Hardening

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To promote survival and growth following outplanting, nursery stock must first undergo proper hardening. Hardening increases plant durability and resistance to stress by gradually acclimating plants to field conditions before outplanting. Without proper hardening, plants are likely to suffer from transplant shock, grow poorly, or die on the outplanting site. It is important to understand that native plant nurseries are different from ornamental nurseries in that most native plants planted in reforestation and restoration projects must endure an outplanting environment in which little or no aftercare is provided.

Hardening refers to practices during the nursery cycle that prepare plants for the stresses of handling, shipping, outplanting, and field establishment (Longman and Wilson 1998, Landis and others 1999). Plant hardiness primarily develops internally, although certain external characteristics such as thickening stems and reduced succulence in the foliage are indicators of hardiness. This process takes time and a common mistake of nursery growers is not to schedule adequate time to harden their crops.

To properly harden plants, it is important to consider the Target Plant Concept presented in Chapter 3, Defining the Target Plant, and crop planning presented in Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records. Using knowledge of the expected conditions of a given outplanting site, nursery cultivation may be adjusted to acclimatize plants for site conditions by promoting specific traits. For instance, on sites where drought is anticipated, a larger proportion of roots relative to shoots may be desirable to improve plant resistance to moisture stress. Based on the client's anticipated outplanting date, the propagation schedule can then be developed to include an appropriate hardening period in the nursery before plants are delivered to the client.

In this chapter, we illustrate the importance of proper hardiness in promoting plant performance following outplanting, discuss how hardiness changes through the nursery growing cycle, describe how plants may be conditioned to prepare them for the characteristics of a particular outplanting site, and suggest treatments that may be used in tropical plant nurseries to help promote hardiness.

Facing Page: *Well-hardened crops at Native Nursery on Maui. Photo by Diane L. Haase.*

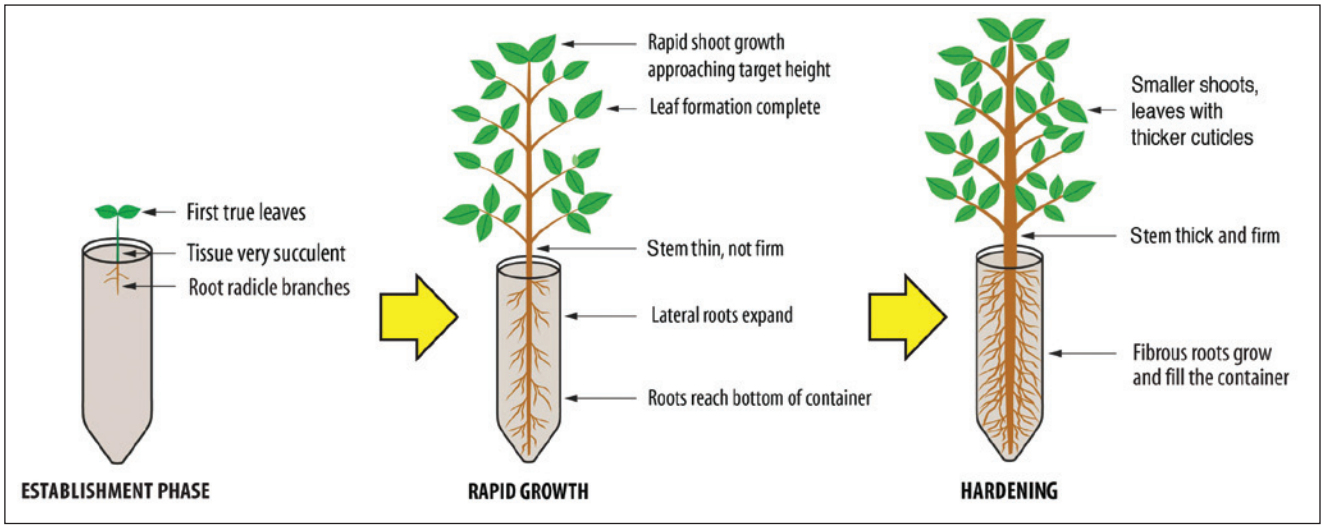

Figure 15.1*—Nursery plants go through three stages of growth: establishment, rapid growth, and hardening. The hardening phase is crucial to plant survival after outplanting, yet is too often neglected by nursery managers. Illustration adapted from Dumroese and others 2008.*

