moisture content can be controlled by using silica gel, charcoal, or chemical solutions, as long as these have no adverse effect on the seeds. For short-term storage, plastic bags are cheap, effective alternatives. If tied properly, they exclude moisture but allow exchanges of oxygen and carbon dioxide with outside air. Remember, however, that plastic bags are not *used* for seed collection (Sec. 6.2.1).

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CHAPTER 7

7. SEED TESTING

Several tests assess the physical and biological aspects of seeds (14). Test results help determine price if seeds are sold, indicate the number of seeds to sow per unit area of nursery for a production run, and evaluate available seed stocks for reforestation programs. Many tests are now standardized internationally, allowing better communication among nursery managers, foresters, and scientists working with seeds.

Seed tests are commonly done immediately following extraction and shortly before actual sowing. Some tests are done periodically on seed lots kept in long-term storage. Only brief summaries of the more common tests are given; detailed descriptions of tests and seed testing problems appear elsewhere (*8*, *10*, *15*).

7.1 Sampling

A single seed lot can be large or small; it may fill an entire cold storage room or one small bag. To guarantee reliability of seed test results for large lots, all tests must be run on representative samples of the entire lot. Seed triers (fig. 7-l) draw seed samples from large bags or boxes. Electrical sample dividers then split the sample into two or more subsamples on which purity or germination tests are run. For small nurseries, common sense, clean hands, a clean workbench, and a large-bladed knife are sufficient for most seed testing tasks.

Required sample sizes vary according to number and kind of tests run. For germination, at least 600 seeds are needed; a complete seed analysis requires at least 2,500 seeds. Minimum working sample sizes for tree seeds are given in table 7-l. If low viability or a large amount of empty seeds are suspected, then minimum sample sizes (weights) should be double or perhaps triple those listed in table 7-1.

If seeds are stored in large boxes or crates, hand samples are taken at the top, center, bottom, and sides of the box. Samples are taken in proportion to size of the box or container. One should take twice the amount of seeds from a 0.5-m^3 box than from a 0.25-m^3 box. When seeds are stored in small bags, mix them thoroughly before sampling. For small lots of 1 to 6 bags, sample each; for more than 6 bags, the rule of thumb is to sample 10 percent of the total number of bags plus 5 (*15*), as shown below.

Number of bags in seed lot	Number of bags to be sampled
8	6
10	6
20	7
35	9
50	10
100	15

For a lot size of 8 bags, 10 percent of 8 is 0.8 or 1 when rounded off; then 1 + 5 = 6 bags to be sampled.

7.2 Weight

Accurate seed weight is necessary to calculate nursery sowing rates. Weight is normally expressed for 1,000 full seeds. Factors affecting seed weight are size, moisture content, and proportion of full seeds in the lot. One can count out and weigh 1,000 seeds, or, as is done more routinely, 10 random samples of 100 seeds each are taken from a pure batch and weighed (*8*). For commercial testing, weights are recorded to three significant digits; for small nurseries, one significant digit is enough. Besides the mean seed weight in grams, other useful data include the standard deviation, standard error, and coefficient of variation of the seed samples (Chap. 14).

To convert the weight of 1,000 seeds in grams to number of seeds per pound:

$$\frac{453{,}600}{\text{weight of 1,000 seeds in grams}} = \text{number of seeds per pound;}$$

similarly,

$$\text{number of seeds per gram} = \frac{\text{reported 1,000 seed weight in grams}}{1{,}000}$$

7.3 Purity Analysis

Purity tests determine the percentage of true seeds and other material in a seed lot. The four recognized components are pure seed, other seeds, weed seeds, and inert matter such as seed wings, broken cone scales, rocks, twigs, or other non-seed material. Commercial germination tests use the pure seed component only. Each component is usually expressed as percentage by weight of the original sample. Thus, if the initial weight of a *P. caribaea* seed sample was 60.124 g and the pure portion weighed 52.467 g, purity of the lot is:

$$\frac{52.467}{60.124} \times 100 = 87.3 \text{ percent.}$$

Purity tests are meticulous, slow operations. Separation is done best by working on a board or raised platform about 8 to 15 cm above normal table height. A multiple-tube daylight fluorescent light is best. Other required equipment are forceps and spatula for seed handling and separating, a wide-field hand lens of 5 to 7× power, a wide-field stereomicroscope with magnification from 10 to 75 ×, seed pans, and a balance. Analytical balances that weigh to three or four significant digits are used in international seed testing labs. Tortion-bar and other balances that weigh to only one significant digit are suitable for small nurseries.

Figure 7-1.—*Seed triers for obtaining representative seed samples for germination' tests. With slots open, triers are inserted into seed lots; when slots are closed, seeds are trapped and can be used for seed testing after trier is removed.*

Table 7-1.—*Minimum sample sizes for seed testing*[1]

Seeds per kilogram	Minimum working sample size	Seeds per gram
Number	*Grams*	*Number*
less than 4,400[2]	500[3]	less than 5[2]
4,400-5,500	300-400	5-7
5,500-6,600	200-300	7-10
6,600-7,700	140-240	10-15
7,700-8,800	100-170	15-20
8,800-9,900	85-125	20-25
9,900-11,000	70-100	25-30
11,000-12,000	60-90	30-35
12,000-13,000	54-75	35-40
13,000-15,000	42-65	40-50
15,000-18,000	36-54	50-60
18,000-20,000	30-46	60-70
20,000-22,000	27-40	70-80
22,000-23,000	24-35	80-90
33,000-44,000	22-32	90-100
44,000-55,000	17-28	100-125
55,000-66,000	15-23	125-150
66,000-88,000	13-20	150-175
88,000-110,000	11-17	175-200
110,000-143,000	9-15	200-250
143,000-176,000	8-12	250-300
176,000-220,000	6.5-10	300-350
220,000-331,000	5.5-8.5	350-400
331,000-441,000	4.4-7.5	400-500
441,000-661,000	3-6	500-750
more than 661,000	3	more than 750

[1]Source: Association of Official Seed Analysts 1970.
[2]Purity analyses are rarely required for seed samples of this size.
[3]Sample should contain at least 500 seeds.

Separation is done manually by placing about 400 seeds on the working board or bench, drawing a few seeds at a time from the main pile, spreading them apart, and finally determining into which component tray or pan the material should be placed. After preliminary separation is made, all components are rechecked.

Imperfect seeds of the same species being checked are not classified as other seeds or inert matter. However, immature, shriveled, cracked, and damaged seeds larger than one-half the original seed size, including those with internal insect damage and those starting to germinate, are designated as "pure" seed. This may seem strange, but germination potential is determined by a germination test, not a purity test.

7.4 Moisture Content

Seed moisture content has an inverse relationship with seed longevity and germination capacity: at high seed moisture ($\geq$ 18 percent), seed germination capacity and longevity are lower. Managers check seed moisture content soon after receiving fresh seeds or seeds that have been in transit a week or more. Also, periodic checking every 6 months is essential for monitoring viability of seed lots kept in long-term storage (*12*).

The common laboratory test for determining seed moisture content is the air-oven method developed by the International Seed Testing Association (*8*). It is prescribed for all tree and shrub seeds except those from fir (*Abies*), cedar (*Cedrus*), beech (*Fagus*), spruce (*Picea*), and hemlock (*Tsuga*). Seed from these genera contain oils and resins that are volatile at 105°C.

In the air-oven technique, a representative seed sample is weighed to three decimal places, dried at 103” $\pm$ 2°C for 17 $\pm$ 1 hour, and reweighed after cooling in a desiccator for 30 to 45 minutes. Percent moisture (i.e., seed moisture content) is obtained by dividing the weight of water lost in drying by the *wet weight* or weight before drying. Duplicate determinations are run on the same seed lot being tested. If results differ by >0.2 percent, another duplicate determination is made, following the same procedures.

For example, assume that wet weights of duplicate samples A and B are 20.197 and 20.186 g. After 17 hours, dry weights for A and B are 18.062 and 18.002 g respectively. Seed moisture contents are:

$$\text{A:} = \frac{20.197 - 18.062}{20.197} \text{ x } 100 = 10.6 \text{ percent, and}$$

$$\text{B:} = \frac{20.186 - 18.002}{20.186} \text{ x } 100 = 10.8 \text{ percent.}$$

Since the difference in moisture contents between A and B was 0.2 percent, no retest is needed.

If seed moisture contents are known to exceed 17 percent, seed subsamples are weighed, predried at 55°C for 5 to 10 minutes, reweighed after cooling, and then run through the normal air-oven technique. Percentage of moisture is determined by dividing the weight of water lost from the two drying periods by initial wet weight.

For example, assume that initial wet weight of a seed sample is 26.000 g and that an electronic seed moisture meter showed a seed moisture content of 32 percent. To check this, the seed sample is dried at 55°C for 10 minutes. The resulting weight (W) of 20.197 is an initial loss of 5.803 g (W_1). After drying for 17 hours at 103°C, the second weight is 18.062 g, an additional loss of 2.135 g (W_2).

Actual seed moisture content for the sample is:

$$\frac{\text{Weight loss } W1 + W2}{\text{inital wet weight}} \times 100 \text{ or}$$

$$\frac{5.803 + 2.135}{26.000} \text{ x } 100 = 30.5 \text{ percent.}$$

When reporting results, one must always specifiy whether percentage of moisture was obtained by dividing by wet or dry weight. In the United States, seed *moisture* content is usually expressed as a percentage of *oven dry weight* after the 17-hour drying. This procedure differs from international custom where expression on a *wet weight basis* is almost always used. Conversion from a wet to dry weight basis is done easily by using the scale shown in figure 7-2.

In commercial seed testing, the toluene distillation method replaces the air-oven method for determining seed moisture content of species having resins or other materials that volatilize at 105°C. The method involves grinding seeds finely, boiling them in a toluene apparatus, collecting condensed moisture in a separate tube, and determining moisture content of the seeds by using their initial weight and weight (or volumes) of water collected in the distillation apparatus. Most nurseries do not have access to such specialized equipment. Therefore, oven drying at 103°C for 17 $\pm$ 1 hour is satisfactory for determining seed moisture content of most species.

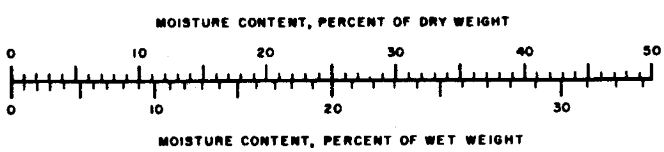

Figure 7-2.—*Conversion from wet to dry weight basis when determining seed moisture content. Taken **from** (15).*

7.5 Germination Potential

Germination potential is determined from the pure seed component of purity tests. Alcohol is sometimes used to separate viable from nonviable seeds (6). When pure seeds are not available, representative samples of lots should be tested as long as estimated purity is ≥98 percent (*1*). Results from germination tests help determine value of the seed lot, whether it should be used in the current planting season, if it can be stored for future years, and what sowing rates must be used in nursery beds to meet established seedling production goals (*16*).

The science of germination testing is complex, covering such areas as equipment (cabinets, rooms, or trays and dishes), suitable medium (paper towels, sand, peat moss, etc.), procedures (moisture, light, and temperature regimens), and (evaluation classifying normal and abnormal seedlings). Once germination test results are judged satisfactory for a particular species, techniques and methodology should be standardized and continued in all future germination tests. When tests are standardized and routine, direct correlations between seed testing results and seedling field performance can be made by nursery and field managers for specific locations and circumstances.

7.5.1 Germination Test Procedures. -In any germination test, seeds must be thoroughly mixed and representative samples drawn randomly by hand or with seed triers (fig. 7-l). Replicated tests are run using at least 600 seeds in 6 replicates. If 100 seeds do not fit in test trays, smaller replicates of 50 or 25 seeds are used. The mean germination rate (expressed in percent) for all replicates is used to calculate the number of seeds needed fqr actual sowing (Appendix 9). Some seeds require pretreating such as cold stratification or fseedcoat scarification before germination (Chap. 8) or require certain temperatures for best germination (3).

Some germination tests are still done outdoors in flats containing sand, peat, vermiculite, or soil. Although such test conditions are good for large-seeded species such as teak, control of moisture and temperature cannot be maintained for outdoor tests. Outdoor tests have added risks of damage or loss of seeds by birds, rodents, or insects.

Indoor germination tests are conveniently run in small or large petri dishes or other trays; homemade cabinet germinators are also used (4). These should be sterilized before a test is started. Common substrata are moistened filter paper, paper towelling, blotters, or commercial paper tissues such as Kimpak. Paper substrata are nontoxic to germinating seedlings, free of molds and other harmful micro-organisms, and provide adequate moisture and aeration. Paper substrata can favor fungi if too much water is added, i.e., when water is seen collecting around seeds in the tray or if a film of water forms on fingers after squeezing the paper. Fungi are controlled by spacing seeds widely and by removing seeds after they are fully germinated. If substrata such as washed sand or perlite are used for large seeds, seeds are covered loosely with the material, usually to a de&h equal to one-half their diameter.

In the tropics, the indoor and outdoor temperatures range between 20°C and 30°C, which are suitable for germinating most forest seeds (*2*). Germination tests should not be done in poorly ventilated buildings where temperatures exceed 30°C or in air-conditioned offices cooled to ≤20°C. One exception is teak seeds, which require alternating temperatures of 35°C to 38°C for successful germination (11). Covering germinating trays maintains adequate humidity and moisture. Seeds exposed to very high humidity and temperature before testing will have low germination, invalidating test comparisons (7). Another exception is ***Pinus ayacahuite.*** Recommended germination for it is 25°C for 44 days or for 28 days after removing 3 to 4 mm of the seedcoat from the radicle end of seeds.

7.5.2 Seedling Evaluation. -Germination is the emergence and development from the seed embryo of all essential structures, showing a seed's capacity to produce a normal, healthy plant under favorable growing conditions. Abnormally germinated seedlings do not count as "being germinated." They may, however, be counted and placed in abnormal germination classes such as weak, rootless, or broken seedlings; albino or translucent seedlings; and stunted or malformed radicles. Seedlings with fungal or bacterial damage can be counted as "germinated" if they are otherwise normal.

Test durations vary according to species and seed size within species (5). At one extreme, teak seeds can take up to 1 year or longer; for other species, 3 to 4 weeks are usually sufficient. Counts should be made every 2 or 3 days, or more often for rapidly germinating seedlings.

Remaining ungerminated seeds are added to the total number germinated to give the percentage of full seed in the sample. If cutting tests reveal many full but ungerminated seeds, pretreatment technique or germination environment should be changed. Retesting is necessary when: 1) a large percentage of seeds remain ungerminated and 2) a variation among test replicates exceeds that judged acceptable by past experience or tolerances commonly allowed (table 7-2). Cumulative germination curves can be prepared and kept to identify higher quality seed lots (fig. 7-3).

"Quick tests" for determining seed viability are also possible. The most common, but least reliable, is the cutting test. Seeds are cut or split with a knife, and only those having healthy, firm, and undamaged endosperms are judged viable (*15*). Biochemical stain-

Table 7.2.—*Germination tolerance among 4 or more replications of 100 seeds each*[1]

Mean germination	Tolerance variation among replications
Percent	
96 or over	5
90 or over but less than 96	6
80 or over but less than 90	7
70 or over but less than 80	8
60 or over but less than 70	9
Less than 60	10

[1]Source: (1).

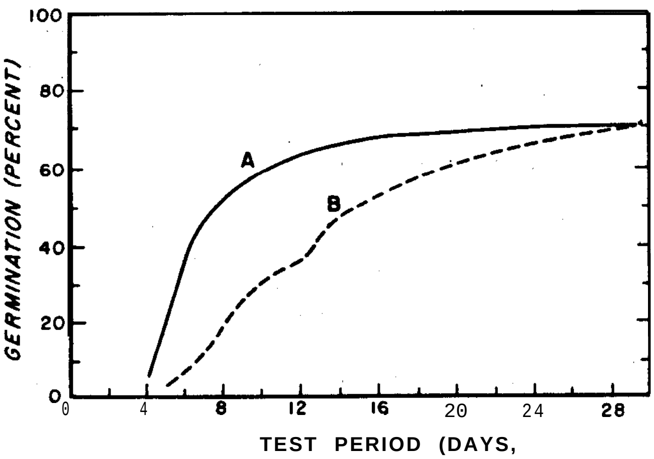

Figure 7-3.—*Typical cumulative germination curves for two seed lots of one tree species.*

ing, using tetrazolium (TZ) salts, or embryo excision tests require experienced technicians for performing analysis and interpretations. Soft X-ray tests are even faster than staining tests and indicate insect or processing damage as well. Initial expense for X-ray units and additional expenses in purchasing and developing film probably limit this technique for most tropical nurseries. The X-ray technique has been used successfully for teak (*9*).

7.6 Other Special Tests

Several other seed tests may have implications for particular nursery operations.

7.6.1 Seed Vigor.-Vigor is a rather loose term used to describe observable germination differences in seed lots of similar or different genetic makeup. For example, seed lots A and B in figure 7-3 both showed cumulative 70-percent germination in 30 days. Lot A, however, achieved this percentage in only 14 days, even though both lots were of the same species and were exposed to the same overall germination conditions. Other examples of vigor besides rapid germination are germination under adverse conditions, resistance to fungal or other diseases, and corresponding vigor carry-over to nursery and planted seedlings.

The most common expression of vigor for tree seeds includes assessing speed of germination, also known as germinative energy. This is defined as the percentage of germination at the peak rate of germination. Slow germinating lots (Lot B, fig. 7-3), are difficult to determine. A more common expression is total number of days required for a certain proportion of total germination to occur (e.g., 85 percent of *P. caribaea* var. *hondurensis* seeds in 14 days). Such definitions are possible from long-term observations or experience of nursery managers, but they are seldom published or quantified through repeated and replicated trials.

7.6.2 Indirect Indices of Seed Vigor. -Indirect indices of seed vigor include biochemical staining tests using tetrazolium. Several vigor classes can be developed, based on partial or complete staining of the embryo and location of dead or damaged tissue. A major problem is standardization of test results. A successful technique exists for eucalyptus (*13*). Other biochemical tests exist, but most require sophisticated techniques and controlled laboratory environment, which are seldom available to field nurseries.

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CHAPTER 8

8. SEED PRESOWING TREATMENTS

Presowing seed treatments (pretreatments) are needed to break seed dormancy resulting from either a hard seedcoat or an immature embryo. A classic example is teak seeds, with a hard seedcoat, which may not germinate for 2 or 3 years after sowing (*4*). Dormancy is beneficial for natural regeneration of a species because it postpones germination until favorable growing conditions exist. But irregular or delayed germination is disastrous for nurseries, where all seedlings must reach uniform outplanting size by specific dates. The purpose of pretreating is to break seed dormancy and to obtain uniform germination.

The ability of pretreatment methods to overcome dormancy varies greatly by species. In general, seeds of species growing in warm and moist tropical areas do not need pretreatment (e.g., *P. caribuea*). However, species from cool temperate and dry tropical areas with distinct seasons may need some sort of pretreatment before uniform germination can occur (e.g., *Pinus tropicalis* and *Albizzia falcata*). Some pretreatment methods commonly used in nursery work for species planted in the tropics and subtropics are summarized in Appendix 8. Sometimes, treatment with chemicals does not break dormancy but enhances germination (3, *8*).

8.1 Breaking Seedcoat Dormancy

Seedcoat dormancy is corrected by breaking the hard and impermeable coat surrounding seeds (e.g., legumes and teak) by chemical or mechanical methods.

8.1.1 Acid Scarification. -A common chemical method is scarification with commercial grade sulfuric (H_2SO_4) acid (*6*). Several safety precautions must be followed when using the acid-soak method. These include using acid resistant wire containers or screens for handling, draining, and washing seeds; providing a good source of running water; establishing a safe area to drain and dilute the acid obtained from rinsing; and finding an area to dry seeds after rinsing.

Complete methodology and precautions are given in Agricultural Handbook 450 (7). Determine the optimum immersion time for individual species needing pretreatment. Some species require 15 to 60 minutes of soaking, others require up to 6 hours. Immersion time is determined by soaking several small seed lots for different times in acid, followed by soaking in water at room temperature for 1 to 5 days. The acid-soak treatment that yields the highest percentage of swollen seeds (caused by water uptake), without splitting seeds or exposing their endosperm, is the best treatment. If differences in seedcoat composition exist between lots, separate treatment times may be required. Lots up to 100 kg are treated effectively by placing a wire screen filled with seeds inside a metal drum (fig. 8-1). Another alternative for thin-coated seeds is to place them in a conical pile on a flat, hard surface, apply acid at a rate of 2.5 kg per 36 kg of seeds, mix thoroughly with a shovel, rinse, and dry the treated seeds.

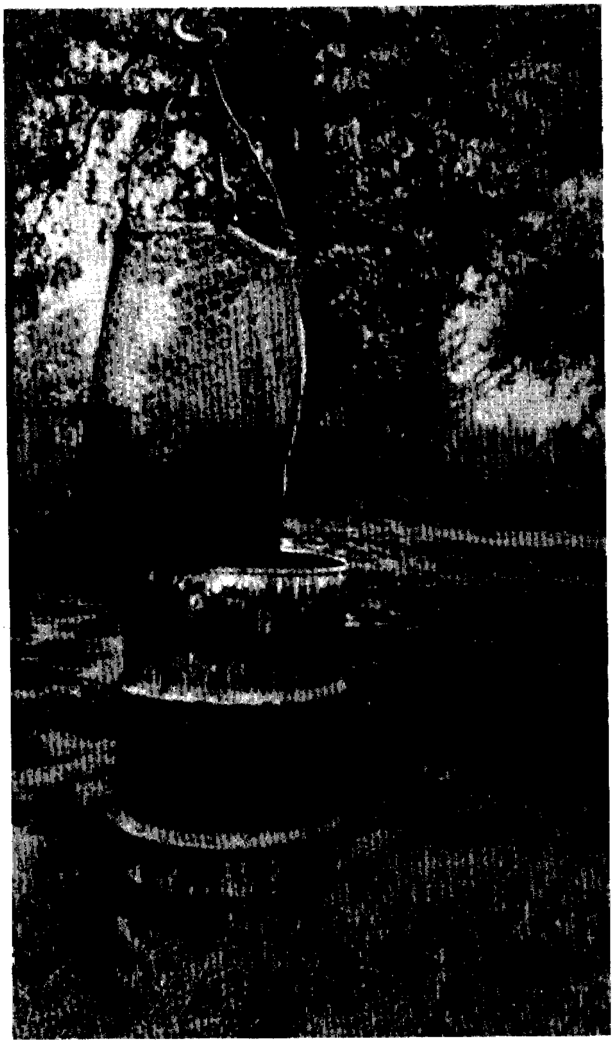

Figure 8-l.-Acid *pretreatment of large seed lots using wire screens and metal drums.*

Advantages of acid scarification are: 1) little or no special equipment, 2) low cost, and 3) recovery of acid for future pretreatment (unless the pile method is used). Disadvantages are: 1) length of treatment must be carefully determined, 2) temperature must be controlled, particularly when large lots are pretreated, and 3) acids are hazardous substances.

When acid is used, *NEVER ADD OR SPLASH WATER* ON *ACID* because a violent reaction or explosion can occur!

X.1.2 Water Soaking.-Alternate soaking in hot and cold water is the other major chemical method for pretreating seeds. For large seeded species like teak and legumes, success is achieved best with hot water. This method involves preheating water, 4 to 5 times the seed volume, to temperatures of 77°C to 100°C, submerging the seeds, and allowing them to soak in the gradually cooling water for 12 to 24 hours. Some species have seeds that tolerate only a few minutes of hot water soaking (e.g., *Leucaena*); they must be quenched in cool water first before the long soak at room temperature begins. Problems arise in: 1) standardizing the technique, 2) maintaining precise control of times and temperatures, and 3) treating large seed lots.

Soaking in water at or near freezing temperature for a few days to 2 weeks has expedited germination of coniferous seeds; cold soaking is not successful for hard coated seeds on which acid scarification is used. Soaking probably leaches germination inhibitors from seeds, softens hard but not impermeable seedcoats, or completes an imbibition requirement for germination. For example, alternate-day soaking in water, and night drying for 7 days before sowing increased the germination percentage of *Terminalia ivorensis* from 30 percent to as much as 70 percent in Ghana (*1*). Germination period for *P. caribaea* was reduced by water-soaking seeds for 48 hours at room temperature (*5*).

8.2 Mechanical Scarification

Impermeable seedcoats can be broken mechanically with files, sandpaper, and electric needles for small lots and with hand or motor-driven scarifiers, such as sandpaper-lined drums and cement mixers, for large lots. Germination tests are needed, as for acid scarification, to determine optimum treating time. One verifies successful seed treatment by observing swelling after water uptake or visual examination with a hand lens. Overtreatment damages seeds by reducing germination and increasing risk of fungal attack.

Advantages of mechanical scarification are: 1) less risk of injury to workers, 2) no need to control temperature, and 3) seeds remain dry throughout pretreating, allowing immediate sowing afterwards. Disadvantages are: 1) seeds are easily damaged by overtreatment, 2) scarified seeds are perhaps more easily damaged by pathogens than are nonscarified seeds, 3) large lots require special equipment, and 4) seeds with resins or fleshy pulp cannot be used in sandpaper-lined tumblers.

8.3 Stratification-Methods

Besides seedcoat or "external dormancy," some tree seeds have "internal dormancy." Before such seeds germinate they must undergo physiological changes in which the seed embryo develops. Cold, moist treatments that artificially cause these changes are called stratification; they are also known as moist prechilling or afterripening treatments.

8.3.1 Cold Stratification. -In cold stratification, seeds are stored in a well-aerated medium such as sphagnum moss and kept at low temperatures of 1" C to 4°C for 2 to 4 months. Three precautions that must be taken are: 1) maintain adequate moisture that can be imbibed by seeds throughout stratification; 2) keep temperatures low, near freezing, to reduce microbial activity, reduce sprouting, and prevent heat buildup from seed respiration; and 3) supply adequate aeration for gas and heat exchange, particularly for long-term stratification of 2 months and longer.

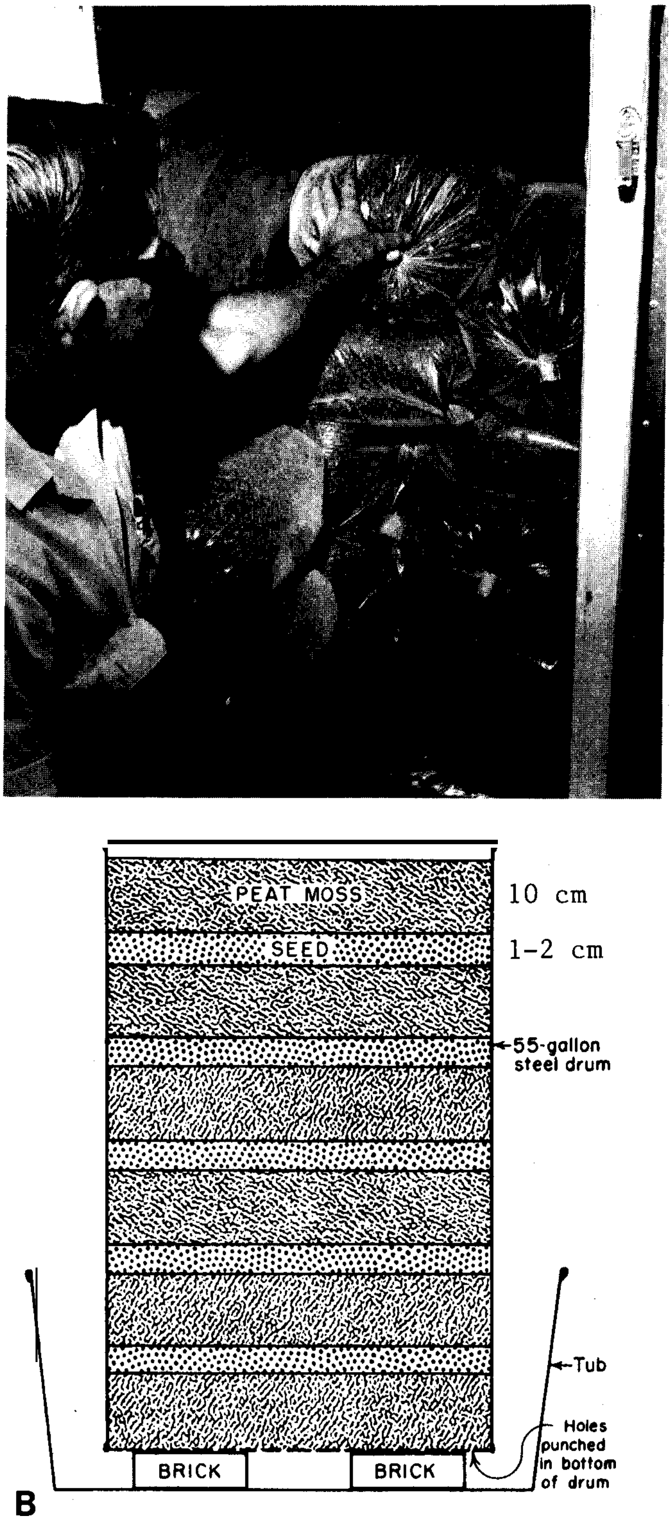

Figure 8-2.—*Stratification can he done (A) for small seed lots by using sealed plastic bags or (B) for large lots by using sealed drums or similar containers.*

Several techniques are used for stratification (7). Before subjecting any large seed lots to stratification, prior history of their need should be documented. Usually, small lots are split and germinated using stratified and unstratified seeds through paired tests.

First, decide whether lot size is small enough for pretreating in small plastic bags or large enough for bags and drums (fig. 8-2). Seeds are brought to high moisture content by water-soaking them overnight at room temperature or up to 4 days for nut-like fruits and pine seeds that have hard seedcoats. Using small lots and different soaking periods establishes the best soaking time when no information is available.

Second, choose a moisture-holding medium such as granulated peat moss, sphagnum moss, or sand. Peat moss is often used because it is slightly acidic and, like sand, dispels heat well. The medium should be just moist enough that squeezing with one's fingers expels some excess water.

Third, seeds are mixed with the treating medium. The entire mixture is placed in canvas bags in large drums or boxes with drainage holes at the bottom (fig. 8-2). If available, cracked ice is also mixed with the medium to assure rapid and uniform chilling. Small seed lots are stored alone in plastic bags or with moss placed over them. Seeds are always stored loosely, never packed. They can also be laid out on cheese cloth over moss in drums or boxes. If seeds and treating medium are mixed in the same containers, a cleaning and separating problem can occur when stratification ends.

Drums and bags must be promptly closed to prevent seeds and medium from drying out. Seeds and medium are inspected every few days for adequate moisture. If stratification is 30 days or longer, bags should be taken out and inspected for mold and drying every 2 weeks. When seeds are checked, they should also be thoroughly turned and mixed. Freezing of moss at the top of bags can occur but is no cause for alarm; it only indicates that the medium is drying rapidly and that additional moisture is needed. Poor aeration is indicated by an alcohol odor, a sign that anaerobic respiration is taking place. If this occurs, seeds are checked more frequently by opening all bags and turning the seeds. Recommended storage temperature is 1°C to 4°C.

At the end of the stratification period, seeds are removed and washed. If seeds and medium were not mixed, washing may not be needed; washing removes potentially dangerous and damaging microorganisms. Immediate sowing is recommended; extreme drying before use may induce a second dormancy in some species. Most southern pine seeds can be stored under stratification for at least 1 year at 4°C without loss of viability.

In temperate areas without cold storage facilities, outdoor stratifying pits are used. Seeds are thoroughly mixed with sand and kept moist in pits 1 to

2 m deep over winter, Stratification occurs during the winter. Where winters are milder, stratifying in aboveground beds exposed to more fluctuating temperatures accomplishes the same thing.

Some species in temperate areas require both warm and cold stratification prior to germination. Examples are green and white ash (*Fraxinus pennsylvanica* and *F. americana)* and black cherry (*Prunus serotina*). Tropical examples are not documented.

8.3.2 Chemical ***Alternatives.*** -Chemical means have been investigated to eliminate the need for either cold or warm stratification. Inorganic ions, organic acids, and growth regulators such as gibberellins have stimulated germination under laboratory conditions (7). Germination of dormant and unstratified *Eucalyptus delegatensis* , *E . fastigata* , and *E . regnans* was improved with application of gibberellic acid (2).

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CHAPTER 9

9. TRADITIONAL SEEDBED PREPARATION AND SOWING

Traditional methods to produce nursery stock include container (3, 5, *14, 15,* ***16*****,** ***27*****,** ***28*****,**) and bare-root (*1* , ***12*****,** ***17*****,** ***29***) methods. Container methods are most common because outplanted seedlings and cuttings (25) with attached soil or other growth medium survive well. Where countries use both methods, container systems were probably used first for organized reforestation work. Because container methods can employ many workers of either sex, they are generally preferred in developing countries where jobs are scarce (18).

In this chapter, the general preparation and sowing techniques for container and bare-root seedbeds are described. Throughout this guide, seedbed is used in a very broad sense. It means ground-level and raised beds where seeds are sown 1) in or on top of the soil, 2) in pots or containers where seeds are direct-seeded, and 3) in pots where seedlings are transplanted. Transplants are usually germinated in flats but can also be produced in seedbeds. Appendix 9 gives specific procedures for sowing, transplanting, and early tending care of several plantation species.

9.1 Container Systems

9.1.1 Selection Criteria

9.1 .1 .l Advantages and Disadvantages. -Container systems are used when reforestation conditions are too harsh (usually too dry and too exposed) for survival of bare-root stock. Even on non-critical sites, potted seedlings have higher survival, and sometimes better growth, than bare-root stock. Advantages of container systems over bare-root systems are:

- good soil is not necessarily needed at the nursery site;
- time in the nursery is shorter;
- roots are not exposed to air and heat during transport to the field;
- faster growth initiation occurs after planting because transplant shock is less;
- planting season can be extended because seedlings are planted with moisture- and nutrient-holding medium around them; and
- start-up time for a new nursery is minimal.

Disadvantages of container systems are:

- they are generally more expensive and time consuming to produce;
- bulky pots pose storage and transport problems;

- fewer seedlings per trip are transported to the field;
- seedling extraction from pots for repacking and transport can be difficult;
- much greater risk of root binding exists after outplanting;
- there is more potential damage to root systems if seedlings are repacked for transport; and
- a continual source of good potting medium is required.

9.1.1.2 Shape/Volume Considerations.-Pot shape and volume both directly influence seedling growth and development in containerized systems. Long pots allow longer and better developed root systems, which are desirable for dry sites (26), and short pots produce smaller root systems, which are adequate for moist sites. Size also affects the amount of growth medium needed to fill pots and their holding time in the nursery. Once the available pot root volume is filled, seedlings must be outplanted quickly or root strangulation and spiraling will occur (*24*). Large pots do not always produce the most vigorous stock (4).

The ideal container will support growth of high quality seedlings in the shortest possible time. For pines, this means growing seedlings 25 to 35 cm tall in 6 to 8 months, or, if they are "forced" with fertilizers, 4 to 5 months. Too often, the ideal pot for physiological development is not available locally and costs too much to import. The most common container used is the plastic bag. It comes in many sizes and is easily manufactured locally. If imported, costs are moderate to inexpensive, depending on freight distance. Dark plastic is best because, if overwatering occurs, algal and fungal growth are less prevalent in dark plastic than in clear bags exposed to more light. In Tanzania, clear bags were reported better for *P. oocarpa* growth (*22*). Other pot types are clay, split bamboo, tarpaper pots, tin cans, and milk cartons.

9.1.2 Selecting and Preparing Pot Media.—Suitable potting media are cheap, readily available materials in the community and can be economically obtained from inside or outside the country. Alternatives are soil alone; soil/sand mixtures; organic based mixtures with various proportions of peat, compost, sugarcane waste, rice hulls, sawdust, or ground bark; and synthetic mixtures (*9*, *13*).

Soil alone and soil mixed with sand and organic materials are used most often. Usually, soil alone is undesirable because of its weight. If nothing else is available, sandy to sandy loam soil is best; heavy clays are undesirable because water drainage is poor. Alluvial soils are good if their texture is sandy loam to silt loam, but these soils in dry limestone regions are often undesirable because of high clay content and high pH. Organic based mixtures are good because they are light and possess good texture, water-holding capacity, and nutrient retention.

Precise ratios of sand, soil, and composts vary according to local materials used. Fertility, acidity, and physical composition are all different for sand, silt, and clay soils and mixtures with or without soil. A 1:3:1 mixture of soil/river sand/decayed manure or organic materials is a good starting point (Sec. 15.2.2.2). Growth is usually, but not always, poor with sand-only medium (*7*, *10*, *23*).

All materials should be screened free of clods, stones, and other debris (fig. 9-l). Screened material, especially soil, can be sterilized but usually is not. When available, methyl bromide or other fumigants are used rather than steam sterilization (fig. 9-2). Proper fumigant use is outlined in Appendix 9.

9.1.3 Filling Pots. -Metal or bamboo funnels help direct potting medium into containers. Potting tables for filling are very practical (fig. 9-1), especially when located under a protective shed (fig. 4-3). Light tamping against the ground or potting table helps settle material in plastic bags; *overtamping should never be done,* especially for a medium of high clay content, because compacting reduces drainage and aeration and causes poor root development. Compacted soil does not have improved moisture retention because of greater capillary pore space (*8*). Rigid-walled containers can be filled with material shoveled from wheel barrows, after lining-out the pots in beds. Excess medium dropped between pots promotes weed growth in these interspaces. While some workers are filling pots, others can be setting them out in neat lines and rows (fig. 9-3).

***9.1.4 Direct-Seeding* Method.**-Germination percentage tests determine the amount of seeds sown (Chap. 7). Generally, about 20 percent more seeds are sown than the number of seedlings needed to allow for natural mortality and culling in the nursery. Appendix 9 has a specific example of determining the seeds needed for a production run.

Direct seeding is the placing of seeds on potting medium in pots. Large to medium-size seeds of pine and *Gmelina* are best suited for this method; small seeds are not unless they are pelletized first. Advantages of direct seeding over transplanting are:

- it avoids additional steps of germinating in trays and transplanting into containers; and
- if two or three seeds are sown per container, the number of "filled" containers (i.e., those with at least one healthy seedling) is high.

After seeds are sown onto the container medium, they are usually covered with a light layer of soil, vermiculite, or rice hulls that protects them against animal predation and damage from irrigation waterdrops. Direct seeding can be done manually or with machines for round- and irregular-shaped seeds (*6*). Care must be used in culling excess direct-seeded plants from pots to avoid damaging the root systems of remaining seedlings (*21*).

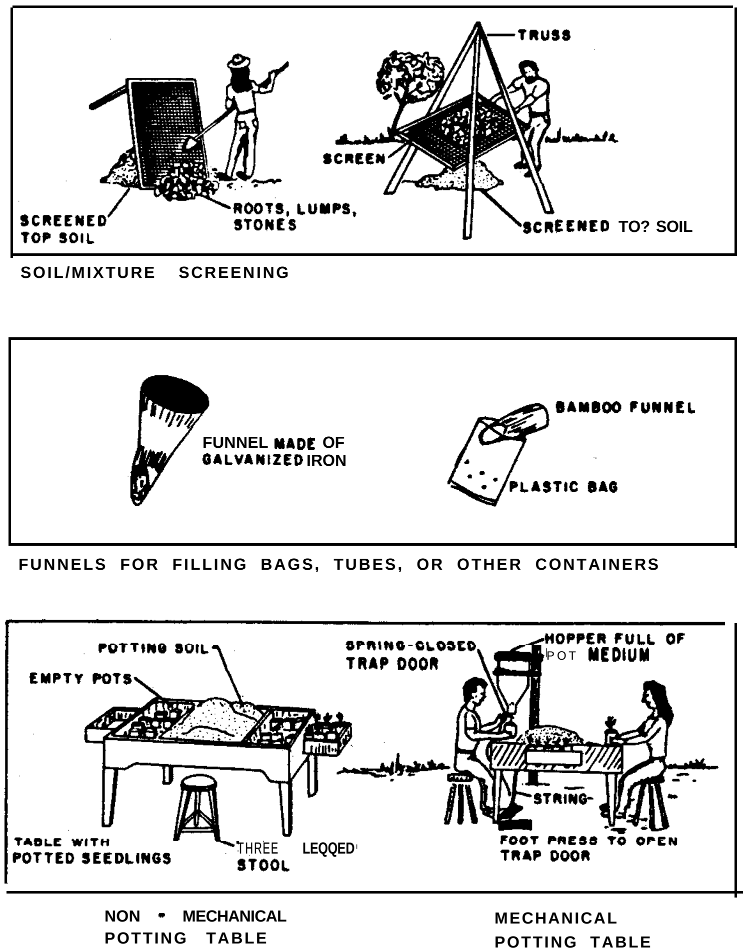


Figure 9-1.—*Traditional containerized nursery techniques. Adapted from (32).*

Figure *g-P.-Fumigating soil in large pots with methyl bromide applied under plastic sheeting.*

9.1.5 Transplant Method

9.1.5.1 Germination Medium. -Possible germination media for seed flats (fig. 9-4) are vermiculite, washed and sterilized river sand or sand/soil mixtures, rice hulls, and tissue paper for very small seeds. Each has advantages and limitations (19).

9.1.5.1.a Sand/Soil.-A 1:1 volume mixture of washed sand and soil is the most commonly used germinating medium because both are readily available. Soil and sand may also be used individually. Particle size should be ≥1.7 mm but ≤2.4 mm, as determined by sieve analysis. Particles of this size range do not cohere easily and therefore will not crust over and puddle when water is added. Aeration and drainage properties are also excellent for seedling emergence and growth. Soil and sand used for germinating trays should always be sterilized to prevent disease and weed growth (see Appendix 9).

9.1.5.1.b Rice Hulls.-In many countries, rice hulls are a cheap, local substitute for sand/soil or vermiculite germination media. ***Unground*** rice hulls are

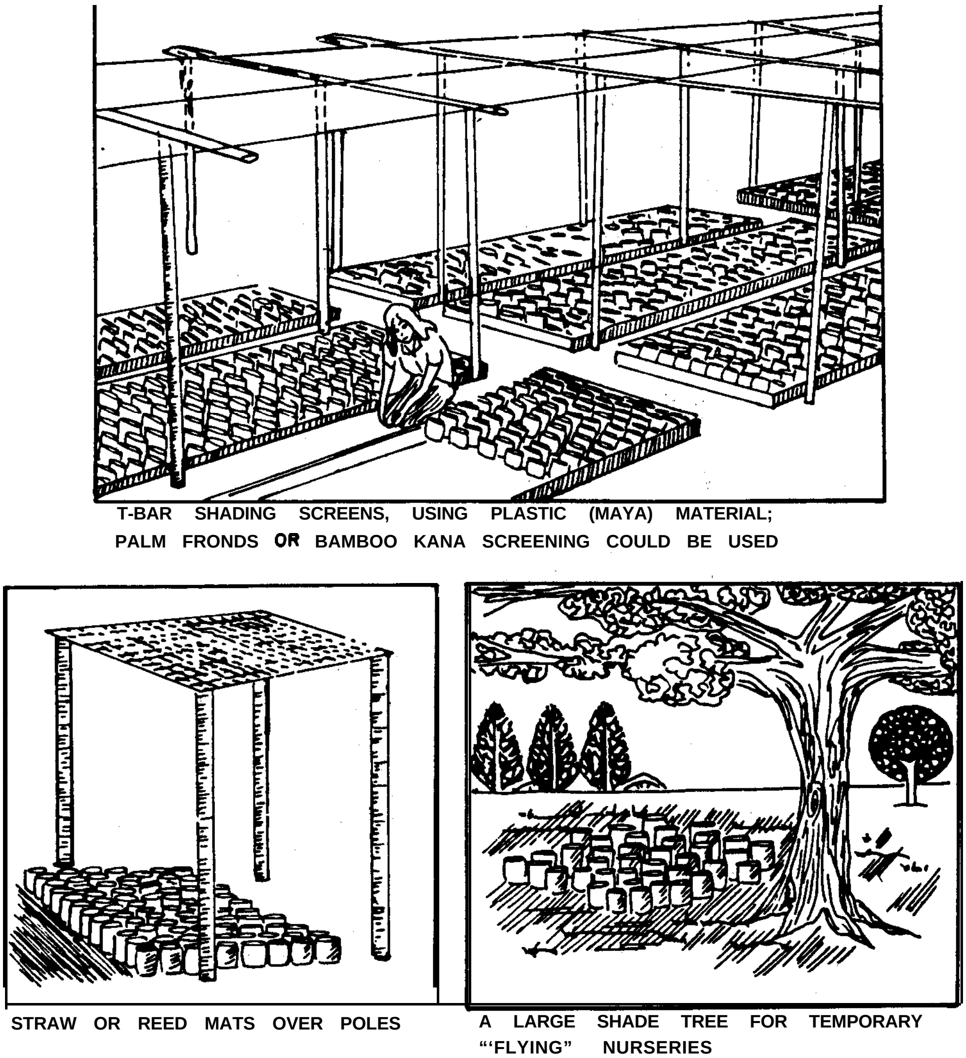


Figure 9-3.—*Nursery shading alternatives.*

light, making moving and lifting of germination flats quite easy. Their uneven and irregular packing in flats gives good aeration and drainage, and rice hulls do not decompose during the germination period. Usually, rice hulls are free of most weeds and pathogens; sterilization is used only when contamination is suspected.

9.1.5.l.c Vermiculite.-When available, vermiculite is the ideal germination tray medium because:

- it is sterile and free of pathogens;
- particle size allows aeration and moisture retention;
- reaction of the medium is essentially neutral (pH 7);
- seedlings easily emerge from underneath a covering layer of the medium;
- seedling root growth is unrestricted; and
- seedlings are easily lifted at transplanting because of the medium's physical properties.

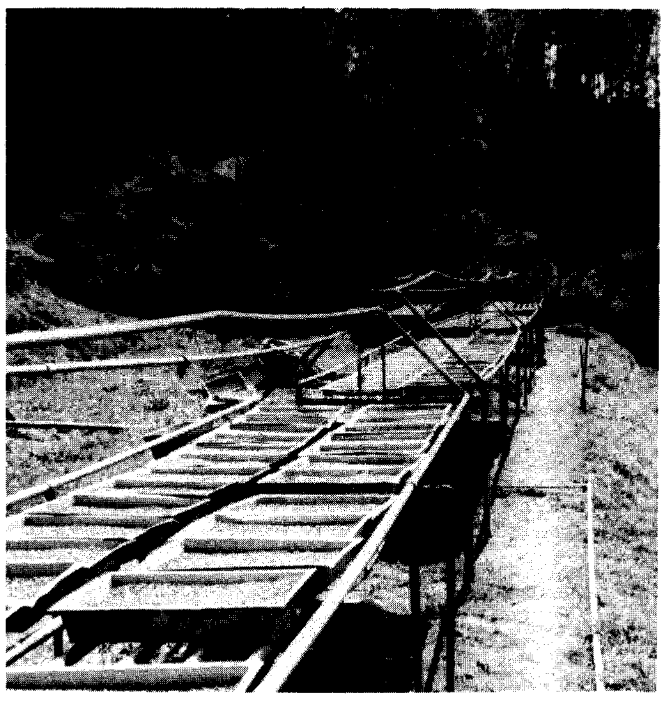


Figure 9-4.—*Standard galvanized metal germination flats*

The major limitation in using vermiculite is cost, because it must be imported. Once used, the material can be resterilized and added to potting medium to increase bulking properties (Sec. 15.2.1.2).

9.1.5.1.d Tissue Paper.-Eucalyptus and kadam seeds are very small and do not grow or transplant well if placed directly on any of the above germinating media. Seeding them first onto moistened tissue paper such as Kimpak, which is used in laboratory work, improves germination. Paper color or type is irrelevant as long as it is clean, light, and very porous.

Finally, all of these germinating media are used for temporary physical support of the germinants; they are not intended to support physiological growth for long periods. Thus, fertilizers should *never* be applied to any of them before germination. Seeds have sufficient nutrient reserves in their endosperm to germinate and grow for a few days until transplanted. If fertilizers are applied, damping-off incidence is very high!

9.1.5.2 Sowing and Germinating. -Germination trays are made from wood or metal. Galvanized metal trays, approximately 30 by 45 by 8 cm, are common (fig. 9-4). After the trays are filled to within 4 to 6 cm of the top, the medium is smoothed and lightly tamped.

Seeds are placed **on** the prepared medium, then covered with 6 to 10 mm of vermiculite, rice hulls, or fine sterilized sand; these coverings allow better seedling emergence than soil alone and protect seeds from animals. Sowing deeper than 6 to 10 mm below the surface prevents emergence (*11*). For small seeds (eucalyptus and kadam), special sowing techniques are used (fig. 9-5). Mahogany and other large-winged seeds are de-winged first, then laid flat on the germination medium; pushing seed into the medium causes formation of J-roots (fig. 10-2).

Seeded trays are placed under 20- to 50-percent shade (fig. 9-6) and watered as needed. Shading methods for small nurseries are simple or complex, using metal frames, wooden T-frames, and shade trees for temporary "flying nurseries" (fig. 9-3).

Overwatering must be avoided to prevent damping-off. A simple test to determine if moisture in germination medium is adequate is to squeeze a small portion of medium between thumb and forefinger. If water can be squeezed out, no additional watering is needed.

