Harvesting and Shipping

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Plants are ready for harvest and delivery to clients after they have reached target specifications (see Chapter 3, Defining the Target Plant) and have been properly hardened to withstand the stresses of handling and outplanting (see Chapter 15, Hardening). The "harvesting window" is the time period during which plants are at target size, maximum hardiness, and most tolerant to stress, that is, they are in the best condition for harvesting, shipping, and outplanting. The harvest window timing needs to be coordinated with the client's outplanting schedule to coincide with optimum conditions on the outplanting site.

Tropical plants do not achieve a deep dormancy condition and are therefore difficult to store and can be vulnerable to handling stresses. Plants need to be handled with utmost care at all times to minimize effects of temperature, moisture, or physical stresses. It is critical that plants be transported quickly and outplanted as soon as possible after leaving the nursery. This chapter describes proper scheduling, harvesting, handling, and shipping procedures for maintaining plant quality from the nursery to the field.

Facing Page: *A nursery staff member from the University of the Virgin Islands, Agriculture Experiment Station, delivers a healthy black olive (*Bucida buceras*) tree to a satisfied project partner. Photo by Brian F. Daley.*

Scheduling the Harvesting Window

In tropical nurseries, scheduling harvesting is based on the condition of both the plants and the outplanting site. Some tropical climates allow for a wide planting window so plants can be outplanted nearly year round if they are properly hardened and if soil moisture and temperature conditions at the planting site are favorable for survival and growth. Other tropical climates have pronounced dry seasons, monsoon seasons, or other times when planting windows are not open. Nurseries growing for projects with limited outplanting windows must schedule crop production carefully to ensure crops are not ready too early or too late (see Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records).

Site Conditions

For sites where a distinct dry season exists, scheduling harvesting according to the calendar along with experience of the nursery and field staff can be quite effective. In general, outplanting is most successful when planting is done just after the onset of the rainy season. The dates are selected based on past weather records and how well plants harvested on those dates have survived and grown after outplanting.

Figure 16.1*—Properly hardened tropical plants ready for harvest have lignified stems, well developed crowns, and healthy, leathery leaves. Photo by Diane L. Haase.*

Plant Characteristics

Growers use plant characteristics as indicators to help determine when plants are hardy enough to harvest and outplant. Hardened tropical seedlings have the following characteristics (Hall 2003) (figure 16.1):

- Firm, lignified stems, often brown in color.
- Sturdy, well developed crowns with leaves extending more than three-fourths of the length of the stem.
- Vigorous, compact, leathery leaves.

Client Communication

One challenging aspect of scheduling the harvesting window is coordinating with the client. Clients sometimes want their plants before the nursery has had adequate time for plants to achieve their target size and hardiness. More often, clients postpone the delivery dates, thereby increasing the likelihood of plants becoming rootbound or vulnerable to pests. Clear, frequent communication is essential to determine exactly when plants are needed for outplanting. It is crucial for the nursery staff to educate the client about the importance of timing and the consequences of hastening or delaying the harvesting window (reduced plant quality, reduced outplanting growth and survival, increased costs for hold over, and so on; see Chapter 18, Working With People, and Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records).

Grading Plants for Outplanting

Before being sent for outplanting, plants can be graded for size and quality according to established standards, outplanting objectives, or specifications agreed upon with the client. "Culls" are plants that do not meet the grading criteria or are damaged or deformed. Sometimes these criteria are adjusted during the grading process based on other cull and shipping factors that become apparent during the process. Typical grading criteria include size measurements such as shoot height and stem diameter at the root collar ("caliper") (figure 16.2). In addition, plants are inspected for root plug integrity, physical injury, or disease.

With single-cell containers in trays or racks, the typical grading process consists of removing each container from the rack, grading the plant within it, and then placing the container into either a "shippable" or "cull" rack. For polybag or larger containers, seedlings can be graded individually and sorted into separate areas based on size and quality. Plants that meet size and quality standards are considered shippable and are counted to establish an accurate inventory. The inventory of shippable plants can then be shared with the client. The nursery can also use the inventory as a