The Importance of Hardening

As described in Chapter 3, Defining the Target Plant, the success of nursery plants is not determined by how nice the plants look in the nursery, but rather by how well the plants survive and thrive after outplanting. As described in Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records, plants need to be cultured through three phases of growth: establishment, rapid growth, and hardening (figure 15.1). During the establishment and rapid growth phases, ideal conditions for development and growth are provided (figure 15.2A). These first two growth phases provide plants with optimal levels of all potentially limiting factors (water, light, nutrition, and so on) while minimizing environmental stresses. Plants should not go out to the field while they are still in their rapid growth phase; these plants look lush and healthy but are not prepared for the stresses of outplanting (figure 15.2B). The hardening phase of nursery culture is essential to acclimate plants to the stresses of handling and transport, and the conditions of the outplanting site.

All good growers will do their best to reduce stresses to plants when they leave the nursery, as described in Chapter 16, Harvesting and Shipping, and Chapter 17, Outplanting. Nevertheless, nursery plants will be exposed to a series of unavoidable stresses when it is time for them to leave the nursery. The harvesting process requires moving and handling plants, which creates potential for physical and internal damage. Following harvesting, nursery plants are transported to the outplanting site (figure 15.3). During transportation and handling at the site, plants are often exposed to unfavorable environmental conditions until

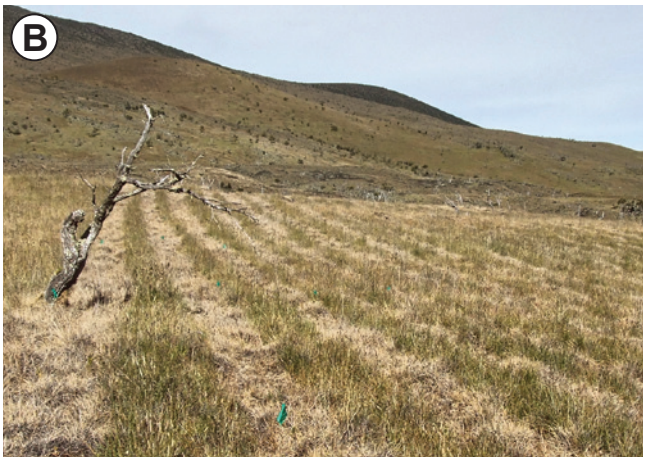

Figure 15.2*—Succulent shoot tissue (A) would be damaged by the stresses of handling, transport, and outplanting. Plants in their rapid growth phase look lush but are not prepared for the stresses of outplanting. The hardening phase creates a controlled amount of stress for plants, gradually acclimating them to the conditions of the outplanting site (B). Photo A by Douglass F. Jacobs, and photo B by J.B. Friday.*

being outplanted. For instance, a ride in the back of a truck, even when protected under a cover, will be bumpy and possibly hot. Sunny and windy conditions on the outplanting site can result in overheating or desiccation damage.

The hardening phase creates a controlled amount of stress for the plants while they are still in the nursery, helping the plants to survive the stresses of handling and shipping and acclimating them to the conditions of the outplanting site (figure 15.2B). Often, these conditions include full sun, low amounts of available nutrients, and limited soil moisture. After outplanting (figure 15.4), the plants may undergo a period of "transplant shock". This shock is primarily because of moisture stress and lasts until the roots are able to grow out into the surrounding soil to access water and nutrients, compete with other plants, resist insect and animal browse damage, and endure extreme temperatures.

Proper hardening takes time, and it is a common mistake to rush the process. This mistake often happens when growing more than one crop per season or when growers try to force a little extra height growth with crops that grow more slowly than expected. Improper hardening can also be an issue if the outplanting window was not properly defined, as described in Chapter 17, Outplanting. For example, for areas with a pronounced dry season, the late or early arrival of the wet season may complicate hardening schedules. Hardening requirements vary by species and outplanting sites, but for many tropical species, hardening phases of 4 to 12 weeks are common.

***Figure 15.3**—Hardening prepares nursery plants for a series of unavoidable stresses they will experience when it is time for them to leave the nursery. These stresses include handling and transportation, such as a ride in the trunk of a car. Photo by Thomas D. Landis.*

Objectives of the Hardening Phase

The objectives of the hardening phase will vary by species and outplanting environments. In general the objectives are to—

- Slow shoot growth.
- Encourage root and stem diameter growth (for good shoot-to-root balance).
- Acclimate to the outplanting environment.
- Condition to endure stress.
- Fortify for survival after outplanting.