9.2 Bare-Root Systems

9.2.1 Selection Criteria

9.2.1 .1 Advantages and Disadvantages. —Bare-root nursery stock is produced by traditional labor-intensive and mechanized methods (Chap. 16). Species successfully grown by bare-root methods are

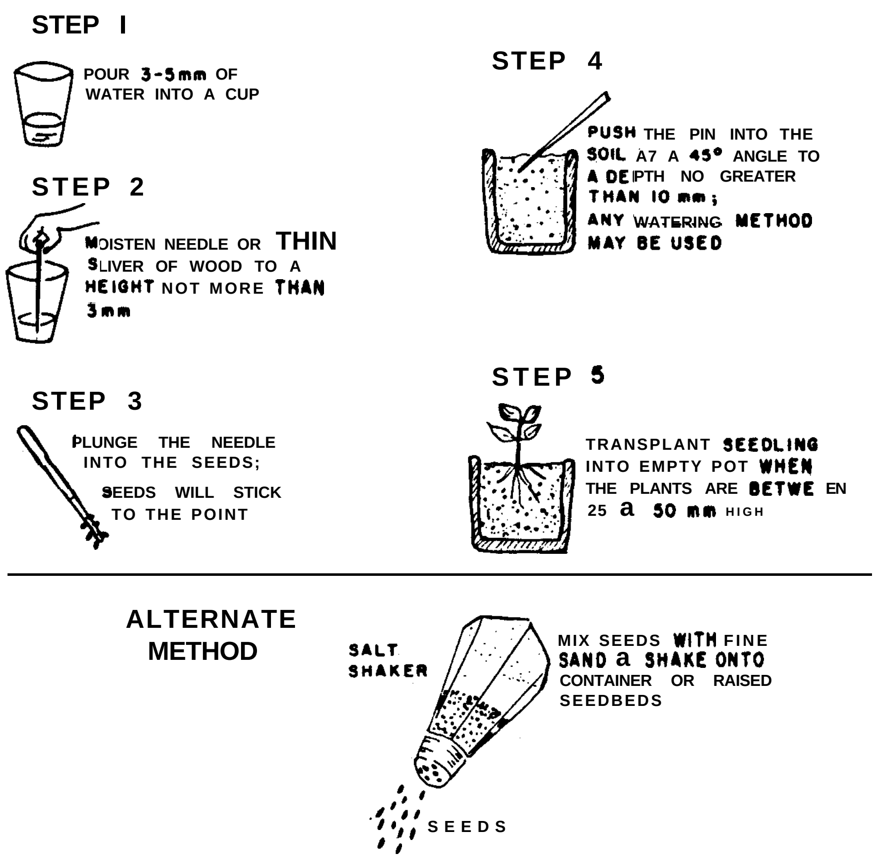


Figure 9-5.—*Seeding very tiny seeds such as eucalypts or kadam. Adapted from (31).*

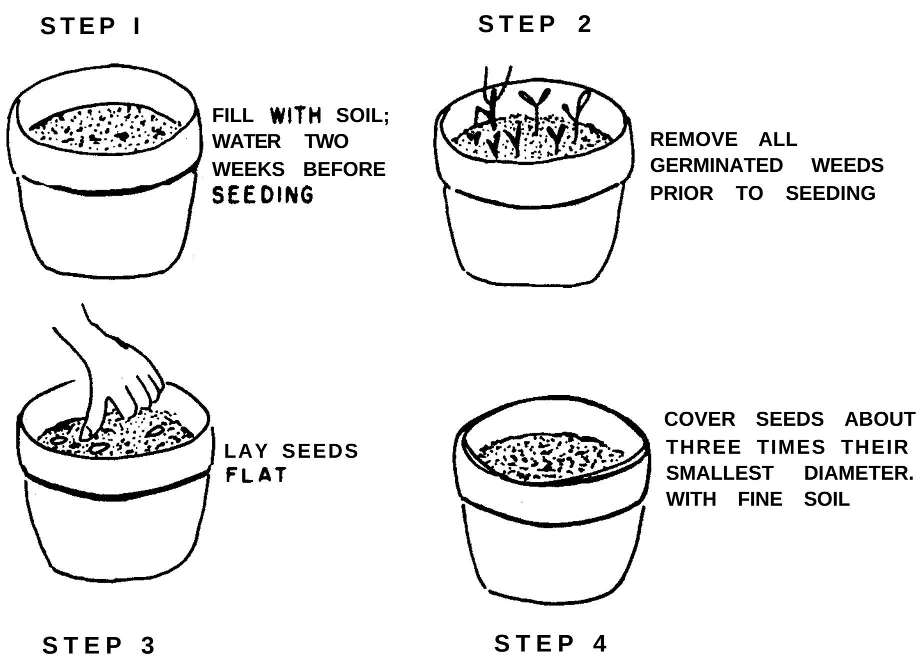


Figure 9-6.—*Seeding procedures for medium and large seeds. The same technique can be followed when seeding onto raised seedbeds. Adapted from (31).*

most pines, teak, *Gmelina, Casuarina,* and kadam. Advantages of these systems over container systems are:

- sowing seeds directly in ground-level or raised beds avoids transplanting after germination;
- early and later tending care are usually easier:
- there is less weight to transport from nursery to field, allowing more seedlings per trip;
- bundling, handling, and packing are fairly simple for treatment; and
- bare roots are the best type of stock for mechanized planting.

Disadvantages are:

- nursery soils need inherently good physical and chemical properties for permanent use;
- seedlings need 2 to 3 months more time for development;
- damage is potentially greater to roots if they are exposed to air and heat after lifting; and
- large amounts of high-quality irrigation water are required.

9.2.2 ***Bed Orientation.*** -Small, shaded bare-root seedbeds in the tropics can run east/west but not north/south as- in temperate areas. Because tropical areas are close to the equator, the sun's rays are more direct there than in more northerly or southerly latitudes. An east/west orientation and covered beds (fig. A4-1, Appendix) under sloped roof sheds provide shade during the hottest part of the day for seedbeds. For large bare-root nurseries, available land and its topography will dictate bed orientation.

9.2.3 Fallows.-Fallows or cover crops are grown on idle nursery land to protect against erosion and to build up soil organic matter. Bed areas that have been in fallow should be plowed 4 to 6 months before sowing seeds. Allowing grass and weeds to decompose first before sowing reduces soil C/N levels to levels that do not limit seedling nutrition. A C/N ratio of 30:1 or less avoids adding supplemental N fertilizers. Typical ratios based on dry weights of C and N are alfalfa, 13:1; legume-grass hay, 80:1; oat straw, 80:1; and sawdust, 250:1.

9.2.4 ***Cultivation.*** -Before cultivation, bed areas can be fumigated (Sec. 16.2); however, this is rarely done in small nurseries. Beds are cultivated by hand or implements pulled by horses, oxen, mules, and tractors. Hand cultivation is limited to beds 5 m or shorter (fig. 9-7). Raised beds with protective covering are also used (fig. 9-8). Standard beds are 1.2 m wide, with seven seedling rows. Within beds, soil can be mounded (fig. 9-9) with hand tools or special plows. Mounding has several advantages, primarily increased aeration and drainage (2) (Sec. 16.1.3). Walkways should be at least 45 cm wide between nursery beds to allow easy access for weeding and protection control.

9.2.5 ***Sowing.*** -Push-type planters or seeders can drill seeds and fertilizers to specified depths at the same time and cover both in one operation. For small beds, furrows are dug along string and stake guides. Seeds are covered to a depth 1 or 2 times their width. Fertilizers are placed alongside or underneath seeds, with an intervening layer of soil in-between; if fertilizers touch seeds or new roots, burning of plant tissue occurs, probably resulting in seedling mortality. Sometimes, seeds are broadcast (direct-seeded) over seedbeds by hand or with cyclone broadcast seeders. Average density is 150-300 seedlings/m^2 (*20, 30*).

9.2.6 Mulching. -After seeding, mulches are spread over seedbeds to protect the seeds from animals, erosion hazards, and weeds, and to conserve soil moisture. Many kinds of mulch are used; none must stop germinating seeds from pushing upward to the surface or rot on top of the seedbeds (Sec. 16.3.3). Mulching may or may not influence seedling survival in the nursery through outplanting time (*22*).

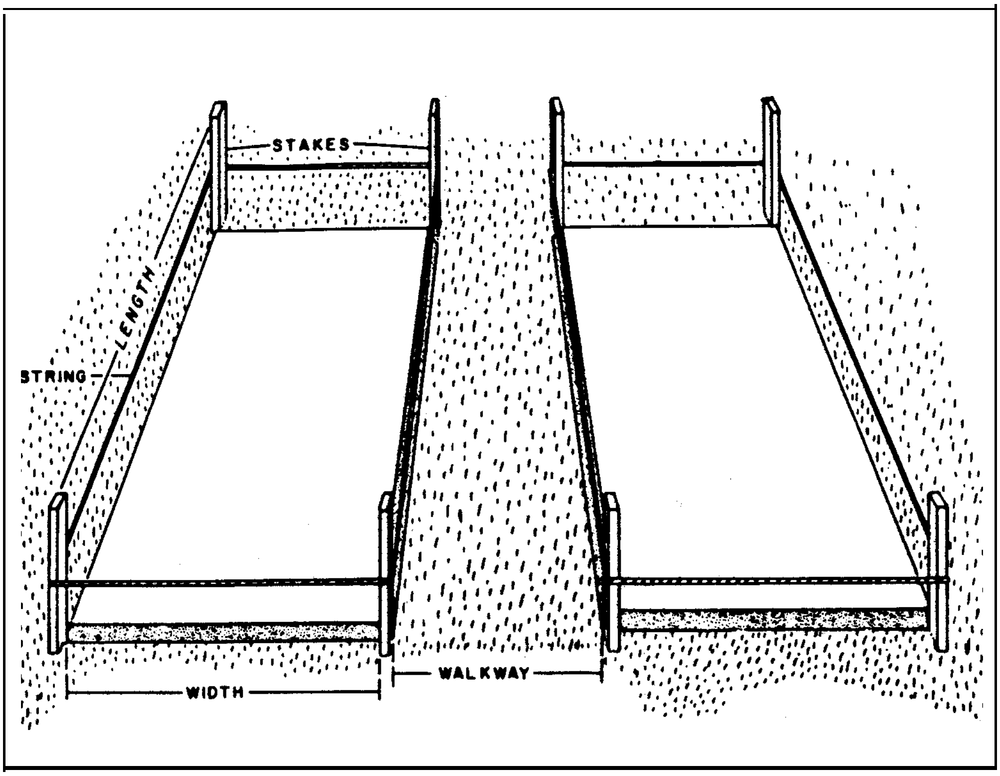
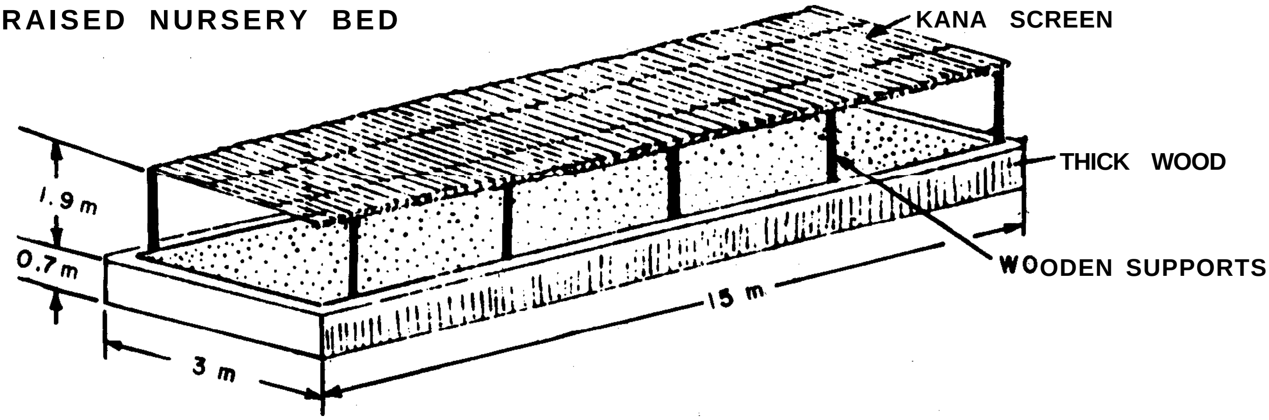
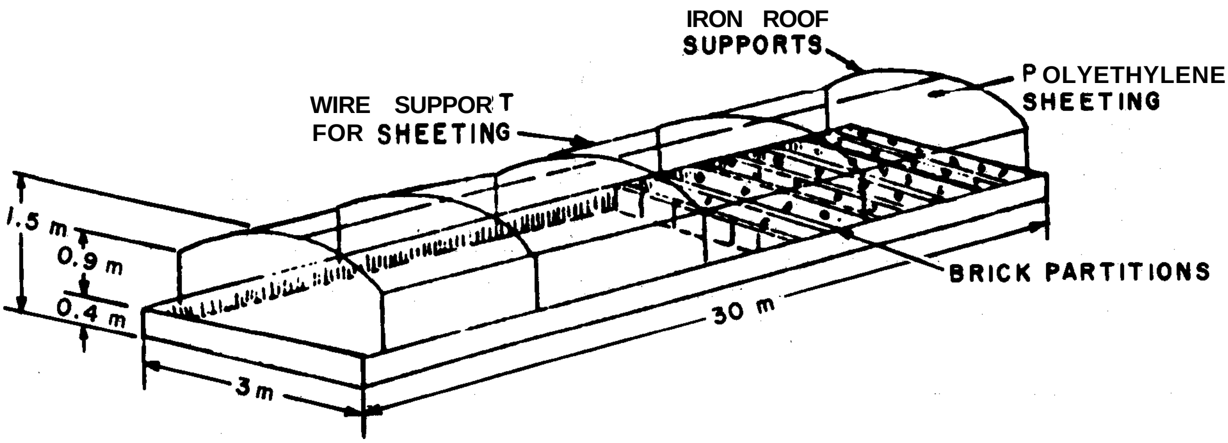


Figure 9-7.—*Proper method of laying-out small, ground-level seedbeds for bare-root nursery stock.*

A. RAISED NURSERY BED



B. SUNKEN BED FOR CONTAINER PLANTS



C. COVERED SHED

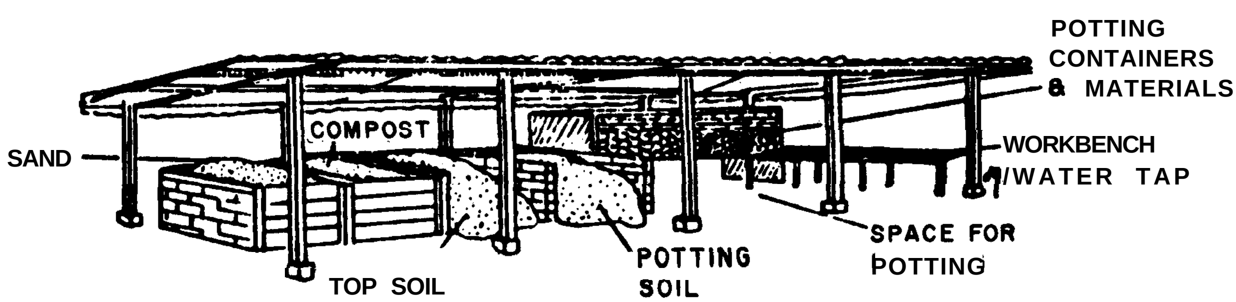
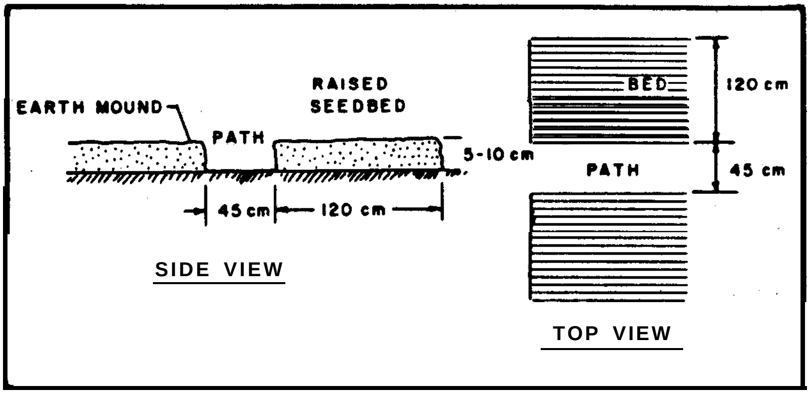
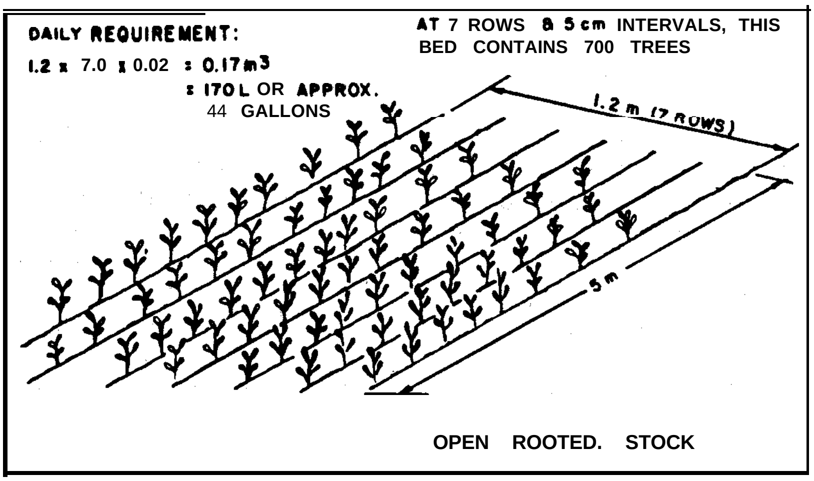


Figure 9-8.—*Nursery structures. Diagrams A and B by A. Krochmal, USDA Forest Service, retired, Asheville, NC; diagram C adapted from (32).*



A. RAISED SEEDBED FOR OVERHEAD IRRIGATION.



B. WATER NEED CALCULATIONS.

Figure 9-9.—*Nursery bed irrigation considerations. Adapted from (31).*

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CHAPTER 10

10. TRADITIONAL EARLY TENDING OF SEEDBEDS AND CONTAINERS

Container and bare-root systems have similar *early tending* requirements for water, shade, and **weeding;** early tending includes the first 4 to 6 weeks of seedling growth, including germination. Container systems may be more complex if they include additional steps of transplanting and associated activities. Throughout this discussion it is assumed that adequate protection, pest control, and nutritional needs are monitored (Chaps. 12 and 13).

10.1 Container Systems

10.1 .1 Transplanting

10.1 .1 .1 Timing. -When transplanting from germination trays, it is essential to avoid stunting of seedlings. Transplanting is done after seedlings are large enough to be handled safely but before they get too large and crowded in the trays. The optimum time to transplant pine germinants is 3 to 6 days after emergence and before the **seedcoat** is thrown (*11*).

For kadam and ***Eucalyptus*** species, seedlings must be at least 2 cm tall or have four or more leaves that are large enough to handle. Because kadam plants are very small, seedbeds are checked daily to find possible transplants.

Early lifting after germination serves two purposes. First, seedlings are lifted before tap roots develop lateral branches. If lateral roots are stripped off older transplants, lost water absorption capacity causes wilting and maybe death. Second, large root systems are easily bent during transplanting, causing development of J-roots (figs. 10-l and **10-2**).

Transplanting into lined-out pots has two advantages over direct seeding in pots (3). First, managers do not have to wait several weeks to see if seedling density is satisfactory; workers ***control density*** in lined-out pots by transplanting one healthy seedling in each pot. Second, once seedlings are ready for lifting, transplanting can be staggered over several weeks or days. This procedure allows grouping transplants by similar age classes so that outplanting is also spread over a longer period. When bulked seeds of several provenances are used, germination may be uneven because of differences in germination rates (*10*). If this occurs, transplanting delays are the only alternative.

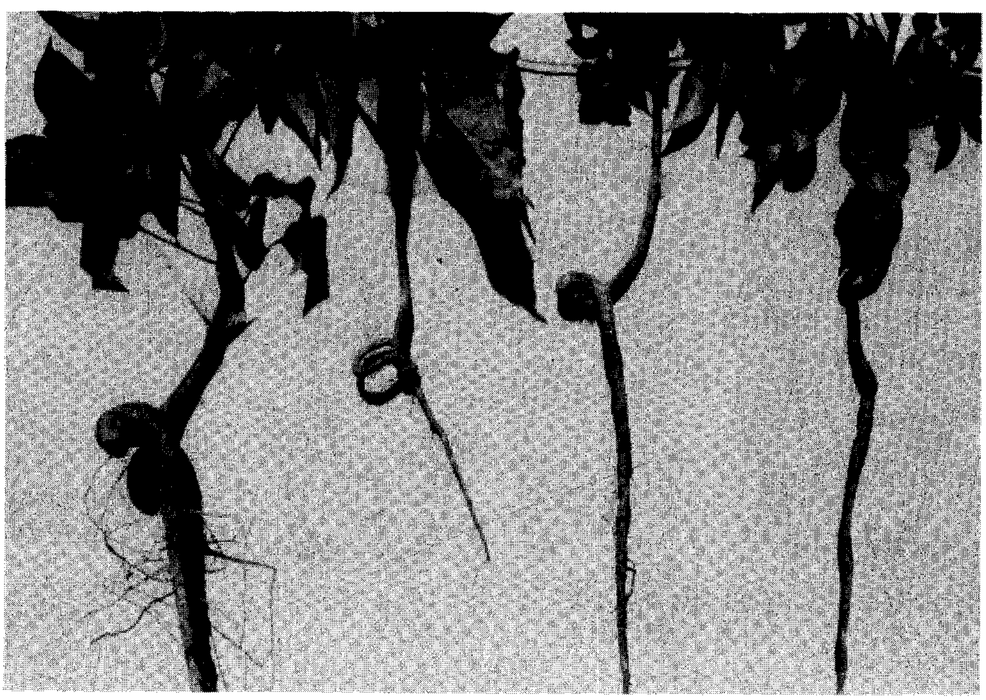
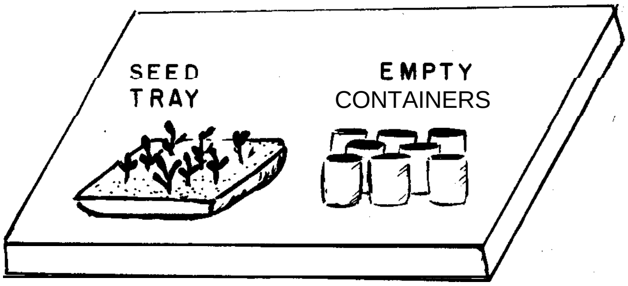


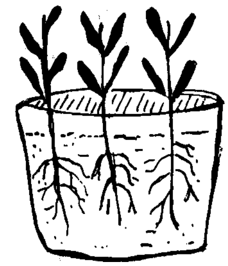
Figure 10-1.—*Typical J-root systems on* **Swietenia** *(mahogany) caused by improper transplanting from germination trays into pots.*

STEP I



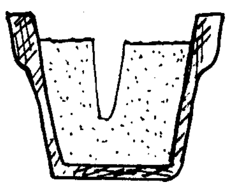
LIFT OUT SEEDLINGS FROM POTS OR SEED TRAY MEDIA WITH STICK

STEP 2



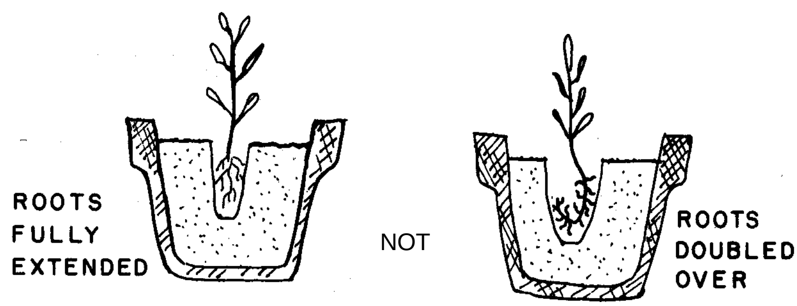
PLACE SMALL SEEDLING BUNDLE IN BOWL OF WATER TO KEEP ROOTS MOIST; IF NECESSARY TRIM ROOTS WITH SCISSORS TO 3-5 cm LENGTH.

STEP 3



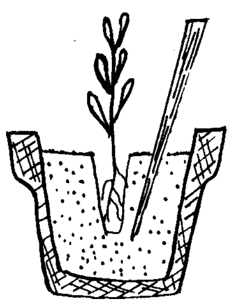
PRICK SMALL HOLE IN CENTER OF POT OR CONTAINER CAVITY WITH SHARPENED STICK, DOWL, OR PENCIL.

STEP 4

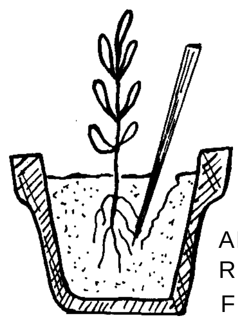


PLACE SEEDLING IN HOLE; MAKE SURE ROOT SYSTEM IS FULLY EXTENDED LENGTHWISE, NOT DOUBLED OVER IN J -SHAPE

STEP 5



FIRM UP SEEDLING & EXPEL AIR FROM HOLE BY PUTTING STICK NEXT TO HOLE & PUSHING SOIL TOWARDS SEEDLING.



AFTER FIRMING UP, REMOVE STICK & FILL HOLE

Figure 10-2.—*Transplanting or pricking-out procedures.*

10.1.1.2 Procedures. -Seedling roots must be kept moist throughout the transplanting process to avoid desiccation and death. Workers "prick-out" appropriate-size seedlings from germination trays and place them in a small container of water. After poking a small hole in the soil (with pencil, nail, or sharpened stick), seedlings are placed in this hole. The soil is then carefully firmed up around each seedling, eliminating air pockets in the root area. Firming up seedlings and closing air pockets is done by 1) putting the planting dibble alongside the seedling and 2) pushing soil towards the seedling to fill the cavity (fig. 10-2). One laborer can transplant about 4,000 seedlings per day; if laborers work in pairs, they may plant up to 10,000 per day.

A risk in lifting several hundred seedlings from different germination trays and placing them in a common bowl of water to avoid root desiccation is the spreading of damping-off and other fungal diseases (5, 6). Submerging infected seedlings in a bowl of water along with other seedlings spreads the disease. There are several solutions. One is instructing trained workers not to place seedlings with suspected infection in the transplant dish. Another safer solution is filling the transplant dish with a captan solution. Thus, each seedling is treated with captan, minimizing spread of infection during transplanting. Once damping-off is noticed, the treatments shown in table 10-l and the precautions given in Appendix-12 are followed.

Another alternative is transplanting seedlings directly from germination trays into pots, avoiding the use of transplant dishes. This is not usually done for two reasons. First, germination trays are frequently filled with heavy soil or soil mixes, making trays difficult to lift and handle. If a tray is dropped, hundreds to thousands of germinants are lost. Second, wet seedling roots plant better than those coming directly from germination trays.

10.1.2 Resowing. -If germination in direct seeding is unsatisfactory (i.e., many empty containers remain), then containers are resowed. When resowing, containers with seedlings are grouped together in one area, and those without seedlings are grouped in another area of the nursery. Regrouping pots before resowing avoids suppression of young germinants by older germinants from the previous sowing. Excess transplants should be put in' separate beds. If voids appear in some beds, they are filled immediately with these extra seedbed transplants. This practice minimizes seedling growth differences among beds and groups seedlings of the same age.

10.1.3 Watering. -Maintaining adequate but not excessive moisture is essential during germination (2). Germination trays should be checked two to three times a day; if the medium is moist to fingers but water cannot be extracted by squeezing, moisture is adequate. A fine (mist) spray from overhead pipes or back pumps prevents washing seeds out of the trays (4). If overwatering occurs, shade is removed temporarily to speed up evaporation.

Some managers water seedlings immediately after transplanting; added water fills air pockets around the seedlings (fig. 10-2). Small squeeze-water bottles

Table 10-1.—*Treatments* to prevent *damping-off*

Type of treatment	Point of treatment	
	Seeds	Germination medium
A. Steam sterilization (before seeding)	NO	Yes
B. Fumigation (before seeding):		
1. Methyl bromide gas	No	Yes
2. Phosphine	Yes	Yes
3. Ethylene dichloride	No	Yes
4. Carbon tetrachloride	Yes	NO
5. Carbon disulfide	Yes	No
C. Drenches (after germination/transplanting):		
1. Dexon	NO	Yes
2. Captan	No	Yes
3. Ferbam	NO	Yes
4. Thiram	No	Yes
5. Zineb	NO	Yes
6. Chloroneb	No	Yes
7. Bordeaux	No	Yes
D. Dust (after transplanting):		
1. Mercury	Yes	No
2. Captan	Yes	No

with a long spout are suitable for this operation. Overwatering creates a soupy mixture in a pot and should be avoided to allow adequate aeration of roots (*9*). Fear that heavy rains will damage or wash out young seedlings seems unjustified. In Puerto Rico, significant seedling losses due to rainfall have never been seen, even after severe downpours.

10.1.4 Shade. -Transplanted seedlings should be placed under at least 30-percent shade for 1 to 2 weeks; some areas use up to 85-percent shade (7). Although it is possible to transplant ***Pinus caribaea*** into sun-exposed containers and obtain high survival, this practice is not recommended. Because seedlings suffer the double shock of removal from shaded germination beds and planting in exposed containers, risk of wilting and death is too great.

For raised transplant beds, shade screens are placed high enough above the pots so that workers have access for tending seedlings (fig. A4-1, Appendix). For ground level beds, posts and T-frame structures are screened to similar specifications (fig. 9-3).

Saran (open-mesh plastic sheeting) shade cloth is expensive but quite resistant to damage from ultraviolet sunlight. With proper handling and storage after use, **saran** can last 10 years. Other shade materials are bamboo **(kana)** screens, palm fronds, and wooden laths.

Small seedbeds can have 20 to 30 percent shade cover for the first month. In open and sunny areas, shade is then gradually removed as seedlings become older to avoid undue stress by sudden exposure to sunlight. Some large direct-seeded containerized operations use no shading unless transplants are used to fill in voids in seedbeds.

Treated wood frames and corner posts last longer than untreated wood. If hot-cold treated wood is used, is must be dried properly before use so that preservative chemicals do not "bleed" onto seedlings below them; such chemicals are toxic to plants and man.

To avoid edge effects by exposure to sunlight, saran and other shade materials should extend 0.3 to 0.5 m beyond bed borders. Early and late in the day, sunrays are best blocked by dropping screens at ends of the beds. As explained in Chapter 4, greater shade extension is needed on the south side of nursery beds than on the north side in lower tropical latitudes.

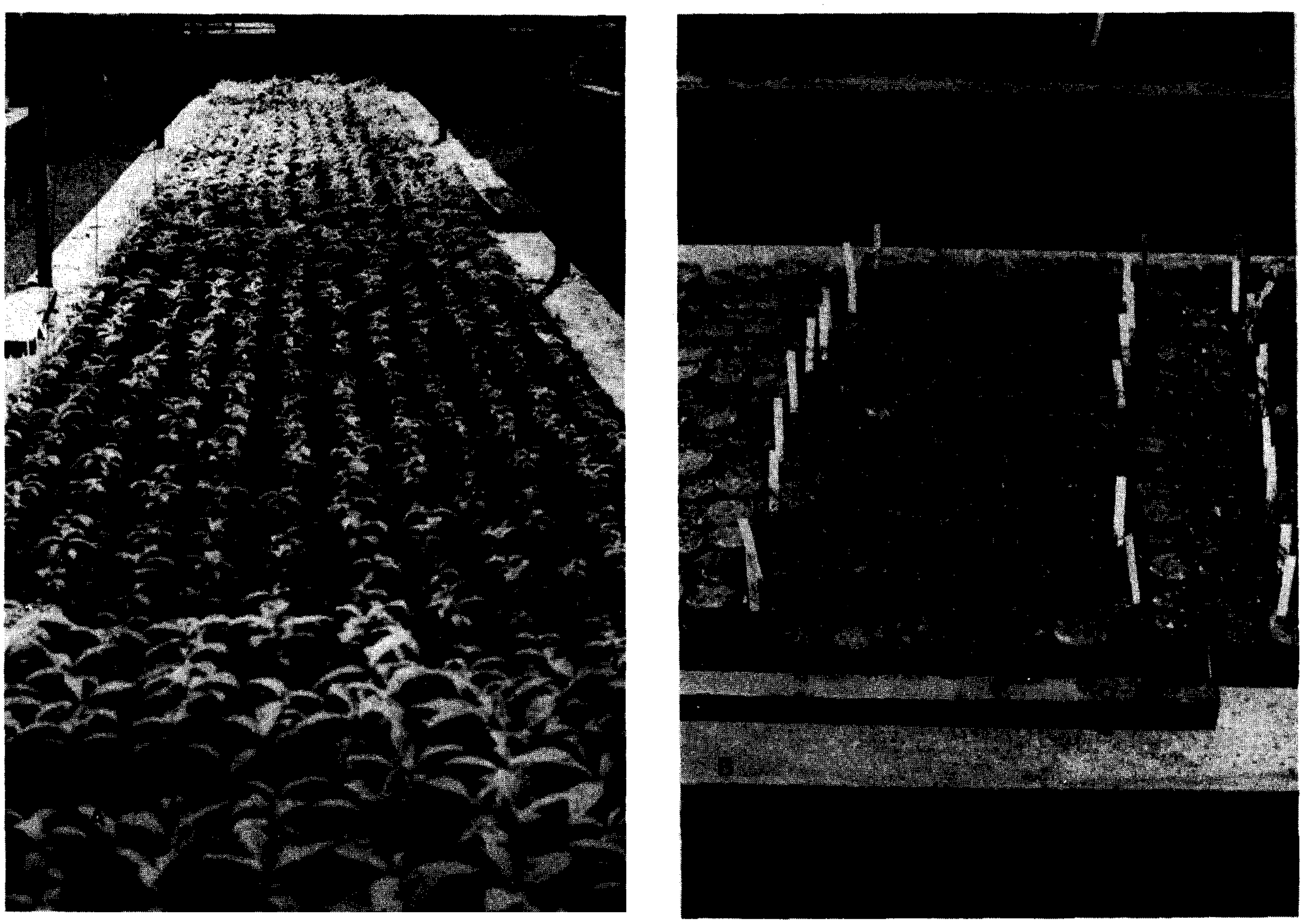


Figure 10-3.—*Early weeding can be done by hand from both sides of small nursery beds for either (A) bare-root* (Cordia) *or (B) containerized* (Araucaria) *stock.*

10.1.5 Weeding. -Only maintenance weeding is needed in the early weeks after transplanting and direct seeding in pots. Hand weeding is most common. Weeding frequency depends on whether the pot medium was sterilized, the extent of viable weed seed in the potting medium used, and the absence or presence of nearby weed and grass seed sources.

Weeds must be pulled when they are small, young, and succulent, *before* their root systems develop too much. When weed roots have spread too far within pots, removing them disturbs seedling roots (fig. 16-2). If workers are not careful, entire seedlings are easily pulled out with weeds. When this occurs, it is almost impossible to replant 4- to 6-week-old seedlings without causing deformed roots.

10.2 Bare-Root Systems

10.2.1 Watering. -Bare-root seedlings are more generally exposed to air and light than container stock. Thus, water needs of unscreened bare-root stock are greater than those of screened container stock (*1*). Beds are checked frequently for moisture and signs of seedlings wilting. Approximately 100 liters of water are needed daily for a bare-root bed 1.2 by 5 m in size (fig. 9-9). Actual water needs vary by site and are related to bed soil texture, amount of solar radiation received, presence or absence of winds, species transpiration rate, and growth stage of seedlings (Sec. 16.4.21.

For medium and large bare-root nurseries, fixed irrigation systems give best water coverage (*8*). For small nurseries, water hoses and sprinkling cans may suffice. With any system, water should be applied as droplets; continuous streams of water wash out young seedlings. On high clay soils, overwatering causes root rot due to soil moisture retention.

10.2.2 Shade.-Saran or lath shade can be provided for small ground-level and raised bare-root beds. This technique is impractical for large mechanized operations (Chap. 16). Shading guidelines for traditional bare-root and container nurseries are essentially similar (Sec. 10.1.4).

10.2.3 Weeding. -Guides for weeding traditional bare-root and container beds are also similar (Sec. 10.1.5). Hand weeding is practical when beds are small and labor is plentiful and cheap (fig. 10-3). When seasonal production in bare-root nurseries reaches 100 to 200 thousand plants, chemical control may be more practical and economical. The major concern is selecting herbicides for weeds that are nontoxic to seedlings. Suitable herbicides and precautions to be followed are given in Appendix 12.

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CHAPTER 11

11. TRADITIONAL LATER TENDING OF SEEDBEDS AND CONTAINERS

"Later tending" includes the time from 4 to 6 weeks after germination until lifting and outplanting. This period is distinct from that of early tending; seedlings have passed the "hurdles" of germination and transplanting and are well on their way to becoming healthy, plantable stock. Some hurdles involving weeds, moisture, and lifting still remain. These factors are now addressed, as well as more special steps that promote proper seedling shoot and root growth. As in Chapter 10, it is assumed that protection, pest control, and nutritional monitoring continue simultaneously (Chaps. 12 and 13).

11.1 Container Systems

11.1.1 Grouping, Sizing, and Lining-Out. -Nurseries must produce healthy seedlings having minimal differences in height, root collar diameter, and foliage characteristics. In container systems, sorting or grouping seedlings in beds by height produces planting stock of uniform height. In bare-root systems, such sorting is impossible and uniform size is achieved by other means (e.g., undercutting, root pruning, clipping), which are discussed in Sections 11.2.4, 16.4.6, and 16.4.7.

Where labor costs are low, seedlings are regrouped as many as three times during their 6- to 8-month stay in the nursery. Because the practice creates employment, it is defended in areas with high unemployment and low labor costs; the reverse is true for areas with high Iabor costs. Periodic regrouping culls inferior stock; this practice reduces lifting and packing chores later and probably reduces disease risk. Similar regrouping is impossible for individual plants in multi-cavity block containers but is possible for single cell design systems (Sec. 15.1.6).

Potted seedlings can be lined-out on the ground or on other surfaces (figs. 9-3 and 11-1) and in permanent raised or sunken beds (fig. 9-8). Raising pots on blocks and wire screens fosters air pruning of roots. Placing containers on hard flooring or on plastic

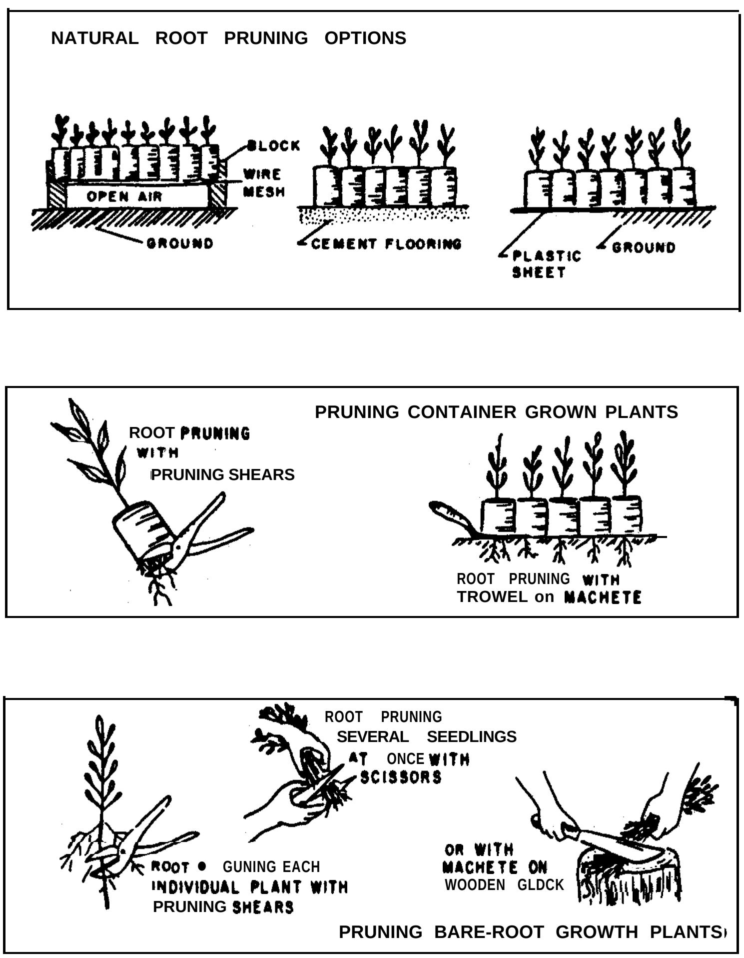

Figure *11-l.-Lining-out, pruning, and lifting of container seedlings. Adapted from (20).*

sheeting prevents root egress into soil under pots. If roots egress into underlying soil, lifting and packing are difficult and root damage from stripping is likely.

11.1.2 Inoculation with Mycorrhizal Fungi.-The function of mycorrhizal fungi on conifer roots is still under study. They appear to help in mineral (*11*) and possibly water uptake, perhaps by increasing root surface area. The fact that pines do not grow without mycorrhizal fungi has been documented in Puerto Rico (3, 18) and Venezuela (7). Thus, all conifer seedlings should be inoculated in the nursery. Mycorrhizal fungi can be added to pot medium before transplanting or 3 to 4 weeks after transplanting. This schedule avoids treating seedlings still in transplant shock but assures effective inoculation before older seedlings have greater moisture and nutrient requirements.

Mycorrhizal fungi can be sometimes obtained locally or, if not, must be imported. They are collected in duff and mineral soil (0 to 2 cm) from a healthy plantation or forest. All material is ground and incorporated into the pot medium. An alternate method is to leach fungal spores from duff material with ambient-temperature water. Water and spores are applied to containers from sprinkling cans or back-pump sprayers. Water temperatures that are too warm (>30°C) can retard fungal growth and seedling development (12). After 2 to 4 weeks, mycorrhizal fungi should be visible to the naked eye or with a hand lens.

11.1.3 Watering. -Seedlings should be watered as needed. This is determined by inspecting potting medium for moisture and by checking for wilting of seedlings. Only combined knowledge and practical experience with plant stress, different pot volumes and medium used, time since last rainfall or irrigation, current moisture status of potting medium, and growth seedling stage will determine actual watering schedules. Early morning watering is best. By afternoon, excess moisture on seedling foliage has evaporated, thereby reducing chance of disease, which can build up on moist foliage during warm, humid tropical nights.

As seedlings grow and root systems expand in the pot medium, moisture status is dependent on container volume, type and texture of growing medium, and ability of pots to void excess water through drain ports. Packed clay soil will not allow water to drain normally throughout the pot. Thus, the medium may be too dry or too wet, depending on how much water is applied. In general, for many pot mixes, if too little water is applied, most of it runs off without infiltrating. Overwatering saturates the medium and aeration is reduced.

Indications of poor drainage and aeration are stunted, yellowish-colored seedling foliage and more concentrated root growth between soil and bag interfaces than in the pot medium. In extreme cases, seedlings die because root rot has destroyed the roots (fig. 11-2). If foliage is only yellow, reducing watering frequency and respacing pots to expose them to more sun and drying may help. When foliage turns brown, seedlings are not salvable. New seedlings need a better drained medium and less frequent watering.

Salinity and acidity should be monitored regularly, particularly if nutrients are added with irrigation water (Sec. 15.4.6.1). During hardening-off, watering frequency is gradually, then rigorously reduced (Sec. 11.3.2).

11.1.4 Weeding.-As seedlings grow, increasing foliage area shades the pot surfaces and helps suppress weed growth. Once weeds are established, they must be removed cautiously (Sec. 10.1.5). Usually, hand weeding suffices. Problem areas are edge rows, particularly for ground-level beds. Unchecked weed growth in these areas shades out adjacent seedlings or provides seed sources for nearby containers. Machetes, shovels, hoes, and other small hand tools are used to remove grass and weeds from bed borders.

11.1.5 Shoot and Root Growth Control.-For container systems, shoot growth control is achieved mainly by grouping seedlings of similar height in the same beds (Sec. 11.1.1). This practice keeps fast-growing seedlings from overtopping and shading out slow-growing ones. If limited overtopping of seedlings occurs and neither additional regrouping nor outplanting are imminent, the fastest growing individuals can be clipped back. This slows top growth and enhances root growth. There must be sufficient pot volume to accommodate extra root growth or root spiraling will result.

Root growth of potted seedlings is controlled by effective pot volume and depth. Once roots fill this volume and reach the pot bottom, seedlings must be out-

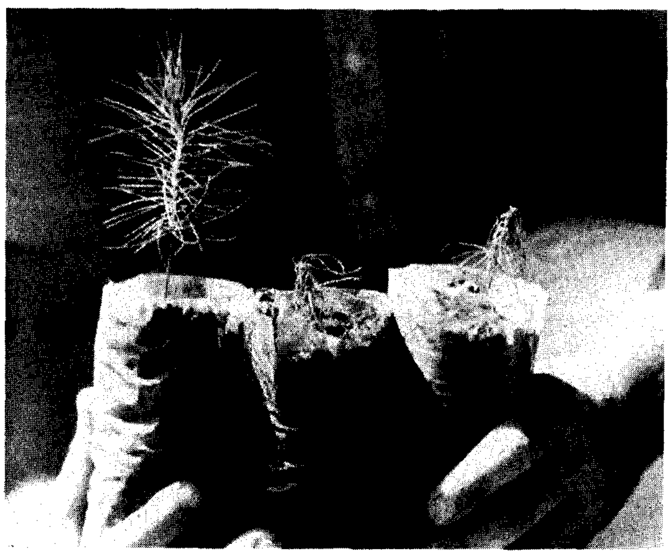

Figure *11-2.-Effect of overwatering and poor drainage on potted nursery seedlings.*

planted. Extra holding time causes root spiraling or strangling. Knowing seedling shoot and root growth rates and outplanting dates are crucial for selecting optimum pot volume and for controlling root and shoot growth.

If unforeseen difficulties delay outplanting beyond 1 to 2 months, two alternatives exist for "holding over" seedlings. If labor is cheap and abundant, seedlings are repotted into larger containers that will accommodate larger root systems. When repotting is not feasible, severe root pruning is needed before outplanting. In both instances, survival and growth performance of hold-over seedlings in the field will probably be less than that of seedlings planted on time.

11.1.6 Lifting and Transporting. -Root systems of containerized stock are self-contained and protected by pot walls. Fewer precautions are needed in lifting and transporting containerized stock than are needed for bare-root stock. If roots have grown through pot bottoms, they must be pruned and trimmed before loading (fig. 11-1).

Containers are placed in transport flats, loaded onto trucks, and securely tied (fig. 11-3). Because wind burn is a real threat to seedlings, truck beds are entirely enclosed with a tarp to protect them from wind and sun. Drivers should inspect tarp fastenings occasionally, making sure they are secure and that wind is not blowing on seedlings.

A 5- to 8-cm head space between each layer of seedlings is left on the truck beds. If light-weight growth medium is used, several tiers can be loaded on trucks without creating a topheavy load. But if the potting medium is soil; fewer tiers are possible because greater weight can create a topheavy condition, endangering truck and driver when maneuvering curves.

In temperate climates, anti-transpirants are sometimes sprayed on seedling foliage before transporting them. Use of anti-transpirants is not usually necessary for seedlings in the tropics because they are not stored as dormant stock. Yet, if seedling tops are too large in relation to container root volumes and there

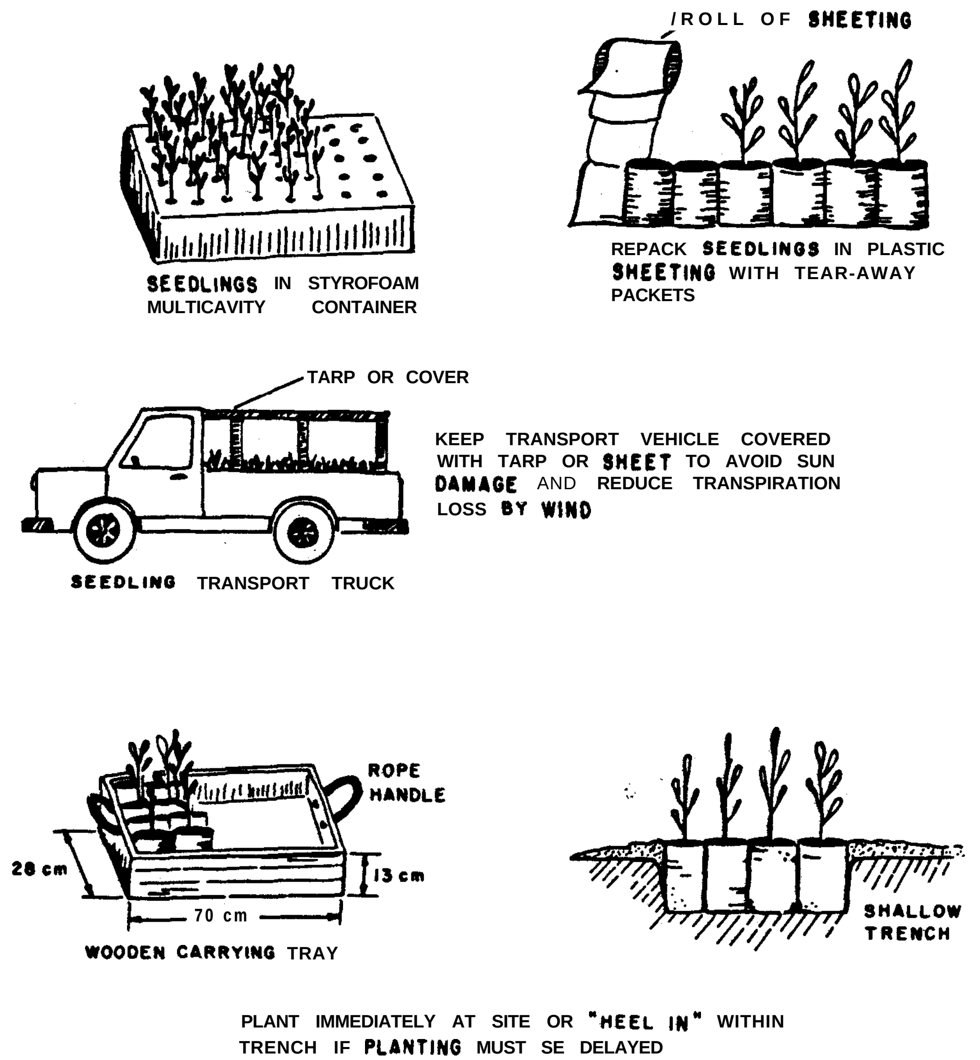

Figure 11-3.—*Transporting of nursery seedlings to field outplanting sites.*

is danger of excessive transpiration, anti-transpirants could possibly be used to reduce short-term water loss. Small research trials will determine the effectiveness of such treatment.