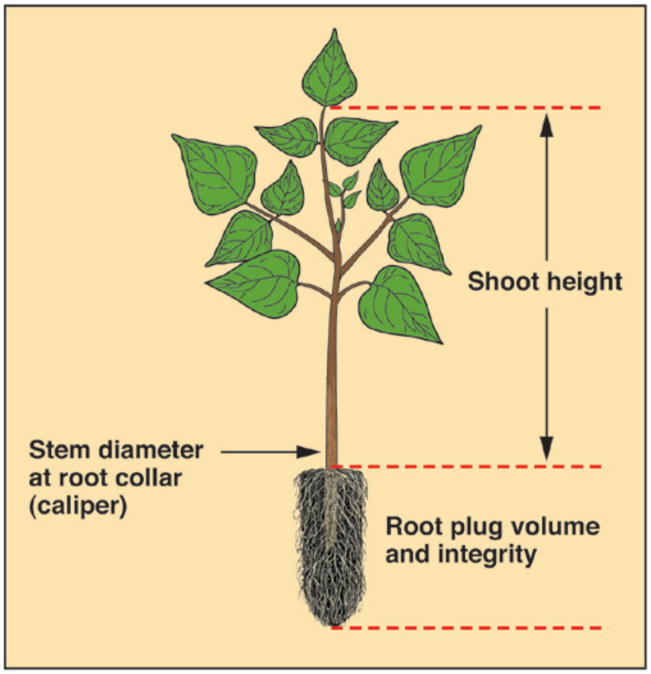

Figure 16.2*—Common grading standards include shoot height, stem diameter at the root collar ("caliper"), and root plug volume and integrity. Illustration by Jim Marin.*

record of plant sales and for planning future crops (see Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records).

Most nurseries grade their stock as part of the harvesting process while others ship ungraded stock to the outplanting site where they are graded immediately before outplanting.

Processing Cull Plants

Culls that are damaged or diseased are discarded or, better yet, incorporated into a compost pile (figure 16.3A). Composted culls can be reused as a soil amendment. For woody species, culls can be run through a hammer mill, tub grinder, or other machinery to hasten decomposition and speed-up the composting process (figure 16.3B). On a smaller scale the plants can simply be chopped with machetes or other hand tools. For some species, undersized but otherwise healthy plants can be held over for additional growth or transplanted into larger containers for future outplanting dates. This approach is common with cultivars that can be outplanted over a large geographic area or for threatened or endangered species where every plant is valuable.

Short-Term Storage

Plants destined for understory plantings or partially shaded sites can be held in a shadehouse (figure 16.4A) until they are shipped. Plants that have been hardened

Figure 16.3*—Culled seedlings, old growing media, and other greenhouse waste can composted (A). Woody materials and other green waste can be ground into smaller pieces by machinery to speed-up the composting process, as shown here at the nursery at Parque Doña Inés in San Juan, Puerto Rico (B). Photos by Brian F. Daley.*

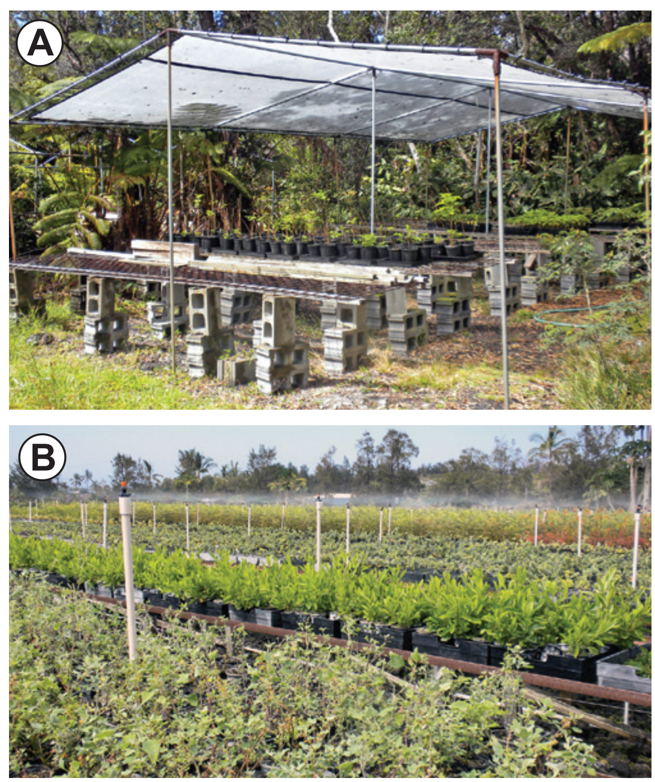

Figure 16.4*—Tropical plants can be held in a shadehouse (A) or open area (B) until they are shipped. Photos by Diane L. Haase.*

for full-sun conditions can be held in an open compound (figure 16.4B) because they may lose their conditioning if stored too long in the shade. Both structures are typically equipped with a reliable water source, so irrigation and fertigation are possible (see Chapter 5, Propagation Environments).