Practices to reach these objectives may include—

- Introducing gradual, moderate moisture stress.
- Progressively exposing plants to sun equivalent to outplanting conditions (full sun in most cases, partial shade for understory plantings).
- Reducing fertilization rates and changing mineral nutrient ratios.
- Providing good airflow and wind exposure.
- Culturing for root health and proper shoot-to-root balance.

***Figure 15.4**—Recently outplanted nursery stock must rapidly develop new roots that can grow out into the surrounding soil to access water and nutrients, compete with other plants, resist insect and animal browse damage, and endure extreme temperatures. Photo by Douglass F. Jacobs.*

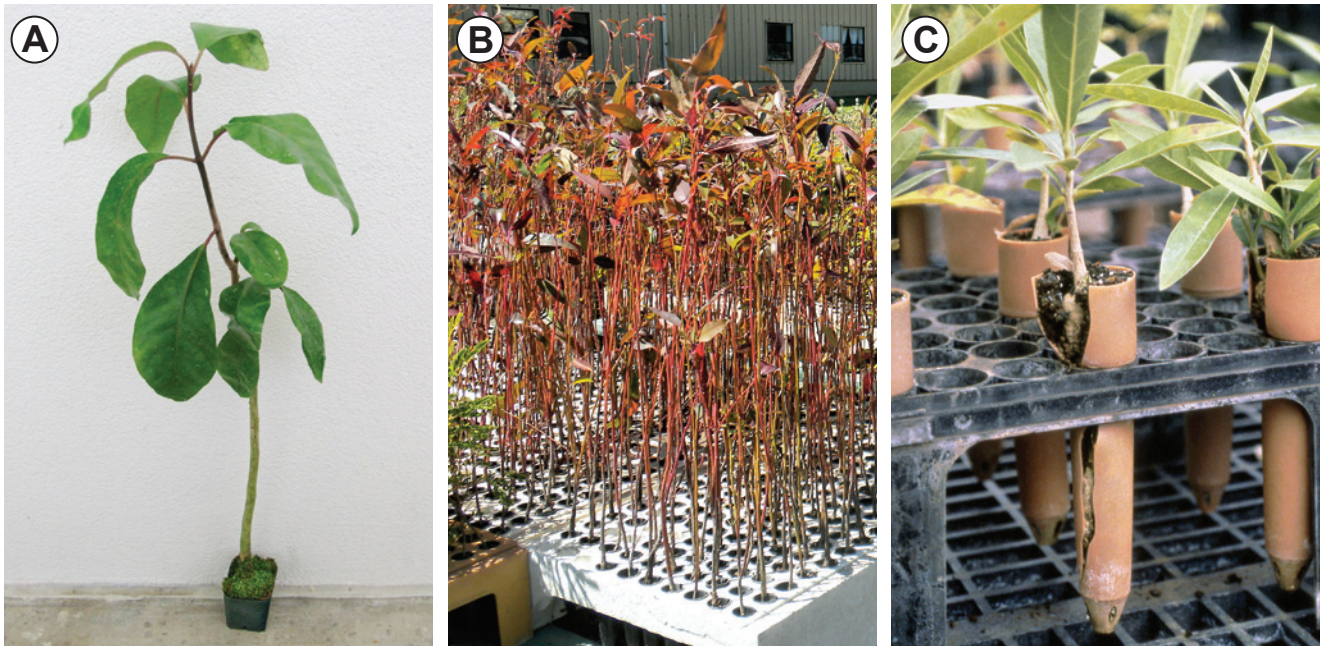

***Figure 15.5**—This native plant grew way too large for such a small and inappropriate container; it is unlikely that this tree would flourish if outplanted (A). These tall, spindly seedlings were grown close to one another and have been held too long (B). These seedlings are root-bound from being held too long (C). Photo A by J.B. Friday, photo B by Diane L. Haase, and photo C by Thomas D. Landis.*

Shoot-to-Root Balance

Shoot-to-shoot balance is the ratio of shoot biomass to root biomass, not shoot length to root length. It is one important way to describe plant size and balance. Growing nursery plants to the appropriate size for a specific container size is critical. Plants grown too long in small containers or too close to one another become tall and spindly and do not have enough stem strength to resist physical stresses after outplanting (figures 15.5A, 15.5B). In addition, these "top-heavy" plants do not have enough roots to provide moisture to the foliage, so water stress can develop after outplanting. In tropical areas, top-heavy plants face the additional risk of storm-force winds and are susceptible to blow overs, particularly in the first few years after outplanting. Roots in containers that are too small often begin to spiral and become compacted (figure 15.5C). In these "rootbound" plants, most roots become woody and less effective in water uptake and, after outplanting, do not grow out from the compacted root mass to promote structural stability.