11.2 Bare-Root Systems

11.2.1 Inoculation. -Seedlings in bare-root beds are inoculated with mycorrhizal fungi, using forest duff and mineral soil or water-borne spores, following procedures used for container beds (Sec. 11.1.2). Inoculation is done before sowing or before seedlings are 4 to 6 weeks old. If healthy plantations exist around bare-root beds (fig. 11-4), natural inoculation may be adequate, especially when bed soil is not sterilized.

11.2.2 Watering. -Generally, bare-root beds have greater water needs than container beds because of their greater environmental exposure (Sec. 10.2.1). Older bare-root seedlings have greater water needs than younger seedlings. Thus, almost daily watering is required until hardening-off is started. Soil moisture must be checked often in well-drained, porous beds. Bed soils with more clay lose moisture less rapidly.

Damaging effects of irrigation droplet impact are minimal for older, larger seedlings. Exceptions are leaky pipes where escaping water can destroy large areas of beds and seedlings (fig. 16-4).

11.2.3 Weeding. -Openness of bare-root beds favors more weed growth than do container beds. Hand weeding suffices for small nurseries; mulches are usually too troublesome to be effective (*15*). For large bare-root nurseries, only herbicides give dependable, long-term control, up to 30 days and longer between applications. When herbicides are unavailable, dilute concentrations of kerosene or other mineral spirits also control weeds fairly well in pine bare-root beds (Sec. 16.4.1). Before applying any herbicide, one must ascertain that its effectiveness is specific only for the plants treated and not toxic to seedlings (*8*, *16*).

11.2.4 Shoot and Root Growth Control.—Undercutting, lateral pruning, and top pruning are techniques to control root and shoot growth of bare-root nursery stock. Root wrenching is practical only in large, mechanized bare-root nurseries. In very small nurseries, none of these techniques may be used because the scale of operation does not demand quality-control stock. Sections 16.4.6 and 16.4.7 contain more detailed discussions of all shoot and root control operations that are used in bare-root nurseries.

Undercutting is done with machetes and shovels in small nurseries (*14*, *17*) and with tractor drawn machines in large nurseries. Clean severing of taproots stimulates lateral root growth but stops shoot growth. The technique is effective in manipulating shoot/root ratios.

Lateral root pruning severs roots between adjacent seedling rows. The technique allows easier lifting of seedlings before packing and transporting. Machetes or machines are used, depending on nursery size.

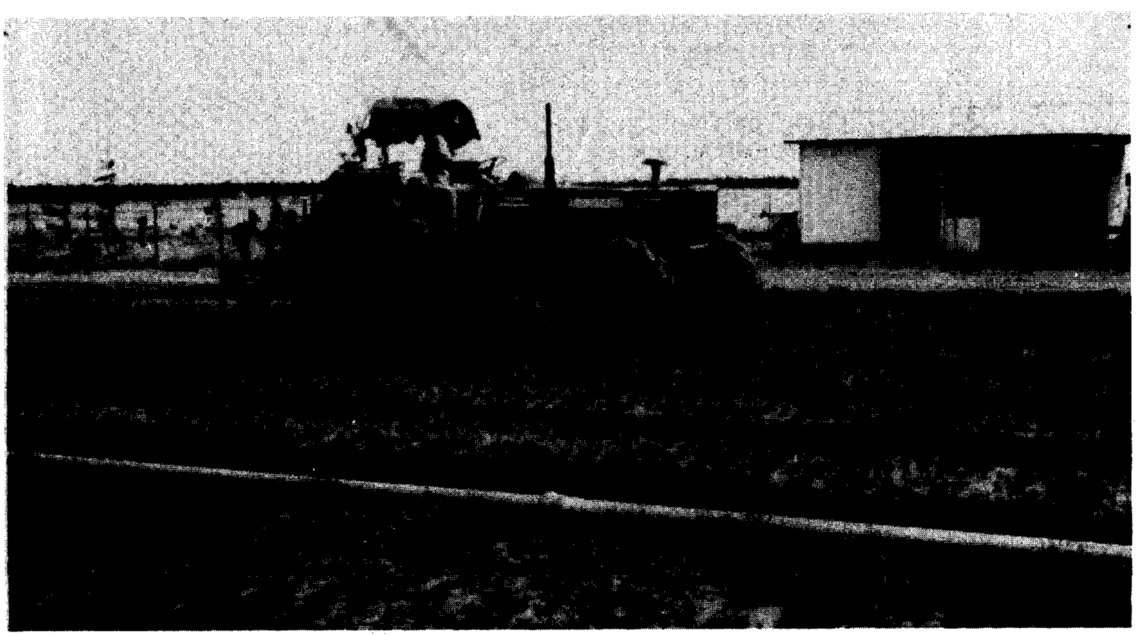

Figure *11-4.-Pine plantations around a nursery complex serve as inoculum sources of mycorrhizal fungi, naturally hy wind-home spores and artificially by man; the latter procedure must be used when hare-root beds are fumigated. Note that urea directly behind work shed was cleared and prepared for new beds so that old beds could be fullowed. Leaving three to four rows of trees would have retained windbreak effect of that area for existing beds.*

Top-pruning (clipping) controls excessive shoot growth. The technique is used selectively for individual seedlings that are overtopping others and for entire beds when all seedlings have grown too fast and must be kept longer before lifting. The operation stimulates root growth and is another method of manipulating shoot/root ratios. Hand shears are used in small nurseries and tractor drawn mowers in large nurseries.

11.2.5 Lifting and Transporting. -The four procedures for taking bare-root seedlings to the field are lifting, protecting, grading, and transporting. Stock should be lifted with shovels, never pulled directly from the soil; the latter can strip rootlets from seedlings, particularly if they are pulled from dry, clay soil. Soil is shaken off roots, which are immediately washed, trimmed, and then stored in water, water slurries, or wet peat moss.

Grading separates plantable from cull seedlings. Grading standards vary by species and geographical area but usually include height, stem caliper, shoot/root ratios, foliage condition, and root mass. For some species, such as neem (*Azadirachta indica*), khaya (*Khaya* sp.), and mahoe, side leaves may be stripped to minimize water loss from tissues (*19*) (fig. 11-5). Only larger, well-developed seedlings should be planted; evidence shows that large seedlings outperform small ones, even up to 5 years after outplanting (*2*). If plants are too large, pruning them back to a total length of 18 to 30 cm may improve outplant survival (*13*).

Planting within a few hours of lifting, or at least the same day as lifting, is the key to successful outplanting of bare-root stock (*4*, *5*). If transporting and planting delays cannot be avoided, *do not lift seedlings.* Seedling roots must be kept cool, in the shade, and moist at all times after lifting and while being transported to planting sites (*1*). Section 16.5 gives other lifting and transporting hints for large bare-root nursery operations.

11.2.6 Stump Planting. -Some species such as Cassia, Gmelina, and teak withstand trimming of the major portions of the seedling stem and root system (*9*). The result is a stump, some 15 to 30 cm long (fig. 11-5). Stumps are easily bundled, packaged, and shipped. Weight is minimal, and many more seedlings are moved per day as compared to containerized and bare-root operations. Shade and protection instructions for stumps are the same as those for bare-root and containerized stock.

11.3 Other Later Tending Considerations

Several nursery operations already mentioned have particular influence on lifting and outplanting success. They are discussed separately to emphasize their importance.

11.3.1 Shoot/Root Ratios. -Determining shoot/root ratios is one way to assess overall seedling health and suitability for outplanting. This is done by measuring oven dry weight or volume of seedling tops and

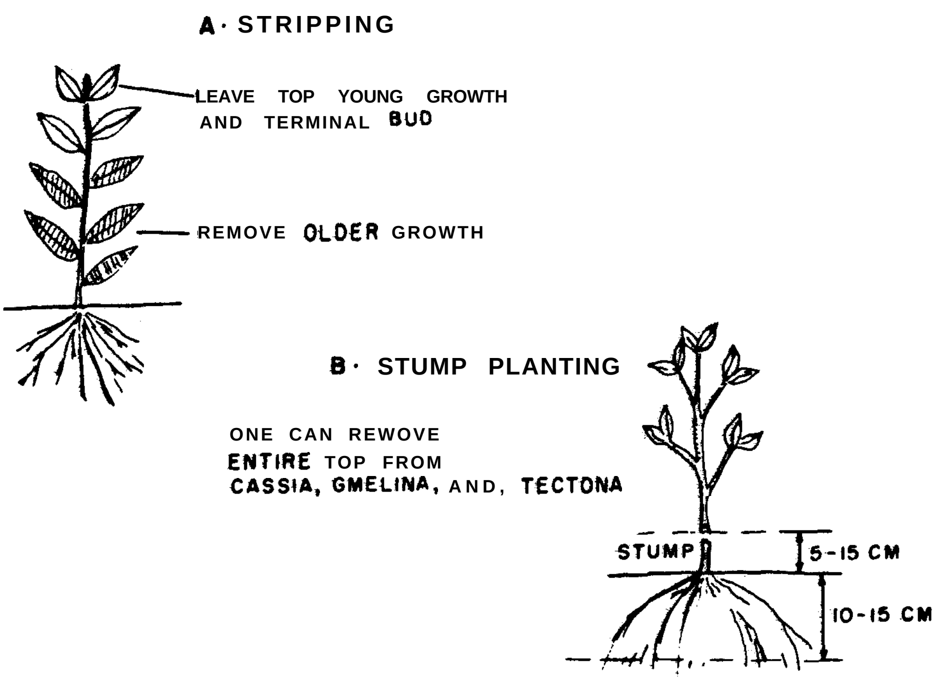

Figure 11-5.-Procedures for (*A*) stripping seedlings before transplanting to field or (*B*) making stumps for outplanting. Taken from (*19*).

dividing by oven dry weight or volume of seedling roots. Shoot-to-root dry weight ratios of 2:1 are acceptable for most seedlings. Higher ratios usually indicate excessive shoot growth for corresponding root growth.

The ratio limit (2:1) must be used cautiously, however, because ratios can be affected by shading and container type (tables 11-l and 11-2). Actual pot volumes and shapes will limit root weights to certain maximum values unless undesirable spiraling occurs within pots.

Type of pot medium also affects root branching and development. Root branching is greater in medium with peat, perlite, and vermiculite than in soil-only medium due to the superior aeration properties of soil-less medium. In soil-only medium, greater development of tap roots and less lateral branching tend to cause root curling or spiraling at the pot bottoms, especially when holding time in the nursery is too long. Large spreading root systems are best because of 1) their greater capacity for absorbing water and nutrients from soil or pot medium and 2) greater surface area from which to extend new lateral roots after outplanting. Planting density also affects the root collar diameter growth of seedlings (*6*).

11.3.2 Hardening-Off. -Special seedling care and treatment in the nursery allows production of green, healthy, and vigorous seedlings of sizes suitable for outplanting. To grow large seedlings in short periods, water, fertilizer, and shade are used to stimulate rapid growth. However, "forced growth" regimes usually produce succulent seedlings that do not survive harsh conditions at planting sites. The hardening-off

Table 11-l.-The *effect ofdifferent shade levels on the height growth, survival, root collar diameter, and shoot/root dry weight ratios of seedlings of* **P. caribaea var. hondurensis**[1]

Measurement	Percent shade level			
	0	20	35	77
Height (cm)	14.1	16.8	21.3	25.0
Survival (%)	95.3	98.5	98.6	97.5
Root collar diameter (mm)	2.31	2.34	2.26	1.90
Shoot/root dry weight ratio	2.17	1.86	2.23	9.83
Mean dry weights (g):				
With LSD:				
Shoot	0.713 ± 0.190	0.706 ± 0.148	0.726 LO.182	0.509 ± 0.132
Root	0.367 ± 0.132	0.446 ± 0.164	0.379 ± 0.142	0.070 ± 0.044

[1]Each shade level represents the mean of 600 seedlings. The seedlings, 6 months old at the time of measurement, were grown in Styroblock 8 cavities tilled with a peat-vermiculite mixture at the ITF experimental nursery in Puerto Rico.

Table 11-2.—*Influence* *of container type on root collar diameter, height, and shoot/root dry weight ratios of seedlings of* **P. caribaea var. hondurensis**[1]

Container type	Volume of containers	Root collar diameter	Shoot/root dry weight ratio	Height
	Cc	Mm		Cm
Polyethylene bags	500	5.36	2.42	36.8
Rootrainer	175	2.88	2.95	22.4
Polypot	250	2.86	2.19	22.4
Polypot	175	2.30	2.47	21.6
Polypot	100	2.11	1.65	18.1
Kraft paper tube	305	3.13	5.04	25.2
Kraft paper tube	190	2.85	6.09	19.9
Styroblock 8	120	2.11	2.59	25.1
Styroblock 4	60	1.78	1.63	21.8

[1]The containers were filled with a peat-vermiculite mixture; no fertilizer was added. The seedlings were direct-seeded, 4 seeds per cavity, and culled to 1 seedling after 2 weeks. The data were taken 6 months after sowing at the ITF experimental nursery in Puerto Rico.

process increases probability that seedlings will survive transplant shock. The process conditions both containerized and bare-root grown seedlings to survive without water and shade as long as possible in the nursery before they are outplanted.

If seedlings have been under continuous shade, the shade should be removed, conditioning seedlings to full sunlight. In the beginning, shade should be removed gradually for 2 hours during the day or for 1 hour in the morning and 1 hour in the afternoon. After 3 or 4 days, length of the shade period is reduced another 1 to 2 hours. By extending shade-free time gradually, seedlings will tolerate full sunlight with a minimum of shock within 2 to 3 weeks. Keeping 40- to 50-percent shade throughout hardening-off, as is done in some countries (*10*), is not recommended.

Hardening-off also involves reducing the amount of water available to seedlings. One method is to gradually extend the time between watering periods by 2 or 3 days. The number of waterless days is progressively extended until seedlings are capable of surviving up to 2 weeks or longer without water. In hardening-off, wilting must be avoided. If it does occur, water is applied until wilting stops; then water reduction begins again, but at less severe regimes.

When hardening-off seedlings in container beds, certain relationships between pot volume, potting medium, seedling size, and hardening-off must be considered. If pot volume is small (less than 150 cc) and filled with a peat: vermiculite medium, hardening-off seedlings for much more than 2 weeks is not possible. Older seedlings will transpire relatively large amounts of water from small containers filled with porous medium. Thus, nursery managers should observe and carefully record all information related to watering, wilting, and density in seedbeds. When information is properly assessed, seedbeds can be efficiently managed with little loss due to improper hardening-off. With accurate information, nursery managers can also tell silviculturists and farmers how often seedlings should be watered if they must be stored for extended periods before outplanting.

11.3.3 Culling J-Root Plants. -Malformed taproots are common among hardwood seedlings grown in nurseries (fig. 10-l). When seedlings are improperly transplanted from germination trays to containers, bent or J-roots occur (fig. 10-2). This is a serious problem because seedlings with J-roots fail to develop properly in the field, and older trees with J-roots are more susceptible to windthrow.

The J-root can be avoided if young seedlings are used and they are carefully placed in transplant holes (Sec. 10.1.1.2). It is best to transplant seedlings ***before*** lateral root branching occurs and before the seedling flush develops.

To avoid bent roots in transplanting, seedlings are pulled through a transplant dish filled with water. The roots trail and coalesce as seedlings are pulled through and lifted from the water. Seedlings are stuck into the hole as deep as possible, pulled up to straighten their roots, and then firmed up with a dibble stick (Sec. 10.1.1.2). If roots are >8 cm long, they should be trimmed back to about 5 cm in length.

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CHAPTER 12

12. PROTECTION AND PEST CONTROL

Nursery stock requires a large investment of time, labor, and monetary resources. Without protecting this investment, large seedling lasses may occur (*3*, 21). Such losses can be catastrophic when communities need seedlings to produce firewood or protect critical watersheds. Large and small nurseries need protection from several physical and environmental elements, as well as from insects and diseases.

12.1 Property and Seedling Security

Daily guard service to protect seedlings and property is very costly. However, it may be the only alternative in areas where animal and human populations are very high, and where small tools can be easily stolen and seedlings destroyed. In poor communities, payment to workers in food rather than direct cash may be best.

Adequate fences deter animals and people. Fences built of treated wood and with proper materials last a long time. In some projects, replacement posts can be harvested from field plantings. When diesel oil and pentachlorephenol are available, hot-cold treating of posts in barrels or drums is relatively inexpensive. Live fences and hedges with thorny plants or local shrubs may be adequate. Diagrams are available on how to construct. self-closing gates and other fencing structures (*22*).

Windbreaks reduce dry winds that evaporate moisture from seedbeds (*16*). Local tree species are preferred, but prolific seeders such as ***Leucaena*** are avoided. Wind blown seed from windbreaks germinate and compete with seedling root systems growing in seedbeds and germinating trays. Removing these invaders is costly, and root systems of seedlings are disturbed in weeding.

Where fires are frequent, a 2- to 3-m firebreak should be maintained around the entire nursery (*22*). Water outlets should be located at several places near the perimeter so that water is readily available if a fire jumps the firebreak.

12.2 Pests and Diseases

Diversity of climate and environments in the tropics precludes simple prescriptions for insect and disease problems of forest nurseries. This chapter is therefore a brief review of some potential problems and is not all-inclusive. A summary of major pests, species attacked, symptoms, and recommended treatments is given in table 12-1.

12.2.1 Symptoms. -When seeds (*5*) or vegetative materials are collected or imported from outside a country, they should be checked immediately upon arrival at the nursery for symptoms of disease or insects. Unfortunately, phytosanitary certificates do not always guarantee that undesirable insects or diseases are absent in imported seeds or plants.

Some insects are apparent from chewed leaves; others are seen on the underside of leaves. Webs and eggs are other signs of infestation. Some common pests are those in figure 12-1.

Disease symptoms can include sooty appearing materials, a form of fungus; rust spots; irregular-shaped blotches or mosaics of different colors; and sticky discharges. Discoloration symptoms can be caused by either disease organisms or by mineral deficiencies (Sec. 13.2).

Table 12-1.—*Summary of major nursery pests and diseases, forest species attacked, and control treatments recommended*

Pest type	Seedling species affected	Control
Insect animal types		
A. Chewing mouth parts:		Ingested poisons:
Cutworms	Mahogany, teak, pines	Spectracide, chlordane
Crickets	Teak	General insecticide
Leaf miners	Mahogany	General insecticide
Shoot borers	Mahogany, Spanish-cedar, and other Meliaceae family species	Systemic insecticides
Sugarcane root/stalk borers	Mahogany	Soil drench insecticides
B. Piercing/sucking mouth parts:		Contact poisons:
Aphids	Teak, kadam, *Gmelina*	Various
Mealybugs	Teak	Various
Thrips	Kadam	Various
Scales/mites	Pines	Various
C. Large pests:		Various controls:
Spiders	Pines	Ingested/contact poisons
Birds	Pines/hardwoods	Chemical repellents added to seeds
Rats/mice	Pines/hardwoods	Chemical repellents; cover seeds; pet cat in nursery
Diseases		
A. Damping-off fungi	Pines/hardwoods	Pot media and soil sterilization; soil drench fungicides
B. Seedling needle blight	Pines	Various fungicides
C. Brown needle disease	Pines	Bordeaux mixture (i.e., copper sulfate)
D. Root rot fungi	Pines/hardwoods	Soil sterilization; good watering control and monitoring

12.2.2 ***Control.*** --When insects or diseases occur, control measures are needed quickly. Appropriate chemicals are applied (*10*) and are used according to labeling instructions, with respirator (mask) and adequate clothing to reduce risk of toxicity to humans during application. The kind of control used depends on which pesticides are locally available and the kind of pest. Sometimes, removing affected seedlings is sufficient.

Insects are divided into two major groups: those that chew leaves and those that suck juices out of plants. The controls for each are quite different. For insects with piercing-sucking mouth parts, a direct contact poison is required, i.e., one that covers and kills them. For those insects with chewing mouth parts, toxic substances deposited on leaves are ingested and eventually cause death.

12.3 Common Chewing Pests

12.3.1 Pine Seedling Cutworm. -Cutworms are noticed when they are about 2 mm long, shortly after emerging from eggs. Larvae feed for 1 or 2 days, chewing on tender needles near the seed cap. Following emergence, they are light yellow in color with a thin brown stripe down the back. As the larvae feed, ingested chlorophyll is absorbed, and they develop a deep green color.

Cutworm larvae eat cotyledons at their point of attachment on the stem; the cotyledons are completely severed, and the seedcoats fall to the ground. Once cotyledons are severed, larvae crawl downward, cut the hypocotyl, and then proceed to other seedlings. After they grow to about 25 mm long and turn light brown, cutworms are easily observed crawling among seedlings. Before burrowing into germination

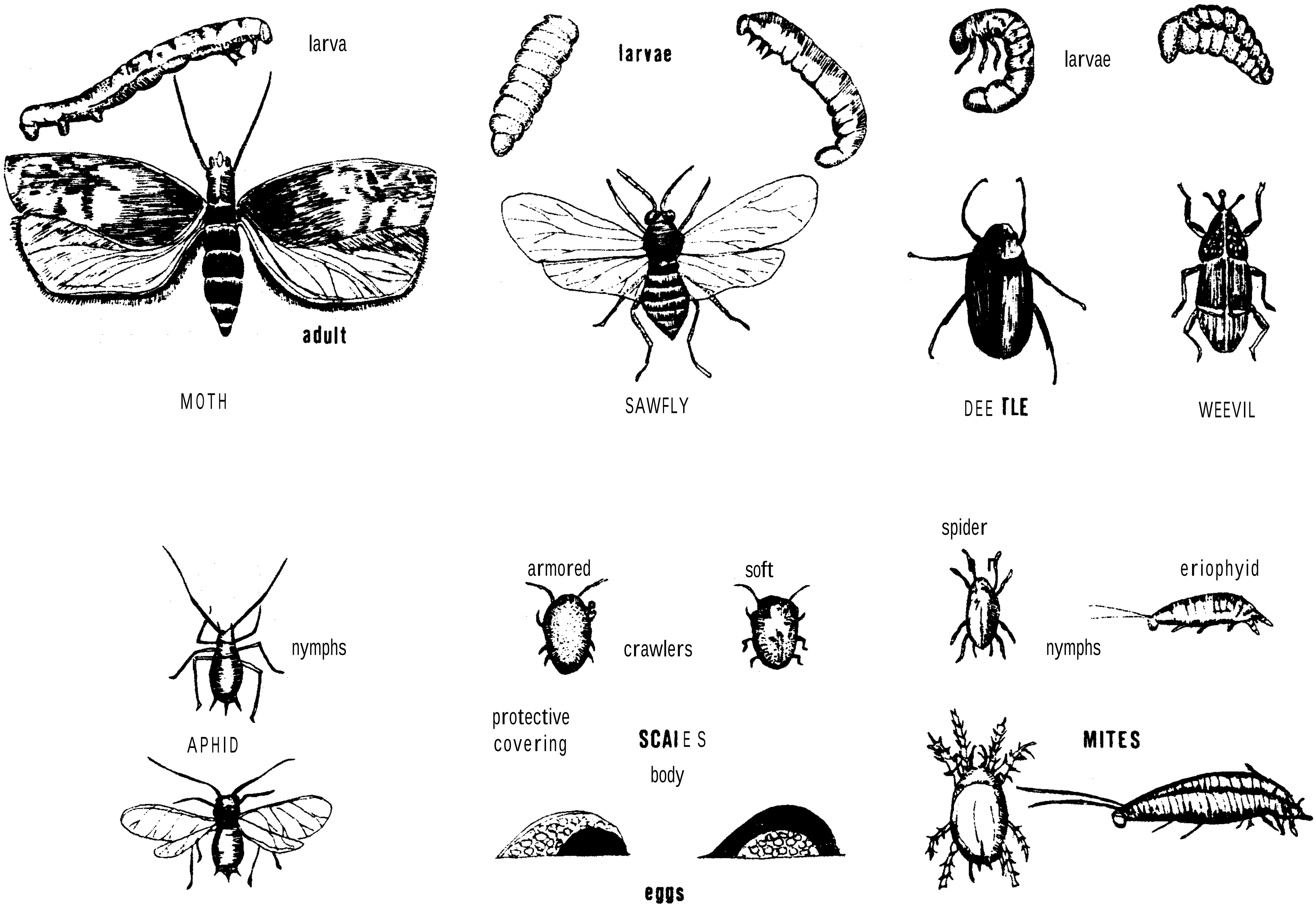

Figure 12-1.—*Common nursery insects. (Drawing from A. Krochmal, USDA Forest Service, retired, Asheville, NC).*

medium for metamorphosis, each cutworm can destroy 20 to 30 seedlings.

Cutworm attack occurs year-round and has been observed on both *P. caribaea* and *P. oocarpa* seedlings (*13*). Cutworms have also killed teak and mahogany seedlings in East Africa. Effective controls were chlordane at 0.45 kg active ingredient (A. I.) per 378 liters of water or Zectran at 0.23 kg per ,378 liters of water. An insecticide such as Spectracide can also control cutworms.

12.3.2 Crickets and Termites. -Other common stem chewers in East Africa are crickets and termites. Major activity was limited to teak seedlings. Several insecticides controlled these pests (*13, 15*).

12.3.3 Leaf Miners. -Mahogany seedlings are also attacked by leaf miners that lay eggs on the backside of the leaf. Leaf miner larvae cause seedling leaves to curl. Although leaves die, seedlings ordinarily survive; thus, leaf miner attacks are not a serious problem.

12.3.4 Shoot and Root Borers. -Perhaps the most serious insect attack in tropical nurseries is that of shoot borers on mahogany and Spanish-cedar seedlings. Although seedlings are seldom killed, the economic damage is high. A major difficulty is training workers to detect shoot borers or their eggs on the undersides of seedling leaves.

The most serious shoot borer is ***Hypsipyla grandella,*** which attacks through the terminal shoot (fig. 12-2). If outplanted (carrier) seedlings serve as breeding habitat in new plantings, virtually all terminal shoots are attacked within a year (*17*). The result is multiple-branched stems that reduce the commercial worth of mature trees. A systemic insecticide can be applied in planting holes when seedlings are outplanted; however, this control is costly and not too effective (*6, 18*).

A second borer, ***Diaprepes abbreviatus*** (the sugarcane stalk borer) attacks both lateral roots and taproots of mahogany seedlings and will work its way up the stem (fig. 12-3). Heavy infestations can kill entire seedling beds (*1*). Soil drench insecticides will control this pest. In its adult form, the borer is a leafeater that causes heavy defoliation.

12.4 Common Sucking Pests

12.4.1 Aphids. -Aphids secrete honeydew that serves as a growth medium for sooty mold, giving plants a dark (sooty) appearance. Aphids attack teak; scaly aphids have attacked kadam and ***Gmelina*** seedlings in Puerto Rico, but damage was not serious.

12.4.2 Mealybugs. -Mealybugs, related to aphids, eat holes in leaves. They are not very visible until reproduction begins and their numbers increase. Mealybugs seldom kill seedlings, but damage can be serious if seedlings lose large amounts of photosynthetic tissue.

12.4.3 Thrips. —Kadam seedlings and trees can sustain heavy leaf damage by thrips (***Selenodthrips rubrocinctus giard***). If attack is widespread in the nursery, infected seedlings easily carry thrips to the field, resulting in the eventual death of some trees.

Figure 12-2.—*Short damage from shoot borer* (Hypsipyla grandella) *attack on mahogany in Puerto Rico nursery.*

Figure 12-3.—*Damage to mahogany seedling roots from sugarcane stalk/root borer* (Diaprepes abbreviatus) *in Puerto Rico nursery.*

12.4.4 Scales and Mites. -Scales range in color from green to brown, and their bodies are covered with wax. Like aphids, scales are not very visible until reproduction allows numbers to increase substantially (*23*). Mite damage occurs as small spots, usually on the undersurfaces of leaves. Mites have eight legs rather than six as do true insects. Spider mite attacks are known for pine seedlings and older trees in Jamaica and naturally regenerated seedlings in Puerto Rico (*1*). As long as seedlings are otherwise healthy, spots and yellowish foliage symptoms will gradually disappear.

12.5 Larger Pests

12.5.1 Spiders. -Spider damage was observed in 1974 on ***P. caribaea*** seedlings planted on Vieques, a small island southeast of Puerto Rico (**ITF**, unpublished data). The unidentified spiders spun webs around the terminal and side shoots of the seedlings and laid eggs inside the nests. Death of some shoots occurred; it was not determined whether death was caused by physical (strangling) or chemical means. An insecticide such as Spectracide can be sprayed to kill spiders that are damaging seedlings.

12.5.2 Birds. -Special efforts are needed to protect newly germinated seedlings from birds (*2*). They eat seeds that are partly exposed in germination trays or that are easily scratched from seedbeds. They disturb pot medium while looking for insect larvae and cutworms (*14*). Birds also eat exposed seeds before cotyledons emerge. If this happens, seedlings generally die because the apical meristem is also eaten along with the seedcoat. A flock of birds can easily eat several thousand seeds per day.

Although repellents (with stickers1 are available to control feeding on seeds by birds, the best method is to completely enclose germination trays and seedbeds with a box frame covered with saran until all seeds have germinated and seedcoats are thrown (fig. 5-2). Such control is impractical for large, direct-seeded seedbeds where repellents must be placed on seeds before they are sown. Large shade houses are the most effective way to keep birds away.

Where bird populations are low, straw or other mulches are used to protect seeded bare-root beds. However, large numbers of birds may feed heavily on mulched seedbeds. For some hardwood species like mahogany, seeds are not too palatable to birds or are so small (kadam and eucalyptus) that birds do not eat them. Birds do not eat seeds of species such as teak because the seedcoat is too hard or the seed is too large.

12.53 Rats and Mice. -Rats and mice can be serious problems if direct-seeding is used. Basically, the same procedure mentioned above for birds is also used to protect seeds from rodents. Because saran shade screens are easily chewed through, they are reinforced with small mesh (6 mm) metal screening at the sides. Seed repellents are also effective controls against rats and mice. Appendix 12 (table A12-3) lists the repellents currently available.

Repellents must be used in conjunction with a sticker. The function of the sticker is to hold the repellent on the seedcoat during germination. Neither sticker nor repellent must interfere with germination.

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12.6.1 Damping-Off. -Damping-off is common throughout most areas of the world and kills seedlings of all species (*15*). In forest nurseries, it is usually most severe among conifer seedlings. Two types may occur: 1) preemergence damping-off where pathogenic fungi attack and destroy seeds before hypocotyl emergence or attack seedlings before they have emerged from the soil and 2) postemergence damping-off where fungi attack seedlings shortly after they have emerged from the soil or germination medium. Postemergence fungi attack seedlings at or slightly above the root collar, causing seedlings to wilt and fall. Attack can be rapid, with entire seedbeds being affected within 24 hours. Postemergence damping-off is identified by a small dark-colored ring-like growth around the lower stem.

Cytological studies have shown that the pathogenic fungi quickly spread throughout stem and root tissue. Thus, once the attack has begun, affected seedlings cannot be saved (*7*, *8*, *11*, *12*, *19*, *20*).

Effective controls are: sterilizing seedbeds; avoiding excess moisture, temperature, and humidity in germination trays; avoiding excess nutrients such as phosphorus and nitrogen in seedbeds; and maintaining acidity of germination medium at a low level, around pH 5.0. Spores of most pathogenic fungi survive for many years in soil. Steam and methyl bromide sterilization are the best treatments for soil or germination medium. An alternate method is drenching with a formalin (2 percent solution in water) mixture. About 2 weeks before sowing, beds are saturated with about 4 liters of the formalin solution per square meter of bed and then covered with a dark polyethylene sheet. After 1 week the polyethlene sheet is removed and the bed material is turned or plowed. After 1 day of aeration, beds can be sown with seeds or transplants can be lined-out.

Once damping-off has occurred in a seedbed, germination medium should be removed if it cannot be sterilized in place. Fresh, sterilized germination medium should be used. Table 12-1 lists other effective disease control treatments.

12.6.2 Seedling Needle Blight. -This disease is sometimes found on pine seedlings; it is usually more prevalent at a late growth stage, such as in plantations (*9*). In Malaysia, weekly spraying with Daconil 2787 and Phelam gave the best control over needle blight caused by ***Colletotrichum*** *floeosporioides* in the nursery. Phelam, however, should not be used because it is reportedly toxic to mammals. Captan, ferbarn, Polyram Combi, Cobosx, and Dieldrex 15 provided less protection than Daconil 2787. ***Cylindrocladium macrosporum*** and ***C. pteridis*** have also attacked ***P. caribaea*** and ***P. oocarpa*** in Malaysia.

12.6.3 Brown Needle Disease.-This disease has occurred in Puerto Rico and in Malaysia on ***P. caribaea.*** The causative agent is ***Cercospora pini-densiflora.*** In India, ***C. pini-densiflora*** was controlled by a 2-week spraying with a copper sulfate (bordeaux solution) based fungicide. Disease symptoms appear similar to those of needle blight, although the infection agents are different. Needle blight disease does not always lead to death, but once a seedling is infected with this disease, death invariably occurs.

12.6.4 Purple Foliage. -Pine seedlings often develop purple foliage while in the nursery. Though no disease organism has been identified, mild attack by a disease cannot be entirely ruled out. Although severe phosphorus deficiency is indicated by purple needles, phosphorus deficiency is not expected in well fertilized seedbeds. Trace element imbalances may also be responsible for the purple foliage. No treatment except monitoring the fertility level of seedbeds or pot medium is recommended, since the purple color disappears once seedlings are outplanted.

12.6.5 Root Rot.-Seedlings often turn yellow-brown, with the succulent terminal flush falling over. Because affected seedlings appear to be under water stress and look wilted, the usual reaction is to water them. Closer inspection may show that the problem is not a lack of water, but rather excess water that has caused root rot. The only proof is to lift some wilted seedlings and inspect their roots. If the taproot is necrotic and lateral roots are absent, then some form of root rot probably exists (*4*). Sometimes the cortex at the root collar is so rotten that it is stripped off as seedlings are lifted from the soil.

The most effective control of root rot is to avoid overwatering. However, if root rot does occur, the problem is probably compounded by poorly drained and poorly aerated pot medium or seedbeds. Potting mixtures can be changed to provide better aeration (Chap. 9).

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CHAPTER 13

13. NURSERY NUTRITION

Growth and performance of nursery stock is related to the nutrition of seedbed soil or container medium in which seedlings grow as well as the genetics and vigor of seeds sown. The fertility of nursery soil is predicted by both chemical and biological methods. If nutrient deficiencies exist, they can be corrected with organic or inorganic fertilizers that are short- or long-term acting. This chapter discusses nursery nutrition and several fertilizer alternatives. Appendix 13 gives practical guides for using and applying fertilizers.

13.1 Essential Elements

There is disagreement on which elements are truly essential for plant growth *(20)*. Generally, carbon, hydrogen, and **oxygen** comprise the bulk of seedling weight. They are obtained directly from carbon dioxide (CO_2) and water (H_2O), which are not usually limiting except in waterlogged or very dry environments. Elements are traditionally called macroelements or microelements, depending on whether plants use greater or lesser quantities. Roots take up minerals principally from the solution or exchange complex of nursery soil or the container medium. Known functions of each element are summarized in table 13-1.

Each tree species, its varieties, and even individuals of a species have distinct nutrient requirements and uptake rates. Thus, table 13-1 is only a guide to the "basics" of plant nutrition. Elemental concentrations can vary by plant component (leaves, twigs, branches, fruits, and roots), age, position within the seedlings (top, center, or lower stem area), season (spring or fall), and climate (dry or wet) (*5*). Generalizations about seedling nutrition are therefore sometimes difficult to make.

13.2 Nutrient Deficiency Symptoms

Visual symptoms are usually the first signs that seedlings are growing abnormally (*20*). Common symptoms are: severe stunting, delayed or abnormal growth (twisted or missing needles), leaf discoloration (bright yellow, purple, or red instead of green), and abnormal root growth. Symptoms develop when internal plant growth processes are interrupted by lack of one or more elements and by the organic metabolites that subsequently accumulate.

Published color pictures show deficiency symptoms for several temperate (19) but few tropical (22) species. Lack of one element can cause divergent symptoms in different species. Also, similar symptoms may be caused by deficiencies of different elements (e.g., general chlorosis by lack of either N or S).

Some symptoms are caused by multiple nutrient deficiencies; others are not nutrient related at all. For example, if seedlings turn yellow, root systems are checked first to see whether overwatering has reduced aeration, thus killing roots and blocking nutrient and water uptake. When deficiency symptoms appear, irreparable damage has probably occurred in shoot or root tissue. Though we recognize the limitations of trouble shooting nutrient deficiencies, a generalized "key" to visual symptoms is given in table 13-2.

Table 13-1.—*Function of major and minor elements in nursery nutrition*[1]

Element	Role in seedling nutrition
	Macronutrients
N (nitrogen)	Essential part of chlorophyll and proteins; fosters vegetative growth.
P (phosphorus)	Promotes root growth and stem strength; important in all energy transfers within plants.
K (potassium)	Promotes starch and sugar formation, root growth, resistance, shoot strength, and plant vigor.
Ca (calcium)	Enhances N uptake, cell elongation, and development of meristematic tissues.
Mg (magnesium)	Major constituent of chlorophyll in plants; important in P metabolism and enzyme activation.
S (sulfur)	Essential for synthesis of S-containing amino acids and nitrogen fixation by legumes.
	Micronutrients
Fe (iron)	Important in chlorophyll production and enzyme activation.
Mn (manganese)	Activates enzymes regulating carbohydrate metabolism and essential for photochemical (Hill) reaction.
Cu (copper)	Metal activator for several enzymes and possibly light reaction in plants.
Zn (zinc)	Metal activator of enzymes.
B (boron)	Responsible for several regulator mechanisms in many plants, including sugar translocation across cell membranes and oxidation processes.
Mo (molybdenum)	Required for N-fixation in legumes and nitrate reduction in nonlegumes.

[1]Sources: (*9*), (*20*).

13.3 Foliage (Tissue) Sampling

Foliage, tissue, or plant analysis is used operationally to determine seedling nutritional status *before* deficiency symptoms appear (12, 14, 24). The rationale for this method is: if adequate elemental concentrations exist for good growth in plant foliage, then concentrations of the same element are adequate in the soil. Through nursery and field fertilizer calibration trials, one determines "critical" concentrations, i.e., elemental levels at which plant growth drops below optimum. Excess amounts of certain elements such as Fe, B, or Mn are toxic to plants. Usually, however, plants absorb excess nutrients without harmful effects. Good plant growth with nutrient levels beyond those normally needed is called "luxury consumption" (5).

In temperate areas, foliage is sampled at first hardening, usually in late summer when nutrient concentrations are less variable than at other times in the growing season. Except for a few instances, monthly and seasonal fluctuations are not known for tropical tree species that grow all year long (table 13-3). However, sampling can be done one-third and two-thirds through the period that seedlings are held in the nursery before outplanting (e.g., for seedlings held 24 weeks, then sample at **1/3** of 24 = 8 and **2/3** of 24 = 16 weeks).

Best results are normally obtained by sampling mature, fully developed leaves or fully elongated needles. If seedlings lack secondary needles, dry and grind *all of the above ground tissues* of several seedlings. If secondary needles are present, dry and grind the needles only, after collecting fascicles from a com-

Table 13-2.—*Key to the classical symptoms of various nutrient deficiencies*[1]

Symptoms	Symptoms may be related to
a. The dominant symptom is chlorotic foliage (discoloration).	
b. Entire leaf blades are chlorotic.	
c. Only the lower leaves are chlorotic, followed by necrosis (tissue death) and leaf drop.	Nitrogen
cc. Leaves on all parts of plant are affected and often have a beige cast.	Sulfur
bb. Yellowing of leaves takes the form of interveinal chlorosis.	
c. Only older leaves exhibit interveinal chlorosis.	Magnesium
cc. Only younger leaves exhibit interveinal chlorosis.	
d. This is the only symptom.	Iron and/or manganese
dd. While younger leaves have interveinal chlorosis, the tips and lobes of leaves remain green, followed by veinal chlorosis and rapid, extensive necrosis of leaf blade	Copper
ddd. Young leaves are very small, sometimes missing leaf blades altogether, and internodes are short, giving a rosette appearance.	Zinc
aa. Leaf chlorosis is not the dominant symptom.	
b. Symptoms appear at base of plant.	
c. At first, leaves are dark green and smaller than normal. Later, purple pigment develops in older leaves.	Phosphorus
cc. Margins of older leaves burn or small necrotic spots appear on older leaf blades.	Potassium
bb. Symptoms appear at top of plant.	
c. Terminal buds die, giving rise to a witches'-broom.	Boron
cc. Margins of young leaves fail to form, sometimes yielding trap-leaves. Growing point ceases to develop, leaving a blunt end.	Calcium

[1] Adapted from material of P. Nelson, Horticulture Department, North Carolina State University, Raleigh.

posite sample of many seedlings. Collections are best made in the early morning, ***before*** seedlings begin synthesizing carbohydrates and utilizing nitrates accumulated at night.

Leaf petioles from large-leaved seedlings (e.g., from teak or mahoe) should not be included in the sample. Total analysis is performed on tissue samples, using standard procedures (*6*, *7*).

Rapid or "quick tissue tests" on plant sap are sometimes used (*20*). Results, however, are not quantitative and should not be substituted for diagnostic analyses. Sampling done in duplicate provides extra material for checking test results.

Foliage analysis interpretations must consider both environment of the seedlings tested and their physiological state. Are seedlings growing vigorously or are they stunted? Are there signs of above ground or below ground insect or disease attack? Is seedbed medium well aerated or is soil moisture excessive? Have climatic conditions before sampling been unusually moist or dry? Is soil pH value or salt content too high? For example, discolored and stunted seedlings with "high" tissue values for N, P, and K does not mean that these nutrients are present in adequate amounts. Poor growth, but seemingly adequate tissue nutrient levels, suggest that some other factor is limiting seedling growth, perhaps underground root borers (fig. 12-3).

Foliage analysis has two disadvantages. Calibration trials to establish high, low, medium, and critical levels for each element are costly and time consuming. Also, techniques and equipment needed for chemical analyses are rather sophisticated, requiring highly trained personnel. If facilities for agricultural foliage research exist, techniques are easily adapted for forest nursery diagnostic work.

Table 13-3.—*Mean foliage concentrations* far forest tree for **comparison**

Foliage element concentrations	*Pinus caribaea* var. ***hondurensis***[1] 3 yr Normal	3 yr Foxtail	4 yr Normal	4 yr **Foxtail**	***Eucalyptus deglupta***[2] **(15 mo)**	***Pinus elliotti***[3]	**Conifers**[4]	**Hardwoods**[4]
N, %	***0.98***	1.25	0.92	1.16	0.64-2.04	0.98-2.16	**1.00-1.10 (deficient)**	**1.00-4.00 (medium)**
P, %	0.08	0.12	0.09	0.10	0.10-0.69	0.12-0.43	0.10-0.30 **(medium)**	0.30-0.50 **(medium)**
K, %	***0.77***	1.09	0.90	1.09	0.44-1.78	0.23-1.73	0.35 **(deficient)**	0.50-1.60 **(medium)**
Ca, %	0.27	0.26	0.25	0.34	0.46-1.40	0.08-0.79	**0.12-0.70 (medium)**	0.30-2.30 **(medium)**
Mg, %	0.08	0.10	0.10	0.13	0.13-0.42	0.08-0.26	....	0.08-0.40 **(medium)**
Na, %	0.14	0.17	0.11	0.18	....	....	....	....
Mn, p/m	491	572	479	724	**8–270**	....	**100-5,000 (medium)**	
Cu, p/m	5.1	5.9	4.8	4.7	2.0-6.4	....	**4-12 (medium)**	
Zn, p/m	30	37	29	38	6-49	....	**10-125**	
Fe, p/m	110	116	50	59	32-148	....	30.40	
B, p/m	12	15	12	12	15-84	....	**10-100**	
Al, p/m	493	469	410	557	....	....	....	....

Sources: [1](*10*), [2](7), [3](*11*), [4](*8*); data for p/m apply to both conifers and hardwoods.

13.4 Soil Tests

Soil tests *directly* determine the nutrient-supplying power of a soil. Methods require a knowledge of chemistry and laboratory instrumentation, usually found at a country's agricultural research station. Soil tests are usually better than foliage tests because they indicate a nursery soil's nutritional status and fertilizer needs *before* seeds are sown or seedlings are transplanted (*23*).

Other objectives of soil tests are:

- to maintain the fertility status of different nursery beds and
- to predict the response of beds to lime and fertilizer additions.

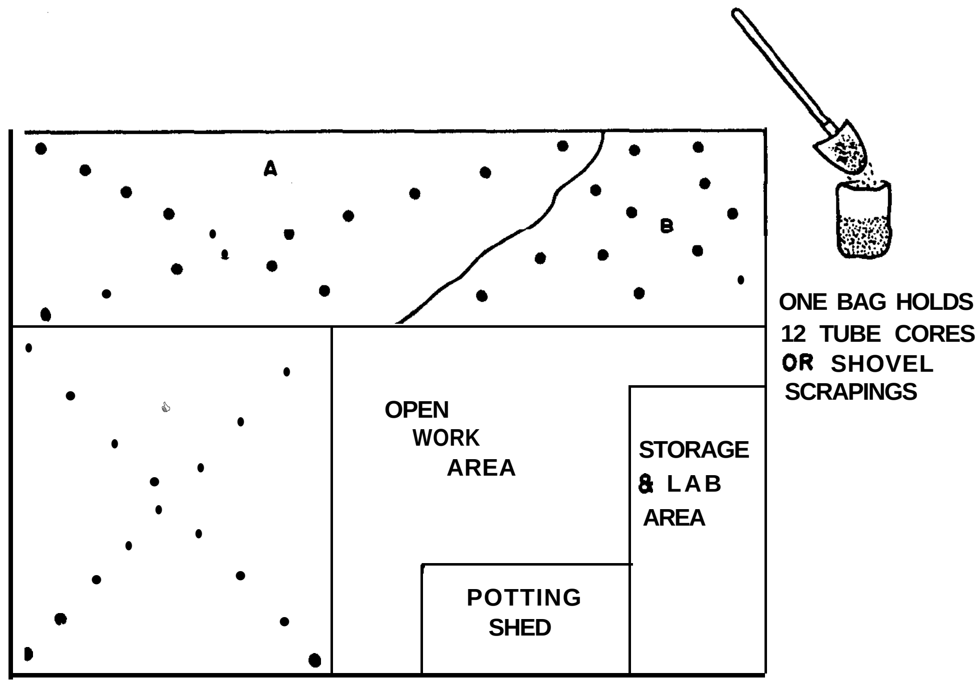
The nutrients of greatest interest are the amounts of cations (Ca, Mg, and K) and P. Organic matter content, pH value, and salt levels are also important.

The most critical part of soil testing is obtaining a representative sample. All areas that. vary in appearance, slope, drainage, soil type, or past treatments should be sampled separately. In areas where fertilizers were previously applied in bands, samples should be taken between the bands. A single 0.5- to l.O-kg sample consists of a composite of 10 to 20 tube cores or spade scrapings (fig. 13-Q usually taken to about 15 cm (normal seedling root depth). All sampling should be done well ahead of scheduled sowing so that fertilizer can be applied if needed.

Many different extracting solutions are used to determine soil nutrient concentrations or contents (*1*). For permanent nurseries, the same extraction procedures must be used from year-to-year to standardize interpretations. Where no prior data exist for new nurseries, soil test data should be taken and analyzed in a manner similar to that used for local or regional agricultural research. Data from crop trials are then used to determine interim fertility levels for nursery soils. Fertility tests should be run on homemade mixes to assure that all essential elements are present in adequate quantities. Examples of soil fertility standards for field nurseries are given in table 13-4.

13.5 Special Soil Problems: Acidity and Salts

Soil reaction or pH value is a measure of the degree of acidity or alkalinity of a soil. A scale of 0 to 14 is used, with 7.0 as the neutral point (fig. 13-2). Soils



● LOCATION Of SOIL CORES OR SHOVEL SCRAPINGS TO DEPTH OF IS cm.

A BARE ROOT PINE AREA; WELL DRAINED SOIL --DIAGONAL SAMPLING

B BARE ROOT PINE AREA; YORE POORLY DRAINED SOIL -- RANDOM SAMPLING

C BARE ROOT HARDWOOD AREA; WELL-DRAINED SOIL-- DIAGONAL SAMPLING

Figure 13-l.-Collecting *nursery soil samples for chemical and physical* **analyses.** *Take 10 to 20 tube cores or shovel scrapings for each distinct soil type, drainage area, andlor bed area devoted to different species. All soil samples are usually taken to a depth of 15 om. They are bulked (mixed) into one composite sample that is eventually analyzed in a soil laboratory. In the example above, at least three samples are taken, one each from areas A, B, and C. Zf size of an area is 1 ha or greater, divide it into smaller divisions, with a composite sample taken from each division. For uniform areas, criss-cross sampling (areas A* and *C) is easiest, whereas random or zig-zag sampling (area B) is best for areas with high soil variability.*

Table 13-4.—*General field soil fertility standards used for southern pine* (A) *and commercial woody plant (B) nurseries in the United States*

Soil property	Major soil types					
	Sands to loamy sands		Loamy sands to sandy loams		Silt loams to loams	
	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]
Organic matter, %	1.5	....	2.0	...,.......	>3.0	....
N, %	0.07	....	0.10	....	0.15	....
pH	5.3-5.8	....	5.3-5.8	...,.......	5.3-5.8	....
P, kg/ha	55-110	15-30	85-1 10	30-40	85-140	40-80
K, kg/ha	85-140	70-110	140-200	110-170	170-280	170-225
Ca, kg/ha	450-670	670-900	670–1,000	1,120–1,800	>1,000	2,240–4,480
Mg, kg/ha	55-65	130	65–100	270	>100	540

Sources: [1](11), [2](3).