Larger containers can be stored in wire racks to keep them upright (figure 16.5A) or on pallets (figure 16.5B) to stop roots from growing into the ground. To aid in drainage, prevent seedling roots from growing into the soil, and retard weeds, plants can be placed on a layer of pea-sized gravel covered with landscape fabric. Fabric impregnated with copper can also be purchased that chemically prunes roots as they emerge from the bottom of the containers (figure 16.6).

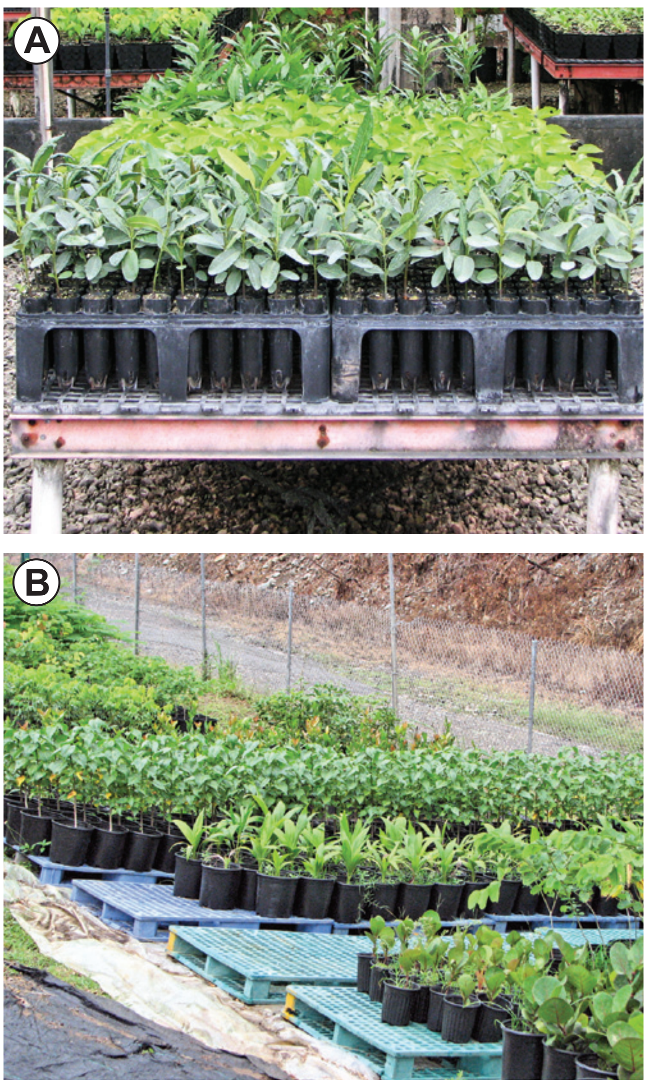

Figure 16.5*—Racks or benches can be used to store large container stock (A) and pallets can be used to keep plants off the ground (B). Photos by Ronald Overton.*

Packing

Tropical container seedlings are typically shipped in their containers. Seedlings in trays or racks can be shipped as is while seedlings in individual polybag containers or plastic pots can be placed in open-topped boxes or crates to minimize toppling and protect against mechanical injury (figure 16.7).

Because containers are expensive, nurseries may wish to remove plants from the containers at the time of packing. If seedlings are removed from containers, however, care must be taken to protect the root plug with plastic wrap or some other covering to prevent desiccation. As an alternative approach, nurseries may wish to charge a deposit or develop some other method to ensure containers are returned to the nursery for reuse.

Plants need to be packed for shipping in a manner that encourages air exchange and allows for possible irrigation on the outplanting site. Restricted airflow can trap the heat generated by plant respiration and result in damaging stresses. After the plants are graded and packed, the final step before shipping is to clearly mark each group of plants with the species, seedlot, number of plants, and other important information.

