Vegetative Propagation

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10

Many desirable and ecologically important tropical plant species can be difficult or very time consuming to propagate by seeds. Thus, nursery growers may want to investigate how to propagate these species by vegetative propagation, which is accomplished by combining classic horticultural propagation techniques with an understanding of the ecological and reproductive characteristics of the species. Plants that inhabit tropical ecosystems often reproduce vegetatively (that is, asexually without seeds or spores). Vegetative propagation is commonly used with species that have short seed life, low seed viability, or complex seed dormancy. All new daughter plants that arise from vegetative propagation are genetically identical to the mother (donor) plant, and these resulting individuals are known as "clones" (figure 10.1).

Facing Page: *Vegetative propagation is the production of daughter plants from the stems, leaves, roots, or other portions of a single mother (donor) plant. Photo by Ronald Overton.*

Comparing Vegetative to Seed Propagation

The following situations favor vegetative propagation over seed propagation:

- Seed propagation is difficult or very time-consuming.
- Viable seeds are produced infrequently or in small quantities.
- Larger nursery stock is needed in a shorter period of time.
- An individual, unique plant needs to be propagated.
- A need exists to shorten time to flower for seed production.
- A uniform stocktype is needed.
- Specific genotypes are desired.
- Disease-free nursery stock is required.

Disadvantages of using vegetative propagation include—

- Greater production costs than seed propagation, usually because of increased labor.
- Reduced genetic diversity.
- Specialized propagation structures may be required, based on the time of year and the species to be propagated.

Depending on the plant species, vegetative propagation can be done with pieces of stems, leaves, roots, bulbs, corms, tubers, and rhizomes. The species, the type of vegetative material used, the time of year that material is collected, how it is handled and manipulated to induce rooting, and proper application of the correct environmental conditions all affect vegetative propagation.

Because vegetative propagation is more costly than growing seedlings, the production system must be efficient. A general rule of thumb is that at least 50 percent rooting must be obtained to produce cuttings economically. If rare species or individual plants are being propagated, however, costs may be less important.

Consider these methods to reduce production costs:

- Develop a smooth production line, from the collection of material to the final product.
- Train nursery staff how to properly collect, process, plant, and grow material.
- Build a dibble for making holes in the rooting medium.
- Keep good records to improve your results and to document production costs.

Figure 10.1*—Propagation of plumeria by cuttings produces genetically identical plants. Photo by Tara Luna.*

Cuttings

A cutting is the portion of a plant that is collected, treated, and planted to develop into a new intact plant complete with stems, leaves, and roots. Cuttings can be collected from mother plants in the wild, or special donor plants can be cultured in the nursery. Selection of mother plants must be done carefully; it is as important as the origin of seeds to ensure that nursery stock is well adapted to the outplanting environment. Collection of cuttings should follow the same ethical guidelines as collection of seeds to establish proper genetic diversity and sustainability of wild populations (see Chapter 8, Collecting, Processing, and Storing Seeds). In addition, the ability of cuttings to root is often clone-specific, so it is important to record the origin of cuttings and subsequent rooting success.

Striking is the process of placing the cutting into soil or a rooting substrate. Often, propagators will say that cuttings have been "struck" to indicate that the cuttings have been placed in the rooting substrate.

Shoot or Stem Cuttings

Shoot cuttings, also referred to as stem cuttings, are the most common type of cuttings and can be broadly placed

Figure 10.2*—Hardwood cuttings are collected during the dry season or when deciduous tropical species shed their leaves. Photo by Thomas D. Landis.*

into three categories depending on the stage of growth they are in when collected. Hardwood cuttings are made from the previous year's mature wood of trees and shrubs and are usually collected during the dry season in the tropics, when the leaves of deciduous species have dropped (figure 10.2). Semihardwood (greenwood) cuttings are collected towards the end of the active growth season when stem tissues have hardened and terminal buds have formed or just after a flush of growth has taken place and the wood is partially matured. Softwood cuttings are collected when stems and leaves are actively growing.

Hardwood Cuttings of Deciduous Species

Tropical deciduous hardwood stem cuttings are the easiest, least expensive type of cuttings because they are easy to prepare, are not as perishable as softwood or semihardwood cuttings, can be stored in coolers or shipped if necessary, and require little or no special equipment during rooting. They are sometimes struck directly on the outplanting site or brought back to the nursery to grow as bareroot or container stock.