One key to developing a plant with a sturdy shoot and well-balanced root system is to select a container that is appropriate for the species and conditions on the outplanting site (figure 15.6). Plants should be moved from the shaded or protected areas in the nursery as soon as they have reached their target height. Experienced growers know that moving plants from a protected area of the nursery to an open compound is an easy and effective way to keep them in proper shoot-to-root balance. Managing light, nutrition, airflow, and other factors are also important, as described in the following sections.

Conditioning Plants for Outplanting

To induce plant hardiness and properly condition plants to resist stresses, nursery practices are gradually adjusted.

***Figure 15.6**—Some keys to developing a plant with a sturdy shoot and well-balanced root system are to select an appropriate size container; to move plants from protected areas to open compounds; and to otherwise manage light, nutrition, airflow, and water. Photo by Ronald Overton.*

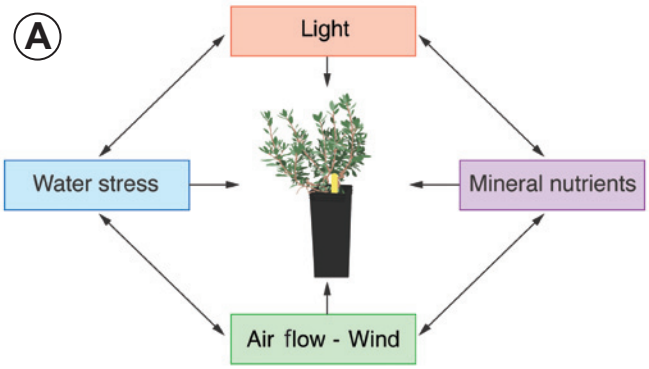

Figure 15.7*—Nurseries manipulate environmental factors—light, nutrition, airflow, and water—to slow shoot growth and induce hardiness (A). At the Metropolitan Arboretum nursery for Parque Doña Inés in Puerto Rico, native palm seedlings are hardened on weed barrier cloth in full sun (B). The pots are mulched with locally available white stones to reduce weeds and water loss from evaporation. Illustration A by Jim Marin, and photo B by Brian F. Daley.*

Figure 15.8*—Reducing irrigation to induce a mild moisture stress helps harden crops (A). Severe water stress to the point that plants wilt (B) is harmful, however. Photos by Thomas D. Landis.*

These adjustments must not be too severe, however, because overly stressed plants will actually be less hardy. To understand how nursery practices affect hardening, growers need to know the role that environmental conditions play in creating hardiness in plants. In the tropics, the main environmental factors that affect plant hardiness are light, water, and nutrition (figure 15.7). Wind, airflow, and other conditions also affect plant hardiness. When nursery plants have reached their optimum ("target") size, growers adjust shade/sunlight, water stress, fertility, airflow/wind, and physical factors such as root or shoot pruning to slow shoot growth and induce hardiness.

In determining how to properly condition plants for the intended outplanting site, it is important to consider the characteristics of the species and the outplanting site. For instance, is this a light-demanding species or a shade-loving species? Will plants be outplanted in an open field or underneath an existing canopy of trees? Will the site be prone to extended dry periods? Do other extreme site conditions exist such as high wind, poor soils, or salt spray? Understanding the character of the site is best accomplished by interacting closely with the client ordering the plants. These factors all reflect the main principles of Chapter 3, Defining the Target Plant, which suggest that the characteristics of nursery stock be matched to those of the intended outplanting site. Experience is the best teacher—experiment on a few plants and discover which hardening practices work best in your nursery circumstances and outplanting sites.

Water

Reducing irrigation duration or frequency creates a mild moisture stress, slows shoot growth, and helps condition nursery stock to withstand drier conditions on outplanting sites (figure 15.8A). This reduced water availability decreases the possibility of producing top-heavy plants and encourages the formation of smaller leaves with thicker cuticles that transpire less (lose less water) after outplanting. Smaller shoots are also less likely to be physically damaged during transplant.