Shipping

When nursery stock is ready to outplant, it must be transported to the client or outplanting site. The most appropriate delivery method depends on the distance involved, the number of plants, and the hardiness of the stock. Most nursery stock in the tropics is delivered by truck or sometimes by boat. Nursery plants can be subjected to severe mechanical shocks during transport, especially on gravel or dirt roads,

Figure 16.6*—Copper-treated fabrics are ideal for ground storage because they chemically prevent plant roots from growing into the ground. Photo courtesy of Stuewe and Sons, Inc.*

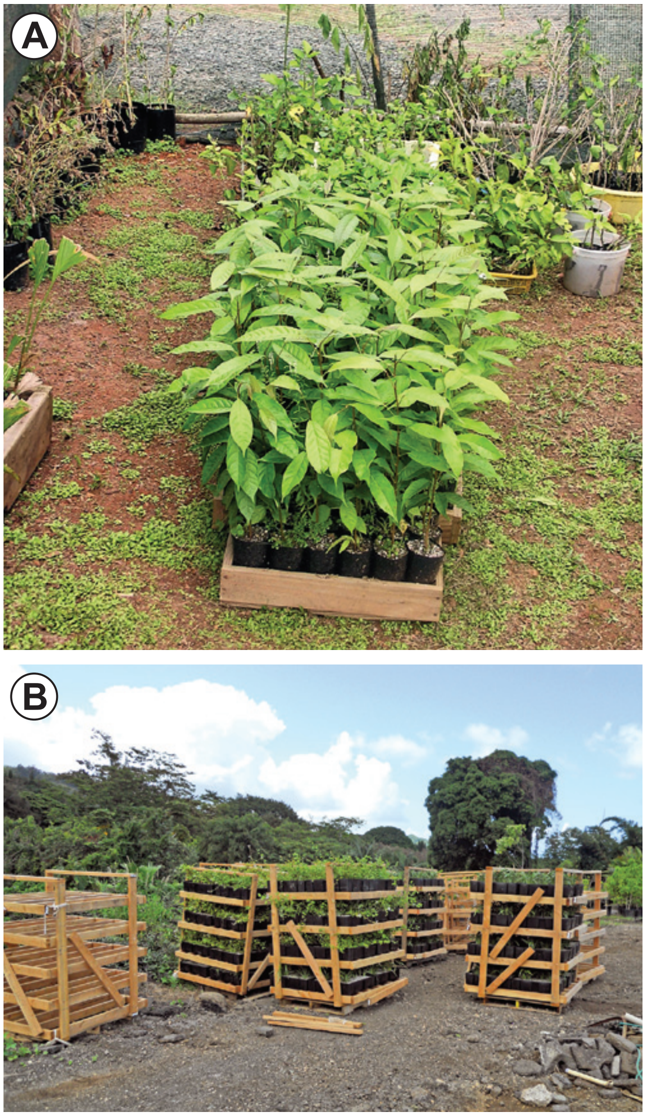

Figure 16.7—Plants need to be packed for shipping to minimize toppling and protect against mechanical injury. Photo A by Ronald Overton, and photo B by J.B. Friday.

Figure 16.8—Large container stock can be grown in special racks like these at the Forest Service J.H. Stone nursery in Central Point, Oregon (A). These plant can then be transported to the field in their nursery racks (B). Photos by Thomas D. Landis.

and reducing speed will minimize potential injury (Stjernberg 1997). When shipped by boat, the plants need to be packed so that they do not come in contact with sea spray, which can severely damage foliage and roots, although the damage is usually not visible for several days later.

Containers in racks, pots, or polybags are usually placed carefully on the floor or stacked on metal or wooden shelves inside the delivery vehicle. Large container stock can be transported in the same racks used at the nursery (figure 16.8).