If deciduous hardwood cuttings are struck directly on the outplanting site, they can be live stakes (12- to 16-in [30- to 40-cm] long), poles (12- to 16-ft [3.6- to 4.9-m] long), or branched cuttings (2- to 6-ft [0.6- to 1.8-m] long). These cuttings are collected during the dry season until the early onset of the rainy season and outplanted when the cutting is leafless and the soil at the outplanting site is wet. Live stakes and branched cuttings are usually driven into the ground with a mallet and need to be planted deep enough to reach moisture in the soil profile with only three to four nodes (buds) above ground. Poles are much longer and are also driven deep enough so they can be in contact with the water table, but the aboveground stem is much longer. Hardwood pole cuttings of *Erythrina*, *Gliricidia*, and other species are commonly used this way for windbreaks, living fences, and restoration projects.

If hardwood cuttings are struck in the nursery, they can be straight, heel, or mallet cuttings (figure 10.3). Straight cuttings are made from straight hardwood stems and are the most common type for easy-to-root species. Heel cuttings are made from 2-year-old side shoots. To make a heel cutting, pull the side shoot away from the tip so that a section of older wood remains at the base of the cutting. Mallet cuttings include a cross-section of older stem at the base of the side shoot.

All hardwood stem cuttings have an inherent polarity and will produce shoots on the distal end (nearest the bud) and roots on the proximal end (nearest the main stem or root system). If planted upside down, the cutting will not root. When using straight or live stake deciduous cuttings, the tops and bottoms of the stems need to be distinguished. The absence of leaves can make it difficult to discern the top from the bottom, so it is useful to cut the bottoms diagonally and the tops straight across. The diagonal cut maximizes water uptake area at the base, and the straight cut minimizes the water loss area at the top.

Figure 10.3—*Left to right: straight, heel and mallet cuttings. Straight cuttings are used on easy-to-root species, while mallet and heel cuttings are used on species that are more difficult to root. Photo by Tara Luna.*

Hardwood Cuttings of Evergreen Species

Hardwood cuttings of broadleaf tropical evergreen and coniferous species are usually taken during the dry season or just after a new flush of growth during the growing season. Unlike deciduous hardwood cuttings, evergreen cuttings must be struck into a special rooting environment (see Chapter 5, Propagation Environments) as soon as possible because they cannot be stored for any length of time. Evergreens are best rooted in special rooting environments after being wounded or treated with rooting hormone (described in the following sections). Cuttings are usually 4 to 8 in (10 to 20 cm) long, with all leaves removed from the lower half. Green tips and side shoots also need to be removed. The large leaves of tropical broadleaf evergreen plants are usually cut in half to reduce water loss during rooting (figure 10.4). Straight, mallet, and heel cuttings are also used with evergreen species (figure 10.3).

Semihardwood Cuttings

Semihardwood (greenwood) stem cuttings are made from newer shoots of leafy broad-leaved evergreen plants and leafy deciduous species. Cuttings are taken just before the onset of the dry season, towards the end of the active growth season when stem tissues have hardened, or just after a flush of growth when the wood is partially matured. In many cases, the terminal bud has formed. Semihardwood cuttings are propagated in the same manner as evergreen hardwood cuttings.

Softwood Cuttings

Prepared from the new growth of deciduous or evergreen species, softwood cuttings generally root easier than other types of cuttings but require a special rooting environment and more attention to prevent desiccation. The best cutting material has some degree of flexibility but is mature enough to break when bent sharply (figure 10.5). Extremely fast-growing tender shoots are not desirable.

Herbaceous stem cuttings are softwood cuttings made from nonwoody plants. They are handled in the same way as softwood cuttings (figure 10.6). Many succulent tropical plant cuttings, including some cacti, are easily propagated in this manner; cuttings need to be allowed to develop callus for a week before inserting the cutting into rooting media. Succulent cuttings root readily without misting or high humidity.

Root Cuttings

Although not used as much as other types of cuttings, root cuttings can be made by dividing roots into individual segments containing dormant shoot buds capable of developing into new plants. Root cuttings are typically used on species that fail to root well from stem cuttings. Breadfruit (*Artocarpus* species) and noni (*Morinda citrifolia*) are commonly propagated from root cuttings (figure 10.7). Root sections are collected any time of the year in the tropics.