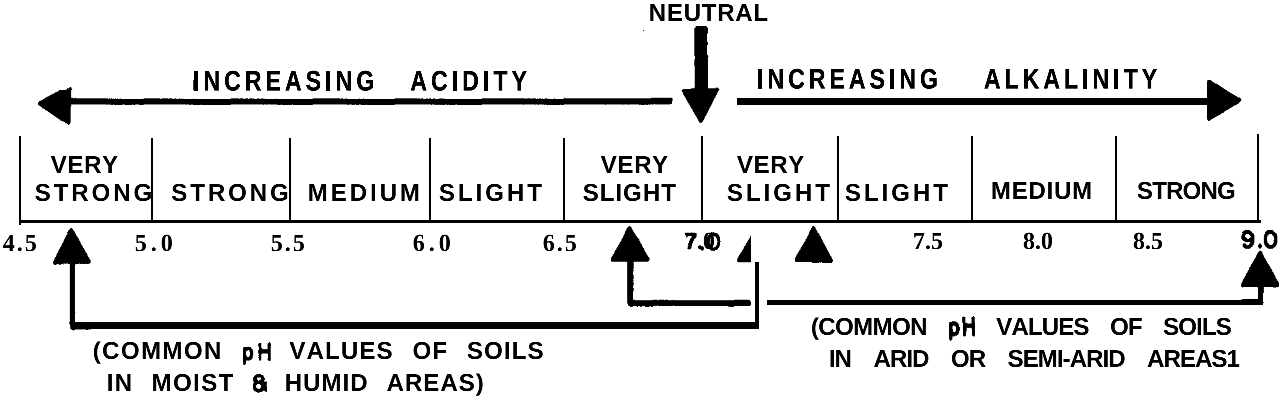


Figure 13-2.—*Soil pH values and their relationship to acidity and alkalinity. Taken from (9).*

with pH values less than 7 are *acid*, and those with values *greater than* pH 7 are *alkaline*. The pH scale is a logarithmic one; thus, an increase or decrease of one pH unit means a tenfold change in acidity or alkalinity. For example, a soil with pH 5.0 is 10 times more acidic than a soil with pH 6.0, but a soil with pH 4.0 is 100 *times more acidic* than a soil with pH 6.0 (*9*).

Soil acidity has a strong influence on nutrient availability in nursery soils or pot mixes. For example, macronutrients are readily available within a range of pH 6.0 to 8.0, but availability decreases rapidly as pH value decreases (*21*). On the other hand, Fe and Zn are almost unavailable if the soil pH is over 7.5 (fig. 13-3). Pine seedlings grow best in acid soils ranging from pH 4.5 to 6.0. In soils with high pH values (>7.0), pine seedlings will develop a deep yellow color because Fe is "unavailable" to the seedlings.

Where the soil is too acidic for plant growth, pH values can be raised by applying limestone. Amounts of limestone needed will vary according to the degree of pH change desired, existing soil texture, organic matter content, and form of limestone used. The amounts of limestone needed to raise soil pH to 6.5 for different textured soils having varying initial pH values is given in table 13-5. When the pH value is too high, it can be lowered by applying acid-forming fertilizers (table 13-6).

Table 13-5.—*Approximate* amounts *of finely ground pure limestone (kg/ha) needed to change acidity of an 18-cm layer of soil* [1]

Soil type	pH change	
	4.5 to 5.5	5.5 to 6.5
Sand or loamy sand	600	900
Sandy loam	1,100	1,550
Loam	1,700	2,200
Silt loam	2,700	3,100
Clay loam	3,350	4,200

[1]Values listed are "approximate" because amounts needed for a given change are highly influenced by actual particle size and purity of lime used as well as active and reserve acidity of the soil being limed. Source: (*9*).

Soluble salts should be monitored regularly. Many species will not tolerate saline conditions and may be injured by high levels of Na, B, and chlorides found in irrigation water. Fertilizer components can also break down into soluble salts that accumulate in nursery soil or potting medium.

Salt levels can be measured with a solu-bridge. A sample of soil is mixed with distilled water, and the solution is tested for its ability to conduct electricity. Either a saturated paste or distilled water/soil dilution methods (in 2:1 or 5:1 ratios) are used. Interpreta-

Table 13-6.—*Ways of lowering soil pH value with acid-forming fertilizers*'

Fertilizer	Pct N in fertilizer	Kg of pure limestone needed to counteract acidity produced per —	
		45.4 kg of fertilizer	0.45 kg of N[2]
Ammonium nitrate	33-34	27.2	0.8
Ammonium sulfate	20-31	49.9	2.4
Ammonium phosphate	16	39.9	2.4
Urea	45-46	38.1	0.8
Mono-ammonium phosphate	11	26.3	2.4
Di-ammonium phosphate	21	33.6	1.6

Source (*9*).

"Values in this column are most important for judging fertilizer effectiveness: ammonium sulfate, ammonium phosphate, and mono-ammonium phosphate are three times as acid-forming as ammonium nitrate and urea.

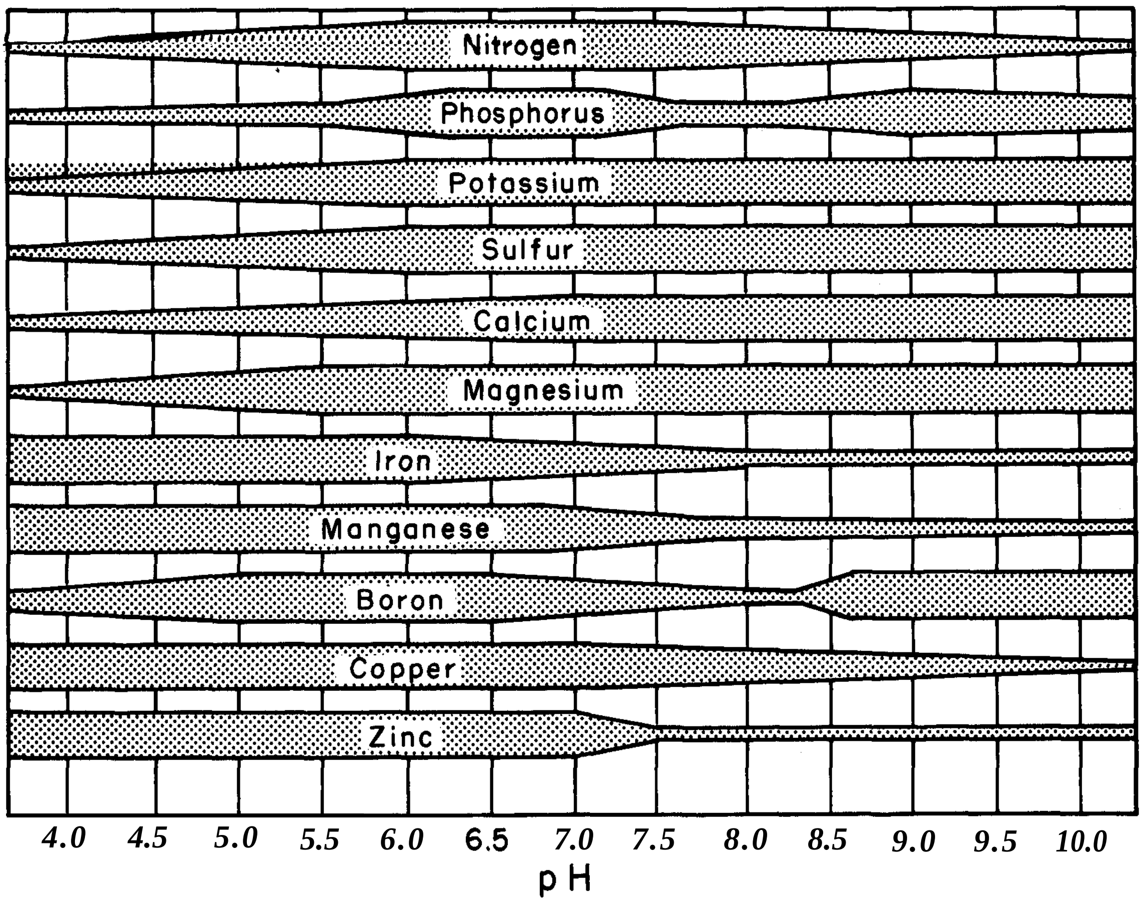


Figure 13-3.—*Relationship of soil acidity and alkalinity to nutrient availability. Taken from (9).*

tions of solu-bridge data are given in table 13-7. Irrigation water can also be tested for excess salts using similar methods. For nursery production, irrigation water should have less than 250 micromhos/cm (*9*).

13.6 Fertilizers

Fertilizers are classified as inorganic or organic and natural or synthetic (table 13-8). They can be single- or multi-element in composition and are available in dry and liquid forms. Complete fertilizers have the three primary elements, expressed as percentages of elemental N, P_2O_5 (phosphate), and K_2O (potash). Thus, a label with 5-10-5 means 5% N, 10% P_2O_5, and 5% K_2O. In 1 kg this is 50 g of N, 100 g of P_2O_5, and 50 g of K_2O. Inorganic fertilizers may have acid, alkaline, or neutral reactions (table 13-9). Natural organic fertilizers or composts vary greatly in amounts of N, P, and K (*13*) (table 13-10).

Three alternatives for applying fertilizers are:

- mix dry fertilizers directly with the growing medium;
- put soluble fertilizer solutions on the soil; or
- formulate and use dry fertilizer mixes and soluble solutions on site.

Each alternative has distinct advantages and disadvantages, depending on whether field- or container-grown seedlings are produced.

13.6.1 Mixing Fertilizers With Growing Medium. -This alternative is commonly used for dry (commercial) fertilizers applied before sowing or transplanting. The fertilizer is placed in bags with pot medium or is incorporated with soil of bare-root beds. Mix proportions depend on whether soil test values are high or low and on actual fertilizer proportions available in the mixes. Import restrictions may limit availability of fertilizer mixes in some countries.

Dry fertilizers can also be broadcast by hand or applied by machine with drills on larger areas or in bands between seedling rows. "Top dressing" alternatives are not suitable for containerized nurseries (*19*). Disadvantages are the trouble and high cost of mixing different fertilizers and pot medium for different stages of seedling growth (e.g., rapid growth phase vs. hardening-off phase) and the tendency of most slow-release dry fertilizers to raise medium pH value. Large traditional nurseries still incorporate fertilizers with pot mix (*15*).

13.6.2 Using Soluble Fertilizer Mixes. -This alternative is ideal for small nurseries needing minimal

Table 13-7.—*Soluble salt levels in soils and irrigation water and their influence on plant growth as determined by electrical conductivity*[1]

Electrical conductivity		
Millimhos/cm	Micromhos/cm	Diagnosis
Soils		
Less than 2	Less than 2,000	No adverse effect.
2	2,000	Yields of some salt sensitive crops are affected.
Below 8	Below 8,000	Only moderately salt tolerant crops can be grown.
8-16	8,000–16,000	Only salt tolerant crops can be grown.
Above 16	Above 16,000	No profitable cropping possible.
Irrigation water		
0.1-0.25	100-250	Low salinity: safe to use on practically all crops and soils, but some leaching is needed to keep salts moving downward; problems may develop on poorly drained soils.
0.25-0.75	250-750	Medium salinity: medium salt tolerant crops are needed; soils must be relatively permeable.
0.75-2.25	750–2,250	High salinity: only for salt tolerant crops; adequate subsurface drainage is essential, as is sufficient water for leaching out excess salts.
Above 2.25	Above 2,250	Very high salinity: should not be used for irrigation except under certain ideal conditions (i.e., permeable *soil* and/or tile drains for good drainage, high water rates for good leaching).

[1]Source: (9).

Table 13-8.—*Chemical and physical properties of fertilizers*[1]

Chemical properties	Physical properties
A. State:	A. State:
1. Organic:	1. Dry:
(a) Natural	(a) Pulverized
(b) Synthetic	(b) Granular (prills)
	(c) Tablet
	(d) Packet
	(e) Encapsulated
2. Inorganic:	2. Liquid:
(a) Natural	(a) Water-soluble
(b) Synthetic	(b) Suspension
B. Element:	B. Release rate:
1. Single	1. Rapid
2. Double	2. Slow (controlled)
3. Triple (complete)	
4. Multi	
C. Long-term effect on soil acidity:	
1. Acidic (lowers pH value)	
2. Neutral	
3. Basic (raises pH value)	

[1]Source: (*3*).

Table 13-9.—*Element content, reaction, and solubility of common fertilizer chemicals*[1]

Common fertilizer name	Chemical formula	Fraction of element in compound (× 100 = %)							Long-term reaction[2]	Solubility[2]
		(NO_3) N	(NH_4) N	P	K	S	Ca	Mg		
Potassium nitrate	KNO_3	0.139			0.386					
Ammonium nitrate	NH_4NO_3	0.175	0.175						Acid	High
Calcium nitrate	$Ca(NO_3)_2 \cdot 4H_2O$	0.119					0.169		Base	Medium
Diammoniumphosphate	$(NH_4)_2HPO_4$		0.212	0.235					Acid	Low
Ammonium sulfate	$(NH_4)_2SO_4$		0.212			0.242			Very acid	High
Nitric acid	HNO_3	0.222							Very acid	High
Orthophosphoric acid	H_3PO_4			0.316						
Potassium metaphosphate	KPO_3			0.228	0.287					
Concentrated superphosphate	$Ca(H_2PO_4)_2 \cdot H_2O$			0.246			0.159			
Potassium carbonate	K_2CO_3				0.565					
Calcium-magnesium carbonate (dolomite)	$CaCO_3 \cdot MgCO_3$						0.217	0.130		
Magnesium sulfate	$MgSO_4 \cdot 7H_2O$					0.130		0.097		
Potassium sulfate	K_2SO_4				0.448	0.184				
Sulfuric acid	H_2SO_4					0.326				
Meta phosphoric acid	$P_2O_5 \cdot H_2O$			0.437						
Potassium oxide (potash)	K_2O				0.830					

[1]Adapted from (*19*).
[2]Missing data were not available.

Table 13-10.—*Average nutrient content of fresh animal manures before composting*[1]

Nutrient or element	Cattle	Chicken	Horse	Sheep	Swine
			Percent		
Nitrogen (N)	0.53	0.89	0.55	0.89	0.63
Phosphorus (P_2O_5)	0.29	0.48	0.27	0.48	0.46
Potassium (K_2O)	0.48	0.83	0.57	0.83	0.41
Calcium (Ca)	0.29	0.38	0.27	0.21	0.19
Magnesium (Mg)	0.11	0.13	0.11	0.13	0.03
Copper (Cu)	0.00079	0.0006	0.00079	0.00079	0.00016
Manganese (Mn)	0.003	0.003	0.003	0.003	0.0008
Zinc (Zn)	0.0016	0.0021	0.002	0.002	0.0006
Chlorine (Cl)	0.03	0.08	0.08	0.08	0.03
Sulfur (S)	0.036	0.06	0.036	0.06	0.03
Boron (B)	0.016	0.016	0.016	0.016	0.0005
Organic matter	16.74	30.70	27.06	30.70	15.50
Moisture	18.33	64.82	68.85	64.82	77.56
Ash	2.06	4.72	6.70	4.72	6.02

[1]Since moisture percentage of any manure is highly variable, indicated nutrient percentages are general values. Source: 9).

amounts of fertilizer or for very large nurseries having good irrigation equipment (*2*). Commercial powders or granules are dissolved in water, and solutions are applied to seedlings with hand-pump sprayers or are injected into irrigation systems. This method is adaptable to nurseries growing several species. However, what works in one location might not work well in another because of differences in local water quality, inherent chemical properties of nursery soils and pot medium, and existing environmental factors. Systems should be tested on small plots before they are used operationally.

Commercially formulated soluble fertilizers are easily prepared with minimal instructions or precautions. Some drawbacks can be: insufficient knowledge about the "carrier" or chemical compounds used to supply the nutrient ions; use is limited to the nutrient proportions available in the mixes; salts used as nutrient carriers can modify soil solution acidity, requiring a separate pH adjustment; and workers preparing solutions cannot easily compensate for Ca, Mg, or micronutrients that are naturally available in local water supplies, thus risking the possibility of adding excess salts.

13.6.3 Formulating Nutrient Solutions on Site. — This alternative involves making "homemade" fertilizer solutions to be applied by hand sprayers or injected into irrigation systems. Technical grade chemicals are added to water according to a formula adjusted for local water supplies and the species grown. Homemade solutions are not practical for small nurseries. However, they are very cost effective for large, highly mechanized container systems where managers have ready access to chemical compounds and need to tailor their fertilizers to particular crops, pot mixes, and water composition.

Disadvantages of homemade solutions are: the user must be trained in chemistry and be able to handle hazardous materials carefully and safely; large stocks of chemicals must be safely stored, identified, and weighed before mixing; opportunities for mixing errors are greatly increased over those encountered in using premixed fertilizers; and, when optimum concentrations are unknown, fine tuning of the formulation is time consuming and requires technical expertise.

Appendix 13 gives hints and methods for mixing commercial fertilizers. Other important considerations for correct fertilizer application are timing, i.e., not too wet or too dry (*18*); interaction effects between species and fertilizers (16); type of soil being fertilized, i.e., not all soils respond to fertilizer additions (*17*); and age/health status of seedlings (*4*) being fertilized.

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CHAPTER 14

14. NURSERY EXPERIMENTATION

14.1 Planning the Experiment

Experiments are important in permanent nurseries because they produce information for managerial or technical guidelines (*18*). For example, experiments can indicate whether top dressed granular or liquid N fertilizer is best for a particular bare-root nursery in a wet climate. Experiments may also indicate which of several locally available postemergent herbicides gives the longest coverage in comparison with traditional hand weeding.

Experimentation is often excluded from nursery and reforestation efforts because its purpose is misunderstood or because it is confused with statistics. *Experimentation is the systematic observation, classification, and analysis of facts and data;* it emphasizes the *why* and *how* of what is done. Statistics, on the other hand, are mathematical measures that describe *organized* raw experimental data. The most commonly used measures are the *mean, standard deviation, variance,* and *coefficient of variation.*

Commonly used statistical measures are given in table 14-1. A hypothetical experiment is explained here to illustrate how experimentation is important for effective decision making in reforestation projects.

14.1.1 Traits Assessed. -Experiments can be done in the nursery or in the field. Many measurement traits or variables can be measured or assessed. Examples (*2*, *5*) are:

Seed/Seedling Traits	*Container/Irrigation* Traits
Average seed weight and size	Container volumes in tapered and non-tapered cavities and their influence on root development
Mean germination time for seeds	
Percentage of seeds germinated within stated periods of time	Potting mix proportions of 20, 40, and 60 percent peat and their influence on seedling growth
Number of cotyledons	Hand- and mechanically-seeded containers and their effects on seedling growth
Seedling height in centimeters, at stated periods of time or before lifting	Overhead versus side sprinklers and their effects on reducing seedling mortality from persistent drip
Seedling root collar diameter in millimeters, using calipers	
Seedling survival, in percent, at different growth stages of nursery	

In each instance, events or traits are recorded according to *previously formulated plans and designs* (*11*). In a few cases, unusual phenomena are also reported *(15, 17*).

14.1.2 Sources of Vuriation. -Nurseries generally have less environmental variation than do field sites. Nurseries occupy small areas within which skilled researchers can control light, temperature, soil moisture, soil nutrients, and soil aeration more easily than on larger field sites. Small amounts.of plant materials used in nursery research are also less variable than are larger amounts of field planted materials. Exceptions occur when individual plants are used as treatments. In such cases, plant-to-plant variation, particularly in yield, may be great. Averaging many plants together to obtain treatment values avoids excessive variation (e.g., grinding up 10 seedlings-not l-per treatment replication to obtain shoot/root ratios of seedlings grown in one type of container having different pot volumes).

Investigators studying nursery and greenhouse experimental designs (*4*, 6, *8*) have identified several sources of variation:

- temperature differences around benches caused by steam pipes and proximity to doors, ventilators, and exhaust fans;
- shading effects from nursery structures and surrounding trees;
- moisture differentials caused by air currents (drift) and clogged irrigation nozzles;
- non-uniformity of physical and chemical properties of pot medium caused by using medium prepared in different production runs; and
- changing light intensity and duration as growing seasons change.

Properly designed research trials avoid such variation whenever possible or at least account for it by adequate replication.

14.1.3 Experimental Procedures. -An overall research plan is essential when conducting experiments. It should always answer: Who? Why? What? Where? When? How? and How much?

The first step is outlining the objectives and questions to be answered. Always *restrict* objectives to a few simple ones. Written objectives and a written work plan are critical for maintaining longer trials that continue after their originator has left.

Consider a postemergent herbicide trial to control weeds in bare-root pine seedbeds. Two important questions are: which herbicide controls weeds for the longest time without reapplication? Are the herbicides used non-toxic for the pine species tested? Obviously, all herbicides and pine species cannot be tested. How, then, does one limit the scope of the proposed herbicide trial?

14.1.3.1 Restricting Experiment ***Objectives.*****—Restricting** the objectives can be done by considering data on herbicides from elsewhere, including local results from agricultural or horticultural trials. Local product availability can limit the herbicides eventually chosen for testing. After reviewing available in-

Table 14-1.—*Summary statistics for two data sets*

Statistic[1]	Data set I			Data set II		
	A	B	C	A_1	B_1	C_1
	8	5	1	8	5	1
	8	6	2	9	7	5
	9	8	5	9	9	8
	10	10	10	10	10	10
	11	12	15	10	11	12
	12	14	18	11	13	15
	12	15	19	12	15	19
Sum	70	70	70	70	70	70
Mean ($\bar{x}$)	10	10	10	10	10	10
Standard deviation (s)	1.7	3.9	7.5	1.3	3.4	6.1
Variance (s^2)	2.9	15.2	56.2	1.7	11.6	37.2
Coefficient of variation (CV-%)	17	39	75	13	34	61

[1] $\bar{x}$—The sum of individual observations divided by total number (n) of observations in a sample or set of values. Each of the six data groups has an n of 7 (observations); thus, each of the six sums is divided by 7 to obtain the mean.

s-A summarization unit for interpreting whether individual observations are clustered around or spread away from the mean. Symbolically it is calculated:

For group A of Data Set I:

$$s = \sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}{n-1}} \quad \frac{(8)^2 + (8)^2 + (9)^2 + (10)^2 + (11)^2 + (12)^2 + (12)^2 - \frac{(70)^2}{7}}{6} = 1.7$$

Group A has the *lowest* s in Data Set I; thus, observations in group A are very clustered around the mean of 10. Observations in Data Set II are all more clustered around their means, since the s of groups in Set II are all lower than those in Set I.

s^2—The square of s, or for data group A $(1.7)^2 = 2.9$. Statisticians use s^2 in analysis of variance for testing whether various treatments are significantly different from one another.

CV-It is used to evaluate results from several experiments measuring the same variable or trait. It is calculated:

$$CV = \frac{s}{x} \times 100; \text{ for data group A,}$$

$$\frac{1.7}{10} \times 100 = 17.$$

In field experiments, CV values usually range from 15% to 50%; ≤15% in nursery experiments. If values are higher, there was too much variability in plant materials or site and nursery conditions, and the experiment must be done again.

formation, one might decide to test different concentrations of one locally available herbicide on the most promising pine species for reforestation. A concise statement of experiment objectives would be:

"To determine the effect of three concentrations (high, medium, low) of Goal herbicide and hand weeding (control) on weeds common in ***P. caribaea*** var. ***hondurensis*** bare-root seedbeds."

The traits assessed could be: coverage, or the maximum number of days between first and subsequent applications needed to control (kill) weeds; seedling height and root collar growth and survival at specific times (2, 4, 6, and 8 months) in all beds where herbicides are applied and in hand-weeded control plots; and seedling damage for all treatments and the control over the duration of the experiment (i.e., some herbicide concentrations may be selectively toxic to certain pines and hardwood species).

14.1.3.2 Replicating the Experiment. -If a forestry company performs the experiment, it may conduct trials at two or more nurseries that it owns. This is beneficial because site conditions, particularly soil properties, may be dissimilar at the different sites. If herbicide coverage is related to site properties, the company should know this for long-term planning. ***Replicating*** the experiment is rather simple because the nursery locations are fixed in this example. In species adaptability trials, potential trial sites are almost infinite. Thus, in field research, it is usually difficult to choose (at random) small experimental areas that are typical of large areas that will be reforested.

A word of caution! Confounding two or more factors must be avoided. For example, if one conducts nursery experiments at two or more sites, major operational activities at each are assumed to be identical, whether they be sowing, undercutting, watering, or applying herbicides. Using different equipment and equipment operators having different levels of skill at two or more nurseries can influence seedling growth and development in significant ways that have nothing to do with herbicide treatments. When such differences are significant, confounding has occurred. Interpretation of research results is impossible when *unplanned* confounding occurs.

14.1.3.3 Randomly Assigning Treatments. -The last step is establishing the herbicide experiment in predetermined areas within the two nurseries. To avoid confounding, sites as uniform as possible are chosen at each nursery. Certain experimental designs take into account unidirectional or bidirectional site gradients that cannot be avoided (Sec. 14.2). Whatever the design chosen, all treatments (herbicides and control plots) are assigned randomly to all blocks. If not, some treatments will always appear next to others with possible confounding effects.

In summary, experimentation is an important, integral component of decision making in nursery projects. When conducting experiments, follow these three cardinal rules (the 3 R's) (*1*):

1. *Restrict* objectives to simple and manageable ones.
2. *Replicate* research plots on several sites if possible, and in several blocks at each site.
3. *Randomly assign* treatments to each experimental block at each site.

14.2 Experimental Design Considerations

14.2.1 Plot ***Shape.*** -Regular, compact experimental blocks have less microsite variation and are preferred over irregular shaped ones (fig. 14-l). When known moisture or other variation exists at a field site, place the long side of blocks *parallel* to the gradient (fig. 14-2). Sometimes, outside factors will dictate block shape and orientation, e.g., location of nursery roads and buildings (fig. 14-3). Making blocks or plots a convenient portion of a hectare (e.g., 0.01 or 0.02) simplifies converting raw data to a whole hectare basis.

14.2.2 Plot Size.-Optimum plot size depends on several factors, including available land, numbers of seedlings tested (i.e., some may be sacrificed or lost), seedbed spacing or container cavity density, and experiment duration. For example, nursery trials assessing hypocotyl color and chlorophyll content of primary and secondary needles require many seedlings because traits are highly variable (*13*, *14*). Conversely, if only mean seedling height and root collar diameter are assessed at different phases of nursery development, fewer seedlings and smaller plot sizes are used (*16*).

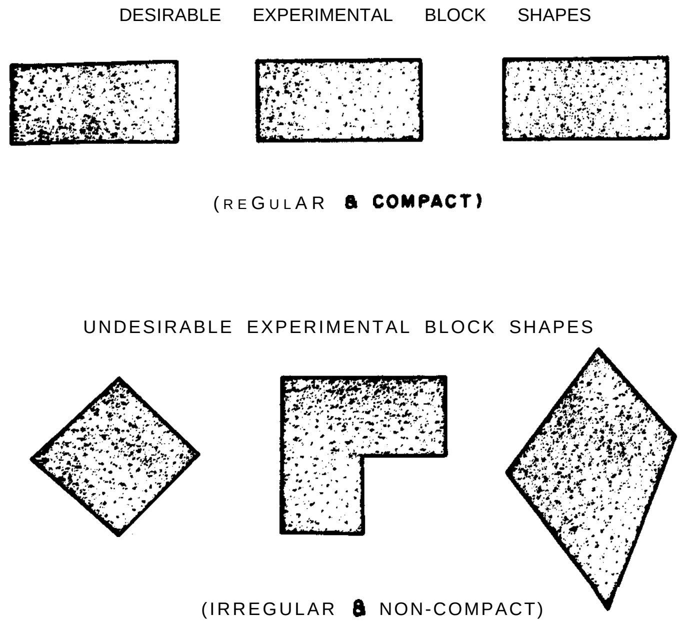
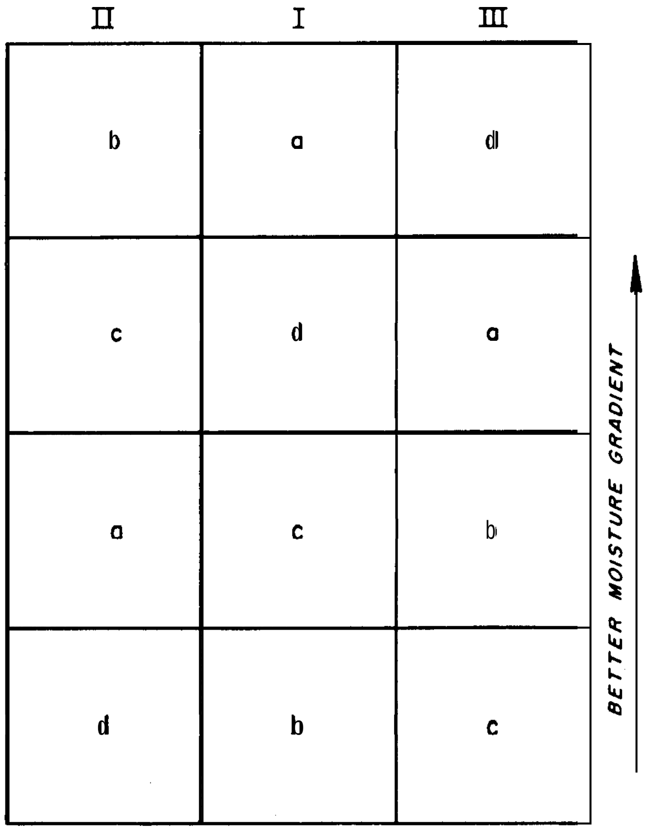


Figure 14-1.—***Desirable and undesirable plot shapes*** *for forestry* ***experimentation.***

14.2.3 Border, Surround, or Edge Rows. -Edges of seedbeds are more exposed to light, wind, and nutrients (excluding container cavities) than are interior rows. Thus, seedlings (or grasses in fallow studies) in edge rows are not assessed in nursery trials because estimates of height growth and other traits may be biased, upwards or downwards, from estimates of interior seedlings (*10*). Leaving out one or more edge rows, depending on seedling density and plant material availability, is common for nursery experiments.

14.2.4 Number of Replications. -Fewer replications (blocks) are needed in a nursery than in field trials (Sec. 14.1.2). Two or three replications are the minimum number for most nursery experiments; four to five replications are the minimum for field trials and nursery experiments where there is a large variation in sites or plant materials. When nursery studies are outplanted, the same replication and randomization scheme should be followed.

14.2.5 Experimental Designs. -The four most commonly used experimental designs in nursery research are described below, including discussion of: when a particular design is appropriate and the assumptions involved, its advantage over other designs, its limitations and restrictions, and a practical example for its use. Basic texts on statistics (*3*, 7, 9, *12*) contain instructions on calculating sums of squares and error mean squares for analysis of variance and multiple comparison tests of treatment means. Factorial experiments are omitted because they are more



I, II, III - EXPERIMENTAL BLOCKS
a - LOW DOSAGE HERBICIDE
b - MEDIUM DOSAGE HERBICIDE
c - HIGH DOSAGE HERBICIDE
d - CONTROL (I.E., HAND WEEDING)

Figure 14-2.—*Appropriate randomized complete block design for nursery experiments where site gradient is in one direction.*

complicated in theory, implementation, and analysis.

14.2.5.1 Completely Random. -When experimental conditions and materials are quite uniform, a completely random design is used. It is simple to set up and analyze data obtained. There are no restrictions on the number of replications and treatments. In the example shown in figure 14-4, four fungicides (A, B, C, and D) are tested to control damping-off in germinating trays. Sixteen trays with seeds are prepared and randomly assigned to a particular treatment. The trial lasts as long as normal germination continues. This design assumes that all trays have the same germinating medium, are seeded with the same amount of seeds from similar lots (having equal percentages of germination), and are watered and tended equally. Also, it assumes that there are no changes in temperature, light, etc., from bench A to bench D.

14.2.5.2 Randomized Complete Blocks.-When variation exists in one direction, the randomized complete block design requires fewer replications and is more precise than a completely random design. Ad-

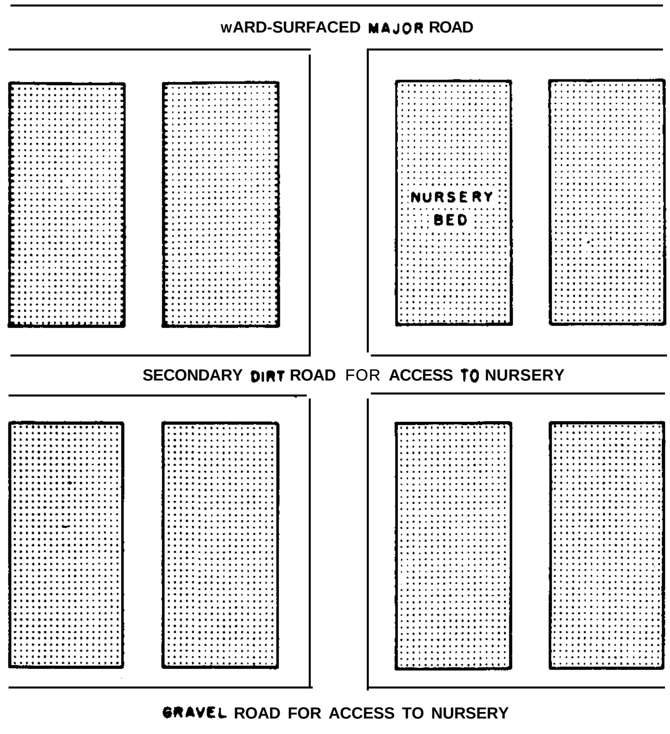
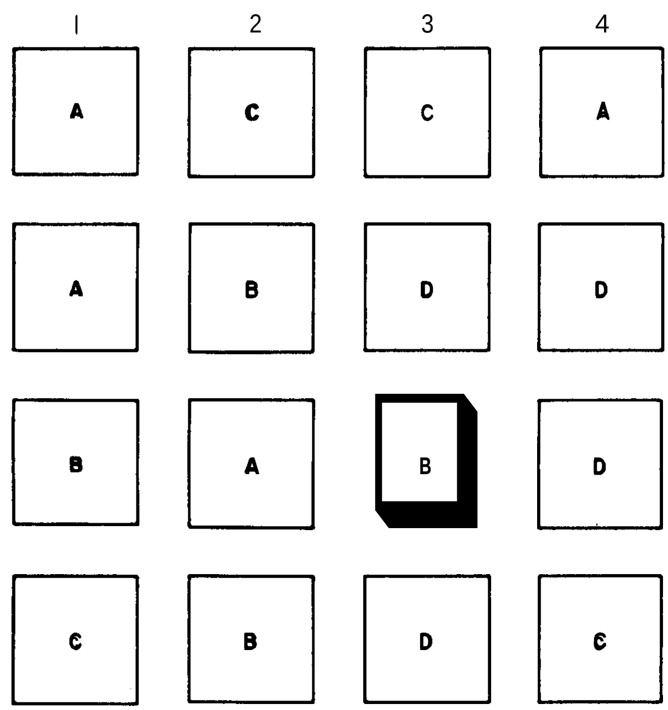


Figure 14-3.—*Outplant design for nursery site that is affected by physical constraints that place four beds on east and four beds on west side of major access road to nursery.*



1, 2, 3, 4 - NURSERY BENCHES
A, B, C, D - FOUR FUNGICIDES (ONE PER EACH SEED-GERMINATION FLAT)

Figure 14-4.—*Completely random experimental design for comparing effects of four fungicides (A, B, C, and D) on controlling damping-off in pine germination flats.*

vantages of randomized complete blocks are: simple installation and easy data analysis, even when there are missing or lost plots. The design is not appropriate when: within-block variation is great, blocks interact with treatments, or the number of treatments is large. The major restriction is that the same treatments are applied in each block.

Figure 14-2 shows a randomized complete block layout for the herbicide trial mentioned in Section 14.1.3.1. Long sides of Blocks I, II, and III are placed parallel to a known moisture gradient. Within each block, the four treatments are randomly assigned. Note that the "control" is a hand-weeded plot, not a no-weeded plot. If a plot is not weeded, weeds in it can invade adjacent plots, limiting the effect of herbicides.

Bed preparation techniques and tending operations, particularly watering, are assumed to be the same. Other within-block site variation must be minimal (no residual nutrient gradient from past fertilizer or fallow treatments).

14.2.5.3 Latin Square. -When site variation exists in two directions, the latin square design is used. Its advantages are: control of experimental error in two directions and the ability to omit columns or rows from analysis because of excessive plot mortality or damage. The major disadvantage or restriction is that the treatment number must be equal to the number of rows and columns in the design. This usually restricts treatments to 10 or less.

For example, figure 14-5 shows the herbicide trial, adapted to a site where moisture and fertility variation exist. Each row and column has all four treatments (three herbicides plus hand-weeded control). All tending operations are assumed to be the same for each plot.

14.2.5.4 Split Plot.-This design is used when some treatments are best applied to large plots and others to small plots. In practice, this means establishing large plots first, then splitting them into small plots to which minor treatments are assigned randomly.

Figure 14-6 shows a split-plot design to test the effects of two potting mixes and three seeding procedures on germinating pine seed in containers. Medium 1 (M1) is a 1:1 mixture of peat and vermiculite; medium 2 (M2) is a 1:1 mixture of local compost and vermiculite. Sowing operations are direct (hand) seeded (S1), fully automated by vacuum plate (S2), and semi-automated box seeder (S3); two seeds are sown per cavity.

Because of variability in seeding operations, five replications are used. Traits assessed are: time for each seeding (small plot) treatment to obtain 90 percent germination, total number of seeds germinated in 3 weeks, percentage of full cavities (i.e., at least one seedling per cavity), and mean height of germinants after 3 weeks for each seeding treatment on each growth medium. Watering, damping-off control, shading, etc., are assumed to be equal for all containers.

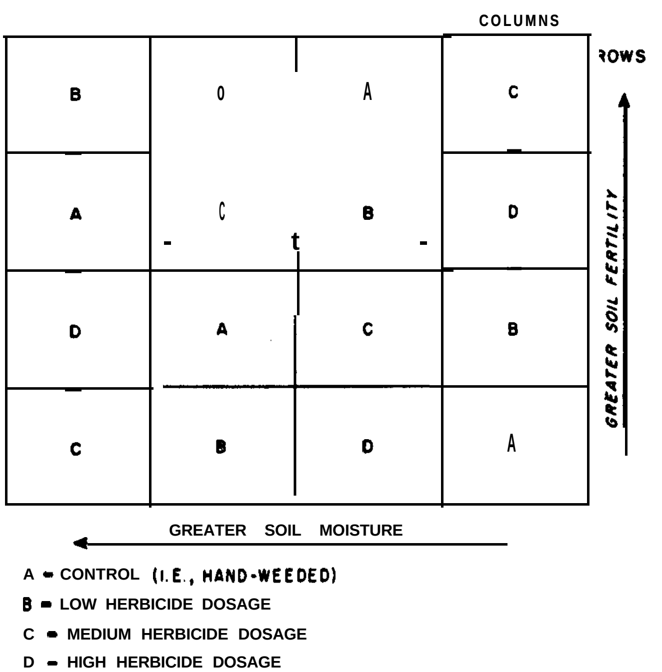


Figure 14-5.—*Latin square design for nursery experiment testing of three concentrations of a postemergent herbicide and hand-weeding. Bare-root pine seedling beds have moisture and fertility gradients.*

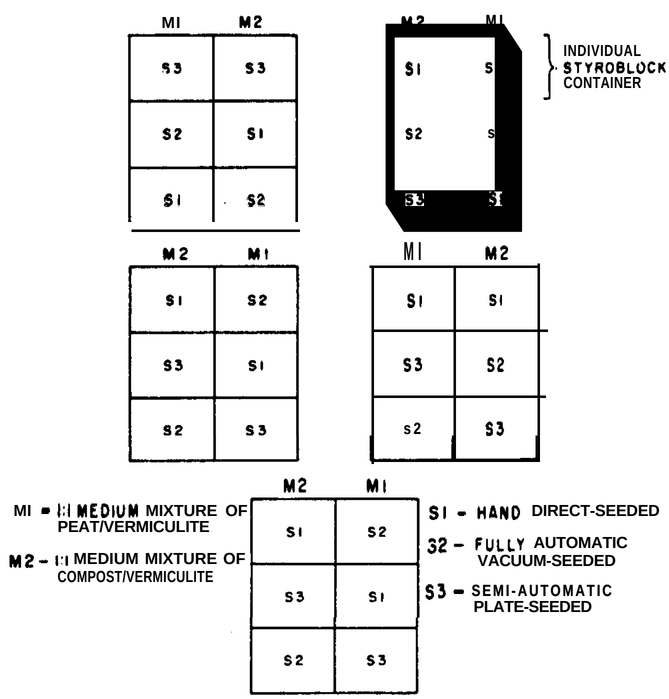


Figure 14-6.—*Split-plot design for nursery experiment testing of effects of two potting mixes and three seeding operations on germination and growth of pine seedlings in the same-size Styroblock container.*

14.8 Data Recording and Record Keeping

Accurate record keeping is essential for evaluating experiments. Insufficient data or improperly recorded data will prevent experimental questions from being answered adequately. Thus, experiment work plans should include data-sheet examples of the nursery traits assessed (fig. 14-7), instructions on how and when assessments will be made, and guides on summarizing raw field data. Also, each study should have its own experimental design, clearly indicating blocks, replications, and position sequence for trees located in seedbeds.

Individual items may seem trite, but many experiments have been lost because sowing, tending, or measurement dates were not recorded or were

Study name/number Block No. Rep. No.

Assessment date

Tree No.	Root collar diameter	Height	Tree No.	Root collar diameter	Height	Tree No.	Root collar diameter	Height
1			21			41		
2			22			42		
3			23			43		
4			24			44		
5			25			45		
6			26			46		
7			27			47		
8			28			48		
9			29			49		
10			30			50		
11			31			51		
12			32			52		
13			33			53		
14			34			54		
15			35			55		
16			36			56		
17			37			57		
18			38			58		
19			39			59		
20			40			60		

Notes — Total No. Living

Means

Root Collar diameter (mm) Nos. 1 to 20	Seedling Height (cm)	Root Collar diameter (mm) Nos. 21 to 40	Seedling Height (cm)	Root Collar diameter (mm) Nos. 41 to 60	Seedling Height (cm)

Summary	Age	N	$\bar{D}$	$\bar{H}$	% Survival

N = Seedlings surviving at assessment.
$\bar{D}$ = Mean root collar diameter (i.e., arithmetic mean of all surviving seedlings).
H = Mean height (i.e., arithmetic mean of all surviving seedlings).
% Survival = $\frac{\text{No. of seedlings surviving at assessment}}{\text{No. of seeded cavities in Styroblock}}$

Figure 14-7.—*Example of a field data sheet for nursery research.*

recorded illegibly. Below is a list of procedures that researchers should follow when recording data.

14.3.1 Data Recording Do's and Don'ts. -No matter what format is used, *ALL DATA SHEETS SHOULD CONTAIN:*

1. Species or provenance planted and trait assessed.
2. Date of assessment-the month and day should be *written* out instead of using a numbering system that is not uniform throughout the world (e.g., November 4, 1982 instead of 11/4/82, which is also written as 4/11/82). Recording the exact date is critical for calculating seedling and tree growth rates in tropical regions where a dormant season is absent.
3. Names of person(s) who made the assessment and the traits they were responsible for (e.g., John Doe: seedling heights, Jane Doe: data recorder).
4. Notations on whether data are in metric or English units.
5. Complete identification codes for all treatments, including block and plot numbers for replicated experiments.
6. A separate column for unusual things observed in any plot or at the research site (e.g., insect attack, wind damage, or persistent drip damage from irrigation lines).
7. Numbers that are clearly and distinctly written-handwriting differs from one person to another, but if numbers are not recorded *clearly,* summarization by someone other than the recorder may be impossible.
8. Results of data that are summarized and analyzed *as soon as possible* after they were obtained-waiting months or years is not recommended because data become "cold" and inconsistencies are not caught in time.

Finally, before leaving the nursery, check that appropriate items have been completed on all data sheets and that assessment dates appear *on each page.* Catching errors and correcting them *before* returning to a distant office can save a l-day trip back to the nursery site; simple omissions or inconsistencies can be spotted and corrected if accuracy is constantly checked.

14.3.2 Basic Statistics and Data Summarization. -Simple statistics used to summarize data from nursery experiments are the mean, standard deviation, variance, and coefficient of variation. A definition for each and an example of its calculation is shown in table 14-1.

Summarization of raw data, especially when done with a computer, is simple if the data are coded correctly on data sheets. One example is shown in figure 14-7. Formats will vary, depending on the study design and traits assessed. Each sheet should be developed well ahead of any measurement to ensure its ease of use and versatility.

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CHAPTER 15

15. MECHANIZED CONTAINER PRODUCTION

15.1 Criteria for Selecting Containers

To select a suitable container, nursery managers must answer several questions. What is the minimum container volume needed for high seedling outplanting survival? Which containers provide this volume? What are delivery costs for the containers having these volumes? And, what are anticipated overhead (wages, administration, and facility depreciation) and direct (temporary labor, fuel, fertilizer, and pesticide) costs.

Of the many kinds of containers having the same effective root volume, some are reuseable; those not reuseable represent overhead or direct costs. Also, freight charges and import duties in overseas countries can be high for "bulky" containers. Factors affecting container volume and the major kinds of containers used are discussed below; other authors treat the same topics in greater detail (*1*, 5, ***14, 22***). With this information, managers can select the "optimum" container for their needs and decide whether it is best purchased locally or elsewhere.

15.1.1 Length. -Before 1970, lack of research data made it difficult to select optimum container length. Today, data show that optimum container volume is closely dependent upon length (*21*, 23). In general, short containers, 13 to 15 cm long, are best for areas having long wet seasons. Long containers, 20 to 25 cm, are best for areas having irregular and long dry spells where seedling root systems must be placed deeper into the soil to avoid rapid desiccation.

15.1.2 Shape. -The most common cross-sectional shapes are round and square. Container configuration is important because of its relationship to total volume. For example, a box container 5 by 5 by 20 cm in size has a volume of 500 cm^3; a round container 5 cm in diameter and 20 cm long has a volume of 392 cm^3, 22 percent less volume. Nursery benches and planting boxes can hold equal numbers of each container because of their geometrical design (fig. 15-l). Some containers are tapered at the bottom, reducing effective volume for a given length (fig. 15-2). Hexagonal shapes are common in expandable paperpots.

15.1.3 Volume/Design Influences on Roots.

15.1.3.1 Ribs.-Container design influences root formation and root growth pattern. Four or more internal vertical ribs (fig. 15-3) direct roots downward and prevent root spiraling within containers. Round, rigid containers usually have ribs that make them superior to non-ribbed containers.

15.1.3.2 Holding Time. -Container volume influences the length of time that seedlings are held in the nursery once they reach outplanting size. For small volume containers, holding time decreases, and for large volume containers, holding time increases, allowing more flexibility to accommodate planting schedules. Keeping seedlings for long periods after roots have reached the container bottom creates unbalanced root/shoot ratios, J-roots and spiraled roots. After they have reached outplanting size, seedlings should not be held more than 45 days when using small volume containers (<300 cm^3) and not more than 75 days when using large containers (>550 cm^3).

15.1.3.3 Drainage/Root Egress Openings. -Openings at bottom and sides of containers keep pot medium adequately drained. Bottom holes allow root egress and prevent root spiraling at container bottoms (fig. 15-4). Openings must be large enough to allow free drainage and root egress when necessary, and yet small enough to prevent loss of pot medium in filling, handling, and stacking operations.