Watering frequency needs to gradually be reduced to ensure that plants do not permanently wilt or experience severe water stress (figure 15.8B). Adjusting irrigation for hardening requires close observation and experience. The best way to quickly and accurately evaluate the water status of container plants is to weigh the growth container. See Chapter 11, Water Quality and Irrigation, for a discussion of irrigation monitoring with container weight.

After plants are hardened, they will still require a full watering before outplanting and will need good soil moisture availability at the outplanting site during their early establishment in the field. Many tropical areas have pronounced wet and dry seasons. Planting shock can often be minimized by outplanting after the onset of the rainy season, as described in Chapter 3, Defining the Target Plant, and Chapter 17, Outplanting.

Sunlight

The use of sunlight and shading as a conditioning treatment depends on the conditions on the outplanting site and the light needs of the species. Plants that will be planted into full sun conditions should receive minimal or no shading during nursery cultivation, especially during the hardening phase. If plants were started in a covered area (figure 15.9A), they need to be progressively exposed to a level of sunlight equivalent to the outplanting site (full sun in most cases, partial shade for understory plantings) (figure 15.9B). Growing plants in outdoor areas also exposes them to ambient temperatures.

Install shadecloth or move the crop to a shadehouse to reduce the amount of light a crop receives when it will be outplanted in understory or partial shade conditions. Shading is probably an overused treatment in nurseries, however, because most species (even those classified as shade tolerant) tend to grow best in full sunlight. In addition, many tropical plants often grow excessively in height ("stretch") under high shade, which may create a shoot-to-root imbalance. Nonetheless, if the species is shade loving and will be planted onto a site underneath an existing canopy, then shading may be a useful treatment.

Mineral Nutrition

Reducing or stopping fertilization along with reducing irrigation slows shoot growth and hardens plants. Among the mineral nutrients, nitrogen, particularly in the ammonium form, is the primary driver of shoot growth. During hardening, it can be helpful to reduce or stop nitrogen fertilization to induce a mild nutrient stress. (Note: the use of controlled-release fertilizers with long release periods can prevent or delay hardiness from developing.)

Some fertilizers have been specifically developed to aid in plant hardening, often containing a low-nitrogen–high-potassium formulation. Calcium nitrate is also a useful hardening fertilizer because it contains the nitrate form of nitrogen, which does not promote shoot growth. Calcium also helps develop strong cell walls and leaf waxes. Be sure not to use a similar product known as

***Figure 15.9**—Shade may be used during early phases of plant growth (A), but shade should be removed in the hardening phase to expose plants to a level of sunlight equivalent to the outplanting site (B). Photo A by Thomas D. Landis, and photo B by Diane L. Haase.*

calcium ammonium nitrate because the ammonium can stimulate shoot growth.

Air and Wind

Increased distance between individual containers improves air circulation, allows more sunlight to reach lower leaves, encourages the development of shorter plants with larger stem diameter, and also promotes thickening of the leaf cuticle. Containers with individual, removable cells can be changed to every other slot to increase spacing within the trays during the hardening period (figure 15.10).

An interesting wind simulation treatment is known as "brushing." This practice came about after growers observed plants repeatedly handled during crop monitoring tended to develop greater stem diameter. The effect is replicated by gently moving a horizontal pole (such as a clean length of bamboo, or a light PVC pipe) through the crowns of the plants in both directions. Of course, this practice must be done gently, especially when the foliage is still succulent. Nurseries with traveling irrigation booms have mechanized the process by hanging a PVC pipe from the boom. A good time to brush plants is right after overhead irrigation because the rod also shakes excess water from the foliage and reduces the potential for foliar diseases such as Botrytis.

***Figure 15.10**—Containers with individual, removable cells can be changed to every other slot to increase spacing within the trays during the hardening period. Photo by Diane L. Haase.*

Root Culturing

A vigorous, fibrous root system distributed evenly throughout the container will rapidly proliferate after outplanting. Containers with vertical ribs facilitate healthy root structure by limiting root spiraling and are designed to promote air pruning at the drainage hole. Other root culturing features such as sideslit air pruning and copper pruning are effective, especially with vigorous rooted species. See Chapter 7, Containers, for more information on these features.