Figure 10.4—*The leaves of some broadleaf evergreen cuttings are usually cut in half to reduce the amount of water loss during rooting. Photo by Thomas D. Landis.*

Figure 10.5—*Rooted softwood stem cuttings of hibiscus. Softwood stem cutting material has some degree of flexibility but is mature enough to break when bent sharply. Photo by Tara Luna.*

***Figure 10.6**—Many herbaceous tropical species, such as āwikiwiki (*Canavallia *species) can easily be rooted from cuttings using the application of a rooting hormone and a mist environment or an enclosed poly propagator. Photo by Tara Luna.*

***Figure 10.7**—Root cuttings, such as those sown here from breadfruit (*Artocarpus *species), can be used when stem cuttings do not root well. Photo by Thomas D. Landis.*

Root cuttings are planted horizontally in planting beds or containers with the dormant leaf buds on the upper side. Some root cuttings are also planted vertically, but it is important to maintain the correct polarity. Root cuttings generally do not require a special rooting environment unless shoots are cut from the root piece and treated as a stem cutting.

Selecting Cuttings From Mother Plants

A variety of factors such as seasonal timing, juvenility, plagiotropism, species, and cutting size and quality can greatly influence the rooting success of cuttings. Collectors need to be aware of these factors and, with experience, will be able to discern the right type of cutting material to collect.

Some species can be readily propagated from cuttings collected in any season of the year, while others have very specific seasonal trends when they will form roots. For any given species, small experiments are required to determine the optimum time to take cuttings, which is related to the physiological condition of the donor plant at collection time rather than any given calendar date. Recordkeeping is important to improve rooting results from year to year.

All plants progress from a juvenile phase (incapable of producing flowers) to a mature or adult flowering phase. Different parts of the plant, however, can be at different stages of maturity at the same time. Sometimes the juvenile phase can be distinguished from the adult phase by differences in leaf shape or color or by the overall habit of the plant. Some broadleaf species, such as eucalyptus, have distinct juvenile leaves that differ from adult leaves. In conifers, juvenile wood is usually found on the lower portion of the tree crown and the adult, cone-bearing wood is located in the upper crown. In broadleaf plants, juvenile wood is found near the stem base or root crown and can be discerned as the long, nonflowering shoots (sucker shoots). Cuttings collected from this region of the plant root more easily than those from older, mature wood. In some cases, many difficult-to-root species will root only from stems collected from young seedlings. Hedging or coppi cing is the practice of regularly cutting back donor plants to maintain juvenile wood and is an efficient means of generating many long, straight cuttings from a limited number of plants. Donor plants in natural stands can be selected for hedging on an annual basis if cuttings will be collected from the area for several years. Otherwise, mother plants can be held in the nursery and used as a source of cuttings as described in the next section.

Plagiotropism is the habit of a cutting to continue to grow in the direction it was growing on the donor plant. Plagiotropism can be strong or weak depending on species and on the original position of the cutting on the donor plant. *Plumeria* is an example of a tropical broadleaf genus with strong plagiotripism. Often, plants produced from cuttings from lateral shoots will maintain a lateral habit, whereas plants produced from terminal shoots will grow vertically. This tendency can create problems with the growth habit of the nursery stock and is more of a concern with conifers than broadleaf species (Landis and others 1999) (figure 10.8).

Figure 10.8*—Plagiotropism is the effect of the position of the branch on the growth habit of the progeny, The terminal shoot on the juniper cutting on the right was collected from a lateral branch and still exhibits lateral growth tendency. Photo by Thomas D. Landis.*

Cutting size varies from species to species and by cutting type and seasonal timing. Easily rooted plants can be collected as long poles for rooting or made into small microcuttings. Microcuttings consist of one bud and a small section of internode stem and are typically less than 2 in (5 cm) long (figure 10.9). Hardwood cuttings vary in length from 4 to 30 in (10 to 76 cm). At least two nodes are included in the cutting. The basal cut is made just below a node and the top cut is made above a node. If more than one cutting is being made from a stem, be certain that nursery workers maintain the correct polarity. The very tip portions of the shoot, which are usually low in carbohydrates, are usually discarded. Central and basal portions of the stem usually make the best cuttings, but exceptions exist. Good cutting wood has some stored carbohydrates that will supply the cutting with food reserves until roots form. Very thin or elongated shoots are not desirable. If cuttings are collected from natural stands, harvest from individuals that are growing in full sun to partial shade and avoid those in deep shade. Often, the ability of a cutting to produce new roots changes from the base of the cutting to the tip. Softwood stem cuttings are usually straight, 3 to 6 in (7.5 to 15 cm) long with two or more nodes. In general, softwood cuttings root better from terminal shoots. Semihardwood cuttings are usually 3 to 6 in (7.5 to 15 cm) long with leaves retained in the upper end. Semihardwood cuttings usually root best from lateral shoots.