The risk of injury to nursery stock increases with the shipping distance. High temperature is the major risk factor during nursery stock transport. The temperature inside the truck, van, trailer, or cargo container needs to be monitored during transit. Delivery vehicles should be aluminum or painted white to reflect sunlight and parked in the shade during stops and when they reach the outplanting site. An insulated truck liner can also be used to protect seedlings from heat (Anonymous 2006). Adding "blue ice" in the boxes of small shipments can help keep temperatures down although it could increase delivery costs. In some areas, refrigerated cargo containers are available; they are commonly used to transport produce but can be rented for transporting plants. Usually no need exists to turn on the refrigeration (it might cool the seedlings too much) because the containers are well-insulated and can keep plants cool and protected during transport even without the refrigeration on. Cargo containers can be left at the nursery and outplanting

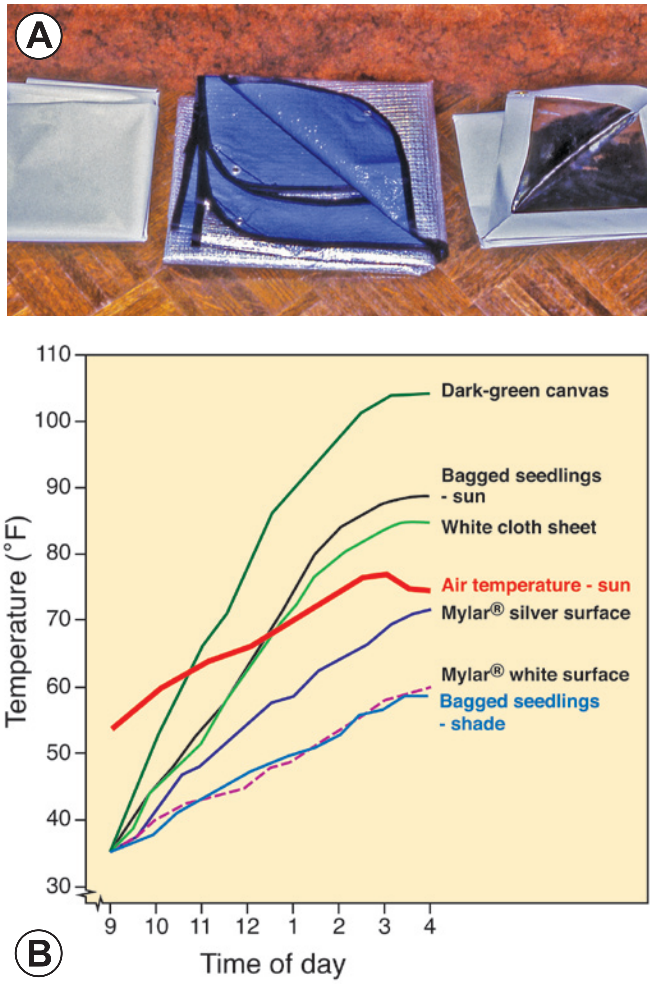

***Figure 16.9**—Special tarps protect nursery plants from direct exposure to sun and wind during shipping (A). Research has shown that reflective Mylar® tarps provide much better insulation than standard green canvas ones (B). Photo A by Thomas D. Landis, and illustration B modified from DeYoe and others (1986).*

site for a few days to allow time for loading and unloading but should be monitored for temperature and kept ventilated with a fan.

If open pickups must be used, then plants need to be protected from wind and sun damage by covering with a reflective tarp. A frame needs to be constructed to suspend the tarp above the seedlings so it does not crush the shoots or inhibit air circulation. Specially constructed Mylar® tarps with white outer and silver inner surfaces are available from reforestation supply companies (figure 16.9A). In operational trials, plants under such tarps were as cool as those stored in the shade (figure 16.9B). Dark colored tarps, such as army green canvas tarps, however, allow plants to heat to damaging levels and should never be used (DeYoe and others 1986).

Regardless of the vehicle used for shipping, air circulation created by spacers (such as wooden boards or foam blocks) between racks, pots, and boxes can be used to reduce heat buildup and to prevent the load from shifting.

Handling

Nursery plants are in a period of high risk from the time they leave the protected environment of the nursery until they are outplanted. Proper care when handling nursery stock during this vulnerable time is critical to ensure that it has the best chance for survival and growth after outplanting. During handling and shipping, nursery stock may be exposed to many damaging stresses including desiccation, extreme temperatures, or mechanical injuries (table 16.1). This period incurs the greatest financial risk because nursery plants have reached their maximum value right before shipping (Paterson and others 2001). In fact, handling nursery stock is considered a more important factor affecting plant quality than the type of outplanting tool (Adams and Patterson 2004).

It is important to emphasize to everyone who will be handling nursery stock that nursery plants are alive and perishable, and so should be treated with utmost care at all times. It is a waste of time and money to produce or purchase high-quality plants only to have them die or grow poorly after outplanting as a result of unnecessary stresses.