15.1.4 Container Construction Materials. -Helpful questions to ask when considering ideal container construction materials are: Will containers be reused? Will the container be planted with the seedling, requiring it to be biodegradable? Will seedlings be machine-planted or hand-planted? Must seedlings be carried to planting sites far from roads? Which con-

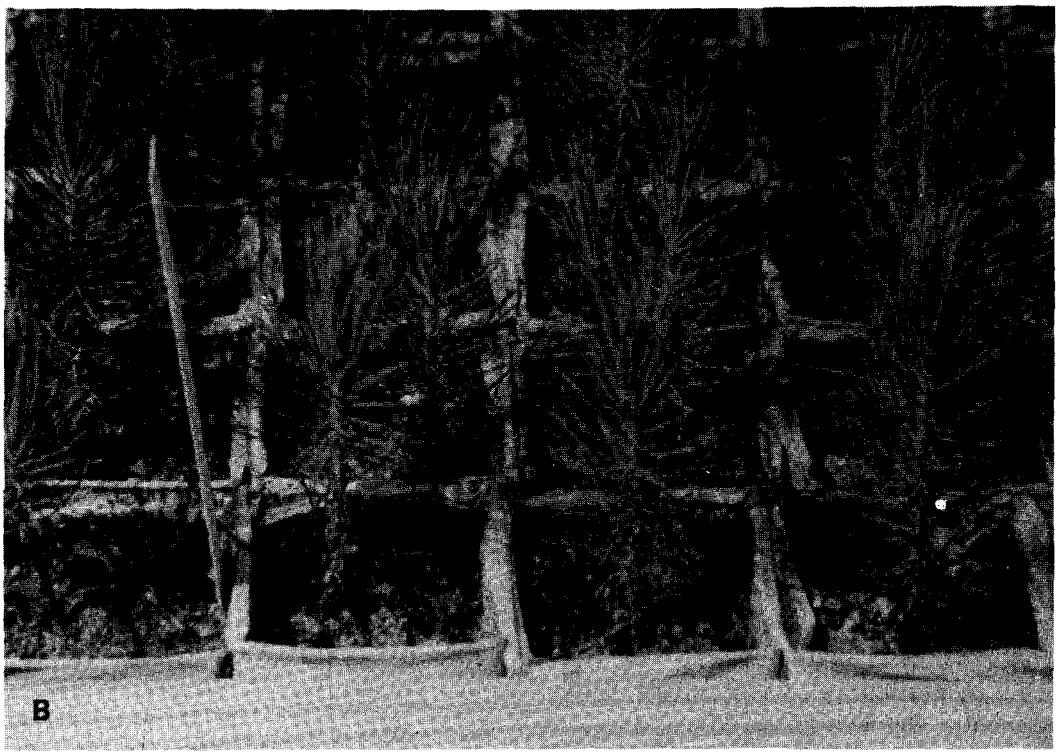

Figure 15-1.—*Shape/size* **pot considerations determine amount** *of* **medium needed,** *affect root growth and* **development, and dictate bench or ground space needed** *for* **lining-out. Volume of individual plastic bags** *(A)* **is** ± 22 **percent less than that** *of Poly-pot* **containers** *(B)* **having same height and width;** *yet geometrical design of both types allows a given bench area or transport box to hold* **equal numbers** *of* **each container.**

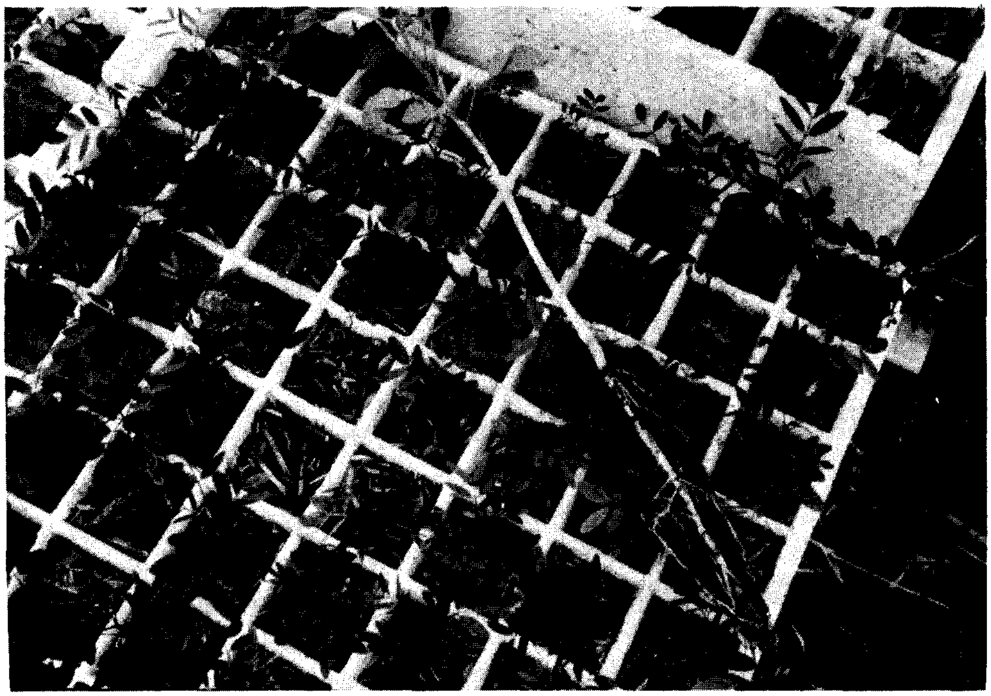

Figure 15-2.—*Cavities in the Todd Planter Flats have block cells that are tapered rather than having the same diameter at top and bottom. Taper severity influences calculation of potting medium needed, plug extraction at lifting, and root contact with soil when seedlings are outplanted.*

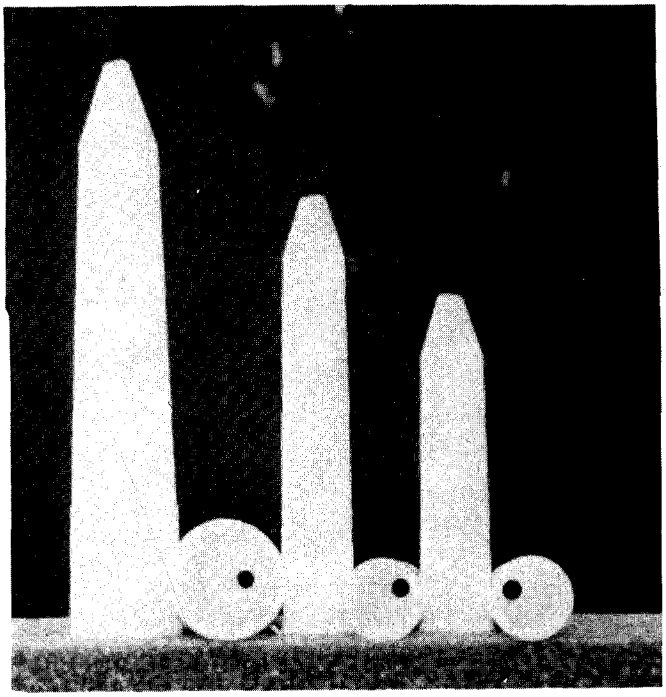

Figure 15-3.—*Leach Cone-tainer individual cell units of 10.2, 15.2, and 24.8 cm in length. All have internal ribs, running the length of each cell, which prevent root spiraling.*

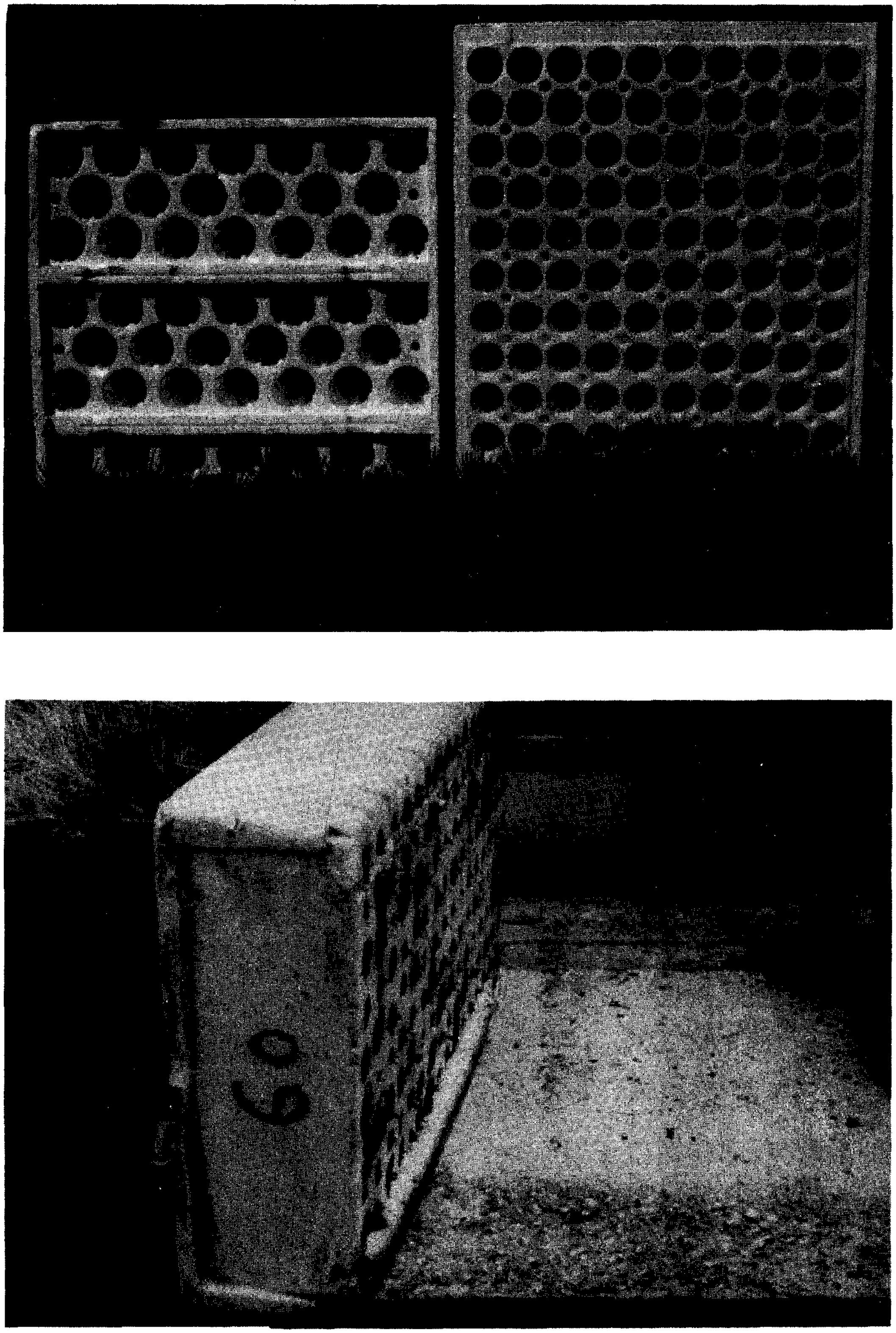

Figure 15-4.—*Top view (A) of Styroblock containers, showing large and small diameter cavities. Bottom view (B) shows root egress/drain vents and "runners" that keep the block off the ground to allow air-pruning of roots.*

tainer type utilizes available nursery space most efficiently?

These are important questions because container type affects the entire production operation, including the degree of mechanization possible. For example, processing of plastic bags, including filling, sowing, covering seeds, and transporting to the field (fig. 15-1), cannot be as highly mechanized as processing of Styroblocks (fig. 15-4).

Several lists of container product manufacturers have been published (*1*, 22, 25). Unfortunately, lists are quickly outdated as new product lines are added and old ones are eliminated. Some manufacturers and their products are listed in Appendix 15.

15.1.5 Container Systems: Some Historical Perspectiues. -Ornamental and vegetable nurseries have used mechanized seedling production techniques for over 100 years (*5*). But only in the last 15 to 20 years has enough interest developed to use highly mechanized sytems for forest seedling production.

Interest came from decisions to reforest marginal, drier, cutover lands in North America and Europe. On such lands, survival rates of container-grown stock are greater than those of bare-root stock. Simultaneously, because affected countries have high labor costs, research began on mechanized techniques to lower production costs. Today, containerized stock reaches correct size for field planting in a much shorter time than does bare-root stock, and large-scale mechanized container systems for pine may be competitive with bare-root operations (*11*).

In the tropics, abundant, cheap labor has restricted development of mechanized container systems. In the last decade, however, two events caused a reevaluation of containerized systems for tropical areas where local pot materials are available (*8*, *14*, *15*): high demand for bagged pine seedlings (Surinam, Venezuela, and Brazil) and more demand for hardwood seedlings planted in dry areas for agroforestry and fuelwood projects (Haiti and Brazil). One of the most successful operations was that of CONARE (Compañia Nacional de Reforestacion) and CVG (Corporacion Venezolana Guyana) in Venezuela in which 100,000 ha were machine-planted with containerized pine (in plastic bags) between 1972 and 1979 (*3*).

Diverse handmade container types commonly used include clay balls, split bamboo pots, plastic bags, clay pots, tarpaper pots, tin cans, and milk cartons. In general, nonrigid containers such as plastic bags (fig. 15-1) are filled individually by hand; rigid containers such as tarpaper pots and tin cans are lined-out upright and filled by shoveling sieved, loose soil over them. One disadvantage of the latter method is that soil packs between containers and serves as a medium for weed growth. Another problem with containers is that, if roots egress and grow into soil under them, the root system must be pruned or much of it is lost by stripping when pots are lifted. Some species are not suited for container production (*9*).

15.1.6 Major Container Systems of the 1970's and 1980's. -Container types and systems are discussed from different approaches. One approach lists three types: tubes, plugs, and blocks (*1*). Another lists two broad types and several divisions within each type (*22*), as follows:

A. Containers ***planted with*** seedlings:

Al-those filled with rooting medium: open mesh plastic tubes, and several paperpot systems (e.g., Conwed open mesh tubes, Walters' square bullets, and Alberta peat sausage).

A2—those not filled with rooting medium: molded blocks of peat, woodpulp, or plastic foam and fiber (e.g., Polyloam, Tree Start, and BR-8 Blocks).

Both Al and A2 are respectively equivalent to the tubes and blocks of Barnett and McGilvray (*1*). But Walters' bullets are square, not round, and should not be confused with solid cells.

B. Containers ***not planted with*** seedlings:

Bl-cells are individual units that can be unitized in trays or racks for easier handling; cells and racks are usually made of polyethylene (e.g., Leach Cone-tainer; fig. 15-5);

B2—*blocks* are units of separate cavities or cells that are ***permanently attached*** to each other;

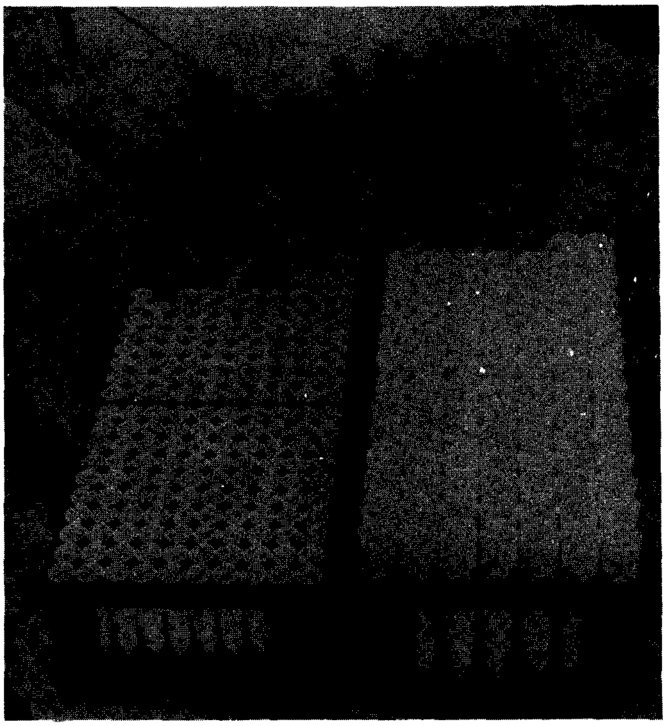

Figure 15-5.—*Polyethylene multipot tube containers that are unitized in raised trays or racks. Cells with cull seedlings or non-germinants are easily replaced with full cells.*

materials are high density polyethylene multipots and expanded bead polystyrene (e.g., Styroblock and Todd Planter Flats; figs. 15-2 and 15-4);

B3—books are units of cavities in rows formed from thin polystyrene sheet plastic; sheets have hinges and open like books (Spencer-Lemaire Rootrainer; fig. 15-6) or come in two pieces that snap together (Tubepak).

Cell and block/book designs correspond to Barnett and McGilvray's tubes and plugs respectively; "Speedlings" are really Todd Planter Flats, made by Speedling Inc. Book designs are also called "Rootrainers", because internal ribs direct root growth downwards.

Five container systems *particularly adaptable* to tropical areas are discussed in Appendix 15: Rootrainers, rigid polyethylene tubes, paperpots, Styroblocks, and Poly-pots. Some types are highly desirable because they are reusable.

15.2 Selecting Growing Medium

15.2.1 Ideal Medium Properties. -A suitable growth medium provides anchorage, nutrients, and moisture for growing seedlings (Chap. 9). Mechanized container operations also require that a growth medium be light, be easily handled, maintain constant volume when wet or dry, be free of pests, be readily stored for long periods without change in physical and chemical properties, and be easily blended into reproducible materials. Sand and soil are excluded because of their weight limitations. Properties of several "soil less" products having these special qualities are briefly discussed below; more detailed descriptions are given by others (*5*, *22*, 23).

15.2.1 .I *Peat.* -Sphagnum peat is the basic component of pot medium used in growing containerized seedlings for forestry, horticultural, and agricultural purposes (*5*). It is also used for root cuttings (*18*) and air-layering vegetative propagation techniques (6). Managers are cautioned that "peat moss" is a catchall for many separate components, including natural sedge peat, peat humus types, and many commercially available mixes. Of these, sphagnum peat has the best physical and chemical properties.

Sphagnum moss, on the other hand, consists of undecomposed materials and is not suitable for containerized growth medium. All peats are mineral poor, requiring fertilizer to maintain seedling growth; acidity should be in the pH value range of 4.5 to 6.0. Because the mineral and acidity status of peats are variable, caution must be used when purchasing them so that the delivered peat actually has the pH value and nutrient levels advertised. For container mixes, up to 75-percent is used; 50-percent peat is usually adequate. Other components mixed with peat are vermiculite and perlite.

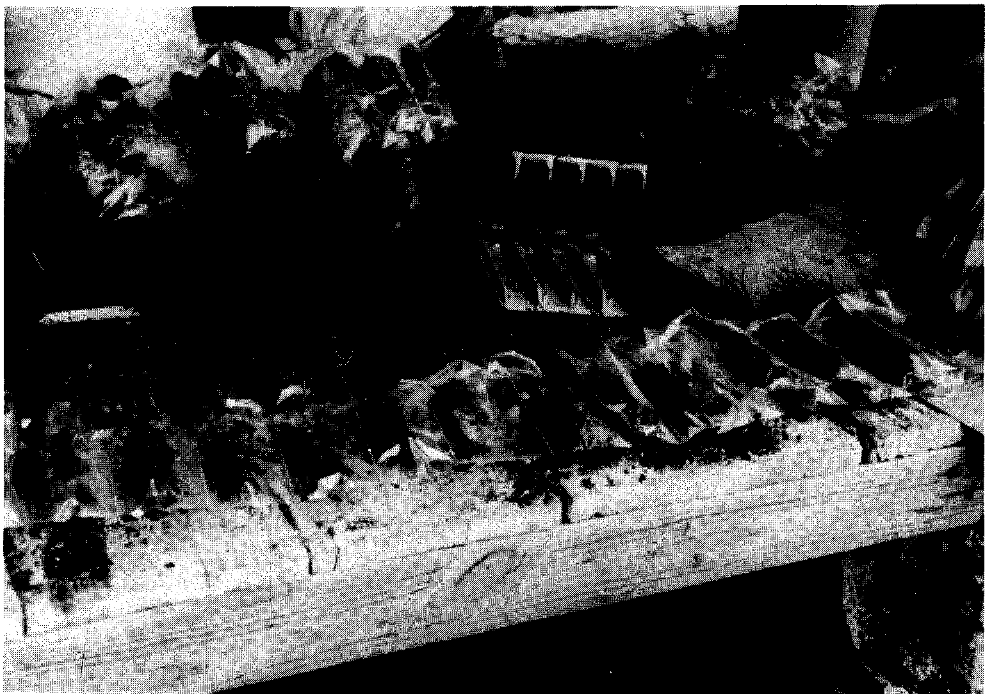

Figure 15-6.—*The* ***Spencer-Lemaire Rootrainer (book planter) can be opened any time without disturbing the seedling to check for root development or to remove plugs for outplanting. When closed, internal ribs keep roots from spiraling. Containers are easily unitized in raised trays. If seedlings must be repacked before transporting and outplanting, this container is one of the easiest to use.***

Cost is the biggest drawback to using peat, particularly when it is shipped overseas. Yet, when seedlings must be carried to remote planting sites, when no suitable local substitute for peat exists, and when funds are available, the advantages of peat exceed cost disadvantages. Peat moss costs are crucial when deciding ideal container volumes for species to be planted (i.e., the greater the volume filled, the more peat used and subsequent higher costs).

15.2.1.2 Vermiculite. -Vermiculite is a bulking agent in pot mixes that keeps the growing medium from settling and compacting and maintains good aeration and drainage. It is a light, expandable, plate-like 2:1 silicate mineral. After mining, vermiculite is run through high temperature (1,000°C) furnaces that force bound water out and plate layers apart. This process forms sterile, porous, sponge-like kernels that moisten and dry readily. Kernels are graded into various sizes, from horticultural grade No. 1 (5 to 8 mm) to No. 4 (0.75 to 1 mm). Products termed "attic fill" and "poultry/kitty" litter are cheaper versions of grade No. 1; "block-fill", however, is water-repellent treated and should not be used. Coarse sizes are best for large containers and finer sizes for seed germination trays and small volume containers.

Other advantages of vermiculite are:

- neutral reaction and high buffer capacity;
- high water retention capacity unless compacted (squeezed) when moist;
- high cation exchange capacity; and
- enough natural Mg and K to supply most plants.

15.2.1.3 *Perlite.* -Perlite is another light, usually granular bulking agent made by heating crushed lava. The resulting sponge-like, sterile granules hold 3 to 4 times their weight in water and have a pH value of 6.0 to 8.0; particle sizes are 1 to 3 mm. Unlike vermiculite, perlite lacks buffering capacity, cation exchange, and mineral nutrients. Its usefulness is to increase aeration and moisture retention in pot mixes.

15.2.1.4 Sugar-cane Waste. -Another lightweight material with potential for pot mixes is the filter-press cake that remains after refining sugarcane. The material is abundant and relatively cheap in many tropical areas. Some of its physical and chemical properties have been studied (table 15-l).

The following data and recommendations are taken from a report on filter-press cake by Samuels and Landrau (19): It easily absorbs moisture when dry and its volume-weight ratio is low. Of the major plant nutrients, filter-press cake is highest in P and P_2O_5; N content is somewhat lower. The K content is low and averages 0.44 percent as K_2, with a range of 0.02 to 1.77 percent; the higher figure is extremely rare.

Calcium content is high, averaging about 3 percent as CaO. Magnesium and minor elements such as Mn, Fe, and B are present in sufficient amounts for use by plants. Except for the lower K content, the fertilizer value of filter-press cake may be as great as that of animal manures. Its main advantages are cheapness, slow release of nutrients, minor-element content, high bulk and high water holding capacity, high exchange capacity, and mulching properties.

Table 15-1.—*Chemical composition of filter-press cake residue of sugarcane*[1]

Constituent	Composition on a dry weight basis	
	Average	Range of values
	------------ *Percent* ----------	
Nitrogen (N)	2.19	1.07–3.13
Phosphorus (P_2O_5)	2.77	1.34-6.30
Potassium (K_2O)	.44	.02–1.77
Calcium (CaO)	3.05	.98-6.24
Magnesium (MgO)	.49	.42–.58
Manganese (MnO_2)	.17	.10–.24
Iron (Fe_2O_3)	1.05	.26-4.71
Boron (B_2O_3)	.01	.00–.02
Organic matter	39.50	....
Loss on ignition	42.20	....
Sucrose	3.00	2.00-4.00
Moisture(fresh)	61.00	59-69
Moisture(stored)	15.00	9-47
Volume weight[2]	.375	.372–.378

*Source:(19).

[2]Calculated on a dry-weighted basis.

Filter-press cake is an attractive lightweight substitute for peat. A major disadvantage is its high pH value, which ranges from 8 to 10. Obviously, this value must be lowered to about 5.5 if this material is to be used for growing pine seedlings. This can be done by composting filter-press cake with animal manures, then treating it with an acidic fertilizer that lowers pH value and supplies N (table 13-9).

15.2.1.5 Rice Hulls.-An excellent substitute for vermiculite is rice hulls. They are lightweight, have high bulk, hold moisture well, and are easily obtained in rice-producing countries. Depending on processing standards, grinding may be needed to increase flowability of rice hulls in mixing and filling operations. Rice hulls can be used in composts and as a germination medium in seed trays.

15.2.1.6 Compost.-Compost is a useful potting medium ingredient if the composting process is closely controlled. Potentially desirable traits of compost are:

- low weight, depending on major components used;
- low shrinkage;
- good moisture retention;
- inexpensive once local sources of raw materials are identified;
- high fertility if properly prepared;
- easily shredded and screened to uniform size;
- mixes well with sand, perlite, and vermiculite; and

- does not immobilize nitrogen or other nutrients.

Major criteria for judging compost are how well it provides good aeration, maintains acidity, and reduces unit seedling weight in containers. Fertilizer amendments provide elements that are missing or in short supply in the compost. Potential problems in making compost are:

- obtaining a steady source of homogeneous, raw compost materials (rice hulls, horse manure, cow manure, etc.);
- making compost in time so that material is ready for the beginning of production runs;
- obtaining an end product that is free of pests and disease organisms; and
- avoiding C:N ratios that are too high (≥30:1) in finished compost material.

Appendix 13 outlines procedures to produce compost of desirable physical, biological, and chemical composition (*16*).

15.2.1.7 Wood Products. -Sawdust, wood shavings, and ground bark can be used in place of sphagum peat in pot mixtures. Sawdust and bark are not used exclusively but are mixed with other materials. Aged or composted wood products are best because fresh materials have high C:N ratios, ≥150:1 (22), that immobilize N and make young seedlings chlorotic. Some fresh barks have chemicals that are toxic to plants.

Advantages of wood products in pot mixes include lightness and ease of handling when ground, moderate cation exchange, and small but significant amounts of all major and minor elements. When cost is not a limiting factor, sphagum peat is still preferred because it has higher cation exchange, better C:N balance, and fewer problems with harmful organisms and toxic substances.

Table 15-2.—*Procedures for determining total porosity, aeration porosity, and water retention porosity of container media*[1]

Materials	Procedures
Container with drain hole at bottom, plug for drain hole in container, and graduated cylinder or other device for measuring water volume.	1. Plug drain hole and till container with water; measure volume of water in container (= *container volume).* 2. Empty container and fill with soil mix; slowly and thoroughly saturate mix by adding water at one edge of container and keeping track of water added (= *total pore volume).* 3. Unplug drain and catch water that runs out; measure volume of water drained (= *aeration pore volume*). 4. Porosity is obtained by dividing pore volume (step 2) by container volume (step 1). 5. Aeration porosity is obtained by dividing aeration pore volume (step 3) by container volume (step 1). 6. Water retention porosity is obtained by subtracting aeration porosity (step 5) from porosity (step 4).
In Summary:	
Porosity (%)	$= \frac{\text{container mix pore volume}}{\text{container volume}} \times 100.$
Aeration porosity (%)	$= \frac{\text{aeration pore volume}}{\text{container volume}} \times 100.$
Water-retention porosity (%)	= porosity - aeration porosity.

[1]Source: (*21*).

15.2.2 Optimum Growth Medium

15.2.2.1 Porosity and Aeration Considerations.— The "optimum" growing medium for a given situation depends on several factors, including requirements of the species grown, container volume, and available pot mix (*12*). Seedlings do better in moist rather than dry or wet media. Shallow containers with fine textured materials have better moisture retention but poorer aeration than deep containers with coarse textured materials because of less medium porosity. Porosity determines the space available for water, air, and root growth. Large pores aid aeration, whereas small to fine pores aid water retention; thus, both are important.

Spomer (*21*) developed a simple procedure for determining container porosity, aeration porosity, and water-retention porosity (table 15-2). Generally, aeration porosity values <10 percent are considered low; values >25 percent are considered high.

15.2.2.2 Examples of Mix Proportions.-A 1:1 mix of shredded sphagnum peat and vermiculite minimizes weight and facilitates container handling in most mechanized operations. Other mixtures used are 3:2 and 3:1 ratios of the same components (22). Some nurseries successfully use peat without vermiculite or perlite. Examples of homemade medium are 2:1:1 mixtures of bagasse (sugar-pressed cane fibers), rice hulls, and alluvial soil in Haiti (20); 2: 1 alluvial soil, filter-press cake mixtures at the Monterrey nursery in Puerto Rico; 1:4 and 2:3 ratios of topsoil and sand and 2:3 ratios of rotted cow manure and builders sand (13); and a 4:3 mixture of sand with well sieved compost (7). Most tropical countries do not use "soil less" medium.

The proportions of medium component affect seedling growth by changing porosity and drainage. Adding more vermiculite or perlite to peat increases aeration and drainage (*4*). But too much vermiculite allows pot mix to fall through drainage holes, which can cause seedling plugs to fall apart when they are removed from containers. Areas of constant humidity and high rainfall require better drained (coarser) mixes, whereas dry areas need finer medium with more moisture retention.

15.2.2.3 Synthetic Mixes. -Commercial pot mixes offer advantages to some nursery managers, Examples are Jiffy-mix, Pro-mix, and Redi Earth. All come pre-mixed to be placed directly into containers. Most are sterile and have pre-added nutrients. Disadvantages are their high cost, no control over components in the mix, unneeded or nonbeneficial nutrients, and less than ideal aeration and drainage. Buying containers prefilled with synthetic mix may be cost effective when seedlings are needed in the shortest time possible, as in erosion control and landslide stabilization. Appendix 15 lists commercial suppliers of pot mixes and their addresses.

15.3 Basic Equipment

The right equipment is essential for mechanized container systems. Design and parts may vary by country, but the functions of basic pieces are the same. Equipment used at the ITF nursery in the late 1970's to produce pine seedlings in Styroblocks (26) is discussed below. Gravity feed systems compliment machines whenever possible in all operations (see Appendix 15).

15.3.1 Compost Shredders. -Shredders (fig. 15-7) process agricultural byproducts such as filter-press cake, coffee chaff, rice hulls, coconut hulls, straw, etc., before they are composted. Shredding forms small particles, increasing surface area for more rapid decomposition. After composting, a final shredding breaks up remaining clumps; improves filling and settling of medium into small cavities; and allows better mixing with perlite, vermiculite, and other medium components.

Shredders are integrated into production operations in two ways. In one method, equipment is set on a level area. Shredded material falls onto a mechanical conveyor, is transported to a large mixer, and is uniformly mixed with other components before being transported to a filling hopper.

In the second method, shredders are in the upper level of a split-level building; gravity then feeds shredded material into a mixing hopper on the first level (Appendix 15), thus eliminating the need for a conveyor belt.

Shredders come in various sizes. Those with the capacity for grinding about 7.5 m^3 of material per hour are adequate for nurseries producing $\leq$ 1 million seedlings per year. Electric models are less noisy than gasoline powered shredders. Either types must be highly mobile and relatively trouble-free in operation. Raw shredded material, ranging from 0.2 to 0.5 cm long, should be screened so that the final product (3 to 6 mm) is homgeneous.

Figure 15-7.-A ***small, very mobile, gas-powered compost shredder capable of processing 7 m^3 per hour of rice hulls, sugarcane waste, straw, and other materials.***

15.3.2 Soil and Compost Sievers.—Unsieved pot medium can cause poor aeration and poor drainage. Final medium should have a consistency that minimizes silting and that has sufficient large-size particles. Up to 50 percent of the pot medium should fall through 1.4- to 2.4-mm sieve openings. Very fine sand, perlite, vermiculite, and expanded polystyrene beads are excellent lightweight materials that increase bulk and improve drainage, porosity, and aeration.

Mechanical sievers can sieve 3 to 5 m^3 of material per hour. Hand sieving is done if machines are not available. Ideally, a mechanical siever is placed between the shedder or soil mixer and the mixing tank.

15.3.3 Medium Mixer.-Concrete mixers or some similar machine (fig. 15-8) should have a 3 to 10 m^3 capacity. Medium ingredients enter by gravity feed or by conveyor belt. The mix is wetted to improve flowability; the material is moist to the touch, but excess water cannot be squeezed out with the fingers (Sec. 15.4.2). After mixing, the final medium is transported to a filling hopper.

15.3.4 Potting Machine. -Vibrating plate-type machines are capable of filling a tray with containers

Figure 15-8.-*A small electric mixer capable of processing 3 to 10 m^3 of potting material per hour.*

in 20 seconds. A single machine can fill 80,000 to 300,000 cavities per each manday of work, depending on cavity volume, kind of pot medium used, and container types (e.g., rigid types being easier to fill than flexible or assembled types). For less mechanized operations, one worker can take medium from the filling hopper and fill containers by hand or by gravity feed (fig. 15-9). After flats are filled, they are sent by conveyor belt to the semi-automatic seeder.

15.3.5 Semi-Automatic Seeder. -Before seeding, compactors push pot media down about 1 cm, creating space for seeds (fig. 15-10). Vacuum controlled seeders fit exactly over cavities of multiple cavity flats (fig. 15-11). After aligning the plate with seeds over the containers, vacuum is cut and the seeds fall into the cavities. One operator can easily seed 100,000 cavities in an 8-hour day.

A hand-operated seeder can be made of plexiglass to fit any cavity configuration. It has two sliding plates with matching holes, the bottom plate having a slightly larger diameter hole than the top plate. When the holes are unaligned, each hole is filled with seeds. Sliding the top sideways allows the seeds to fall straight through the bottom plate into underlying cavities. Commercially made seeders can be purchased to desired specifications.

15.3.6 Final Filler.-Machine or hand spreaders place a small amount of vermiculite or other grit cover over seeded cavities as they pass under a hopper (fig. 15-12). Excess covering of seeds will lower germination. After applying the filler, mist watering keeps it from blowing away. A final filler is not needed in tightly enclosed, high-humidity germination houses.

15.3.7 Forklift and Wagon.-Seeded flats are stacked manually on pallets, loaded by forklift onto wagons, driven to seedbeds, and lined-out (fig. 15-13). Lining-out is a potential bottleneck because workers need considerable space for maneuvering a forklift and accommodating the flats. Lift operators must be skilled to avoid spilling loaded trays and damaging flats. Pallets can serve as permanent bench tops.

15.4 Other Operational Techniques

Other operations are essential to produce healthy, vigorous seedlings. We review these operations below, giving alternatives whenever possible and their potential problems,

15.4.1 Medium and Facility Sterilization. -Pot mixes with peat, vermiculite, and perlite as major components do not ordinarily require sterilization. Mixes with ground bark, sawdust, compost, and soil should be sterilized. In research trials, all mix treatments, including the control, are sterilized (except trials on the effects of sterilization treatments).

Steam heat sterilization is preferred for "soil less" mixes. Chemical fumigants can bond to vermiculite and finely ground peat and compost, being toxic to plant roots even after treated material is aerated. If fumigants are used, mixes should be moist, but not wet; fumes dissipate in 2 days to 2 weeks, depending on the product used. Steam heating at 82°C for 30 minutes effectively kills most pathogenic pests and weed seeds. Since steam heating is used extensively for horticultural and vegetable crops, a wide range of sterilization equipment is available. Dry-heat sterilization can alter soil chemical properties (*17*).

Medium mixing and filling areas, plus the equipment involved, should be kept clean and free of weed seeds and other contaminants. Disinfecting alternatives are washing with solutions of commercial bleach (50-percent sodium hypochlorite) diluted 10:1 with water, boiling water, rubbing alcohol, and live steam (*22*). Flats, tools, and nursery walls and floors should be disinfected before each production run.

15.4.2 Filling Container Cauities. -Slightly moist medium flows better through the potting machine and does not fall out of root egress holes as does dry medium. Water is added to all components when they are mixed. Peat and other finely ground materials do

Figure 15-9.—*A semi-automatic potting operation in which a worker hand-fills containers passing underneath the medium hopper on a conveyor belt.*

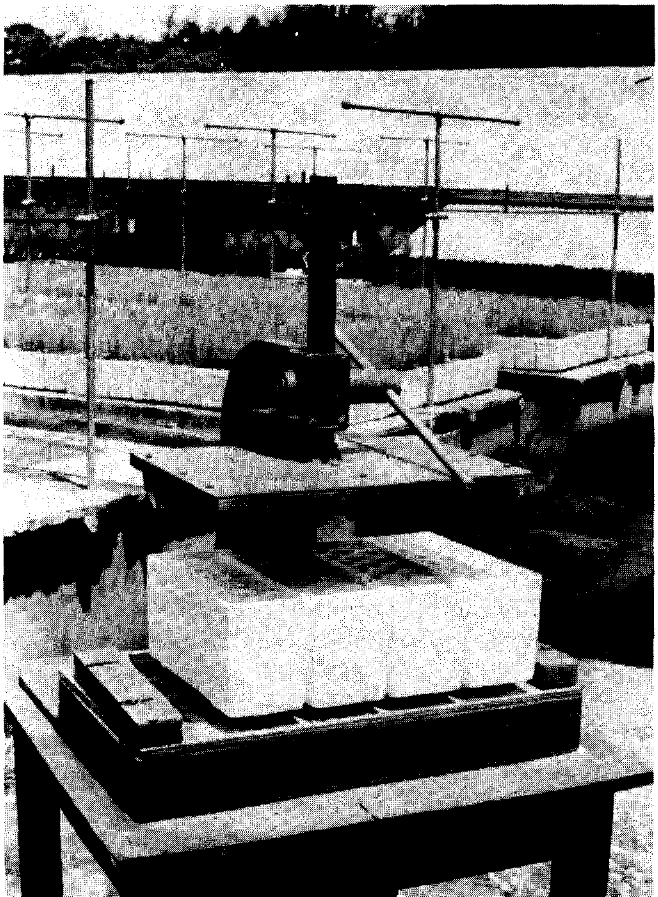

Figure 15-10.—*A hand operated mix compactor that presses down pot medium. Hand-operated plate seeders function the same way.*

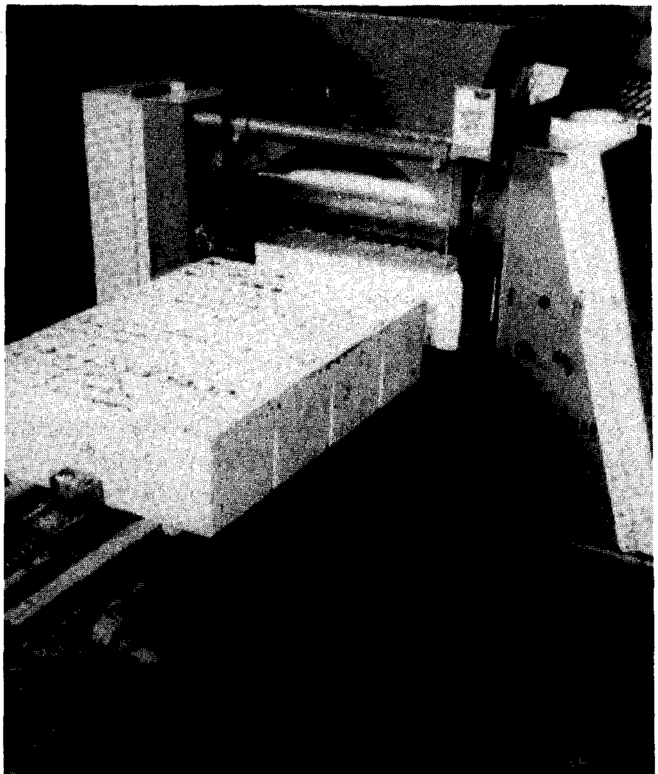

Figure 15-11.—*A vacuum controlled mechanical seeder that fills all container cavities simultaneously as Styroblocks pass underneath on conveyor belt.*

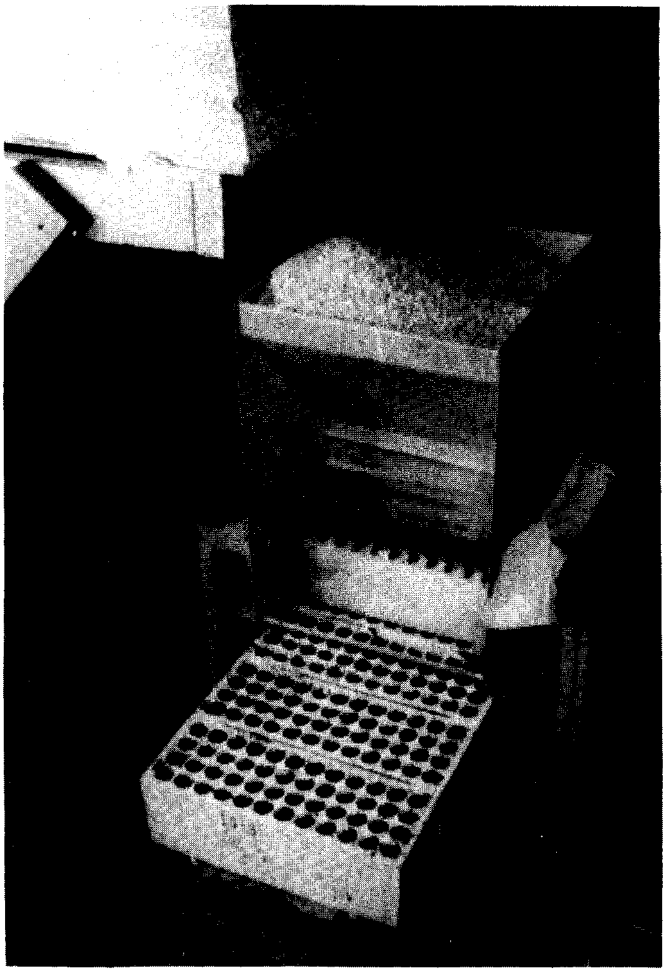

Figure 15-12.—*Mechanical final-fillers drop a thin layer of vermiculite or other grit over seeds in Styroblocks to conserve moisture around seeds and protect against birds.*

not wet well when dry because of their nonwettability (hydrophobicity) properties. Commercial wetting agents improve moisture uptake, but chemicals in them can lower the percentage of seed germination (22). Once pot mix is damp, it must be used before drying out.

Motion of the potting machine helps fill containers when pot mix is damp. Operators must not force extra medium into cavities with their fingers. A flat-handle brush smooths away any excess, which is eventually used.

15.4.3 Sowing.-Germination percentage of seed lots determines sowing rate. If germination is low, more seeds are sown per cavity, increasing the probability that each has at least one germinated seed. If germination percentage is high or seeds are scarce, then only one seed is sown per cavity.

If seeders pick up and drop only one seed per cavity, the entire operation is repeated 2 or 3 times. Automated seeders are faster than hand seeders but are subject to more mechanical problems. When automated seeders break down, hand sowing gets the job done (Sec. 9.1.5.2). After sowing, containers are sprayed with a fine mist to moisten seeds before going to the final filler.

15.4.4 Lining-Out and Germinating

15.4.4.1 Stacked Method.-Stacked containers in a germination house save outside bench space and reduce seed loss to birds and mice (fig. 15-14). The method is only suitable for species, including ***P. caribaea,*** that germinate uniformly in short periods and grow well in low light conditions. One drawback to the method is the need for placing wooden "stickers" between Styroblocks. They create space between block layers to prevent fast growing early germinants from bending over block tops. Seedlings straighten up if they have not been bent over too long, but mishandling blocks in lining-out will sever seedling tops that are bent over block edges.

Blocks stacked in criss-cross fashion cannot be watered. Thus, germination houses are used only for species having fast, uniform germination that is completed within 7 to 10 days in a high-humidity environment.

15.4.4.2 Lined-Out Method.-This method involves placing seeded containers directly on outside benches (fig. 15-13). Placing flats under about 30-percent saran shade for up to 21 days prevents loss from pests. Elevated shade is better than clear or dark plastic sheeting placed over containers. In the tropics, the latter practice can cause extremely high temperatures under the sheet that are lethal to germinating seedlings. Frequent and careful watering will keep medium and seedlings moist but not too wet; overwatering favors damping-off.

To reduce overtopping of border by interior seedlings, Styroblocks should be placed in long, narrow rows about 10 blocks wide. If peat or other sterilized pot medium is used, weed growth is minimal in exposed cavities. A wide walkway (76 cm) between rows can be narrowed to a small path (38 cm), which is adequate for inspecting seedling stock for pests and general growth performance. Narrow walkways leave more space for containers per unit of nursery area.

15.4.5 Thinning, Transplanting, and Grading. — Early germinants remain in the original container. From the 7th to 13th day after germination, small excess seedlings in each cavity are lifted and transplanted into empty Styroblocks. After the 14th day, small excess seedlings are removed and discarded. Small, less vigorous seedlings are not transplanted because they perform more poorly than do early germinants (24).

Long lateral roots on thinned seedlings should be carefully clipped rather than removed; this procedure avoids disrupting the growing medium around seedlings left in each cavity. Transplant holes should not be closed over J-roots (Sec. 10.1.1.2).

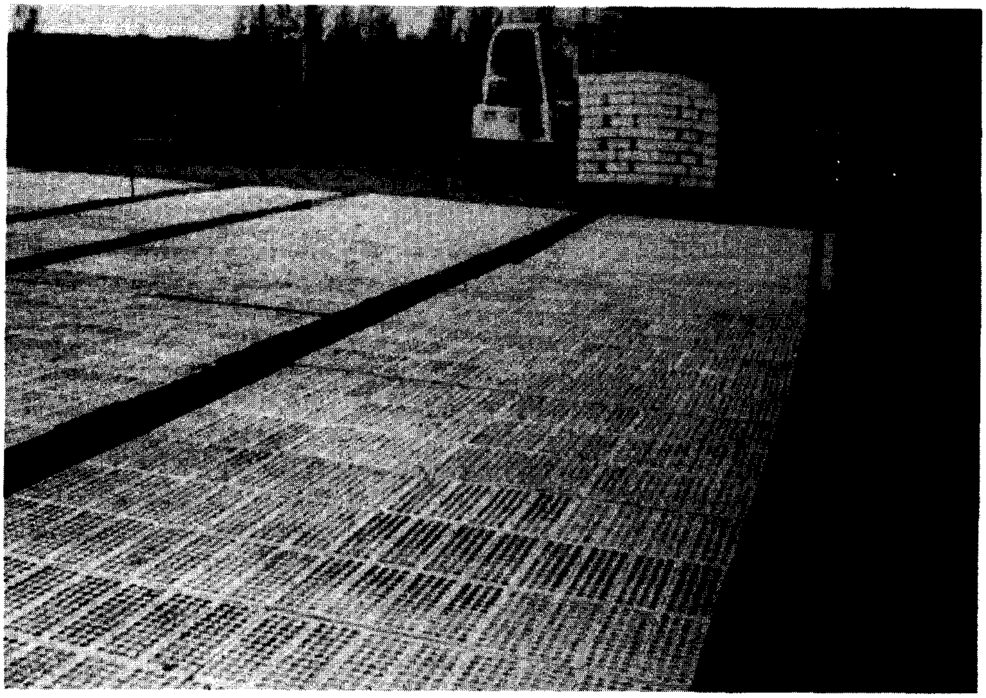

Figure 15-13.—*In large operations, forklift tractors are handy for lining-out seeded Styroblocks for germinating in the open air.*

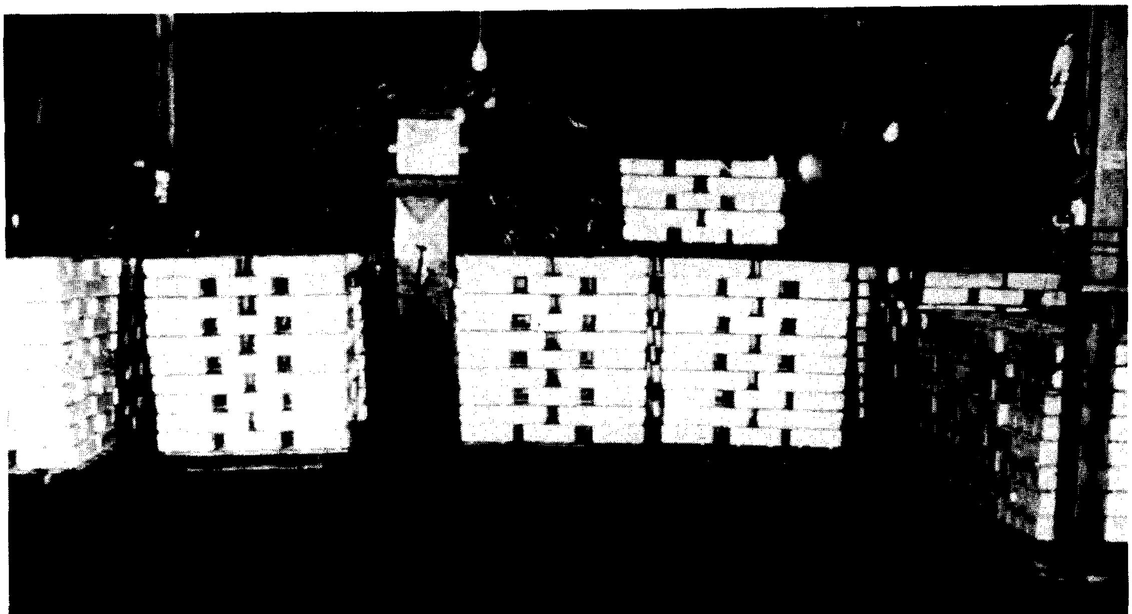

Figure 15-14.—*Germinating seeded Styroblocks by the stacked method inside an enclosed germination house.*

These thinning and transplanting techniques separate germinants into three classes: early, more vigorous germinants that are left in original containers and lined-out in one sector of the nursery; later, excess germinants that are transplanted into separate Styroblocks; and late germinants that are culled. Sometimes, late germinants are kept if germination is poor or if seeds are scarce. The result is seedlings graded according to date of germination.

15.4.6 Later Tending Care

15.4.6.1 Moisture and Fertilizers. -The moisture and fertilizer needs of seedlings are different for germination, juvenile, exponential, bud development, and stem lignification growth phases (*22*). Specific guides will depend on the containers used and species grown. Some general guides and suggestions are given in this section. For container operations, fixed irrigation systems are used more than mobile ones. Systems producing small and medium droplets (mist, semi-mist, and fine spray-nozzle types) are better than those producing large droplets. Smaller droplets do not damage young seedlings or wash out pot mix.