Figure 10.9*—Microcuttings are small stem cuttings with one or two nodes. Photo by Tara Luna.*

Many tropical plant species are dioecious, meaning that male and female flowers are borne on separate plants (table 10.1). For example, Hawai‘i has the highest degree of diocity in its native flora than anywhere in the world. In such cases, collectors may not realize they have collected cuttings of only one sex. Outplanting plants of only one sex onto the restoration site may compromise project objectives because seed production over the long term will be impossible. Therefore, be sure to collect both male and female cutting material (see Landis and others 2003).

Establishing Mother Plants at the Nursery

Some nursery managers find it advantageous to maintain donor stock plants at the nursery as a continual source of cutting material in a convenient location. Most broadleaf tree species will coppice (regenerate stems from cut stumps), which can provide new cuttings year after year. Maintaining stock plants at the nursery can be more efficient than collecting from wild populations, especially if the same ecotypes will be used for a long-term restoration project. The disadvantage to using mother plants grown at the nursery is that they require nursery space and must be intensively managed.

Mother plants are usually planted in field beds at the nursery or, in some cases, are kept in large containers. These areas are often referred to as “stooling beds”

Table 10.1*—Tropical dioecious species.*

Scientific name	Common name
Aleurites moluccana	Kukui nut
Broussaisia arguta	Kanawao
Cycas species	Cycad
Morus species	Mulberry
Pandanus tectorius	Podocarp
Piper methysticum	Kava
Pittosporum hosmeri	Ho`awa
Zanthoxylum flavum and *Z. thomasianum*	Yellow prickle

or "hedgerows." Mother plants must be clearly labeled as to species and origin. If mother plants are in field beds, an accurate map should be kept. Mother plants should be hedged on an annual basis to maintain wood juvenility, discourage thick shoots or dominant leaders, and encourage production of numerous straight shoots to use as cutting material. When hedging, it is important to leave enough leaves to keep the root system alive. Moderate shade will encourage shoot elongation, thereby resulting in longer internodes and more easily rooted cuttings (Longman 1993). Mother plants also need periodic watering and nutrients and should be kept free of weeds by mulching or other means.

Collecting, Transporting, and Storing Cuttings

Some basic equipment and supplies are necessary to efficiently collect cuttings and ensure their health until they are struck (figure 10.10). The following items are recommended:

- High-quality, sharp pruning shears and pruning poles for collecting from trees.
- Spray bottles filled with disinfectant (1 part bleach [5.25 percent sodium hypochlorite] in 10 parts water) to disinfect pruning shears.
- Permanent labels and marking pens for noting origin of collection.
- Large, white plastic bags with ties for bulk collections.
- Spray bottles filled with water to keep cuttings moist in the plastic bags after collection.
- Portable, insulated coolers for transport back to the nursery.
- Newspaper, moss, or other materials to moisten and wrap around cuttings.

Figure 10.10—*Equipment used to collect cuttings includes sharp tools, a cleaning agent for tools, and a cooler to keep cuttings from drying out during transport. Photo by Tara Luna.*

When collecting and handling cuttings, it is important to—

- Collect only from healthy donor plants.
- Keep cuttings cool to avoid wilting and desiccation.
- Handle cuttings carefully so that tissues are not bruised.
- Make sure that some buds or leaves are present on stem cuttings.
- Collect from nonflowering shoots. In general, cuttings root better before or after flowering.
- Place cuttings in the same direction when bundling to avoid mix-ups with polarity.

Cuttings should be collected on cloudy, cool days or during the early morning. All cuttings should be handled with care. Cuttings need to be kept cool and shaded during collection and transport back to the nursery to avoid water loss and physical damage. Wrap cuttings loosely in moistened newspaper (or other moistened material to protect from desiccation), place them into white plastic bags, mist them, and label with origin information and the date. When collecting from mother plants, make a proper cut that facilitates healing of the mother plant. Take the cutting just above a node, ensuring that you do not leave a stub. Then trim the base of the cutting to just below the node where rooting is more likely to occur. Between collection sites, disinfect the pruning shears with the bleach solution to avoid spreading disease.