Plants are best able to tolerate stress when they are not actively growing. Nonhardened, succulent plant tissue is much more vulnerable to stresses. Regular monitoring of plant condition, close supervision of nursery and field personnel, periodic testing of plant quality, and maintenance of detailed records are essential during shipping and handling.

Moisture Stress

Desiccation is the most common stress encountered during handling, shipping, transport, and planting, and can have a profound effect on survival and growth. When exposed for only 5 minutes, seedlings can exhibit increasing moisture loss with increasing air temperature and wind speed (figure 16.10). A comprehensive evaluation of the various types of stresses affecting plants during handling and outplanting (DeYoe 1986) revealed that desiccation of the root system was the most damaging factor and that direct sunlight and high temperatures were significant only as they increased moisture stress. Plant water potential influences every physiological process and at stressful levels can greatly reduce growth even if survival is unaffected. These damaging effects can persist for several seasons after outplanting. Roots are very vulnerable to desiccation because, unlike leaves and needles, they have no

Table 16.1—Nursery plants are subjected to a series of potential stresses from harvest through outplanting. Adapted from Landis and others (2010).

Process	Potential for Stress			
	Temperature extremes	Desiccation	Mechanical injuries	Storage molds
Nursery storage	High	Low	None	Medium
Handling	Medium	Medium	High	None
Shipping	Medium	Low	High	None
Onsite storage	High	High	None	High
Outplanting	High	High	High	None

waxy coating or stomata to protect them from water loss. Fine root tips have greater moisture content than woody roots and are therefore most susceptible to desiccation; if fine roots appear dry, then they are probably already damaged or dead.

Roots of container plants are protected somewhat by the growing medium, which serves as a reservoir of water and nutrients. If the plug becomes too dry, however, desiccation damage can be severe. After roots have dried, subsequent growth reductions are inevitable, even when shoot water potential recovers (Balneaves and Menzies 1988). Moisture stress can be avoided by making sure plugs are kept moist (but not saturated) throughout their journey from nursery to outplanting. Container stock should be irrigated 1 to 2 days before harvesting depending on weather conditions (Fancher and others 1986). This approach allows the plugs to drain to field capacity; saturated media is unhealthy for roots; it increases shipping and handling weight and increases the potential for mold development.

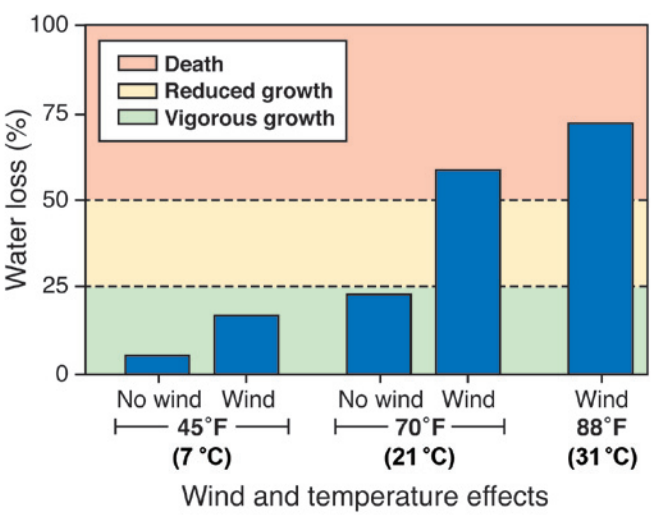

Figure 16.10—When bareroot conifer nursery stock was exposed for 5 minutes, plant moisture loss increased with higher temperatures and wind until plant survival and growth were adversely affected. Adapted from Fancher and others (1986).

Temperature Stress

Either hot or cold temperature extremes can quickly reduce plant quality during handling and shipping. Exposure to warm temperatures can damage stock by causing moisture stress or heat stress. Plants are alive and respiring and when they are exposed to warm temperatures, their respiration adds heat to their environment; this condition is particularly serious when air circulation is inadequate. Maintaining good air circulation will minimize heat buildup because of plant respiration. Exposure to direct sunlight results in a rapid temperature increase and can quickly dry out plants. During outplanting, the nursery stock usually sits for short periods during packing, shipping, and staging. It is important to have any or all of these activities occur in the shade to reduce temperature stresses.