Persistent drip of fixed systems may wash out seedlings or medium from containers. Alternatives to prevent this are supplying water from beneath (2) or alongside benches (i.e., not from overhead), drawing water from the top of overhead pipes, draining out excess water after each use, and running a line down from the nozzle to the bench surface between containers (22). Large spray-nozzle and impulse-type systems are more adapted to irrigation of bare-root nursery beds.

Combining slow-release fertilizers with pot mix or top dressing fertilizers on container surfaces (*10*) is not usually done in mechanized container operations because:

- soluble fertilizer pellets or granules are readily leached from the pot mix;
- when seedling growth stages change, certain nutrients must be added or reduced; if they are already in the mix, controlled additions or reductions are impossible;
- pellet and granule dissolution are uncontrollable; thus, specific nutrients are not always provided when needed most; and
- slow dissolving fertilizers often tend to raise medium pH value and salt content; lowering both requires flushing with excess irrigation water.

For containerized systems, nutrients are usually applied through the irrigation system. Fertilizer formulation, concentration, and application frequency are easily controlled. The general scenario of watering and fertilizing for different seedling growth stages is:

1. ***Germination*** stage-frequent but controlled waterings to keep medium moist but not wet; no nutrients are added that provide "rich" materials for damping-off or other pathogenic organisms.
2. ***Juvenile stage-less*** frequent irrigation that allows the growth medium surface to dry between waterings; high P and K and lower-level N fertilizers are added to maximize early growth; a final rinse of foliage with plain water is needed to avoid possibility of salt burn and alga growth.
3. ***Exponential*** growth-reduce watering; balanced N-P-K fertilizers are added; seedling growth rates (too fast or too slow) are closely monitored to anticipate change to next water and fertilizer regime or other corrective action such as top-pruning.
4. ***Bud development or stem hardening-when*** seedlings reach desirable height and are purposely drought stressed (hardened); this process is done by heavy watering to remove N and then subsequent drying of seedlings almost to the wilting point; they are rewatered to stop wilting and then infrequently rewatered with low N and high P and K fertilizers to facilitate hardening.

Other nutrients are added according to the needs shown by periodic foliage testing (Chap. 13). Unexpected micronutrient deficiencies are usually corrected by applying foliage sprays rather than solid materials.

15.4.6.2 Protection and Pest Control. -The guides discussed in Chapters 12 and 16 can be followed. In general, reduced exposed area and use of uncontaminated pot medium reduce weed growth more in container than in bare-root nurseries. Consequently, weeding is minimal and confined to borders of benches and is controlled by hand or by chemicals. Judicious use of asphalt, cement, turf, and gravel for roads and walkways will reduce weeding.

Having a cat or two around germination houses, potting sheds, and outside benches is an effective control against mice, rats, and birds. Pathogen buildup is avoided by composting or burning thinned, cull, and other seedling materials. Otherwise, looking constantly for problems and using approved pesticides should keep most pests in check.

15.4.6.3 Inoculation with Mycorrhizal Fungi. -For large potting operations, collected mineral soil and duff with inoculum is kept fresh for long periods by storing in burlap sacks lined with plastic or in bins lined and covered with plastic sheeting. When pot components are mixed, inoculum is added 2 to 3 percent by volume. Adding inoculum this way has risks that are minimized by collecting inoculum from healthy plantations and by careful monitoring for damping-off, root rot, and other problems as inoculated seedlings develop.

15.4.6.4 Root/Shoot Growth Control. -Mechanical root pruning is not possible for containerized stock. Root growth is controlled by the shape-volume-design characteristics of containers used (Sec. 15.1). Since root volume is finite, estimating outplanting dates must be accurate because long-term holding of seedlings is impossible. If seedling top growth has been excessive in relation to root growth, tops may be clipped back. This procedure stops top development, encourages more root development, and produces better shoot/root ratios (see Chap. 11).

Using wide rows minimizes border or edge effect around containers and reduces overtopping of interior by border seedlings. Effective windbreaks and properly maintained irrigation systems reduce water and nutrient drift from bench edges, giving edge and interior seedlings the same moisture and fertilizer dosages.

Experience at the ITF Nursery showed that bench color and container placement affected seedling growth. When concrete benches were new and highly reflective, seedling mortality was sometimes great near bench edges when containers were set far to the inside (i.e., exposed to the reflective bench surface). Apparently, localized heating or higher evapotranspiration was responsible (fig. 15-15). Alternative solutions are using less-reflective surfaces, such as wood or screens, over elevated pipes (fig. 2-2B); painting new benches with less-reflective paint; and positioning containers so they extend over bench edges.

15.4.7 Lifting, Packing, and Transporting. -In the tropics, delivering containers directly to the field for outplanting is preferred. The lifting and repacking procedure (fig. 15-16) is not recommended because it is time and labor consuming, can cause severe root damage, and augments transplanting shock. Local

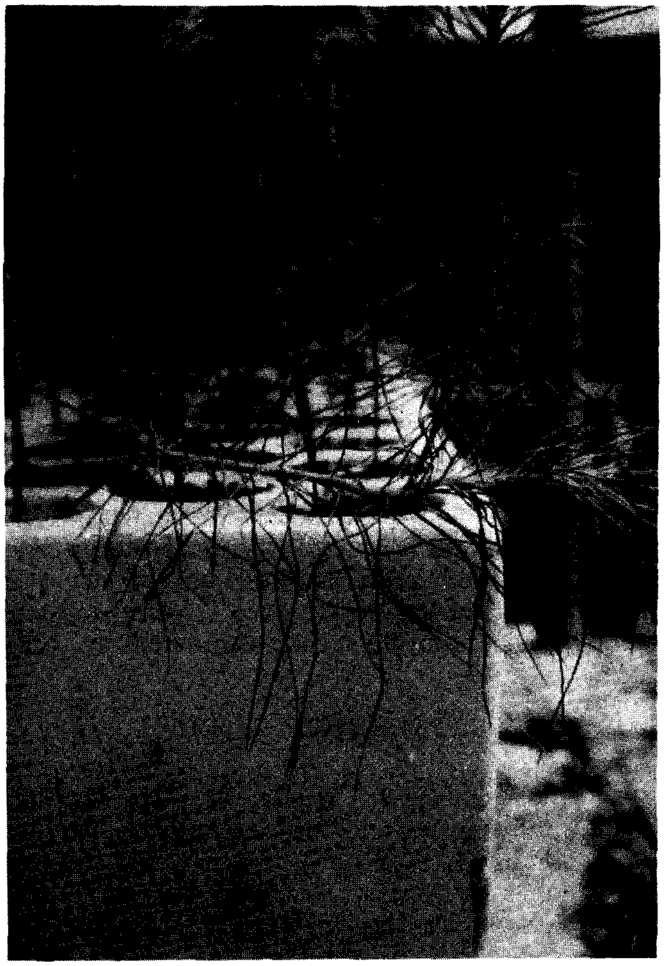

Figure 15-15.—*Mortality of pine seedlings at edges of Styroblocks may have been caused by localized heating and/or higher evapotranspimtion on raised cement benches.*

Figure 15-16.—*Food packaging techniques using plastic wrap are easily adapted for transporting containerized stock.*

situations can override these factors. Examples are a source of cheap and plentiful labor, a mandate to employ that labor, a need to reuse containers, a lack of transport vehicles, and an inability of planting crews to cull effectively in the field.

Single cells and book planters are highly adaptive for repacking (fig. 15-16); block systems are less so because of plug extraction difficulties. Complete drenching of containers 2 to 3 days before lifting, without subsequent rewatering, aids lifting. Food wrapping paper and wax-lined cardboard boxes are readily adapted to repacking and transporting forest seedlings. From lifting until planting, seedling protection from sun and wind is essential.

Outplanting success is highest when seedlings are planted quickly. Lifted and repacked seedlings are more susceptible to drying than seedlings left in their original containers. But seedlings transported in original containers damage easily if they are moved to and then held at field sites where watering and protection are less controlled than at the nursery.

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CHAPTER 16

16. MECHANIZED BARE-ROOT PRODUCTION

Advantages and disadvantages of bare-root nurseries were discussed in Chapter 9. Because bare-root seedlings take longer to develop than containerized seedlings, considerable more lead time is needed for the production stages shown in figure 5-1. Procedures described in this chapter are based primarily on operational practices used in large commercial pine nurseries in the Southern United States (*P. taeda*), Australia (*P. radiata*), and Eastern Venezuela (*P. caribaea*). Large scale nurseries are highly specialized farming operations that use many techniques common to cultivating crops. Only generalized procedures are discussed because different types of machines and tending practices are used in individual nurseries over several months (*10*).

16.1 Bed Preparation

16.1.1 Plowing and Disking. -Raised beds usually have less than 0.5 percent slope to minimize erosion; orientation can be east-west for small beds (Chap. 4). Beds are prepared by plowing and disking with tractors. A typical bed is 1.2 m wide and up to 200 m long. Virtually all commercial nursery equipment is manufactured for 1.2-m-wide beds. Since tractor paths are usually 0.6 m wide, only 67 percent of the nursery is actually cultivated.

16.1.1.1 Soil Compaction. -A serious problem in nurseries is soil compaction and its effects on seedling root growth near tractor paths. Compaction forces from vehicles spread out at a 45” angle from the point of compaction. Thus, a wide tire running down a 0.6-m lane can cause compaction effects within an entire 1.2-m-wide bed. One solution is keeping the same tractor paths throughout the life of a nursery.

16.1.1.2 Deep Plowing and Ripping.-Plow pans are frequently created by a plow and undercutting bar passing through the soil over and over at the same depth. Pans restrict root growth and impede drainage. Deep plowing occasionally to 30 cm breaks up plow pans, as does “ripping” with a power-mounted ripper or vertical blade that reaches a depth of 30 to 50 cm.

16.1.2 Fallows and Cover Crops.-Fallow beds must be turned over 4 to 6 months before seed sowing; this allows fallow material time to decompose. Seedling and fallow rotation periods should be such that bed fertility and organic matter levels are maintained. Some nurseries utilize a 2:1 crop to fallow rotation, i.e., 2 years of beds and 1 year of fallow; others utilize a 2:2 rotation. Legume crops are preferred because of the extra N they fix. Sometimes a grass cash crop is grown on fallow land to increase nursery income.

Many nurseries incorporate cull seedlings back into the nursery beds. For best results, seedlings are chopped and turned under immediately. This practice is only suitable for beds that will lie fallow for 1 to 2 years or are being prepared for a cover crop. Chopped seedlings take at least 1 year to decompose into usable organic matter and may harbor disease organisms.

Additional organic matter can be added to beds by spreading sawdust, bark chips, or manure. Manure should be composted to kill weed seeds before it is spread on the nursery bed. All organic matter should be thoroughly incorporated into nursery beds ahead of cover crops and be allowed to stabilize. An overlooked aspect of maintaining high organic matter levels in the nursery is the buffering effect of organic matter on changes in acidity.

16.1.3 Mounding. -Mounding is done with a plow, which throws soil inward from two sides, forming a raised bed about 15 cm high. Beneficial aspects of mounding are: 1) increased aeration in loose soil, which is vital for good root growth; 2) increased drainage that reduces that threat of waterlogged soils; and 3) reduced effects of compaction in the bed itself (fig. 16-l).

Immediately trailing the mounding plow, a roller levels the mound and forms a flat surface. If nursery beds are scheduled for fumigation or sterilization, this is done before mounding.

16.2 Fumigating

When nurseries are highly mechanized, seedling crops are extremely valuable. For example, in the Southern United States, cash value of forestry seedlings may exceed $40,000 per ha. Therefore, managers must pay special attention to control of weeds, nematodes, pathogenic fungi, and soil pests. Steam sterilization of soil is the most effective way to control nursery diseases and pests. But this method is only practical for containerized operations, using small to medium volumes. For bare-root operations, fumigating is just as effective and more practical for large volumes of soil that must be treated.

16.2.1 Methyl Bromide Procedures. -The most popular and effective commercial fumigant for bare-root nursery beds is methyl bromide (table 10-l). It kills most weed seeds, pathogenic fungi, soil insects, and nematodes. Chloropicrin is usually mixed with methyl bromide to increase its effectiveness against soil insects and to act as a warning agent because of its odor and tear-gas effect on eyes.

Methyl bromide is highly toxic. Because it is normally applied as a gas mixture, special precautions are needed to keep the gas in the soil. Gas activity is greater in warmer climates. Because of the diverse climates in tropical regions, suitable application rates must be obtained from local pesticide officers or pesticide distributors in each country.

The normal method of applying gaseous fumigants is with chisel plows having injection valves attached to plow prongs (*6*). The plow prongs can be adjusted to apply gas at precise depths. After the gas is injected, the soil is covered with plastic sheeting ≥0.04 mm thick by 3.3 m wide. Injection and covering is a single mechanized operation for entire fields or on single strips. Sheet edges are covered with soil to keep the gas from escaping into the atmosphere and to prevent the sheets from blowing away. Injection depths should be at least 25 cm. Methyl bromide gas diffuses most readily in dry, loose sand (large pore) soils. Several factors reduce overall effectiveness of fumigants: low soil temperature, high soil moisture, high clay (small pore) soils, and high organic matter.

16.2.2 Other Considerations. -Some promising soil sterilization research exists with clear polyethylene sheeting and solar energy. Apparently, success of solar sterilization depends on consecutive, bright cloudless days to create constant high temperature in covered soils. If effective soil sterilization can be obtained by solar energy, significant savings can be expected. Normally, fumigating nursery soils is

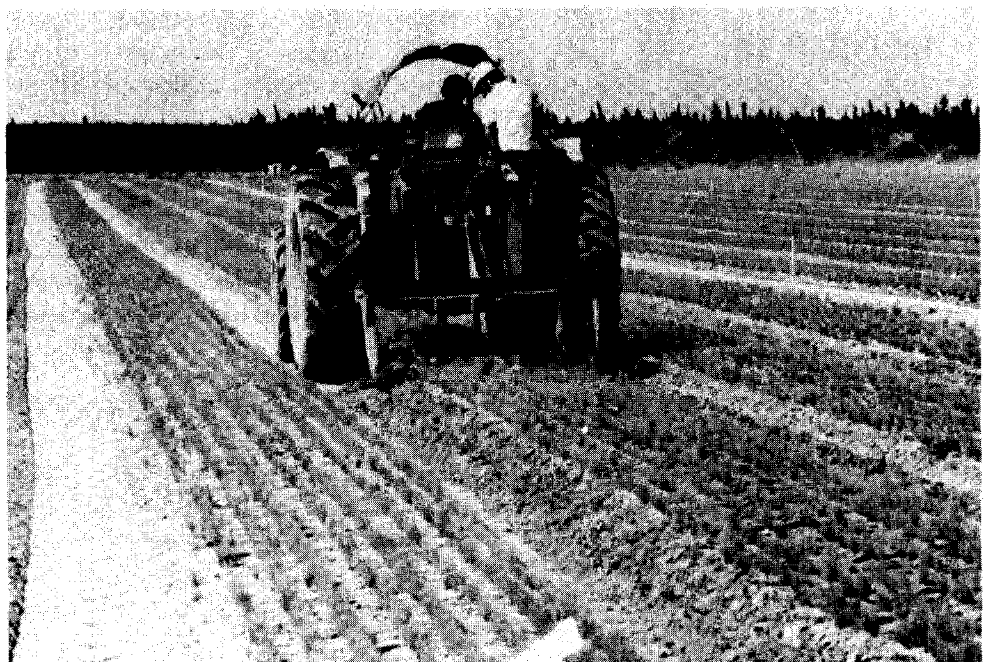

Figure 16-1.-A ***hydraulic tractor-mounted blade being used for undercutting pine seedlings on raised or mounded seedbeds.***

quite expensive, as much as $2,900 per ha. Because of this high cost, most managers fumigate only once every 2 or 3 years, depending on seedling/fallow rotation cycles. In some areas, operational fumigation is too costly (*15*).

Soil fumigation reduces or completely eliminates mycorrhizal fungi populations. Thus, following fumigation, one must reinoculate seedbeds with mycorrhizal fungi spores mixed with soil or sand. New commercial equipment can spread a thin strip of mycorrhizal fungi, cultured in vermiculite, in a furrow along with drilled seeds. But a competent machine mechanic can build a suitable spreader for a fraction of the commercial cost.

16.3 Seed Sowing

16.3.1 Sowing Procedures. -Seed sowing is a simple, fairly precise, machine-controlled operation. A tractor-pulled seed drill is adjusted to deliver so many seeds per linear meter. Small plows open furrows immediately preceding drill knives. Seeds are automatically dropped into the furrows, then are immediately covered by a trailing roller.

Seeds are planted at desired depths by adjusting the furrow plow. Periodic checks are needed to assure that the drill is not clogged and is delivering seeds into the furrows. Wrongly assuming that sowing is normal causes unnecessary replanting and germination delays that in turn upset seedling development and scheduled lifting dates. Before they are sown, seeds are sometimes coated with repellents or fungicides (Sec. 16.4.3)

16.3.2 Planting Densities. -Most nurseries grow seedlings at densities of 150 to $300/m^2$. At a planting density of $300/m^2$, 1 hectare of seedbeds produces about 2 million seedlings, assuming that one-third of the area is non-growing space for alleys, roads, irrigation pipes, etc. Some nurseries use densities of $350/m^2$ or greater. However, as seedbed seedling density increases, there is a corresponding increase in cull seedlings. Recently, there has been a general trend to raise seedlings at lower densities of 150 to $200/m^2$ (*18*). The assumption is that lower planting densities give individual seedlings more growing space and thus better root systems, i.e., higher quality seedlings.

16.3.3 ***Mulching.*** -Immediately after planting, a thin mulch is spread over seedbeds. Mulch provides a protective cover and prevents drilled seed from being washed out by rain. Other benefits of mulch are 1) reduced erosion of the seedbed surface until seedling foliage covers the beds and 2) conservation of soil moisture to aid germination and seedling growth.

Mulches must be non-toxic, biodegradable, and resistant to water droplet impact. Also, they must not stop egress of germinating stems to the surface and should not rot or ferment on top of the seedbed. All mulches must be able to withstand considerable overhead and sideways splash pressure from irrigation systems, even though they are applied as thin layers over seedbeds. Mulches commonly used are: sawdust; grit or sand; vermiculite; chopped, dead pine needles; shredded newspaper; chopped straw or similar agricultural byproducts; chopped pine bark; commercial Hydro-mulch; and rice hulls. The latter are inexpensive and readily available in rice-producing countries.

Managers often hesitate to use mulches, fearing they contain noxious weed seeds or pests. They prefer fresh materials such as pine bark, pine needles, straw, and sawdust. With proper planning, even compost can be used as mulch without fear of harboring pests. Compost pits should be started a year or so before mulch is needed. Compost purity is checked by making weed germination tests before applying mulch. Properly prepared compost mulch (Appendix 13) will not induce nutrient deficiencies or chlorosis in seedlings as it decays.

16.4 Tending Seedlings

16.4.1 Herbicides. -Some people dislike herbicide use in forest nurseries. Alternatives for reducing weeds, complete soil sterilization and hand weeding, have several limitations. Soil sterilization is not always feasible because of costs. Sterilizing or fumigating soils also destroys beneficial microorganisms, including mycorrhizal fungi. Sterilization can even alter soil acidity. Hand weeding is effective but expensive, particularly for a nursery producing millions of bare-root seedlings. Poor supervision of workers and letting weeds get too tall would make hand weeding undesirable for commercial bare-root operations (fig. 16-2).

Preemergent and postemergent. herbicides are very effective and cheaper than hand weeding. Table A12-3 (Appendix 12) lists some common herbicides used in nurseries in the Southern United States and Venezuela. The only requirement is that herbicides be non-toxic to the tree species grown.

Some herbicides are toxic for conifers but not for hardwoods, and vice versa. One example is Roundup, which is toxic for *P. caribaea* seedlings. Some herbicides, including Roundup, are extremely toxic to humans and animals. Correct use requires using safety equipment, minimizing unnecessary drift, and timing applications in early morning or late afternoon when winds are calmest. Goal was particularly effective and non-toxic to *P. caribaea* and *P. oocurpu* seedlings at CONARE nurseries in Venezuela. Up to 30-day coverage was obtained; 60-day coverage may be possible with a Goal-Lasso mixture. When postemergent herbicides are not available, mineral spirits or kerosene at ≥200 liters per ha kills weeds, does not affect conifers or mycorrhizal fungi, but does kill most hardwoods.

Figure 16-2.—*Hand weeding is too labor intensive and dangerous for most large-scale bare-nwt operations. If weeds are left too long before being pulled, weed and seedling roots become entangled, making it almost impossible to eliminate weeds without also pulling out seedlings. Uprooted seedlings are seldom replanted correctly, causing high and expensive mortality.*

For most herbicide applications, a tractor is used to pull a high pressure pump and tank sprayer having a 6-m boom-extension pipe system on either side. Before spraying, all nozzles and pipes must be clean and open; cleaning is best done immediately after spraying. Improperly cleaned equipment means clogged nozzles and weed-filled beds that are impossible to clean, even by hand (fig. 16-3). Research control plots not receiving herbicides should always be installed to check herbicide selectivity. To avoid costly mistakes, herbicides are tested on small experimental plots before using them on a commercial scale.

16.4.2 Moisture Considerations

16.4.2.1 Watering *Frequency.* -Seedlings have different water needs and problems at different stages of their nursery development (Appendix 16). When young and succulent, seedlings are watered enough to keep them growing but not so much that beds erode or get damping-off. Thus, young seedlings are checked every day for adequate moisture, particularly at levels 2 to 10 cm below the surface where water is needed most. (*9*)

As seedlings develop, the biggest problem is **under**-watering. If seedlings are underwatered during periods of normal growth, both overall growth and vigor are seriously affected.' Generally, sandy bare-root beds are well drained and difficult to overwater. Exceptions are natural low spots or areas where **compaction** and plow pans impede drainage. About 3 months before seedlings are lifted and outplanted, water is purposely cut back to start hardening-off processes.

16.4.2.2 Irrigation Systems. -Several overhead irrigation systems exist: mist, continuous spray, impulse, and trickle irrigation (7, *8*). Each system has advantages and disadvantages, depending on nursery size, type of water available (well vs. far away stream), and available pressure head (natural or manmade). Sometimes, water soluble fertilizers can be injected into irrigation water; several injector designs are available (Appendix **16**).

Cleaning and maintenance are a must for any water system, particularly when natural or added dissolved salts are high. Salts corrode pipe and motor fittings and clog openings of small-aperture nozzles. Failure to clean or replace defective nozzles can cause high mortality in several beds when young seedlings are either washed out or dried out (fig. **16-4A**). Water from loose pipe connections can cause large **seedbed** areas to wash away (fig. **16-4B**).

Nursery managers must not hesitate to use water, but irrigation water should be considered a supplement to rather than a substitute for rainfall. Each watering system should deliver up to 55,600 liters of water/ha/day. However, even greater capacity is needed because a large part of irrigation water is lost

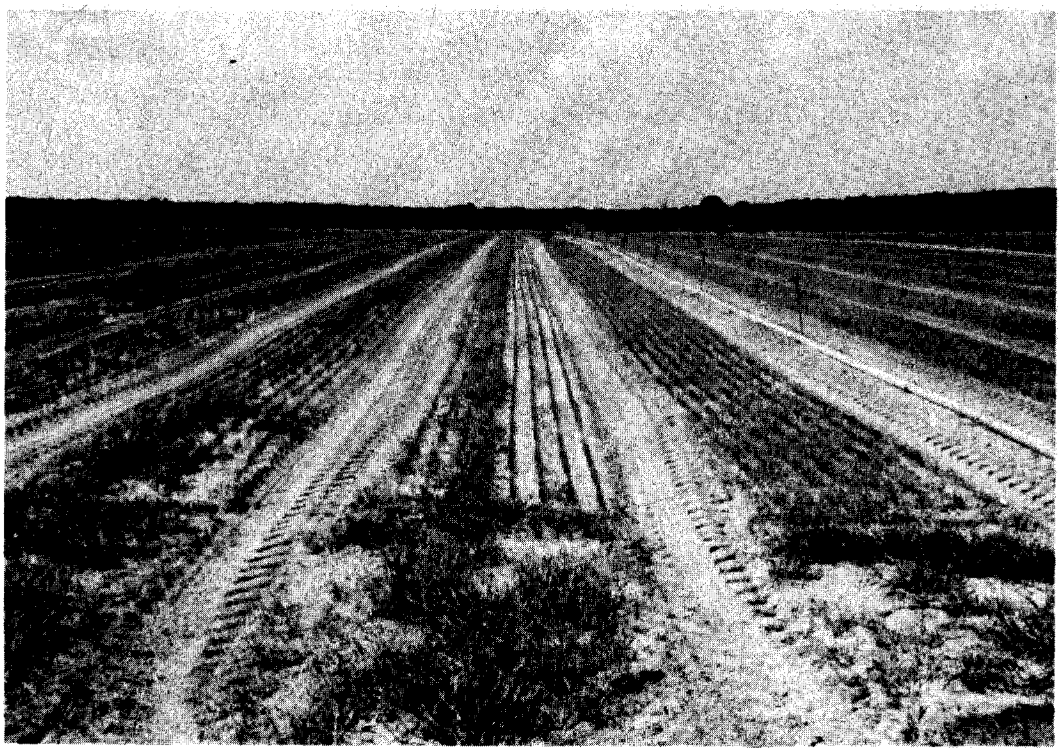

Figure 16-3.—*(A) Weeds out of control in bare-root pine beds. (B) Weed-filled beds caused by improperly cleaned herbicide spraying equipment.*

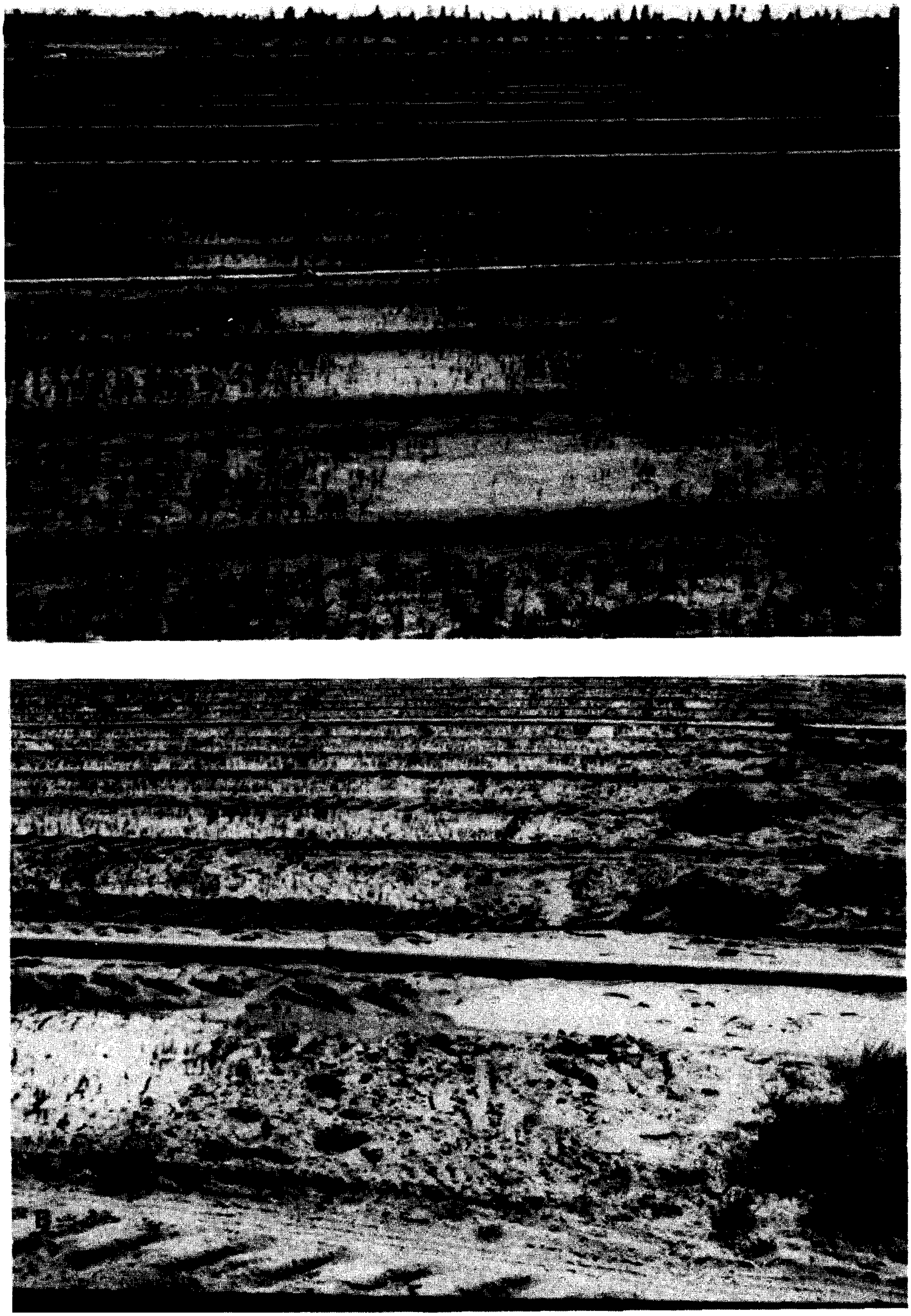

Figure 16-4.-(A) *Unnecessary seedling mortality occurred when water from non-functioning impulse irrigation nozzle washed out seedlings from bare-root pine beds. (B) Just as disastrous and unnecessary seedling mortality occurred when loose pipe connections went unattended for a long time.*

to evaporation and runoff; excess watering is also necessary to flush away salts that accumulate at the soil surface from evaporation (12).

More detailed information on water schedules, overhead watering systems, and nutrient injector systems for overhead irrigation are given in Appendix 16.

16.4.3 Repellents and Pesticides

16.4.3.1 Seedcoat Repellents. -Large seeds (e.g., *Pinus sp.)* are subject to predation by birds, insects, and mice because of their long germination periods and shallow sowing depth. Coating or covering seeds with a repellent such as anthraquinone, a bitter-tasting chemical, discourages predation. The repellent stays on the seedcoat as seedlings germinate, preventing plucking by birds. Combining a fungicide such as thiram with repellents on the seedcoat simultaneously lessens the chance of damping-off and repels animals.

16.4.3.2 General Pesticide Guidelines. -Selected nursery personnel must be trained to detect insect and disease problems before serious seedling damage occurs. Frequent checking of seedbeds helps spot signs of pests or disease (Chap. 12). Appendix 12 summarizes the use and effectiveness of herbicides. Generally, diseases are more serious than most insect attacks and are much harder to treat and control.

Because of the diversity in local climate, soils, and tree species planted, general pesticide recommendations are difficult to make. Experienced forest pest specialists are usually in short supply. But agricultural or horticultural specialists can usually handle most problems because many insect and disease problems affect crops as well as forest trees. Before specific treatments are imposed, nursery managers must be sure that they will not harm mycorrhizal fungi or other soil organisms. In severe cases, pesticide treatment and subsequent reinoculation with mycorrhizal fungi may be needed.

16.4.4 Fertilizers. -Fertilizers and organic amendments are essential for commercial nursery operations. Both kinds of nutrient supplements help maintain the nutrition of soils that produce nursery crops for decades, sometimes for a century. Special monitoring of soil fertility, including acidity and soluble salts, is needed (Chap. 13).

Fertilizers can be applied in several ways. For large operations, slow release granules are drilled alongside seeds at sowing; they dissolve within 6 to 8 months after application. Water soluble fertilizers can be incorporated into irrigation water, but this technique is less preferred than incorporating granular fertilizers in seedbeds because it requires more technical expertise in mixing and maintaining salts at acceptable levels. Specific fertilizer formulations will depend on the recommendations made after soil samples are analyzed.

16.4.5 Inoculation with Mycorrhizal Fungi. -As explained in Section 16.2, soil sterilization controls weeds and harmful soil microorganisms, but it also kills mycorrhizal fungi. If plantations or scattered trees having mycorrhizal fungi exist close to the nursery, reinoculation should occur quickly from wind-disseminated spores. In other areas, particularly where no native pines exist (as in native savannas and grasslands), artificial inoculation is required.

Techniques exist for applying vegetative inoculum with seeds at sowing (Sec. 16.3.1). Usually, spore inoculum is used. The procedure involves collecting duff and topsoil (O-2 cm) from underneath already-infected trees in nearby plantations, bringing the material to the nursery, and grinding and incorporating it in seedbeds. An alternative method is soaking the material in large volumes of water and applying the water containing spores over nursery beds with spraying equipment. Pesticide spraying equipment should not be used unless it is thoroughly cleaned and no other equipment is available. A few seedlings can be lifted at random from seedbeds in 4 to 6 weeks to check inoculation success. If inoculation is unsuccessful, the seedlings have poorer root growth and develop severe yellowing of foliage (fig. 16-5A). Figure 16-5B shows properly inoculated seedlings.

16.4.6 Root Growth Control. -Healthy, well-developed root systems help seedlings maintain vigorous development in the nursery and adapt quickly to new environments after outplanting. Several operations stimulate good root growth and development: wrenching, undercutting, and lateral (side) root pruning. Advantages of maintaining adequate shoot/root ratios are outlined in Chapter 11.

16.4.6.1 Wrenching. -Repeated wrenching is an effective method of stimulating lateral root development in the seedlings of some species, including *P. radiata* (3) and *P. caribaea* (16).

Wrenching is done with a tractor-mounted blade that moves back and forth under the seedbeds. Forward blade travel is about half that of sideways travel. The wrenching blade is tilted at a 15” to 20” angle, which helps lift-up the soil. Lifting-up and subsequent falling-back of soil on the seedbeds leave many cracks in the soil, providing good aeration in the root zone and resultant bushy root growth. The first wrenching is done about 10 cm below the surface. Subsequent cuts are made at 21- to 30-day intervals, about 15 cm below the surface.

The wrenching blade must be kept extremely sharp for a smooth, clean cut. The first wrenching should be made as soon as seedlings average about 18 cm in height; evidence suggests that lateral root development on the tap root is greatest for young tap root tissue. Thus, if wrenching is delayed too long, the upper part of the tap root is unable to develop lateral roots.

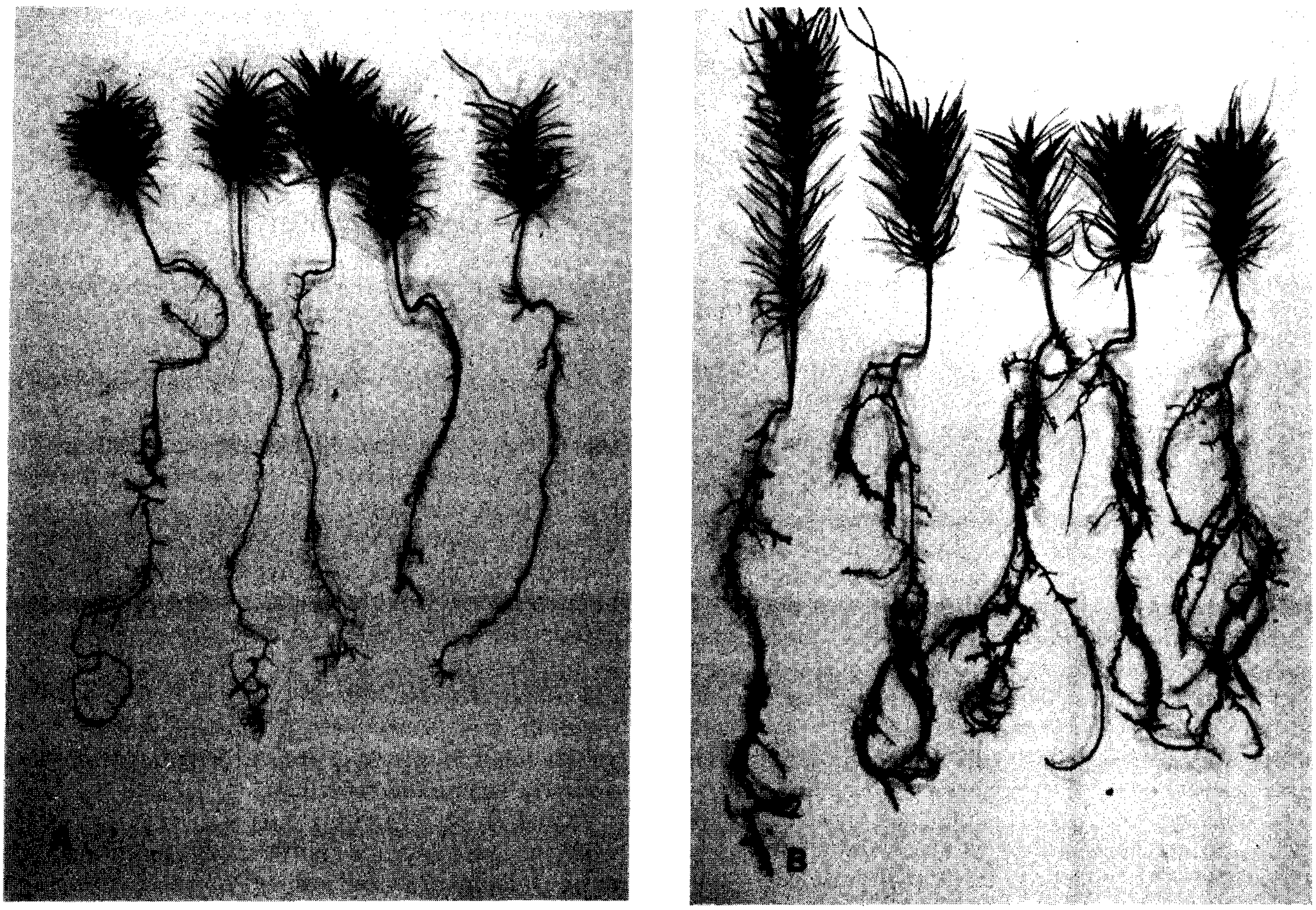

Figure 16-5.—*(A) Uninoculated seedlings. (B) Properly inoculated pint? seedlings have* ***visible mycorrhizal*** *fungi-root associations within 4 to 6 weeks.*

Lateral bushy roots that develop after wrenching are very small in diameter and are delicate. Special care must be taken to avoid stripping these **3rd-, 4th-,** and **5th-order** roots from the seedlings during lifting. To some degree, lateral root pruning negates the benefits of wrenching because a large percentage of the root system is lost in lateral pruning.

Seedlings with large, bushy root systems have high field survival (15). Abundant roots formed from wrenching absorb water well and regenerate new **rootlets** readily after seedlings are outplanted. However, frequently wrenched seedlings have lesser amounts of carbohydrates and lipids than **un**wrenched seedlings. These "food reserves" may be important for survival of bare-root seedlings, particularly in times of drought stress following outplanting.

16.4.6.2 Lateral Root Pruning. -Lateral root pruning is an operational procedure in which roots growing between seedling rows are severed. Afterwards, it is easier to lift seedlings because the remaining root mass is confined to within the rows. Lateral root pruning is done immediately before lifting. This procedure also cuts down on the time required to separate seedlings during grading and packing.

The most popular method of lateral root pruning is with a tractor-mounted rolling coulter driven down seedbeds with coulter blades between the seedling rows. Coulter blades must be kept between the rows, otherwise seedlings will be sliced and destroyed. There is no evidence that lateral root pruning stimulates additional primary lateral root growth; it does stimulate secondary and tertiary lateral root branching.

16.4.6.3 Undercutting. -Undercutting stimulates lateral root branching and stops shoot growth ***(13, 17).*** Undercutting is done by pulling a rigid blade with a sharpened leading edge that cuts the tap root clean (fig. 16-l). If the tractor speed is too fast and the soil is too wet, seedlings, can be pulled underground. The same problem occurs if the blade is dull or if seedlings are too small and have insufficient lateral roots for anchorage. Failure to lower the blade soon enough *before* entering the beds causes high seedling losses (fig. 16-6).

Undercutting has some negative aspects. The most serious problem is the plow pan created by pulling the blade at the same depth. Plow pans impede drainage and may cause J-root-shaped root systems for many seedlings.

The first undercutting is at about 18 to 29 cm below the surface. A second undercutting is usually **sufficient** to curb excessive height growth of dominant

Figure 16-6.—*Undercutting losses in bare-root pine beds when tractor operator lowered the hydraulic blade too slowly.*

seedlings. However, if a third undercutting is needed, it should be done at least 1 month before seedlings are lifted; this gives them time to repair wound damage and to recover from the general shock of large root loss.

After undercutting, seedlings should be overwatered. Because they have lost most of their tap root, they need excess soil moisture so that the remaining portion of tap root and the lateral roots can maintain a proper water balance in the plant.

16.4.7 Shoot Growth Control

16.4.7.1 Top Pruning. -Most conifer seedlings are top-pruned after the fifth month, after 30 percent of the seedlings are between 25 and 30 cm tall. Top pruning slows the height growth of seedlings that threaten to suppress slower growing seedlings; unpruned smaller seedlings continue to grow *(14)*. The end result is seedlings of more uniform height at lifting. Clipped seedlings do not develop new shoot growth for at least 3 or 4 weeks after clipping.

Top pruning also fosters a more uniform shoot-to-root ratio among seedlings. Removing growing shoots from dominant seedlings results in less carbohydrate transfer to the roots and, consequently, less root growth. Thus, top pruning is a tool for developing seedlings of different morphological classes and for increasing root biomass while keeping shoot biomass constant. Seedling stem diameters also increase after top pruning.

Top clipping is done with flat rotary mowers, sickle-bar mowers, and reel-type cutters; all are pulled behind tractors. Problems that arise from top pruning are: 1) seedlings are accidently cut back too short when mowers hit low spots in the tractor paths and 2) wounded stems and needles serve as entry points for disease organisms such as brown spot needle blight.

16.4.7.2 Hardening-Off. -Reducing watering frequency in hardening-off slows shoot growth and reduces production of succulent foliage. Hardening-off is needed for both container-grown and bare-root-grown seedlings. A more thorough discussion of this subject is given in Chapter 11.

16.5 Lifting and Transporting

16.5.1 Historical Reuiew. --Lifting and preparing seedlings for distribution is a crucial process. In temperate climates having a well-defined dormant season, seedlings are lifted and stored up to 120 days without excessive loss of vigor. Seedling roots are kept moist, and internal storage temperature is between 0 and 4°C. Survival rates of 80 percent are expected after stored pine seedlings are planted.

Outplanting survival in temperate or tropical climates is closely correlated to 1) adequate soil moisture at the time of planting and 2) adequate root regeneration in the soil before the dry season begins. Thus, it is always best to lift and outplant seedlings early in the rainy seasons (*1,* 5).

Historically, few bare-root planting operations for pine have been reported in the tropics. Venator and others *(20)* reported that *P. caribaea* var. *hondurensis* was successfully bare-root planted when seedling roots were kept moist, outplanting was done shortly after lifting, and sites had adequate soil moisture at the time of planting. Since the late 1970's, bare-root pine stock has been successfully planted on a large scale (1,000 to 10,000 ha annually) in Venezuela and Brazil. With careful attention to detail, it should be possible to expand bare-root plantings throughout the tropics, for conifers and hardwoods alike.

16.5.2 Lifting. -Lifting operations at large-scale tropical pine nurseries are similar to those used in temperate climates. Seedlings are undercut and machine-lifted with care taken to keep roots moist and shaded from the sun. In Venezuela, lifted seedlings are kept moist in buckets of water, a procedure less messy and more effective than clay-water slurries, sphagnum moss, and other alternatives *(7)*. The crucial procedure is outplanting seedlings *within a few hours after lifting.* This process is not difficult for a large corporation if 1) it has firm control over the entire operation, 2) it can organize and coordinate both lifting and planting, and 3) it has access to good roads.

16.5.3 ***Grading.*** -Grading is labor intensive, yet is necessary because evidence shows that larger seedlings outgrow smaller seedlings (*2, 4*). Thus, smaller grade 3 seedlings, following Wakeley's classification (*21*), are inferior and should be culled from the seedling tables.

Some nurseries now grade on the basis of root collar diameters because larger diameter seedlings perform better after outplanting (19). Grading by overall size and root collar diameter is much faster than grading by shoot/root ratios and root area indices. Trimming excess lateral and tap roots before packaging is done with machetes and chopping block or hand shears.

Low sowing rates (i.e., low seedling densities) in seedbeds (Sec. 16.3.2) usually result in less intensive culling practices during grading and packaging. Operations that do not cull in the nursery depend on planting crews to cull rejects as they plant. Nursery costs are reduced, but slightly higher planting costs exist because grading is an added step. Field grading must be done by trained, conscientious planters; otherwise, inferior seedlings will be planted, resulting in eventual harvestable volumes that are less than those expected from superior grade seedlings. If costly planting machines are used, nursery grading saves valuable time and money over field grading.

16.5.4 Packaging and Delivering. -If same-day planting is used, time consuming packaging in bales, bags, and wraparound crates is avoided (*11*). Huge metal or plastic buckets and tubs filled with water are used to store seedlings temporarily between lifting/grading, transporting/delivering, and machine outplanting. Throughout lifting, grading, packing, and delivering, seedlings must be protected against exposure to sun and wind, particularly at midday to early afternoon when the sun is directly overhead. The principal safeguard against unnecessary injury to planting stock is adequate supervision of workers by nursery supervisory personnel.

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Appendices

The Why and How-To-Do-It Section

Appendices are not ordered consecutively but refer to actual chapters where a major topic is discussed. For example, the first is Appendix 4 because shading and nursery bed orientation are discussed in Chapter 4.

Appendix 4

Shading Procedures for Small, Covered Nursery Beds in Tropical Areas

The sun's angle of inclination at a nursery site and the orientation of seedbeds are used to determine shading arrangement. The following example can be used to determine positioning of shade cover over small seedbeds. For simplicity, it is assumed that the sun rises at 6:00 a.m. and is perpendicular to the nursery beds by 12:00 noon, i.e., directly overhead (fig. A4-1). Thus, the sun has moved through a 90” arc in 6 hours at a rate of 15” per hour. The problem is then reduced to one of trigonometry, where the distance of penetration under the shade is:

$$\text{Depth of sun penetration under overhead shade} = \frac{\text{Height of shade above seedbeds}}{\text{Tangent of the sun's angle of elevation}}.$$

Table A4-1 summarizes various penetration distances of the sun for several shade heights.

Puerto Rico lies approximately 18” N. latitude from the equator. For a short time during the year, the sun is to the north of Puerto Rico as it changes from 18” to 23” N. and back again. During this period, maximum shade protection is obtained by tilting the shade roof accordingly.

Shade screens should be placed about 1.0 to 1.5 m above 1.0-m nursery bed walls and extend about 0.3 to 0.5 m past bed edges. Such placement allows workers access to tend seedlings without much extra effort.

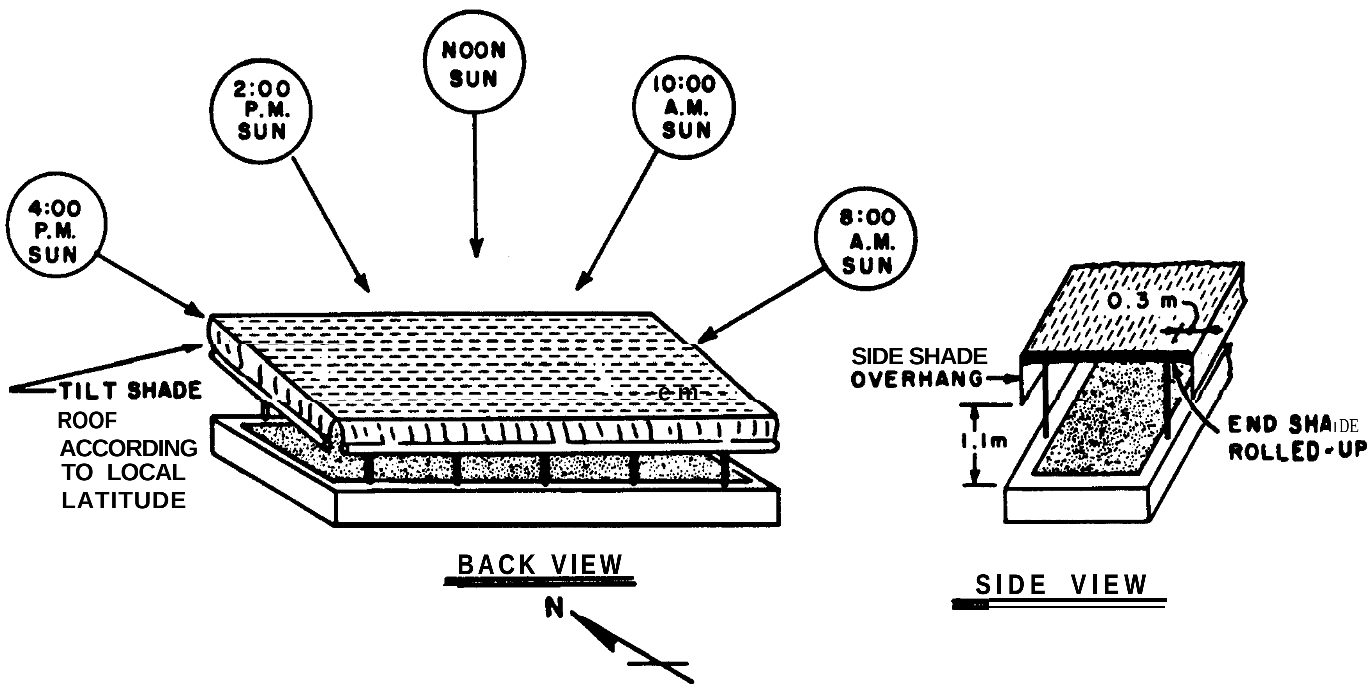

Figure A4-1.—*Small shaded nursery beds in tropical areas are best oriented in east/west direction; shade roof is tilted to sun according to local latitude (e.g., ± 18” in Puerto Rico). At early and late hours of the day, shade screens are rolled down to keep out low angle rays.*

Table A4-1.—*The penetration distance of sunlight under overhead shade for different heights at different hours throughout the day*

Hours A.M.	Hours P.M.	Sun's angle of elevation	Tangent sun's angle of elevation	Depth of sun penetration (m) when shade height (m) is . . . 0.6	0.8	0.9	1.1	1.2	1.8	2.1
7:00	5:00	15"	0.27	2.3	2.8	3.4	3.9	4.6	6.8	8.0
8:00	4:00	30"	0.58	1.1	1.3	1.6	1.8	2.1	3.2	3.7
9:00	3:00	45"	1.00	0.6	0.8	0.9	1.0	1.2	1.8	2.1
10:00	2:00	60"	1.73	0.4	0.4	0.5	0.6	0.7	1.1	1.2
11:00	1:00	75"	3.73	0.2	0.2	0.2	0.3	0.3	0.5	0.6

Appendix 5

Flow Chart for Scheduling Mechanized Production of Container Nursery Stock

1. Receive seedling requests

2. Purchase seed on basis of viability report

3. Inspect and repair equipment:
watering system
power driven equipment
pesticide applicators
tractors and forklifts
soil loaders and shredders
soilmixers
soil sterilizers

4. Inventory supplies:
containers
shade materials
germination media
pesticides
handtools
germinating flats
fertilizers
labels
reoordfonns
miscellaneous items

5. Sterilize germination media

6. Fill containers

7. Preparegerminating beds:
shade
protectionfran
birdsandmice

8. seed germination beds or direct seed

9. Check germination 2-3 times daily for:
water
insects
disease
hunidity

10. Water seedbeds

11. Cull multiple seeded containers

12. Line-out filled containers:
shade
labels

13. Transplant if necessary 2-3 days after germination; begin survival counts

14. Check 2-3 times daily for:
waterneeds
insects
disease
shade
humidity
fertility

15. Change insect and disease checks to daily basis

16. Begin periodic weed check on 3rd week; maintain weekly check

17. Begin daily water check; water every 5 days

18. Remove shade after 6-8 weeks

19. Begin fertilization after 2 months; apply monthly thereafter

20. cull and group seedlings by size: water after grouping

21. Measure heights at 120 and 200 days: mean heights of 20 plots

22. Begin hardening-off after 4-5 months depending on species, local conditions

23. After hardening-off and before outplanting, check and sever all roots that have penetrated into soil from bags or blocks

24. Outplant when seedlings are 6-8 months old

Appendix 6

Non-Oven Procedures for Drying Pine Cones, Mahogany Pods, or Similar Seed-Bearing Fruits at Traditional Nurseries

Ground Drying

Cones, pods, and fruits are spread out on a smooth, dry surface similar to that used for drying coffee beans; radiant energy is used for drying. This method works when seed viability is not appreciably affected by open exposure and when seeds are extremely abundant. Many small, temporary nurseries use this method to extract seeds.