Deciduous hardwood cuttings can be wrapped in moist peat moss or burlap and stored in a shaded, dry environment with periodic moisture to prevent dessication. Cuttings can be stored for several days but generally no longer than 4 to 8 weeks. Inspect stored cuttings frequently to make certain that tissues are slightly moist and free from fungal diseases. Hardwood and softwood evergreen cuttings, deciduous softwood cuttings, and semihardwood cuttings should be struck in propagation beds the same day of collection and should never be stored for longer than 1 day.

Types of Rooting

The development of new roots on a shoot is known as "adventitious root formation" (figure 10.11A). Two types of roots occur depending on whether buds capable of producing new roots are present. Many tropical species have buds present and the resulting roots are termed "preformed" or "latent." In the nursery, cuttings of these species are usually struck directly into containers because they do not require a special rooting environment. This method is the easiest and most economical way to produce these species because no additional transplanting is needed.

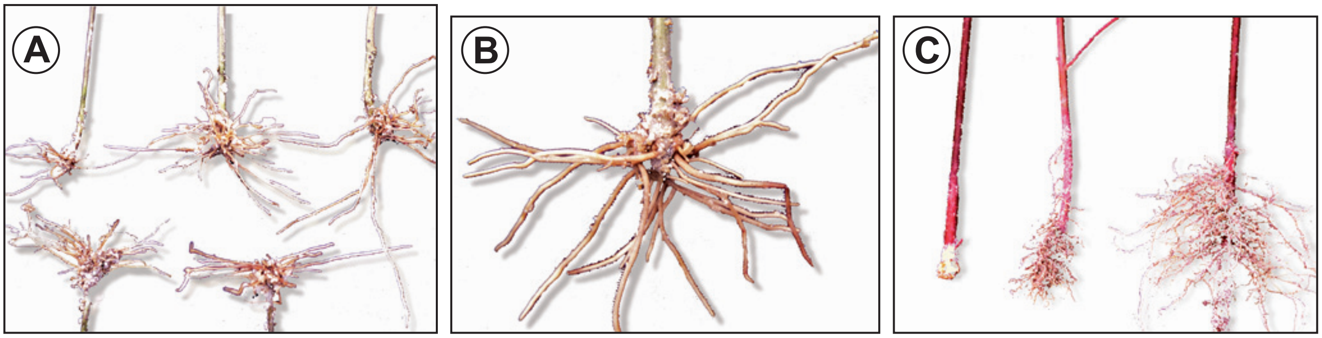

Figure 10.11*—Adventitious roots of a cutting (A), callus and roots forming at the base of a cutting (B), adventitious root formation during a 6-week period (C). Photos by Tara Luna.*

If no buds are present, then the roots are termed "wound-induced" and new roots will form only in response to the wound caused by preparing the cutting. Species requiring wounding can vary considerably in their ability to form new roots. After a cutting is wounded, callus tissue forms at the base, primarily from the vascular tissue (figure 10.11B). In easy-to-root species, callus formation and root formation are independent processes that occur at the same time because of similar environmental triggers (figures 10.11B, 10.11C). In difficult-to-root species, adventitious roots arise from the callus mass. In some cases, excessive callus can hinder rooting and is a signal to use a lower concentration of rooting hormone. Often, excess callus needs to be scraped away and the cutting replaced in the rooting environment.

In general, all species with wound-induced roots must first be rooted in a special propagation environment with tightly controlled air and medium temperatures, high relative humidity, reduced light levels, and "moist, but not wet" medium (figure 10.12). See Chapter 5, Propagation Environments, for more details on propagation environments. Easy-to-root species are often struck directly into containers filled with regular growing medium and, after they are rooted in the special propagation environment, they are moved into the regular nursery. Hard-to-root species are often struck into trays or beds containing a special rooting medium and, after roots form, they are transplanted into containers to continue their growth.

Cutting Preparation

While preparing cuttings, it is important to keep the work area clean. Use sharp, well-maintained shears and knives to make clean cuts. Disinfect these tools often to reduce the possible spread of disease. Preparing cuttings standardizes their size and shape, promotes side shoots, and eliminates shoot tips that often die back. It is important to maintain polarity during this process, especially for deciduous hardwood cuttings. Cuttings that will require hormone treatment to encourage rooting, such as those of hardwood narrowleaf evergreens or any softwood or semihardwood cuttings, should have one-third to one-half of the leaves and buds removed to reduce the amount of water loss from the cutting. Any flower buds also need to be removed. It is important, however, to retain some buds or leaves on the cutting so that the cutting can manufacture food during rooting.