Physical Stresses

Rough handling can result in reduced plant performance after outplanting. Each person involved in the handling and shipping of nursery stock needs to receive training on how to minimize physical stresses. The potential for physical damage to nursery stock can come from dropping, crushing, vibrating, or simply rough handling. Studies have shown that the stress of dropping boxes of seedlings reduced root growth potential, decreased height growth, increased mortality, and increased fine-root electrolyte

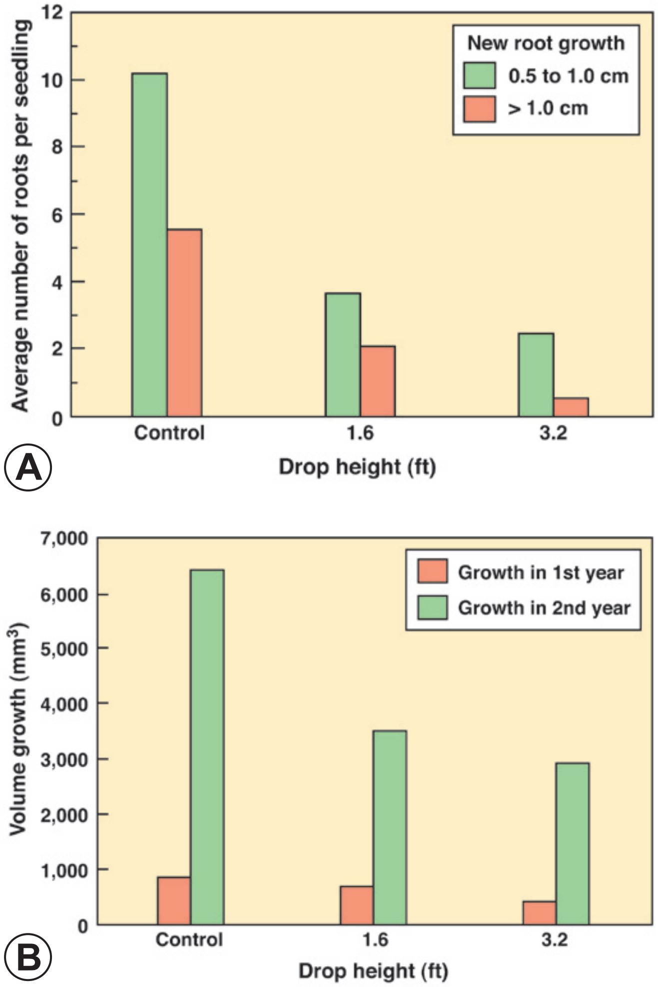

Figure 16.11*—When bags of conifer seedlings were dropped from different heights, their ability to produce new roots (root growth capacity) was significantly reduced (A). This mechanical injury still affected plant growth 2 years after outplanting (B). Adapted from Stjernberg (1996). [Metric conversions: 1 in = 2.5 cm; 1 ft = 0.91 m]*

leakage (Tabbush 1986, Sharpe and others 1990, McKay and others 1993). Stjernberg (1996) did a comprehensive evaluation of the physical stresses that nursery stock is subjected to during transport from the nursery to the outplanting site and found that white spruce seedlings produced fewer new roots as the distance the seedlings were dropped increased (figure 16.11A). Volume growth of these seedlings was still depressed 2 years after outplanting (figure 16.11B).

Accumulated Stresses

Nursery plants are at their maximum quality immediately before they are harvested at the nursery, but they then must pass through many hands before being outplanted. Outplanting success is dependent on maintaining plant quality by minimizing stress at each phase of the operation. As stress increases, the plant shifts energy from growth to damage repair. Physiological functions are damaged and survival and growth are reduced. These effects are exacerbated further when plants are outplanted on harsh sites. Extreme careless handling of planting stock usually manifests itself immediately after outplanting—plants die within days or weeks. Stressful injuries incurred between harvesting from the nursery and outplanting, however, may not always be evident until several weeks or months after planting. Symptoms include browning, chlorosis (yellowing), poor survival, or decreased growth.