Drying fruits on the ground involves several problems. Rodents and birds can feed on seeds. Protecting seeds requires constant attention by laborers who may be more profitably employed elsewhere. When sudden showers occur, seeds or pods must be picked up and taken into a sheltered area. When several consecutive rainy days occur, mold and fungus can attack bagged moist cones or pods. Likewise, outdoor surfaces must be dry before cones are respread. Finally, cones or pods must be turned frequently so that shaded undersides are also dried. In summary, open-air drying is best only for small seed lots.

Elevated Drying

This method of seed drying is also inexpensive. The equipment used is elevated racks with screen bottoms that allow air to circulate from above and below (fig. 6-1). A hinged top can be added for covering cones or pods during light showers. As soon as the rain stops, the top can be removed for renewed drying. Cones should not be piled more than 4 to 5 layers deep in such racks. If a solar dryer is available, cones can be dried in 3 to 4 days. A small solar dryer is a wise investment for permanent nurseries.

A complementary method of drying cones or pods rapidly is placing them on drying racks over a light fire. Empty cones or pods from the previous year's collection can be used for fuel. However, extreme care must be used in spreading burning coals uniformly under the drying racks to prevent spots where hot temperatures would roast cones and seeds. As heated air from the fire rises, it passes through the cones and dries them. With experience, one can control this kind of fire so that air temperature in the area of the cones is kept at less than 38°C. Where conditions permit, combined use of air conditioning by day and dehumidifying by night will open *P. caribaea* cones within 3 to 4 days of storage in office or laboratory buildings.

As soon as cones or pods begin to open, they should be placed in a large tumbler and rotated until the seeds fall out. After falling free from the tumbler, the seeds should be dewinged, cleaned, and dried down to a moisture content of 8 to 10 percent and prepared for cold storage. Mahogany seeds should be dewinged and dried to a moisture content of 10 to 12 percent before storing under refrigeration.

Appendix 8

Summary of Seed and Nursery Characteristics for Forest Tree Species Commonly Growing or Planted in Tropical and Subtropical Regions'

Species	No. seeds per kilogram	Storage recommended	Presowing treatment	seeding method	Special requirements	Germination and growth
Acacia Senegal Willd.	7 to 8 thousand.	None	Boiling water till cool.	Potted or direct sown.	....	No data available on germination. Plantable size in 3-4 months.
Agathis dammara L.C.Richard	16 to 21 thousand.	None	Soak in cold water for l-2 days.	Potted	Seedlings require shade.	Germinates in 7–14 days. Plantable size in 12-18 months.
Albizia lebbek (L) Benth	1 to 11 thousand.	Ambient temperature for several years.	Boiling water till cool.	stumps; direct sown.	....	....
Anthocephalus chinensis (lamk) Rich	6 million.	Dry, cold, and airtight for up to 1 year.	None	Potted	Very susceptible to damping-off.	Germinates in 7-14 days. Plantable size in 3-4 months.
Araucaria angustifolia (Bert) O. Kuntze	100 to 200.	None	*None*	Potted	Require 50% shade.	Germinates in SO-100 days. Plantable size in 21-27 months.
Araucaria cunninghamii Sweet	2.4 to 2.8 thousand.	None	*None*	Potted	Susceptible to damping-off and requires 50% shade.	No data available on germination. Plantable size in 18-24 months.
Araucaria hunsteinii K.Schumann	1.7 to 1.8 thousand.	None	None	Potted	Require 75% shade in early months.	No data available on germination. Plantable size in 18-24 months.
Azadirachta indica A. Juss	4 to 4.5 thousand.	None	Soak in cold water for l-2 days.	Potted; stumps; direct sown.	....	Rapid and uniform after 10–12 days. Plantable size in 11-14 months
Bombacopsis quinatum (Jacq.) Dugand	2.3 to 2.7 thousand.	....	None	stumps	....	Germinates in 8-20 days. No data on growth in nursery.
Callitris glauca R. Br. ex R.T. Bak et H. G. Sm.	70thousand.	Dry, cold, and airtight for several years.	None	Potted		....
Cassia siamea Lam.	35 to 40 thousand.	Dry, ambient temperature for several years.	Boiling water till cool.	Potted; stumps; direct sown.	....	Good and uniform after 7 days. Plantable size in 10–12 months.
Casuarina equisetifolia L.	700 to 800 thousand.	Ambient temperature for l-2 years.	None	Potted; bare-rooted plants.	Shade in nursery.	Germination in 40 days. Plantable size in 3-4 months.

Cedrella odorata L.	45 to 60 thousand.	Dry, cold, and airtight for l-2 years.	None	Potted; striplings.	Prefers some shade in nursery.	Germinates in 14-28 days. Plantable size in 12-15 months.
Cordia alliodora Cham.	1 to 2 million.	Dry, cold, airtight; shortlived viability.	None	Stumps; direct sown.	....	Germinates in 15-30 days. Plantable size in 9-12 months.
Cryptomeria japonica Don.	330 to 400 thousand.	....	None	Potted or cuttings.	Low germination capacity: use large plants.	Germinates in 14-28 days. Plantable size in 12 months.
Cupressus lusitanica Mill. (incl. *C. benthamii* Endl.)	170 to 320 thousand.	Dry, cold, and airtight for several years.	Stratify in damp sand for 30 days.	Potted, bare-rooted plants.	Frost-tender in nursery.	Germinates in 35 days. Plantable size in 15–18 months.
Cybistax donnellsmithii (Rose) Seibert	....	Dry, airtight in ambient temperature for up to 1 year.	....	Potted; stumps; bare-rooted plants.	....	Germinates in 12-18 days. Plantable size in 6 months.
Eucalyptus camaldulensis Dehn (Northern Prov.)	700 to 800 thousand.	Dry, cold, and airtight for several years.	None	Potted	....	Germinates in 4-15 days. Plantable size in 4 months.
Eucalyptus camaldulensis Dehn (Southern Prov.)	700 to 800 thousand.	Dry, cold, and airtight for several years.	....	Potted	Early shade beneficial.	Germinates in 4-15 days. Plantable size in 4 months.
Eucalyptus deglupta Blume	1 to 2 million.	Dry, cold, and airtight for l-2 years.	None	Potted	Susceptible to damping-off. Bequires shade.	Germinates in 4-20 days. Plantable size in 3-4 months.
Eucalyptus globulus Labill	120 to 140 thousand.	Dry, cold, and airtight for several years.	None	Potted; direct sown; bare-rooted plants.	....	Germinates in 12-14 days. Plantable size in 4-6 months.
Eucalyptus grandis Hill ex Maiden	600 to 650 thousand.	Dry, cold, and airtight for several years.	None	Potted	....	Germinates in 4-10 days. Plantable size in 6 months.
Eucalyptus robusta SM	500 to 600 thousand.	Dry, cold, and airtight for several years.	None	Potted	....	Germinates in 7-10 days. Plantable size in 4-6 months.
Eucalyptus saligna SM	600 to 650 thousand.	Dry, cold, and airtight for several years.	None	Potted	....	Germinates in l-20 days. Plantable size in 4 months.
Eucalyptus urophylla S. T. Blake	210 to 300 thousand.	Dry, cold, and airtight.	None	Potted	Good vegetative propagator.	Germinates in 7-12 days. Plantrble size in 4 months.

Appendix 8 (continued)

Species	No. seeds per kilogram	Storage recommended	Presowing treatment	Seeding method	Special requirements	Germination and growth
Gmelina arborea Roxb.	700 to 1,400.	Shortlived viability, up to 1 year.	Soak in cold water for 1-2 days.	stumps; potted plants or direct sown.		Germinates in 14-28 days. Plantable size in 6 months.
Leucaena leucocephala (Lam.) de Wit (Hawaiian type)	27 to 30 thousand.	Ambient temperature for several years.	Soak in water 80°C for 2 minutes.	Potted	May require importation of *Rhizobium* strain for nitrogen fixation.	Germinates in 8–10 days. No data on growth in nursery.
Leucaena leucocephala (Lam) de Wit (Salvador type)	26 to 30 thousand.	Ambient temperature for several years.	Soak in water 80°C for 2 minutes.	Potted	May require importation of *Rhizobium* strain for nitrogen fixation.	Germinates in 8-10 days. No data on growth in nursery.
Ochroma lagopus SW	70 to 100 thousand.	Dry, cold, and airtight for 1-2 years.	Boiling water till Cool.	Potted or direct sown.	50% shade, but is very susceptible to damping-off.	Germinates in 5-18 days. Plantable size in 3-4 months.
Parkinsoniu aculeata L.	12 thousand.	Ambient temperature for up to 1 year.	Soak in cold water for 3-6 days.	Potted	....	Germinates in 10–14 days. Plantable size in 4-5 months.
Pinus merkusii Jungh & de Vriese (Island Prov.)	60 thousand.	Dry for 1-2 years.	None	Potted	*No grass stage.* Requires mycorrhiza and some shade.	Germinates in 10–12 days. Plantable size in 8 months.
Pinus occidentalis Swartz	35 to 40 thousand.	None	None	Potted	Mycorrhiza required.	No data available on germination. Plantable size in 10–12 months.
Pinus oocarpa Schiede	41 to 55 thousand.	Dry and cold for several years.	None	Potted	Mycorrhiza required. Susceptible to damping-off.	Germinates in 14-21 days. Plantable size in 6-8 months.
Pinus patula Schiede and Deppc.	100 to 140 thousand.	Dry, cold, and airtight for several years.	None	Potted, bare-rooted plants.	Requires mycorrhiza. Susceptible to damping-off.	Germinates in 15-16 days. Plantable size in 6-12 months.
Pinus caribaea Morelet var. *bahamensis* Barr & Golf	80 to 85 thousand.	Dry, cold, and airtight for several years.	None	Potted	Mycorrhiza essential. Susceptible to damping-off.	Germinates in 8-20 days. Plantable size in 5-7 months.

Pinus curibaea Morelet *var. caribaea* Barr & Golf	55 to 60 thousand.	Dry, cold, and airtight for several years.	None	Potted	Mycorrhiza essential. Susceptible to damping-off.	Germinates in 8-21 days. Plantable size in 5-8 months.
Pinus curibaea Morelet var. *hondurensis* Barr & Golf	52 to 72 thousand.	Dry, cold, and airtight for several years.	None	Potted	Mycorrhixa essential. Susceptible to damping-off.	Germinates in 8-21 days. Plantable size in 5-6 months.
Pinus kesiya Royle ex Gordon	55 to 62 thousand.	Dry, cold, and airtight for several years.	None	Potted	Requires mycorrhixa. Susceptible to damping-off.	Germinates in 15-30 days. Plantable size in 4-6 months.
Pinus radiata D. Don	33 to 50 thousand.	Dry, cold, and airtight for several years.	None	Potted, bare-rooted plants.	Requires mycorrhixa. Susceptible to damping-off.	Germination is rapid and uniform. Plantable size in 24 months.
Prosopis juliflora (Swartz) D.C.	20 to 26 thousand.	Without difficulty at ambient temperature.	Leave in boiling water till cool.	Potted or direct sown.	....	Germinates in 5-6 days. Plantable size in 3-4 months.
Samanea saman Merrill.	4.4 to 7 thousand.	Dry, ambient temperature for several years.	None	Potted	....	Germinates in 14-20 days. Plantable size in 4-6 months.
Swietenia macrophylla King	2 to 2.5 thousand.	Dry, cold, and airtight for up to 1 year.	None	Potted or striplings.	Requires full shade for 2-3 weeks, then half shade for 1 month.	Germinates in 14-28 days. Plantable size in 6-24 months.
Tectona grandis L.	0.8 to 2 thousand.	Dry without difficulty.	Soaking frequently practiced.	Stumps or potted stock.	Several embryos per seed.	Germination often protracted. Plantable size in 12 months.
Terminalia superba Engl. and Diels	5.5 to 6.6 thousand.	Dry, cold, and airtight for up to 1 year.	Alternately wet and dry.	Potted, striplings; stumps.	Requires light shade after germination.	Germinates in 14-50 days. Plantable size in 4 months.
Toona ciliata M.J. Roem var. *australis* F v M	300 to 380 thousand.	None	None	Striplings; potted stock.	....	....

'Adapted from Webb. D.B., P.J. Wood, and J. Smith. 1980. A guide to species selection for tropical and subtropical plantations. University of Oxford, Commonwealth Forest Institute, Tropical Forestry Paper 15. United Kingdom.

Appendix 9

Practical Guides for Fumigating, Sowing, and Transplanting

I. Recommended Procedures for Use and Storage of Soil Fumigants
II. Calculation of Materials Required for Producing 1 Million Bagged Pine Seedlings
III. Sowing and Transplanting Procedures for Important Species of Tropical Trees
IV. Publications on Particular Tree Species

I. Recommended Procedures for Use and Storage of Soil Fumigants

GENERAL INFORMATION

Methyl bromine-chloropicrin (MBC) fumigant formulations consistently provide good soil treatment. The two most commonly used forms in forest tree nurseries are MBC-33 (67 percent methyl bromide, 33 percent chloropicrin) and MBC-2 (98 percent methyl bromide, 2 percent chloropicrin). Over 90 percent of all forest nurseries in the Southern United States use either MBC-33 or MBC-2. MBC-2 provides broad treatment of soil fungi, weed seeds, nematodes, and soil insects. MBC-33, on the other hand, is used in specific instances where more resistant root disease organisms occur and where highly susceptible seedling hosts will be grown (2).

In large bare-root nurseries, MBC fumigants are usually applied with chisel injectors to depths of 20 to 25 cm. Where soil disease organisms threaten deep-rooted seedling species, fumigants can be injected to a depth of 30 cm or more. Dosage rates for large field applications are 280 to 640 kg/ha.

For smaller nursery operations, MBC or other fumigant mixtures are applied to soil surfaces. The chemicals are released from pressurized containers into evaporating pans placed under polyethylene sheeting. This method is very suitable for treating small seedbeds and transplant beds as well as for fumigating compost medium used in container operations. Dosage rates for bulk materials are 0.59 kg/m^3 for either MBC-33 or MBC-2.

Because of its suitability for small nursery operations, the pan evaporation method is described here in detail, using one MBC fumigant.

DOWFUME MC-2

Although only Dowfume MC-2 (hereafter called Dowfume) is discussed here, most procedures and cautions for its use and storage are applicable to other fumigants (table 10-l). For specific use restrictions and precautions, including toxicity to certain plants or organisms, it is best to consult product labels and current editions of yearly review guides, such as the Farm Chemicals Magazine (3) and the Weed Control Manual (*1*).

Dowfume contains methyl bromide with 2% chloropicrin added as a warning agent against overexposure to methyl bromide. When a gas mask is worn, chloropicrin cannot be depended on as a warning agent. Dowfume is applied under a gasproof cover when treating soil and other medium in which seedlings are grown for nonfood and food crop uses.

Dowfume is a liquid under pressure while in the container. It turns to a gas when released and must be confined under a plastic or coated fabric gas-proof cover. Both liquid and gas forms are poisonous and may cause burns on contact. The product label contains detailed instructions for use and handling precautions.

INSTRUCTIONS

Seedbed Soil Preparation

Dowfume is effective only to the depth that soil is properly prepared. Suitable treating conditions are moist, fine, and loose soil having no lumps or clods. Soils should be moist but not wet; gas will not spread uniformly through wet soils, and control of weeds and soil pathogens will be poor. For best results, fumigate to 10-cm depth when soil temperature is above 16°C. If soil temperature is between 10” and 16°C, double ***the recommended exposure time. Do not fumigate if soil temperature is below 10°C.***

Dosage

Determine dosage from information on the product label. Dowfume controls most weed seeds, nematodes, and insects present in the soil at time of treatment when used at recommended rates. Certain species with hard seedcoats may require a higher dosage or longer exposure time.

Application Equipment

Materials required include evaporating containers, a gas-proof cover of polyethylene or other material impermeable to Dowfume, cover supports, polyethylene tubing, and an applicator to dispense the fumigant.

Dig a 10- to E-cm-deep trench around the border of the area to be treated; this provides an effective way of sealing the gas-proof cover before releasing the fumigant. Next, place cover supports at regular intervals on the prepared bed. They must be high enough to hold the cover above the soil surface and evaporating containers so that fumigant vapors circulate freely. Supports must not puncture or tear the cover; they can be made from inflated polyethylene bags, crumpled fertilizer bags, burlap bags stuffed with straw, inverted flower pots, bottles, or cardboard boxes (fig. 9-2).

With the supports in place, evaporating containers are set about 9 m apart in the area to be treated. The containers aid volatilization and uniform dispersion of the fumigant and keep it from soaking into the ground as a liquid. Pan or basin materials that are used include glass, porcelain, and tin, but not containers made of aluminum or its alloys. Containers should be shallow, 4 to 5 cm deep at most; this depth allows ready dispersion of fumigant vapors and assures sufficient capacity to hold about a 0.2-liter volume for each 0.7-kg can of Dowfume dispensed.

After placing the evaporating containers in the beds, a polyethylene applicator tube is fastened to each, with one end directed into the container. Tubes should be long enough to allow easy attachment of the fumigant applicator.

The gas-proof cover is laid over the area to be treated, its edges placed in the trench previously dug, and the edges sealed with earth. Earth should cover the edges to a width of 15 to 25 cm and be tamped down firmly. During this operation, special care is taken to avoid damaging the cover. Covers will last several years if handled and stored properly.

Apply Dowfume with a standard opener that punctures the can, gaskets the opening, and allows the fumigant to discharge through an attached tube into the confined area being treated. When using any applicator, these simple rules should be followed to avoid possible contact with Dowfume:

1. Place can in applicator cradle and draw handle quickly toward body of can until piercing point has entered the can and the gasket is seated. Avoid puncturing the can side seam, and keep the point of puncture at the *lowest point on the can* being emptied so that internal can pressure forces all liquid from the can. If the can is punctured high, fumigant vapors rather than liquid will flow through the tubing, and internal pressure will be reduced so that it is difficult to get liquid out of the can.
2. Never open cans without checking that fumigant *will be dispensed where desired.*
3. Do not disconnect the applicator from can or from the polyethylene tubing until can is *completely empty.* The applicator does not have a valve to stop fumigant flow after a can is punctured.
4. If the applicator breaks or fails to puncture and seal a can properly, *keep away from the can* until all the fumigant has evaporated and vapors are carried away.

Only one applicator is needed because it is transferred from one polyethylene tube to the next. CAUTION: Transfer applicator to next tube only *after the can* of Dowfume to which it is connected *is completely empty.* Cans should be warm (15” to 32°C) so that fumigant flows rapidly through the polyethylene tube into the evaporating container. After application is complete, do not disturb either gas-proof cover or polyethylene applicator tubes because gas may escape and create a hazard to the operator and also reduce effectiveness of the soil treatment.

An alternate method of application involves vaporizing Dowfume before releasing it under the gas-proof cover. This method obtains a uniform concentration of gas throughout the treated area as quickly as possible. Because the fumigant is released as a gas rather than a liquid, evaporating containers are not needed. Dowfume is vaporized by puncturing the can in the conventional manner, immediately turning it upside down, and submerging both the punctured can and attached applicator in hot water. Keep submerged until empty. Additional water, kept hot by a camper’s cook stove, should be kept available; the original hot water supply will be cooled by rapid vaporization of the fumigant.

For the vaporization method, openers are designed specifically for a 0.7-kg can and serve both as a can-piercing device and as an evaporation tray. They are used only for soil fumigation *under polyethylene covers.*

Application procedures are:

1. Place tray(s) (one for every 5-m^2 area to be treated) upright on prepared seedbeds. Carefully insert two 0.7-kg cans into nail guides at the bottom. CAUTION: Do not allow nail to puncture can.
2. With tray(s) positioned near edge of seedbed, cover tray(s) and bed with polyethylene, using soil to seal all edges in prepared trenches. Walk toe-to-heal around entire perimeter, compacting solid to prevent wind from breaking cover-earth seal during fumigation.
3. From outside the gas-proof cover, press palm down firmly against each can in turn to puncture it against the nail. Use palm of hand only--never use foot, board, shovel or other *hard object that might tear the plastic and permit fumigant escape.* Have masking tape or plastic tape available to repair accidental punctures. Do not attempt to remove trays or cans until cover is removed, after a 24- to 48-hour exposure period. The longer exposure period is needed when soil temperature is *below* 16°C.

Exposure and Aeration

The fumigated area is left undisturbed for the 24- to 48-hour period. Remove cover and let the soil aerate for 24 to 72 hours or more. Work it thoroughly to speed further aeration. Some kinds of seeds can be planted immediately after initial aeration. Sensitive species cannot be planted until after several days of aeration. Do not set out living plants for at least 1 week.

NON-SOIL MATERIALS

Compost and Manure

Follow the general instructions above for soil treatment. Conduct fumigation outdoors or in a well ventilated place. Materials should be loose, moist enough for good seed germination, and at a temperature ≥16°C. For best results, pile the materials ≤30 cm deep on wet ground or on a concrete floor. Piles up to 1 m high can, when necessary, be fumigated if perforated every 30 cm. The cover is supported several centimeters above the material to permit gas to diffuse thoroughly. **Dowfume** is introduced at the ***highest point*** of the pile. After exposure, let the pile stand covered for 24 to 48 hours. Then the material is aerated for 1 day, stirred thoroughly, and reaerated 48 hours or longer before using.

Mulches

Straw or hay should be thoroughly soaked several days before treatment. At time of treatment, pile the bales up, cover them with a gas-proof cover, and seal the edges in the same manner as recommended for covering soil.

USE PRECAUTIONS

Dowfume gives excellent results with a wide variety of soils and plants. However, for reasons not clearly understood, plant growth has occasionally been unsatisfactory following treatment. Difficulty has been experienced with carnations, conifers, holly, multiflora roses, snapdragons, and certain other ornamental plants and shrubs. Every grower should experiment on a small scale for at least a full season before extensive use. For best results, observe the following precautions:

1. Do not treat soil when it is cold, wet, or dry.
2. **Dowfume** is toxic to all plants. Do not fumigate too close to desirable vegetation. Keep edges of the cover at least 30 cm away from roots of desirable plants; water the root zone thoroughly in the area not hooded by a cover. If possible, pre-soak the root zone around desirable plants immediately adjacent to cover to help contain the gas under the cover.
3. Be sure the treated soil or material is free of **Dowfume** before seeding; working it will speed aeration.
4. Prevent contamination of fumigated areas. Clean shoes carefully before walking from untreated to treated soil. Do not use tools, transplants, or crop remains that may carry pests from nonfumigated areas.
5. Fumigation with **Dowfume** sometimes slows down the rate of **nitrification** (the conversion to nitrates from ammonia by bacterial action). Certain ammonia-sensitive plants, such as tomatoes, may suffer growth inhibition when planted in fumigated soils containing a high amount of ammonia nitrogen. To lessen this hazard, at least one-half, and preferably all, of the nitrogen fertilizer added immediately before or soon after fumigation should be in the form of nitrate nitrogen. This hazard may also be reduced by delaying planting until several months after fumigation.
6. Fumigation of soils high in inorganic matter, such as muck, compost, and heavily manured soil, may occasionally cause conditions of poor plant growth. These soils should be fumigated at least 2 months before planting.

HANDLING PRECAUTIONS

Dowfume (or any other) fumigant is a ***highly hazardous material*** and must be handled carefully while following the precautions given below:

1. Before using, read all label directions and follow them carefully.
2. Do not breathe the vapor.
3. Do not spill. If liquid **Dowfume** spills on shoes or clothing, remove them at once and do not wear them again until they have been aired outdoors for several days. Do not wear gloves when applying **Dowfume** because the fumigant can be "trapped" in them, lengthening exposure time to human tissues.
4. Keep animals and children away from plots that are treated and for at least 30 minutes after the cover is removed. The warning agent in **Dowfume** that irritates eyes dissipates in a few hours; however, the irritant may not keep children or animals from creeping under the cover.
5. When fumigating inside buildings, keep doors and windows open at all times until aeration is completed. Good ventilation is essential for safety and for satisfactory aeration, particularly when fumigating compost and manure.
6. Store **Dowfume** in a cool place away from dwellings.
7. Applying **Dowfume** outdoors often eliminates need of a gas mask during application; however, always keep one on hand for emergency use.
8. Always have a helper to assist with application and for any emergency that may occur.

II. Calculation of Materials Required for Producing 1 Million Bagged Pine Seedlings

POTTING MEDIUM

In the following calculations, it is assumed that vented plastic bags (20 cm long by 10 cm wide) are used. The first step is determining how many bags 1 m^3 of medium will fill. Flat folded bags (20 by 10 cm) have a circumference of 20 cm (2 by 10 cm = 20 cm). Therefore, the diameter of the filled bag is:

c = 3.14 *D*,	where C = circumference,
20 cm = 3.14 *D* or *D* = 2013.14,	*D* = diameter,
D = 6.37 cm	and 3.14 = π.

The area *(A)* of the base (i.e., circle) of the bag is calculated by the formula $A = r^2\pi$. Since diameter equals 2 radii (r), r is determined:

$$D = 2r = 6.37 \text{ cm}/2,$$
$$r = 3.18 \text{ cm}.$$

Once r is known, the area (A) of the container base is determined:

$$A = (3.14)(3.18 \text{ cm})^2 \text{ or}$$
$$A = (3.14)(10.11 \text{ cm}^2),$$
$$A = 31.8 \text{ cm}^2.$$

Then the volume of the plastic bag (i.e., a cylindrical container) is calculated:

$V = AL$,	where V = volume,
$V = (31.8 \text{ cm}^2)(20 \text{ cm})$,	L = length,
$V = 636 \text{ cm}^3$	and A = area of base.

One m^3 of medium contains 1 million cm^3. Therefore, the number of bags that can be filled with 1 m^3 is:

$$\frac{1{,}000{,}000 \text{ cm}^3/\text{m}^3}{636 \text{ cm}^3/\text{bag}} =$$

$$\frac{1{,}000{,}000 \text{ cm}^3}{\text{m}^3} \times \frac{1 \text{ bag}}{636 \text{ cm}^3}$$

1,572 bags, or 1,570 bags per 1 m^3 of medium when rounded for ease of calculation.

Allowing 15 percent cull mortality, about 1,150,000 tilled bags are actually needed to produce 1 million seedlings (see Sec. 52.1). Therefore, the total number of cubic meters of potting medium needed to fill the bags is:

1,150,000 bags/1,570 bags per 1 m^3 of potting material = 732 m^3, or 730 m^3 when allowing for waste.

One commonly used pot mix is 5 parts sandy loam soil, 1 part sand (11.70 mm sieve), 1 part sand ($\leq$1.40 mm sieve), and 2 parts organic material ($\leq$1.25 mm) such as thoroughly decomposed sawdust, leaves, or agricultural byproducts.

A small quantity of slow-release granular fertilizer (no more than 4 cm^3 per bag) can be mixed into the potting medium to supplement medium nutrient concentration. A 12- to 15-month slow-release formulation will carry over in the field and give seedlings an additional boost. An appropriate volume ratio is 1 m^3 of fertilizer per 200 m^3 of potting medium. Fertilizer should be mixed into potting medium that has been sieved to ensure a complete mixture. The amount of potting medium necessary to fill 1,150,000 bags is broken down into the following components:

$$730 \text{ m}^3/9 \text{ parts} = 81 \text{ m}^3 \text{ per component,}$$

or

Pot Media Component			*Mix Component Volume*
sandy loam soil	(5) × (81 m^3)	=	405 m^3
sand	(2) x (81 m^3)	=	162 m^3
organic matter	(2) × (81 m^3)	=	162 m^3
fertilizer	$\frac{(1 \text{ m}^3) \times}{(200 \text{ m}^3)(730 \text{ m}^3)}$	=	3.6 m^3 (rounded to 4.0 m^3)

The total pot mixture volume needed to produce 1,150,000 seedlings is 730 m^3 of medium + 4 m^3 of fertilizer or 734 m^3.

POLYETHYLENEBAGS

Vented-type bags should be purchased because the small, pre-punched holes in the bag drain excess water. Bags are generally sold in units of 1,000 per box. Therefore, the number of boxes required is:

1,150,000 bags/1,000 bags per box
= 1,150 boxes.

SEEDS

Upon request, seed suppliers will furnish buyers with an estimate of the number of seeds in each kilogram. Most seed dealers also supply area of collection and other seed source information about seeds. The germination information is generally notorized by an independent seed testing laboratory. Assume that *P. caribaea* var. *hondurensis* has 52,800 seeds per kg and that the seed supplier certifies a germination rate of 75 percent. With this information, the seed requirement is calculated. Because of the germination rate of 75 percent, 3 seeds are sown in each bag:

$$\frac{(3 \text{ seeds/bag}) \times (1{,}150{,}000 \text{ bags})}{(39{,}600 \text{ viable seeds/kg})}$$

$$= \frac{3{,}450{,}000 \text{ seeds}}{39{,}600 \text{ viable seeds/kg}}$$

= 87.1 kg of seeds required for all bags (rounded to 88 kg).

Only the early germinants should be kept in each bag (4). Later germinants are thinned out or transplanted into bags in which none of the 3 seeds germinated.

III. Sowing and Transplanting Procedures for Important Species of Tropical Trees

The eight procedures described below have worked well at the ITF nursery in Rio Piedras and the Monterrey nursery in Dorado, Puerto Rico. They should work well in other nurseries where similar germination beds and medium are available. In most instances, a local substitute for commercial products exists (e.g., rice hulls for vermiculite and sterilized compost for peat moss). Also, procedures should be applicable to different species within the same genera or same seed type (e.g., *Pinus* sp., tiny seeded species, and species with hard seedcoats needing scarification before sowing).

1. *Pinus caribaea* and *Pinus oocarpa*

Pinus sp. seeds are spread evenly over germination medium at least 10 cm deep. No more than 1,000 seeds should be sown per 30- by 30-cm area of each germination tray. This is a high sowing rate, but less than 70 percent of germinated seeds are usually transplanted. Moreover, because seedlings are transplanted 3 to 6 days after germination, seedbeds are rapidly thinned.

Seeds covered with 1 cm of grit, sand, or vermiculite germinate without difficulty. Unlike for temperate climate pines, seed scarification and stratification are not necessary. Germination bed shade boxes (fig. 5-2) are either hinged or closed securely at the top. Wire screens (1.3 cm square mesh) over the top keep seed predators away. Some nurseries germinate *Pinus caribaea* seeds in the dark. However, we found that 30- to 50-percent saran shade gives excellent germination in Puerto Rico.

2. *Anthocephalus chinensis* (Kadam)

Seeds of this species are extremely small (about 6 million seeds per kg). Care is needed to avoid washing seeds from seedbeds. Seedlings are raised on aerated loose germination medium, preferably sterilized fine sandy loam soil, spread to a depth of 7 to 8 cm inside germination flats. A 3-ply layer of tissue paper (Kimpak) is spread over the soil, and seeds are sprinkled on top (fig 9-5). The tissue prevents the seeds from sinking into the soil.

Kimpak lasts about 2 to 3 weeks before decomposition occurs; the seeds germinate in this period. A very light cover (0.3 cm) of fine, dry, sandy loam soil can be sprinkled over the seeds to keep them moist; otherwise, exposed seeds will dry out rapidly. White Kimpak material allows control of sowing density by visual inspection because dark seeds contrast well against the paper. Kadam germination flats should be watered with a Fogg-it-type nozzle or with overhead mist sprays. A clock-controlled high pressure misting system works well. The timer is set to spray water for 10 seconds every 30 minutes, the spray rate being adjusted according to ambient humidity. Watering from below also avoids dislodging seeds.

Saran shade (50 percent) is placed 25 to 30 cm above the germination beds. Sides left open allow light to fall on the flats. A plastic sheet placed about 1.8 m above the flats protects seeds from being dislodged by rainfall. Because kadam seeds are small, neither birds nor rodents bother them. Once germination has begun, moisture content of the germination beds is carefully controlled to avoid damping-off.

Proper transplanting time occurs when seedlings form at least four small leaves above the cotyledons, when seedlings are approximately 2 cm high. Seedlings are lifted by holding the leaves and pulling upwards gently, simultaneously lifting roots from below with a spatula. Because kadam seedlings form a very branchy root system, they must be transplanted almost immediately after germination. Avoiding J-roots in transplanting is done by trimming tap and lateral roots to about 3 to 5 cm, pulling them through a dish of water, and planting them in containers (Sec. 10.1.1).

3. *Gmelina arborea*

The fruit of ***Gmelina*** is quite large, with 700 or more drupes/kg. Seeds are sown with 1 cm of light covering (rice hulls, vermiculite, etc.) so that the radicle emerges from the bottom side to prevent J-roots. ***Gmelina*** is generally direct-seeded into beds or bags so that each seed has a minimum of 6 cm^2 of growing space. The maximum growing space recommended is 10 to 11 cm^2. Germination medium is kept moist but well-drained to prevent damping-off.

Since ***Gmelina*** is generally stump-planted, germination beds having loose sandy soil are ideal for undercutting. A loose soil readily shakes free from roots at lifting. A light shade of not less than 20 percent or more than 45 percent is used during germination but is removed after 3 weeks. The seeds must be protected from mice and birds.

4. *Swietenia* sp. (Mahogany)

Most ***Swietenia*** seedlings are planted as bare-root stock. The major problem is formation of J-roots. (fig. 10-l) because of the peculiar method of mahogany seed germination. Seeds should be **dewinged** and scattered on top of germination flats or beds, never pushed into the ground with the wing protruding. As germination begins, the hypocotyl emerges opposite the seed abscission scar and turns downward to establish a root system. The epicotyl develops from the hypocotyl and leaves are formed; cotyledons remain inside the seed, which eventually shrivels and falls off. Germination medium must be loose, permitting uninhibited hypocotyl development.

Dewinged seeds are broadcast on level, **well-**drained beds. A light covering (about 5 mm) of vermiculite, fine sand, or rice hulls (never clay soil) is scattered over the sown seeds. This cover retains medium moisture around the seeds, avoiding fluctuations in **seedbed** moisture. Saran shade cover (up to 50 percent) can be used during the germination stage. Fresh mahogany seeds germinate within 5 to 7 days. Seedbeds are watered two to three times a day if necessary. If sufficient shade is used and if germination medium does not have wide fluctuations in moisture, seeds can be sown directly on top of seedbeds without cover.

5. *Eucalyptus*

Although ***Eucalyptus*** sp. are easily regenerated in the nursery, they have small seeds, often more than **400,000/kg.** Thus, sowing methods are used that avoid applying too many seeds to germination trays. In one method, similar-size sand grains or a dead seed lot are mixed with live seed. The mixture is put inside a salt shaker and sprinkled over the germination beds (fig. 9-5). With practice, workers can develop a fairly uniform delivery rate.

In another method, small amounts of seed are placed in a dish. Workers then gently touch the seed with a moistened stick. Generally, two to three seeds adhere to the stick and are placed in containers (fig. **9-5).** This process is laborious but fairly effective. After several weeks, the containers are checked for multiple seedlings, and the weakest seedlings are culled.

Following sowing, seeds are covered with a light layer (about 0.3 cm thick) of fine sand or fine vermiculite that is kept moist. Watering is done with a mist nozzle. At least **30-percent,** perhaps as much as **50-**percent, shade is used to keep germination medium moist and to shield seedbeds of trays from direct rainfall that would dislodge seeds.

6. *Tectona grandis* (Teak)

Teak seeds are difficult to germinate because they are enclosed within an extremely hard seedcoat. Methods to hasten germination are scarification with hot water or sulfuric acid (Sec. 61.2). Once the **seed-**coat is broken, water is taken up and germination begins, being essentially complete within 2 months.

After scarification, seeds are placed in large flats, slightly elevated for drainage, and filled with a **3:1** mixture of sand and loamy soil. The seeds are placed on the bed, covered with a **1.0-** to **2.0-cm** layer of the same mixture, and then watered. A **30-percent** shade keeps beds from drying out. The seeds are sown at a very dense rate of about 200 per **30-** by **30-cm** area.

Seedlings are transplanted when they have four leaves. They are handled by the leaves, with the roots being lifted out with a spatula. Soil and roots are kept moist between lifting and transplanting. In most countries, seedlings are lined-out in ground-level beds from which they are lifted as stumps and planted. In some countries, because of the way it is field-planted, teak is produced in containers.

In large operations, seeds are sown in drills at **10-**cm spacing. As they germinate, they are lifted when ready, and new seeds are dropped into the empty spaces in the rows. This method is inefficient, however, because a large area is used for a small crop, and control of shading and moisture is more difficult.

7. *Leucaena leucocephalu*

Leucaena seeds, like those of other legumes, have an impervious waxy **seedcoat** that must be treated before seeds will germinate. Soaking with hot water **(80°C)** for 2 to 3 minutes, and additional soaking in water at room temperature for 2 to 3 days, yields up to **80-percent** germination.

In nurseries, seeds are sown in germination flats with sand, vermiculite, and soil, about 1,000 seeds per **30-** by **30-cm** area, and are transplanted to pots. In the field, seeds are direct-seeded on bare mineral soil that is free of weeds. Young seedlings are easily **shaded-**out by fast-growing weeds. However, once rapid **agrowth** has started, field-planted ***Leucaena*** seedlings form a dense mat that shades out weeds and other plants. Inoculation with a *Rhizobium* strain may be needed in areas not planted to *Leucaena* previously.

Stems of old and young *Leucaena* trees sprout vigorously when cut. Several rotations of 5 to 8 years are possible from one root stock. Once vigor is lost, trees must be replaced with new seedlings.

8. *Acacia mangium* (Mangium)

Mungium seeds also have an impervious seedcoat. Soaking in hot water (boiling water just removed from a heat source) for 30 seconds and soaking in tap water overnight breaks the seedcoat. The 30-second treatment time should be followed closely, as well as a seed/hot water volume ratio of 1:10.

The seeds are broadcast on nursery beds and covered lightly with fine sand or soil. Germination starts in 2 or 3 days and is complete in 8 to 10 days. Seedlings are transplanted to pots when the first pair of leaflets form. Direct-seeding in pots is also possible if seed germination is high. Seedlings reach outplanting size, 25 to 30 cm tall, in 2 to 3 months. Nodules on roots should be visible before outplanting; if not, inoculation with a *Rhizobium* strain is needed.

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Appendix 12

Practical Guides for Using Herbicides and Pesticides

I. Herbicide Information
II. Pesticide Information
III. Procedures for Calculating Solution Concentrations

I. Herbicide Information

GENERAL INFORMATION

When used properly, herbicides control weeds in nurseries where hand weeding is too costly or impractical. The objective is to eliminate competing vegetation that stunts seedling tops and roots, causes uneven seedling growth, and decreases seedling survival per unit area of nursery bed.

Weeds are usually classified as grasses, sedges, or broadleaf plants that are annual or perennial in nature. Some weeds are local problems only, whereas others occur across broad regions, even countries. Left uncontrolled, a single weed species can destroy up to 70 percent or more of plantable seedlings (5).

Certain terms are used repeatedly in herbicide use and weed control. Knowing them is essential to understanding how herbicides work and why they must always be considered ***controlled substances.*** A list of these terms with their definitions is given below (3).

Acid equivalent-That portion of a compound or formulation that theoretically could be converted back to the corresponding acid.

Active ingredient-The chemical(s) in a formulated product that is (are) principally responsible for the pesticide effects and that is (are) shown as active ingredient(s) on the label.

Adjuvants-Additional compounds added to pesticides to act as wetting or spreading agents, stickers, penetrants, emulsifiers, etc., to make them easier to handle, mix, or apply.

Broadcast treatment-Applied over an entire area, by ground or aerial means.

Carrier-A gas, liquid, or solid substance used to dilute, propel, or suspend a pesticide during its application.

Concentration-The amount of active ingredient or pesticide equivalent in a quantity of diluent, expressed as percent, lb/gal, ml/L, etc.

Defoliant-A pesticide used for the removal of unwanted foliage without necessarily killing whole plants.

Desiccant-A pesticide used for drying insects or plant leaves and stems.

***Diluent*—Any** gas, liquid, or solid material used to reduce the concentration of an active ingredient in a formulation.

Dormancy-A state of inhibited plant or animal growth.

Emulsifiable concentrate-a pesticide mixture dissolved in a liquid solvent. An emulsifier is included so that the pesticide can be diluted with oil or water and used.

Foliar application -Wetting of foliage with pesticide, usually to the point of runoff.

Formulation-The mixture of active and inert ingredients in a pesticide. Some formulations are ready for use; others must be diluted.

Frill treatment-Application of pesticide to nearly continuous cuts spaced around a tree at a convenient height.

Fumigant-A pesticide used in gaseous form.

Fungicide-A pesticide for control of fungi.

General-use pesticide-A pesticidal product that will not cause unreasonable adverse effects on the environment when used as directed, and that may be purchased and used by the general public.

Granule or granular-A dry formulation of pesticide and other components in discrete particles generally less than 120 cubic millimeters in size.

Herbicide-A pesticide for control of unwanted vegetation.

Insecticide-A pesticide for control of insects.

Integrated pest management-A process in which all aspects of a pest-host system are studied and weighed to provide the resource manager with information for decision making. Integrated pest management is, therefore, a part of forest or resource management.

Label-The written, printed, or graphic matter on, or attached to,' a pesticide container.

Notch or cup treatment-Application of pesticide to cuts spaced around a tree at a convenient height.

Noxious ***weed*** -A weed specified by law as being especially undesirable, troublesome, and difficult to control.

Oil-Aromatic or paraffinic oils used as diluents or carriers.

Preemergence-Prior to emergence of the specified weed or planted crop.

Registered pesticide -A pesticide that has been registered with the Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide, and Rodenticide Act, as amended.

Registration-The process whereby all pesticides are registered by the Environmental Protection Agency (EPA) under authority of the Federal Insecticide, Fungicide, and Rodenticide Act, as amended. All pesticide labels must have an EPA registration number.

Release-The process of removing competing vegetation that competes for soil moisture, nutrients, and light with desirable vegetation.

Repellent-A pesticide used to keep animal pests away.

Restricted-use pesticide-A pesticide product for application only by certified applicators or persons under their direct supervision.

Rodenticide-A pesticide used for rodent control.

Seed protectant-A chemical applied to seeds before planting to protect seeds and/or seedlings from pests.

Surfuctunt-A material that favors or improves the emulsifying, dispersing, spreading, wetting, or other surface-modifying properties of liquids.

Suspension -Finely divided solid particles dispersed in a solid, liquid, or gas.

Tree injection-Application of pesticide into the sapwood of individual trees using tubular injectors.

Ultra low *volume*—Applications of small amounts of pesticide (0.47 to 0.94 liters or less per acre).

Volatility-The ability of a solid or liquid to evaporate quickly at ordinary temperatures when exposed to the air.

Wettable powder-A finely divided dry pesticide formulation that can be suspended readily in water.

Wetting agent-A chemical that helps a pesticide spread and coat (wet) a surface more evenly. It cuts down on the amount of a spray that rolls off smooth or waxy leaves and helps sprays to spread out on hairy leaves. Detergents are sometimes used as wetting agents.

PLANT FACTORS AFFECTING TOXICITY

Herbicides are selective or nonselective. Selective products are more toxic to some plants than others; nonselective products kill a broad spectrum of weeds. Because seedlings are plants; weed control usually centers on selective herbicides. Four major plant factors affecting selectivity differences (*1*) are:

1. *Morphological differences* : Factors such as plant size and shape, leaf shape and size, growth stage, presence or absence of waxy and hairy substances, and location of roots close to or well beneath the surface affect contact and absorption of herbicides.
2. *Physiological differences* : Internal processes determine whether introduced herbicides are broken down into harmless byproducts or block key processes that eventually cause plant death.
3. *Absorption differences* : A combination of morphological and physiological differences allow greater or lesser uptake of herbicide by plant roots and shoots.
4. *Trunslocution differences* : Physiological factors determine whether herbicides are transported with phloem or xylem substances.

ENVIRONMENTAL FACTORS AND TOXICITY

In addition to plant factors, environmental factors that influence herbicide toxicity (*4*) are:

1. *Atmospheric environment:* Lower air temperatures, CO, levels, and barometric pressures reduce herbicide effectiveness.
2. *Soil temperuture:* Higher temperatures usually affect overall weed growth and metabolism favorably, increasing herbicide uptake and translocation.
3. *Water:* Higher relative humidity and good soil moisture (i.e., plant not under water stress) increase herbicide effectiveness.
4. *Light:* Changes in photoperiod, light-induced changes in leaf morphology, and photodecomposition of herbicides affect herbicide effectiveness.
5. *Wind:* Physical plant damage by wind and increased transpiration and water stress caused by wind usually increase herbicide uptake.
6. *Microenvironment:* Localized changes in soil pH value, microflora, and fauna affect plant growth and herbicide effectiveness, negatively or positively, depending on the herbicide used and plant grown.

HERBICIDE APPLICATION

Herbicides are seldom sold as pure chemicals. They are formulations of an active chemical plus various additives that allow uniform application. Major herbicide types (*4*) are:

1. *Sprays* :
   (a) *Solutions:* a homogeneous mixture of two or more substances.
   (b) *Emulsions:* one liquid dispersed in another with each maintaining its separate indentity; emulsifying agents are materials sold to help formulate emulsions.
   (c) *Wettable powders:* very finely ground solid particles that are suspended or dispersed in a carrier such as water or oil and sprayed on weeds.
2. *Granules:* Chemicals usually mixed with carriers such as sand and vermiculite and spread by broadcasting over weeds.
3. *Dusts:* Used for insecticides and fungicides but not usually for herbicides because of drift problems.

APPLICATION EQUIPMENT

Sprayers suitable for herbicide application range from small back-mounted tanks (7 to 15 liters) to tractor-drawn boom rigs (200 to 2,000 liters) capable of covering several hectares. For nonselective herbicides, various "rope wick" or "wiper" applicators treat undesirable weeds but protect small seedlings. Broadcast or hand "cyclone" spreaders and tractor rigs are best for granular herbicides. Properly calibrated and cleaned equipment is essential for large and small spraying jobs (fig. **16-3B**).

HERBICIDE CLASSIFICATION

The herbicide classifications are technical or non-technical. Technical classifications use chemical structures and major functional groups at the highest level of categorization; however, such systems are without standardization (*1*). Table **A12-1** lists one technical classification, with 16 major categories and specific products under each group.

A more practical, non-technical classification for nursery herbicides is that based on when herbicides are applied relative to seedling germination:

1. ***Preplant*** : soil incorporated, applied ***before*** seeding is done.
2. ***Preemergence:*** applied ***after*** seeding but ***before*** germinants emerge from seedbeds.
3. ***Postemergence:*** applied ***after*** seeding and after germinants have emerged from seedbeds.

In all instances it is easier to control germinating weed seeds than to control already established weeds with contact herbicides.

Many herbicides have the same major chemical agent but are sold under different trade names, mainly because of different carrier compounds. Some products have been around a long time (e.g., atrazine), others less so (e.g., Goal). Lists go out of date quickly because of changes in product formulation. Keeping this in mind, table **A12-2** lists major preplant, preemergence, and postemergence herbicides now used in pine nurseries in the Southern United States and Venezuela.