After plants are moved outdoors, it is important not to place the containers directly on the ground (figure 15.11). Instead, plants need to be placed on benches or pallets to facilitate air pruning of roots (figure 15.12). Otherwise, roots may grow directly into the ground, which will require the added task of root pruning during harvest. Root pruning immediately before outplanting can make the plants more vulnerable to pathogenic fungi and may delay quick root outgrowth after outplanting. If plants must be on the ground, placing groundcovers under them that are impenetrable to roots (such as fabrics treated with copper) can be helpful.

Shoot Pruning

Pruning shoots or "top pruning" is sometimes required if the top is too large for the root system. In general, the shoots of grasses, forbs, and some shrubs and trees can be pruned. However, many trees can be negatively affected by shoot pruning, so it is generally only recommended as a problem-solving technique for species known to be tolerant of pruning. Faster growing plants with a multi-stemmed form tend to tolerate shoot pruning whereas slower growing plants or species characterized by a single leading shoot tend not to tolerate shoot pruning. When working with new species, a small pruning trial is the best way to see how the species responds.

Figure 15.11—*Plants grown in direct contact with soil (A) may grow into the ground (B). Photos by Douglass F. Jacobs.*

Figure 15.12—*Plants in a hardening area need to be placed on benches designed to facilitate air pruning and prevent roots from growing into the ground (A) such as the benches used in this nursery in Rota (B). Photos by Thomas D. Landis.*

For species that can tolerate shoot pruning, shoot pruning can help maintain a proper shoot-to-root balance and reduce water stress resulting from excessively high transpirational demand. Pruning also stimulates more stem and root growth. Pruning should be done just above the height of the smaller plants that have been overtopped (figure 15.13). This practice results in additional light for smaller plants and helps them reestablish a growth rate that is consistent with the rest of the crop.

It is critical that shoot pruning treatments not be too severe; a rule of thumb is never to remove more than one-third of the total shoot. Pruned plants should always be healthy and have enough stored energy to rapidly grow new tissue. The International Society of Arboriculture

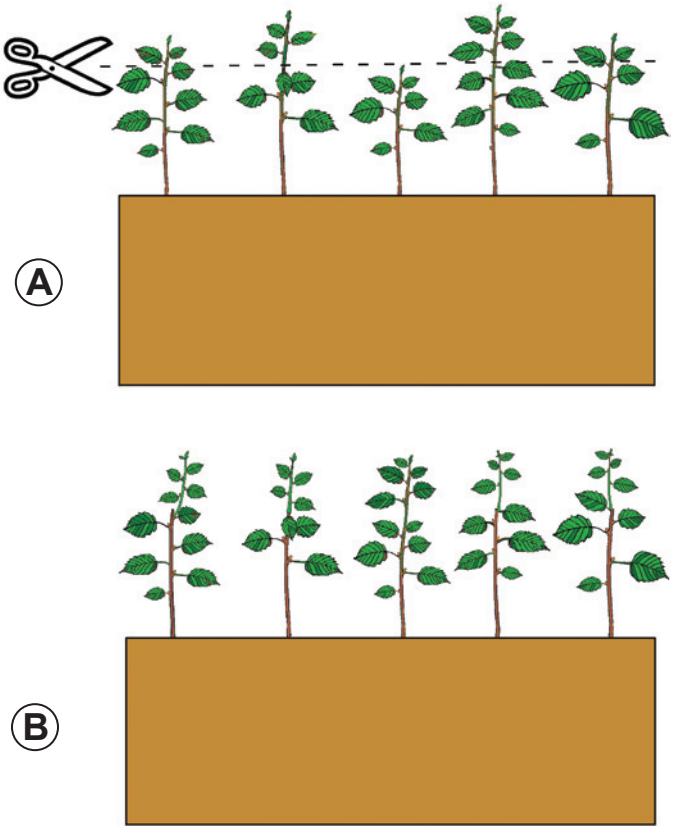

***Figure 15.13**—For species that can tolerate shoot pruning, the objective is to reduce the height of taller plants (A), thereby exposing smaller plants to more light and allowing them to "catch up" (B). Illustrations by Jim Marin.*

(http://www.isa-arbor.com/) publishes extensively on when and how to best prune plants for improved plant health and form. It is best to prune succulent tissue because woody stem tissue has less regenerative ability.

Some growers have delivered "striplings" for outplanting, which are severely pruned saplings, sometimes with foliage also removed. The perceived advantage to striplings is they are easy to transport, harder to damage in shipping, and lose less water to transpiration immediately after planting. This extreme practice is not recommended because stripping plants of their foliage often results in mortality after outplanting.

References

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