It is useful to think of plant quality as a chain in which each link represents one of the events from harvesting at the nursery until planting at the outplanting site (figure 16.12). Because all types of abuse or exposure are cumulative, think of nursery plant quality as a checking account. Plants are at 100 percent of quality when they are at the nursery, and all stresses are withdrawals from the account (figure 16.13). Note

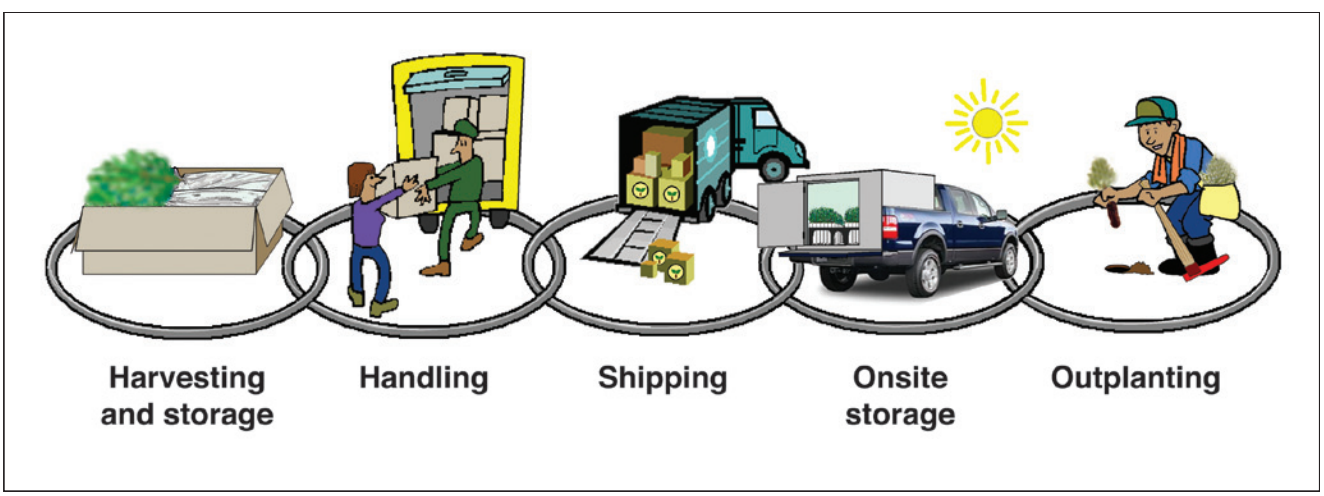

Figure 16.12*—Nursery plants are subjected to a series of stresses from the time they are harvested to when they are outplanted. Each stage in the process represents a link in a chain, and overall plant quality is only as good as the weakest link. Illustration from Landis and others (2010).*

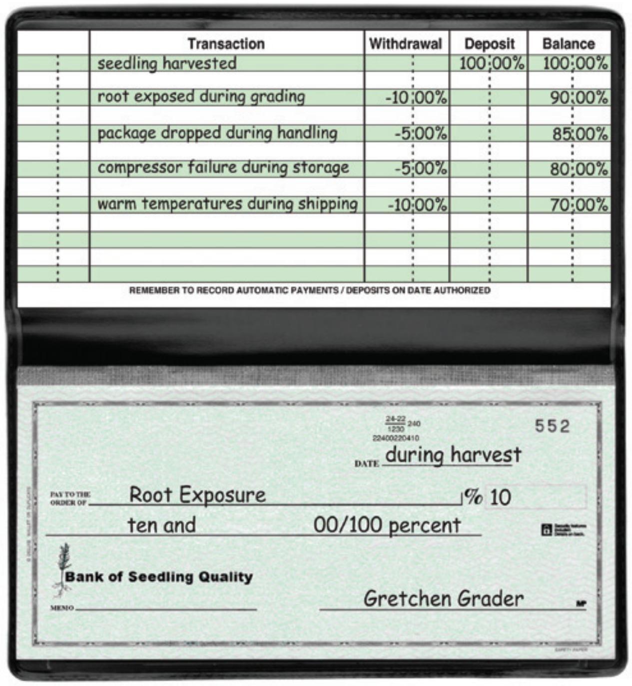

Figure 16.13*—It is useful to think of nursery plant quality as a checking account in which all types of abuse or stress are withdrawals. Note that all stresses are cumulative and no deposits can be made—it is impossible to increase plant quality after nursery harvest. Illustration from Landis and others (2010).*

that it is impossible to make a deposit; nothing can be done to increase plant quality after a plant leaves the nursery. Therefore, care must be taken during all the harvesting and shipping processes to help ensure outplanting success.

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