Table **A12-1**.—*Technical classification herbicide groups*[1]

Herbicide group	Specific herbicide examples
1. Phenoxy compounds	2,4-D; 2,4,5-T; MCPA; silvex
2. Benzoic acids	chloramben (Amiben)
3. Picloram	Amdon
4. Benzonitriles	bromoxynil; ioxynil
5. Bipyridinium salts	paraquat; diquat
6. Amitrole	amerol; cytrol
7. Aliphatic acids	dalapon; TCA
8. Substituted phenols	dinoseb; DNBP
9. Maleic hydrazide	MH
10. Substituted ureas	chloroxuron; diuron, linuron
11. Triazines	simazine, atrazine; prometryn
12. Diazines	pyrazon
13. Amides	diphenamid; propanil
14. Carbamates	chlorpropham; CDEC
15. Trifluralin	Ipersan, Treflan
16. Xylene	dimethyl benzene

[1]Source: (*1*).

Table A12-2.—*Preplant incorporated (PPI), preemergence (PRE), and postemergence (POST) herbicides used in the Southern United States and Venezuela for controlling weeds in pine nurseries*[1]

U.S.A.	Venezuela
PPI	
Eptam	....
Eradicane	....
Sutan	....
Vernam	....
PRE	
Aatrex	Sencor
Lasso	linuron
Sencor	Patoran
Milogard	Dacthal
Princep	Prowl
Surflan	
Treflan	
Caparol	
Enide	
Destun	
Dual	
Devrinol	
Modown	
Coal	
Ronstar	
POST	
Roundup	Diuron
Velpar	atrazine
Poast	Sencor
Attac	linuron
	Mineral spirits

[1]Sources: (*4*), (*2*).

Whenever possible, new products must be tested in replicated nursery trials to detect selectivity traits for forest seedlings and local weeds. For example, one experiment with ***P. caribaea*** var. ***hondurensis*** transplants showed that **26-day** survivals were better when several herbicides were applied to beds 48 to 72 hours before rather than 24 hours before transplanting (*2*).

SPOTTING HERBICIDE PROBLEMS

Failure to carefully follow instructions on herbicide product labels inevitably causes problems. Some of these and their probable causes (*3*) are:

1. ***Poor weed control:*** This problem is caused by failure to use selective herbicides for certain weeds and failure to apply herbicides at correct rates, right time, or in the best manner possible.
2. ***Seedling injury*** : Herbicides are often blamed for injuries that are also caused by insects, diseases, wind, overwatering, nutrient deficiencies, and abnormal weather conditions.

Practices involving herbicides that cause seedling injury are:

(a) Using a herbicide not labeled for a particular tree species;

(b) Failure to clean spray equipment thoroughly, resulting in leftover herbicide being applied to susceptible seedlings;

(c) Planting susceptible seedlings on land treated with herbicide the preceding year;

(d) Using application rates excessive to those recommended;

(e) Improper timing of herbicide application; and

(f) Drift to susceptible seedlings from wind, washing and cleaning equipment, and soil leaching.

To minimize herbicide problems, always read and follow label directions carefully, using only suggested application rates, and ***consider herbicides as toxic substances that must always be used under controlled conditions.***

When any chemical application equipment is **used,** be certain that spray tanks are thoroughly cleaned ***before*** as well as ***after*** use. Follow carefully all directions for mixing, applying, and using materials. Empty bags should be burned. All chemicals should be kept in secure storage to avoid accidental injury or contamination of areas surrounding nursery beds and buildings, particularly when nursery facilities are located in watersheds **from** which potable water is obtained.

II. Pesticide Information

The accompanying list is a generic one because most items are sold under trade names. Package labels must be checked to see if they contain recommended chemicals. The list contains only a very small number of the control materials available, but it includes those most commonly sold in the tropics.

INSECTICIDES

Malathion -widely available, sometimes odorous; useful to control aphids, scales, mealybugs, and some chewing insects.

***Metaldehyde*—useful** for control of snails and slugs.

Nicotine sulfate-an old, reputable, and effective control for aphids and other sucking insects.

***Ethion*—useful** in controlling leafhoppers, mites, and thrips.

Rotenone-a plant material used both as a contact and **stomach** poison; it has no toxicity to man.

***Carbaryl*—a** broad spectrum insecticide; it is extremely toxic to bee populations and should be avoided where production hives are located.

MITICIDES

***Suprucide 2E*—long** shelf life if stored in cool, dry place.

***Ovex*—extremely** effective, but use requires special care; read label instructions carefully.

Chlorobenzilate -used with good results.

FUNGICIDES

Methyl thiophanate-effective for control of soil fungi; used as a soil drench.

Bordeaux mixture-probably the most' practical fungicide available. For very small amounts, dissolve 0.1 liter of copper sulfate in 3.8 liters of water by putting the crystals in a cloth bag and hanging them at the top of water in a bucket. Then add 7.6 liters of water and 0.7 liter hydrated lime solution to make 11.6 liters of 11.6 Bordeaux mix. Use immediately because effectiveness is lost if the mixture stands too long. Adding a little soap to the final solution makes it stick and spread better.

Formaldehyde or formalin-can be used on bare ground before planting; it is **texic** to plants yet excellent as a preplanting drench to control soil fungi. Its fumes are toxic to people.

Lime sulfur-used to control mildews; it is also a miticide.

***Maneb*—useful** in controlling spot diseases, i.e., leaf spot fungi.

SOIL FUMIGANTS

***Ethylene dibromide*—** an effective soil fumigant that controls soil insects and nematodes. Soil treated with this material cannot be planted for at least 3 weeks because it is very toxic to plants. It is also very toxic to humans. It is sold under a number of commercial names.

Nicotine -sold under several trade names; it is safe to use and effective for soil insects.

SPREADERS

Substances to increase the adherence of sprays to plants. A few shavings of ordinary soap or a small amount of detergent will serve the purpose.

SEED TREATMENTS

Thirum-a wettable powder used as a slurry to coat seeds for protection against damping-off, seed decay, seedling blights, and rodents (table A12-3); it is suggested for conifer seeds.

PREPLANTING BED TREATMENT

Captan—applied to nursery beds before planting to control damping-off; it is worked into the top 8 to 10 cm of soil

Table A12-3.—*Listing of bird and rodent repellents and stickers used for forest tree seeds in Latin America*

Birds		Rodents	
Common name	Chemical name	Common name	Chemical name
Repellents			
Anthraquinone	9, 10-Anthraquinone	....	....
Avitrol	4-Aminopyridine	Thiram[1]	Bis (dimethyl-thio-carbamoyl) disulfide
DRC-1339	3-chloro-p-toluidine hydrochloride	Ziram[1]	Bis (dimethyl dithio-carbamato) zinc
Stickers			
Ag-chem activator	...........*.....	....	....
Triton	................*	....	....

[1]Products registered in the United States by U.S. Environmental Protection Agency as fungicides only.

III. Procedures for Calculating Solution Concentrations

Often, the nursery technician needs to dilute or prepare a specific concentration of an insecticide, fertilizer, or other chemical. The best way to explain how a specific concentration can be derived from another concentration is to provide an example.

Assume a typical dilution problem where one has 150 liters of an insecticide, previously diluted to 15-percent strength, and needs 435 liters of the insecticide with a final dilution of 4.5 percent. The problem is: How much of the 150 liters must be used to prepare 435 liters with 4.5-percent insecticide? The following formula can be used to determine the correct dilution:

$$C_1V_1 = C_2V_2 \text{ or } \frac{C_1}{C_2} = \frac{V_1}{V_2}, \text{ or}$$

Where

C_1 = concentration of first solution,
C_2 = concentration of second solution,
V_1 = volume of first solution,
and
V_2 = volume of second solution.

Then

$$\frac{4.5\%}{15\%} = \frac{V_1}{435} \text{ or}$$

$$(15\%)\ (V_1) = (435 \text{ liters})(4.5\%)$$

or solving for V_1,

$$V_1 = 120 \text{ liters.}$$

Thus, 120 liters of the 15-percent strength insecticide combined with 315 liters of solvent (generally water) will yield 435 liters with a 4.5-percent concentration of the pesticide.

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Appendix 13

Guides for Applying Fertilizers and Preparing Compost

I. Important Fertilizer Facts
II. Procedures for Building a Compost Pile

I. Important Fertilizer Facts

GENERAL

The guides provided here are applicable to traditional and large-scale operations using bulk fertilizers. Greenhouse practices for using soluble fertilizers with irrigation water are more complex. An excellent reference on mineral nutrition in greenhouses is that of Tinus and McDonald (4). Since the guides herein are general, caution is needed in their interpretation because soils or local site conditions probably exist for which some guides are not applicable.

DETERMINING FERTILIZER NEEDS

Whenever possible, nursery field test results are compared with known ranges in nutrient levels for various kinds of nursery soils (table 13-4). Where levels are unknown, fertilizer needs are approximated by comparing field test data with "benchmark" low, medium, and high field levels applicable to a wide variety of crops (table A13-1) (2).

APPLICATION METHODS

There are four ways of applying fertilizers. Each has certain advantages and disadvantages, depending on type of fertilizer (*2*):

1. *Broadcasting:* uniform spreading of fertilizer over the soil and working it in by machine or with hand implements before seeding. This method gives best distribution of fertilizers to root systems, has little danger of "burning" seedling roots, and is not labor intensive. Disadvantages that usually outweigh the advantages are: tie up of soil P and K (i.e., makes them less available), ineffective at low application rates, fertilization of both weeds and seedlings, and difficulty in getting equipment for completely uniform application and incorporation.
2. *Localized placement (banding)* : placing fertilizers in bands to the side (5 to 8 cm) or under (6 to 10 cm) seeded rows. When NPK or N and K fertilizers are placed under seeded row and trench irrigation is used, placement must be *under* maximum water height; if not, N and K salts move upward by capillary action as soil dries and burn seedling roots-P does not burn. Other disadvantages are: requires special application equipment, cannot be done manually, and fertilizers must be applied before seeds germinate. Generally, advantages far outweigh disadvantages: maximum efficiency for small or medium application rates, minimal tieup of P and K, less feeding of weeds than in broadcasting, and best method for seedlings with small root systems.
3. *Foliar application:* applying nutrients in solution to seedling foliage. The method is suited for correcting micronutrient deficiencies but not for applying general NPK fertilizers. Over-fertilizing with NPK can cause foliage burn if excess amounts are not washed off. Most foliar fertilizer products are very expensive; discriminate use is the key to effective use.
4. *Irrigation water applications:* applying soluble fertilizers in overhead or trench systems. Methods require special attention, particularly in dry climates where water contains high soluble salts and soil water evaporation is great. Under these conditions, irrigation fertilizer application may be quite wasteful; burning of roots is also a problem when salts accumulate in the root zone.

Table A13-1.—*General field soil fertility levels for agricultural crops* [1]

Element	Low	Medium	High
		Kg/ha	
N	35-55	60-95	100+
P_2O_5	25-35	40-60	70+
K_2O	30-40	50-70	80+

[1]Knowing these "benchmark" field soil fertility levels and the fact that a crop of pine seedlings on sandy soils requires about 1,100 kg/ha of 10-10-10 and 300 kg/ha of ammonium nitrate (*2*), managers can make fertilizer estimates for their nurseries. With experience and record keeping over several years, managers will determine whether benchmark field fertility guides are accurate. For interpreting long-term fertility data, managers should determine a nursery's annual cost of fertilizer, kinds and timing of applications, whether limited capital restricted fertilizer use in any years, and whether fertilizer shortages in any years caused substituting usual products for others.

APPLICATION

General Considerations

For best results, NP and NPK fertilizers are applied at or close to planting time. To reduce N and K leaching, only one-third to one-half of the amounts needed are applied initially. The remaining amounts are applied about one-third and one-half of the way through the expected seedling rotation.

Placement is at least 7.5 to 10 cm deep and 5 to 7.5 cm to the side of seedling rows. Side placement prevents burning by K and N carried upward in soil capillary water.

Specific Considerations

To prevent volatilization, urea-N is always incorporated in the soil, never broadcast on the surface. Because N is mobile, placement does not have to be as deep as for P. Timing of N application is especially critical when cover crops are incorporated; high C/N ratios will tie up N in decomposition unless fertilizer N is added. If N-fixing seedlings are grown, overall N needs are much less for any nursery soil.

Because P is easily tied up in the soil, it is always incorporated deeply, never broadcast. Major P needs are for good root growth after sowing; later applications are wasteful unless specific P deficiencies are found. Adding N with P aids P uptake by seedlings.

Leaching losses of K are between those of N and P. Efficient applications are those incorporating K at or near sowing. Crop residues are usually high in K.

Sulfur is mobile and readily leached. The major S-bearing fertilizer components used will determine application method and placement. Micronutrient availability is very strongly related to soil acidity. Beyond pH value 6.8, availability of most micronutrients decreases (fig. 13-3).

Effects of Adding Excess Nutrients

Beyond certain concentrations, excess nutrients do nothing to stimulate plant growth. In some cases, excess nutrients actually limit plant growth, usually because of interaction effects (*1*) such as:

- excess K relative to Ca and Mg causing Ca and Mg deficiencies;
- excess P tying-up Fe and Zn and creating deficiencies when they are at borderline soil levels;
- excess Ca relative to Mg possibly creating Mg deficiency;
- overliming causing micronutrient deficiencies; and
- excess soluble Cu and Mn causing Fe deficiencies and vice-versa.

Fertilizer Burn

Excess fertilizer salts in the soil inhibit absorption of other nutrients and cause physical burning (i.e., osmotic desiccation) or death of root tissue when concentrations are very high. When symptoms (leaf or root tips turning brown and drying; visible salts on leaf surfaces) are caught in time, applying excess, unfertilized, irrigation water will wash away these salts. Not all fertilizers have the same burn potential (table A13-2). When in doubt, keep all fertilizers away from direct contact with seedling roots and foliage tissue.

Table A13-2.—*Relative burn potential of different fertilizers*[1]

Fertilizer	Formula	Salt index per 9 kg of plant nutrients	
Sodium nitrate	16-0-0	6.0	GREATEST
Potassium nitrate	14-O-46	5.3	
Ammonium sulfate	21-o-o	3.2	
Ammonium nitrate	33-o-o	2.9	
Mono-ammonium phosphate	11-48-O	2.5	
Potassium magnesium sulfate	o-o-22	1.97	
Potassium chloride	O-0-60	1.93	
Urea[2]	45-o-o	1.6	
Di-ammonium phosphate[2]	18-46-O	1.6	
Potassium sulfate	o-o-54	0.65	
Single superphosphate	O-20-0	0.4	
Triple super-phosphate	0-48-O	0.2	
Gypsum		0.25	LEAST

*Source: (2).
[2]Urea and DAP may cause more injury than ammonium sulfate because they release free ammonia.

Fertilizer Mixing Guides and Dosages

If lime is mixed with urea or ammonium-N fertilizers, ammonia gas is formed. Similarly, mixing lime with ammonium phosphates, super phosphates, or any fertilizer containing P will make most or all of the P *insoluble.* Other fertilizer mixing incompatibilities are shown in figure A13-1.

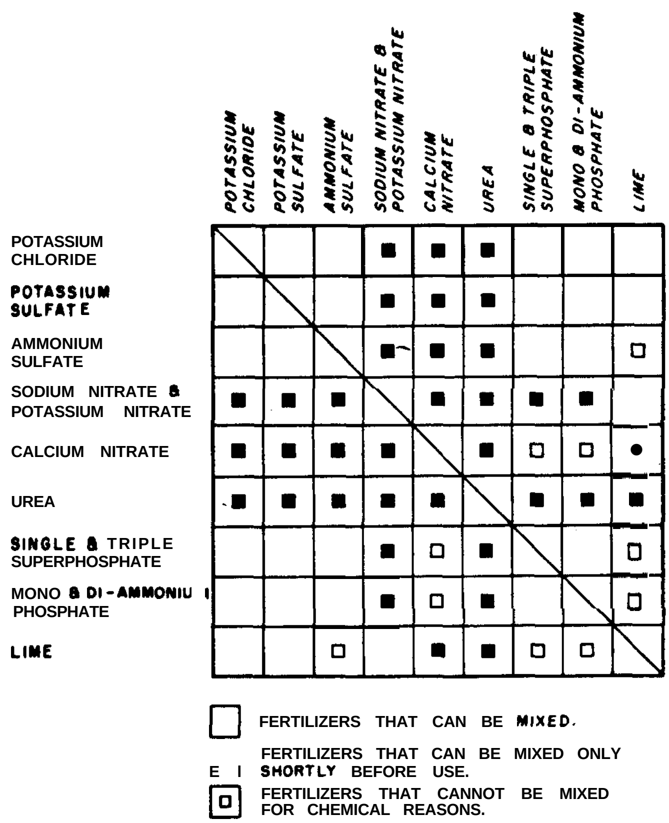

Figure A13-1.—*Fertilizer compatibilities. Taken from (2).*

For small nurseries, application rates are sometimes best expressed as grams/length of row or grams/plant instead of kilograms/hectare. Thus, knowing dosages in terms of tablespoons, handfuls, or other volume measurements is helpful. Converting application rates from a weight to a volume basis is done by determining the density of a particular fertilizer with a scale and calibrated measuring device such as a graduated cylinder. "Relative density" is used because stored, uncovered fertilizers attract water, raising their unit weight. If a fertilizer is suspected of being "wet", a sample is placed in the sun for a few hours or dried in an oven at 70°C for 2 to 3 hours. The measuring device should hold at least 100 cc. Dry weight is then recorded for the amount in the cylinder. Where scales are scarce, one may possibly be obtained from a local pharmacist. With a scale and measuring container (graduated cylinder), a simple table can be developed that gives the relative densities of fertilizers (*1*).

II. Procedures For Building A Compost Pile

Compost is made by letting alternate layers of plant and animal wastes decompose in a pile or pit. The end product is a dark, earthy looking humus soil improver. The first step in making a compost pile is to lay out a 2- by 2-m base of organic (high carbon) material, e.g., leaves, rice hulls, sugarcane waste, and crop stubble. Height of the first layer should be about 20 cm. The next layer is a 10-cm covering of high N material, usually fresh animal manure (table 13-10); do not use composted manure. The nitrogenous layer provides N for fungi and bacteria to break down the organic layer. Alternate carbon and nitrogen layers are added until the pile is about 1.5 m high. The topmost layer is a high N one (*1*).

The final compost should have a carbon to nitrogen ratio of between 20:1 and 30:1 (table A13-3). Straw and wood residues usually have too much C compared to N; microbes cannot break down the material. Immature green vegetation has more N than needed, and microbes turn the excess into ammonia gas, which is lost.

As the pile is constructed, each layer is moistened slightly. To avoid washing layers away, water should be applied with a fine spray nozzle. The mix should feel wet but not soggy.

After the final layer is added, a large depression is made in the center. The depression catches rain or applied water to maintain high moisture (about 50 percent) in the pile. Often the pile is covered with a E-cm layer of leaves, burlap, or other material to protect it from the wind. It also helps conserve heat, generated by the micro-organisms, that is necessary to kill weed seeds and pest organisms in the pile. A large pile at least 1.5 m high by 2 m wide at the base is self-insulating; any length can be used.

A final but important step is taking daily temperature readings at the center and edges of the compost pile over the first 3 weeks. If temperatures >60°C are measured, internal heat of the compost pile has probably killed decomposing micro-organisms (3). When this occurs, the compost pile has "stuck" and must be restored before further decomposition continues. Restoring a stuck pile. involves complete turning to dissipate heat and provide aeration and reintroducing high N animal-waste layers within the pile.

Since microbes need air, maintaining aeration in the pile is critical for completing the cornposting process. The more often a pile is turned, the faster composting is completed. Turning a pile one or two times a week is ideal, but turning it every other week is probably more realistic unless a tractor-mounted bucket replaces hand labor in turning. If the pit method is used, two pits are built; turning involves transferring the pile from the full to empty pit.

An improperly composted pile will not ferment completely, and pathogenic organisms or viable weed seeds may remain. The problem is corrected by recomposting the material. Contamination with weed seed is controlled by using seed-free vegetative material. Length of time for cornposting is 2 to 6 months. Therefore, cornposting must be started several months in advance of seedling production runs. To test for weed contamination, small quantities of compost are used

Table A13-3.—*Carbon-nitrogen ratios of various organic materials*[1]

Material	C:N Ratio
Fresh grass clippings	12
Fresh animal manure	15-20
Clover residues	23
Green rye	36
Leaves	40-80
Sugarcane trash	50
Straw manure	≥50
Corn stover	60
Straw	50-130
Sawdust (rotted)	210
Sawdust (fresh)	400-500

[1]Source: (2).

to germinate tree seeds; if weed seeds also germinate, the material must be recomposted.

Compost is expensive when transporting composting materials is a major cost. Locating a nursery near an animal husbandry complex will reduce transportation costs and will provide a ready supply of manure. Because of approximately equal elemental composition in animal manures (table 13-10), the authors do not recommend one over another; horse manure has perhaps more fiber content than other manures.

Physical location of a compost pile or pit should be given special attention because the very nature of the materials used attracts flies, rodents, etc. Compost pits should be located downwind and far away from the main nursery work area. Although some compost pits are left in the open, placing them under a shelterhouse, having a concrete floor and enclosed, rodent-proof fence around it, is preferred. Also, with a concrete floor, K- and NO_3-rich leachates can be collected and recycled.

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Appendix 15

Specialized Facts for Container Stock Production

I. List of Container Manufacturers
II. Five Types of Containers that are Useful in Tropical Countries
III. Suppliers of Commercial Potting Mixes
IV. Split-Level Nursery Operations for Producing Container Stock

I. List of Container Manufacturers[1]

Supplier	Common name of container	Container material	Biodegradable properties	Root egress
Ameripak 806 Central Ave. P.O. Box 8686 Middletown, OH 45042-8686	Ameripak	Polystyrene	No	No
Capilano Plastics Co. Ltd. 1081 Cliveden Ave. Annacis Island New Westminister, BC CANADA V3M 5V1	Capilano Seedling Tray	High density polyethylene	No	No
Castle and Cooke Techniculture, Inc. P.O. Box 1759 Salinas, CA 93902	Seedling tray; plugs	Expanded polystyrene; polyurethane foam	No No	No No
Colorado Hydro Inc. 5555 Ute Highway Longmont, CO 80501	Colorado Styroblock	High-impact polystyrene	No	No
Colorado State Nursery Foothills Campus Colorado State University Fort Collins, CO 80523	Colorado Styroblock	Polystyrene foam	No (reusable)	No
GASPRO, Inc. 2305 Kamehameha Hwy. Honolulu, HI 96819	Hawaii Dibble Tube	Polyethylene	No (reusable)	No
HGP Inc. 761 Kanoelehua Ave. Hilo, HI 96720	Polybag	Perforated plastic bag	Yes	Yes
Hakmet Ltd. P.O. Box 248 Dorion, Quebec CANADA J7V 7J5	Paperpot	Specially-treated paper	Yes	Yes
Jiffy Products of America 1400 Harvester Road P.O. Box 338 West Chicago, IL 60185	Jiffy pots and peat pellets	Molded peat moss	Yes	Yes
Lannen Inc. 2646 Palma Drive Suite 140 Ventura, CA 93003	Paperpot	Specially-treated paper	Yes	Yes
Mansonville Plastics Ltd. 19402 - 56th Ave. Surrey, BC CANADA V3S 6K4	Styrofoam blocks	Polystryene foam	No	No
J. M. McConkey Co., Inc. P.O. Box 309 Sumner, WA 98390	DEEPOT; seedling trays	High density polyethylene	No	No
Plant-a-Plug Systems P.O. Box 1953 Pine Bluff, AR 71613	Styrofoam blocks	Polystyrene foam	No (reusable)	No

I. List of Container Manufacturers-Continued.

Supplier	Common name of container	Container material	Biodegradable properties	Root egress
Ray Leach Cone-tainer Nursery 1500 N. Maple St. Canby, OR 97013	R/L Single Cell	High density polyethylene	No	No
Sauze Technical Products Corp. 345 Cornelia St. Plattsburgh, NY 12901	Multipot	High density polyethylene	No	No
Silvaseed Company P.O. Box 118 Roy, WA 98580	Styroblock	Polystyrene foam	No (reusable)	No
Speedling, Inc. Old Highway 4'1 S P.O. Box 238 Sun City, FL 34268	Todd@ Planter Flat	Expanded polystyrene	No (reusable)	No
Spencer-Lemaire Industries, Ltd. 11413 - 120 st. Edmonton, Alberta CANADA T5G 2Y3	S/L Rootrainer	Polystyrene	No (perhaps reusable)	No
Treepot Enterprises 12922 Harbor Blvd. Suite 678 Garden Grove, CA 92640	Treepots; Styrofoam blocks	Polystyrene	No	No
Tubepack 402 East 900 South Suite 2 Salt Lake City, UT 84111	Tubepack	Polystyrene	No (perhaps reusable)	No
Western Pulp Products Co. Box 968 Corvallis, OR 97331	Fiber pot	Molded wood pulp	Yes	No (but penetrate pot)

'Adapted from Tinus and McDonald, 1979, and information supplied by Dr. Thomas D. Landis, Region 6, Portland, OR.

II. Five Types of Containers that are Useful in Tropical Countries

ROOTRAINERS

This. container was originally called the Book-Planter (fig. 15-6). A new name was adopted after a design change placed grooves along its entire length to eliminate root spiraling. The basic unit is a molded cellulose acetate sheet that folds (as one closes a book) to rectangular, tapered cavities; a single large hole at the bottom allows water drainage. Several cavity sizes are available, as are high-impact styrene trays, each holding 32 seedlings on elevated runners that allow root egress and promote air-pruning of roots. Rootrainers can be reused once or perhaps twice, depending on the handling care they receive and the amount of direct sunlight, which photochemically breaks down the container walls.

Characteristics of this and similar containers are:

Advantages

1. Root development can be checked anytime with. out destroying roots or seedlings.
2. Ease of handling, since seedlings are carried to the field in the containers.
3. Plugs are quickly extracted.
4. Containers can be saved or thrown away, as desired.
5. If containers are not reused, there is no messy cleaning.
6. Mycorrhizal inoculum can be added directly to roots at any time.

Disadvantages

1. Extra trays are required for handling and shipping.
2. Containers require assembly before filling with medium and seeds.
3. Blank cavities must be reseeded or filled with transplants.
4. If reused, cleaning and reassembling are labor and time consuming.

Outplanting performance of southern pine seedlings grown in Rootrainers has been similar to the performance of those grown in Styroblock containers.

RIGID POLYETHYLENE TUBES

Several rigid design containers are available, the Leach Cone-tainer being the most popular (fig. 15-5). Construction is injection-molded polyethylene, generally reproducible by a local plastics forming industry. Almost any diameter and length combinations are possible. Tubes formed with internal ridges that prevent root spiraling are preferred over those without ridges. Cone-tainer tubes or cells can be placed in racks with holes specially molded to hold them upright. Polyethylene tubes produced for the tropics should be treated to resist greater ultraviolet radiation that causes untreated plastic to become brittle.

Other characteristics of rigid tubes are:

Advantages

1. Special racks allow easy handling of individual tubes and units of 100 or more.
2. Blank cells are easily replaced.
3. Wider spacing is obtained by removing every other cell.
4. There is no root penetration between adjacent cells.
5. Seedlings are easily removed, culled, and graded into equal heights before being sent to the field.
6. Cells are reused for other seedling crops.

Disadvantages

1. Each cell must be handled individually for normal use and recycling.
2. Extracting seedlings is a nuisance, in the nursery or in the field; knocking or kneading of pliable cells is often needed for lifting.
3. If seedlings are removed from cells at the nursery, extra packaging is needed to prevent drying of roots and plug breakage.
4. Recycling the cells is labor and time consuming.

JAPANESE PAPERPOTS

Japanese paperpot systems are used widely in temperate zones, particularly for large-scale conifer production in Finland. Paperpots come in sets of 39 to 1,400 units; each unit is bottomless and hexagon-shaped. For production runs of 1 to 2 million seedlings, capital outlay is small and hand labor is adequate for filling and handling. For production runs as large as 10 million seedlings or more, equipment for complete mechanization should be purchased.

Paper-pot systems use glued bio-degradable paper. Sets are shipped as flat packages that expand into an upright honeycomb for filling in special trays. Tubes are joined by water-soluble glue, allowing separation at planting. The paper itself has plastic fibers and chemicals to increase container durability. A large variety of diameters and lengths are available. Paperpots are one of the few containers for which a complete line of handling, tilling, sowing, and planting equipment can be purchased. Six people can fill and seed up to 2 million pots per day.

Characteristics of paperpots are:

Advantages

1. Connected tubes are easily separated for planting.
2. There is a wide range in size and number of tubes in unit packages, allowing wide choice of container volume.
3. Seedlings are carried to the field in the pots; thus, the root systems are protected from damage and drying.

Disadvantages

1. Roots frequently penetrate adjoining tubes, making separation at planting difficult.
2. Tube paper can break down too soon, making handling and transporting difficult.
3. Paper degrades slowly in the field, slowing root contact with soil around planted tubes.

Overall, timing of lifting is critical for paperpots to prevent overdevelopment of root systems in the nursery and break down of pots. Southern pine seedlings grown in paper-pots have generally had lower field survival and slower growth after outplanting than seedlings grown in other containers (1).

STYROBLOCKS

The original container was made of molded styrofoam, with 80, 135, 160, 192, or 240 cavities per block or flat. Cavity volumes range from 40 to 125 cm^3 and depths from 10 to 20 cm. Interior surfaces of individual cavities have a special glaze that protects against root penetration. Internal ribs orient root growth downward and prevent spiraling. Runners on block bottoms elevate them and promote air-pruning. Some models have "fences" around the top edges to prevent water runoff (fig. 15-4).

The SO-cavity block may be more suitable for the tropics where large seedlings are needed. Venator and Rodriguez (*3*) recommended that pine seedlings be grown in low density blocks; however, Walters (*4*) found that higher density, 192-cavity blocks were adequate for producing large hardwood seedlings in Hawaii. Styroblocks are expensive, but if the blocks can be reused two to three times as claimed by the manufacturer, unit seedling cost will be substantially lower. Blocks are reusable until glaze coating on the inner surfaces is worn away by microbial activity or weathering. Seedling roots tend to grow into Styroblocks without the glaze coating, and it is impossible to remove seedlings without stripping roots. The glazed surface can be protected by washing blocks immediately after extracting seedlings and storing the blocks under shade.

Equipment to fully mechanize Styroblock production systems is available. Simple, low-cost flat fillers, seeders, grit loaders, etc., are available that allow workers to fill and direct seeds up to 300,000 cavities per manday of work.

An older product, Todd Planter Flats (fig. 15-2), is also made from Styrofoam and is now adapted for forestry as well as vegetable nurseries (*1*). Cavity openings in this container are square at the top and taper to a small hole at the bottom.

Characteristics of Styroblocks and similar containers are:

Advantages

1. Cells are unitized in rigid but lightweight blocks that are easily transported to remote planting sites, even when filled with seedlings.
2. Block material insulates seedlings from temperature extremes.
3. Blocks can be reused if handled, cleaned, and stored properly, reducing unit seedling costs over long periods.
4. Glaze coating prevents root penetration of adjacent cells and aids in lifting seedlings out of blocks.

Disadvantages

1. Empty cells must be reseeded or transplanted.
2. Difficulties in seedling extraction will occur if pot mix and moisture are not well controlled and if the glaze deteriorates.
3. Damage to a block beyond a certain amount means losing the entire block, even though some cells are intact.
4. Recycling is labor and time consuming.

Styroblock-produced seedlings usually grow better under stress conditions than do those grown in paperpots and other tubes. Outplanting performance of seedlings from Todd Planter Flats may even surpass that of seedlings from Styroblocks. This is presumably so because the strongly tapered configuration of the plug promotes rapid root egress once plugs come in contact with surrounding soil (*1*).

POLYPOTS

These are rectangular containers, smaller versions of the familiar paper milk cartons, manufactured by laminating polyethylene onto both sides of cardboard. Drainage holes are punched before Polypots are cut to size. Their major drawback is that they must be hand-folded and placed in trays before being filled. If laminating is adequate and handling of individual pots is minimal, Polypots last 12 to 14 months in nurseries before disintegrating. There is no available equipment for mechanized filling and seeding of these pots. However, a good machinist should be able to construct satisfactory equipment cheaply with local materials.

Overall characteristics of Polypots are similar to those of Japanese paperpots. Other features are:

Advantages

1. Most countries have local capability to manufacture Polypots in all sizes.
2. Close nesting in trays prevents inter-cell areas from filling with soil in which weeds can grow.

Disadvantages

1. There are no internal ribs to prevent root spiraling.
2. Air-pruning is impossible unless trays are elevated.
3. Boots frequently entwine between pots via vent holes.
4. More medium is required for filling than for other, similar-length containers having moderate or strong taper.

III. Suppliers of Commercial Potting Mixes

Agritec Co., Inc.
939D Milwee
Houston, TX 77018
(synthetic soils, plant starter blocks)

J-M Trading Corporation
307 S. Lawndale Avenue
Chicago, IL 60623
(HECO soil replacer)

Jiffy Products of America
P. 0. Box 338
West Chicago, IL 60185
(distributor of Jiffy-Mix, Jiff-Mix Plus, Grower's Choice, and Magamp products)

McConkey Co., Inc.
P. 0. Box 309
Sumner, WA 98390
(perlite, soil conditioners, and fertilizers)

Sierra Chemical Co.
7650 Sycamore Street
Newark, CA 94560
(Osmocote slow-release fertilizers)

A. H. Hummert Seed Company
746 Chouteau Avenue
St. Louis, MO 63103
(prepared pot mixes, vermiculite)

E. C. Geiger Company
Box 285, Route 63
Harleysville, PA 19438-0332
(general nursery supplies and equipment)

Griffen Greenhouse Supplies, Inc.
6 Interstate Avenue
Albany, NY 12205
(general nursery supplies, including irrigation equipment)

IV, Split-Level Nursery Operations for Producing Container Stock

In split-level operations, gravity feed is used whenever possible to compliment semi-automatic mechanical equipment. Such a setup reduces energy expenses while reducing need for additional operators and machinery. Efficiency of operation may be somewhat lower for split-level operations than for fully mechanized operations. Yet some countries prefer less mechanized operations that require lower establishment costs, less time to repair when machinery breaks down, and fewer problems in finding workers who can operate the equipment. A key feature of any semi-mechanized operation is a tractor-mounted loader having a capacity of at least 0.5 m^3. End loaders are efficient for loading heavy soil and sand into the soil sieve and for moving sieved potting medium into the mixer (fig. A15-1). Mixers should have a capacity of 2 m^3.

After a proper soil mix is prepared and dumped from the mechanical mixer, the end loader scoops up the mixture and fills each available hopper. Hoppers should be filled early in the morning before the laborers (bag fillers) arrive or late in the afternoon, after workers have left. Hoppers are easily designed to hold 1 to 1.5 m^3 of pot mix. These amounts give bag fillers a full day's supply of mix in their respective hoppers.

Most bag-filling operations in tropical nurseries are run on an incentive basis. A particularly effective method is to employ women on a part-time basis. Since most women have domestic chores at home, they are particularly eager to leave early in the afternoon. If a set price is arranged for emptying a single hopper load, worker morale will be high. In a trial in Puerto Rico, a nursery manager told bag tillers they were free to leave after they had filled 800 bags. Not surprisingly, what was previously an 8-hour task was accomplished in about 6-hours. Other nurseries have effectively employed a fixed price per filled bag. This allows individuals who wish to earn extra money to do so. What should be avoided is a fixed daily wage without any control over production output. Such a policy usually causes a serious work backlog that slows other operations.

From time to time, a quick check is necessary to determine whether the mechanical mixer is mixing

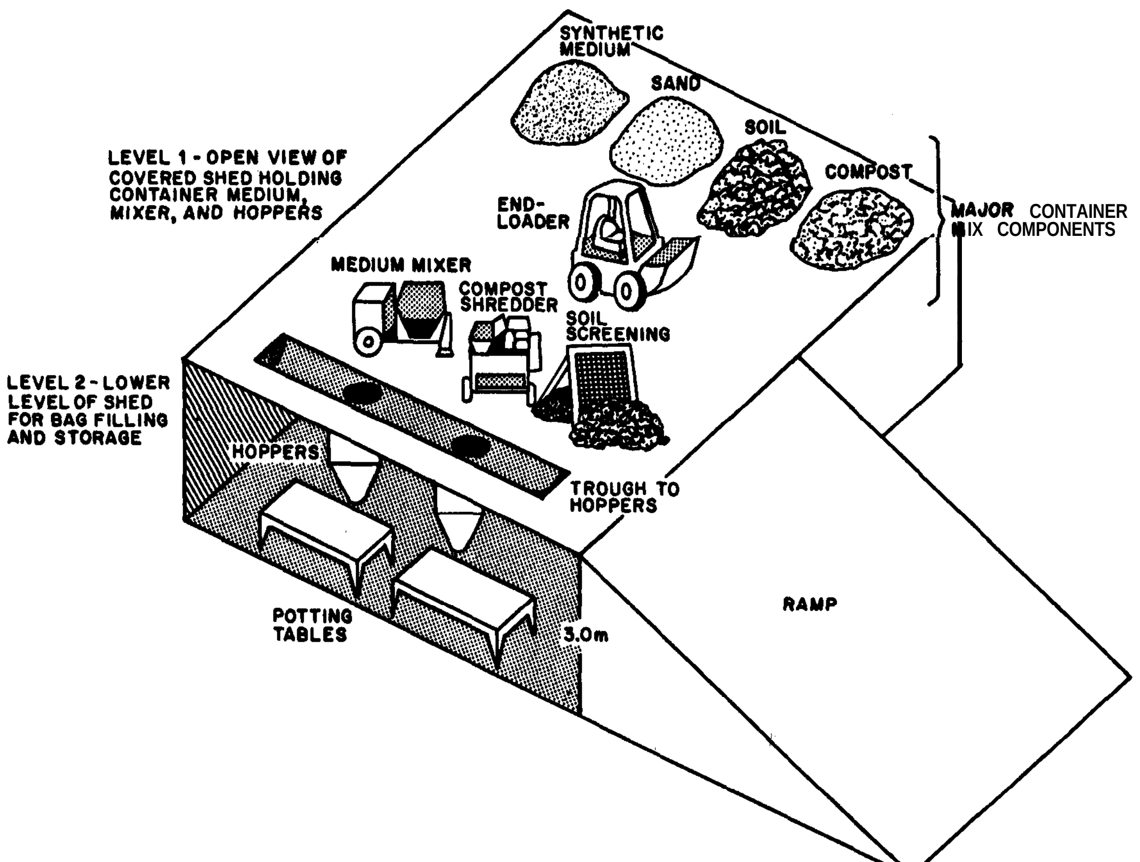

Figure A15-1.—*Overhead view of split-level structure used in producing container nursery stock with semi-automated procedures. Natural topography was used for best placement of structure and approach ramps.*

soil components in desired ratios. A simple sampling method is to pull out about 3 to 4 liters of the mixture and sieve it by hand. This procedure is repeated several times and an average computed. If computed ratios deviate excessively, mix proportions must be adjusted accordingly.

As bags are filled, they are placed in trays (with a capacity of 35 to 45 bags) and loaded onto pallets. Filled pallets are transferred to a flat bed wagon, taken to nursery beds, and off-loaded; workers line-out bags in rows. This operation can also be done mechanically by placing filled trays on roller conveyors and pushing them to a worker who removes the trays and loads them onto a wagon.

Often, natural terrain of a nursery allows construction of a split-level structure. If not, a simple ramp and elevated floor can be constructed by backfilling behind a fence (fig. A15-2).

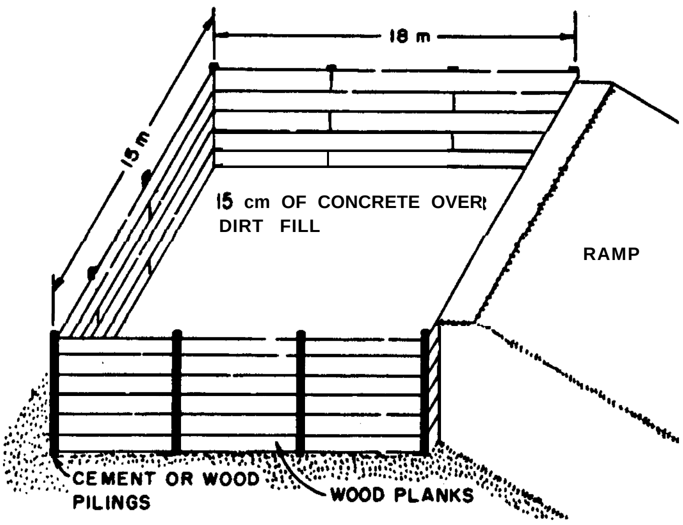

Figure A15-2.—*Split-level structures can also be built on level terrain by filling in a fenced area behind pilings and screen, and hauling in fill dirt for approach ramps.*

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Appendix 16

Practical Guides on Watering and Soluble-Fertilizer Application

I. Watering System Alternatives for Forest Nurseries
II. General Management Scheme for Watering Nursery Seedlings
III. Injector Alternatives for Soluble-Nutrient Watering Systems

I. Watering System Alternatives for Forest Nurseries

Many traditional nurseries and almost all mechanized nurseries have overhead watering systems. Systems with automatic controls save labor and provide dependable water delivery. A multiple water station arrangement, controlled from a single panel, allows one to direct water to some nursery areas but simultaneously to exclude it from others. This feature saves water and maintains flexibility within the nursery complex.

Commercial nursery supply catalogs should be consulted before any system is installed. Three general types of water delivery systems are: mist, continuous spray, and impulse (3). The mist system delivers a very fine, uniform water coverage as long as strong winds do not blow the mist off designated beds. Mist irrigation is ideal for germination flats because the fine water drops do not pack germination medium or wash seeds from the flats. Mist systems require about 280 to 350 g/cm^2 of water pressure for each nozzle. As many as 100 mist nozzles can be operated on one water line if booster pumps and tanks are used to increase water line pressure. Booster pumps are more economical to operate than elevated water-storage tanks that have a high pressure head of water.

Continuous spray nozzles have larger openings and deliver more water in a given time period than mist nozzles; they also cover larger areas. Thus, they tend to clog less than mist nozzles, are easier to clean once clogged, and water droplets are less likely to be blown about by wind.

Impulse systems work by water pressure from ram or other pumps. Water is ejected in a stepwise circular pattern, nozzles rotating several degrees as each jet of water is released. The nozzles are designed to spray a radius of up to 15 m or a diameter of 30 m. Since water is shot into the air, it falls back as large droplets similar to rainfall. This irrigation system is the simplest type. It is readily purchased as a portable system that is hooked into a main water line (>7.6 cm in diameter) within a few minutes.

Impulse systems are most efficient for bare-root beds in which water easily diffuses throughout the soil, a more difficult process when seedlings are in containers. Containizered nurseries in Hawaii and in the Blakawatra nursery in Surinam have successfully used impulse sprinkler systems. However, nurseries in both countries used rigid-walled containers. Nonrigid bag tops, e.g., plastic bags, tend to collapse, impeding water from entering soil in the bags.

Basic knowledge of water pressure and flow are desirable when nursery managers do not have access to a hydrologist or pump technician. The data below were calculated from formulas in a basic text on hydraulics (1). Average atmospheric pressure is assumed to be 1,033 g/cm^2, and the specific weight of water is 304.8 kg/m^2 (at 21°C). If a barometer were constructed using water, the water column at normal atmospheric pressure would rise to 10.3 m; with a slight correction, because of vapor pressure, height of the column would actually be 10.1 m.

By association, a water column that is 0.7 m high exerts a pressure (i.e., has a hydraulic "head") of 70.3 g/cm^2. Estimates of water pressure can then be made for storage tanks of known heights by using this relationship:

$$\frac{P_1}{H_1} = \frac{P_2}{H_2}$$

where P_1 = standard atmospheric pressure (1,033 g/cm^2),
P_2 = potential pressure (g/cm^2) exerted by water in any storage tank,
H_1 = height of water column (m) at standard atmospheric pressure,
and H_2 = height of water (m) in storage tank.

For example, if a water tank is 30.5 m above a nursery area, the potential pressure for any irrigation system is:

$$\frac{1{,}033\ g/cm^2}{10.1\ m} = \frac{P_2\ g/cm^2}{30.5\ m}$$

and, by rearranging and simplifying,

$$(102.3) \times (H_2) = P_2 \text{ or}$$

$$(102.3) \times (30.5) = 3{,}120\ g/cm^2 .$$

Similarly, other reference examples are:

Head or height *of water supply (m)*	***Pressure*** *(g/cm^2)*
0.3	30
3.0	310
4.6	470
15.2	1,550
22.9	2,340
30.5	3,120

II. General Management Scheme for Watering Nursery Seedlings

The following guides should help in determining correct application of water for nursery seedlings. The guides are generally applicable to containerized and bare-root stock in traditional or mechanized systems.

TRANSPLANT STAGE TO 3 WEEKS LATER

1. When necessary, lift several seedlings to check root growth. Check the soil daily for moisture needs during the first 2 weeks. Do not check the surface alone but rather the zone between 2 and 10 cm below the surface; this is the root zone that needs water.
2. If shade is used for 2 weeks following transplanting, adjust watering to actual soil conditions and needs.
3. The first 3 weeks is critical for watering because excess soil moisture causes damping-off. ***Never*** add fertilizer in a water soluble form during this stage.

3 WEEKS TO 2 MONTHS

1. Cut back on watering frequency. If very sandy soil is used in containers, do not under-water.
2. Watch for hypocotyl and stem growth change to woody tissue. When this physiological change occurs, water soluble fertilizers can be applied.
3. Maintain soil surface somewhat drier to avoid moss build up.
4. If not added before sowing, add mycorrhizal fungi to watering can and sprinkle seedlings during the fourth, fifth, and sixth weeks.
5. Inspect bottoms of bags; do not let water accumulate there.
6. Inspect sides of bags. If roots are concentrated in outer space between soil and bag, poor aeration is indicated. Reduce shade, if any, and cut back on watering.

2 TO 4 MONTHS

1. Use water soluble fertilizers at highest rates possible that do not cause excessive branching and excessive greening.
2. When adding fertilizers to irrigation water, do so at the end of watering periods to prevent fertilizer from washing out of containers, but rinse foliage with unfertilized water before ending the irrigation cycle.
3. Water as often as necessary to maintain a vigorous, succulent flush.
4. Avoid water stresses that can make seedlings semi-dormant in this stage.
5. Avoid heavy use of chlorinated or high-salt-content water.
6. When possible, use a soil moisture tester (tensiometer) to determine water tension in the soil. Probes are placed in the root zone area, with at least three readings per bed, each taken at a different position.
7. If a soil solu-bridge tester is used to take conductivity readings, more accurate readings are obtained ***before*** fertilization rather than afterwards. Soluble salts released by fertilizers tend to increase conductivity between the electrodes, causing a bias. Also, use a probe having the smallest possible diameter to avoid physical damage to the roots. Do not excessively wiggle the probe; this allows poor contact with the surrounding soil.

4 TO 7 MONTHS

1. Pine seedlings and most other subtropical species are ready for outplanting 5 to 7 months after germination. Thus, if hardening-off of seedlings is required, now is the time to do so.
2. Hardening-off is not entirely possible with semi-dormant pines. As a minimum, one tries to reduce succulent tissue growth by gradually decreasing watering frequency.
3. Bagged ***P. caribaea*** seedlings in clay loam soil normally survive 24 days or longer without water. However, serious damage occurs to seedlings grown in small volume containers filled with peat-based mixtures if more than 8 days go by without water. Death often occurs within 16 days if there is no watering. The best guide for nursery managers is experimentation with size of seedlings desired, preferred container type, and potting medium used. Because climatic conditions are different for each country, only experience and experimentation will indicate which water regime is best for a given species/container/pot mix combination.

III. Injector Alternatives for Soluble-Nutrient Watering Systems

Several types of liquid fertilizer injectors are available. The basic components of a precisely controlled injection system are:

- storage tank with an internal agitator to keep the solution thoroughly mixed;
- filter on the outer valve of the storage tank;
- pump that controls rate of injection into water lines, and
- pressure relief valve for the storage tank inlet and outlet valves.

Because of the corrosive nature of fertilizers, always use tanks, water lines, and pumps made of corrosion-resistant materials. Some leeway exists about the type of design needed to ensure adequate fertilization through nutrient injectors. Snedigar (*2*) presented the design for a simplified nutrient injector. It operates by air pressure within storage tanks, not by water-operated or motor-driven pumps. A skilled machinist can construct a similar injection system if he has blue prints or a diagram of the system used. Generally, for commercially bought units, the more expensive units give more precise injection rates.

Nutrient injectors are also activated by flowmeters. In one design, a watermeter installed in the water pipe counts the flow of water in liters. A solenoid on top of the water pump receives an electronic signal from the water-meter, which indicates water flow in the irrigation line. The solenoid valve then opens and feeds an exact proportion of fertilizer into the water line to make up the required dilution.

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3. Woodward, Guy 0. 2d. ed. Sprinkler irrigation. Washington, DC: Sprinkler Irrigation Association; 1959. 377 p.

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key-out of the reach of children and animals-and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Liegel, Leon H.; Venator, Charles R. A technical guide for forest nursery management in the Caribbean and Latin America. Gen. Tech. Rep. SO-67. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1987. 156 p.

Presents a comprehensive summary of forest nursery practices for the Caribbean, tropical Latin America, and, to a lesser degree, other tropical areas in the world. Actual and recommended practices are discussed, and the advantages and disadvantages of each are given with specific examples wherever possible. Included are chapters covering overall nursery planning, general seed management, and small- and large-scale nursery operations.

Additional keywords: Seedbed preparation and sowing, container and bare-root systems, pest and disease control, nursery nutrition.