Wounding Cuttings

Wounding, used on species that are difficult to root, increases rooting percentages and improves the quantity and quality of roots produced. Wounding exposes more cells to rooting hormone, encourages callus formation, and, in some cases, removes thick woody tissue that can be a barrier to root formation. Cuttings are commonly wounded by hand-stripping small lower stems and leaves to create wounded areas along the basal portion of the cutting, scraping the base of the stem with a small, sharp knife

Figure 10.12*—Semihardwood cuttings in a shadehouse at the University of the Virgin Islands, agroforestry facility are struck in trays of 100 percent perlite and misted every hour to ensure that no standing water exists, but the cuttings are always moist. The shadecloth around the PVC frame provides a shady, low-wind, high-moisture atmosphere for the cuttings while they produce roots. Rooted cutting are later transferred to small pots in the shadehouse for 2 to 3 weeks and later transferred to full sun. Photo by Brian F. Daley.*

Figure 10.13—*Wounding the lower end of a stem cutting increases rooting with difficult-to-root species. Photo by Tara Luna.*

or potato peeler (figure 10.13), or slicing one or two long, shallow slivers (0.75 in to 1.25 in [2 to 3.2 cm] long) of tissue from the base of the stem, making sure to penetrate the cambium layer of the stem. Slicing requires precision and experience so that cuttings are not excessively damaged.

Rooting Hormones

Auxins are natural plant hormones that encourage root formation on cuttings and are available from natural and synthetic sources. In practice, auxins are commonly referred to as rooting hormones. Most cuttings are treated with synthetic hormones that are available in powder and liquid form, and some preparations may contain chemical fungicides (figure 10.14). Synthetic hormones can be purchased ready to use or can be mixed by growers to specific concentrations using ingredients purchased from horticultural suppliers. Indole-3-butyric acid (IBA) and naphthaleneacidic acid (NAA) are the most widely used synthetic auxins. Often, mixtures of IBA and NAA are more effective than either component alone. The effect of rooting hormones varies widely between species and, in some cases, between genotypes. In general, rooting hormone powders are expressed as a percentage, while liquid solutions are expressed as parts per million (ppm).

It is generally easiest to purchase ready-to-use formulations. It is important to remember that all rooting hormones have a limited shelf life of 18 to 24 months. Therefore, when purchasing or mixing hormones—

- Record the date of purchase on the container.
- Order only what you plan to use within 18 to 24 months. Order smaller quantities more often to ensure that the rooting hormone remains effective.
- Keep containers sealed and refrigerated when not in use to preserve the activity of the rooting hormone.

Many growers prefer powders because several commercial products of varying strengths are available, they are easy to use, and large quantities of cuttings can be treated quickly. Powder must be applied uniformly to all cuttings; variable amounts of rooting powder adhere to the base of a cutting, which can affect rooting results (figure 10.15). The following precautions and special techniques are necessary when using powders:

- Wear gloves during application.
- Transfer enough hormone to a smaller container from the main stock container for use; never transfer unused hormone back to main stock container.
- Make sure the base of the cutting is moist so that the powder adheres; pressing cuttings lightly onto a moist sponge is a useful technique.

Figure 10.14—*Advantages of rooting hormones are (1) increased rooting percentages if applied correctly at an effective concentration, (2) more rapid root initiation, (3) an increase in the total number and quality of roots, and (4) more uniform rooting. Photo by Tara Luna.*

Figure 10.15—*Many growers prefer powders to liquid hormones (A). Apply powder hormones evenly and consistently (B). Photo A by Thomas D. Landis, and photo B by George Hernández.*

- Apply the hormone uniformly. Make sure cuttings are dipped into the powder to a depth of 0.2 to 0.4 in (5 to 10 mm). Make certain that cut surfaces and other wounds are also covered with rooting hormone.
- Remove excess powder by lightly tapping the cuttings on the side of the dish.

Liquid products are formulated with alcohol and often must be diluted with great care to create the desired strength. Some of the advantages of using solutions are the availability of a wide range of commercial preparations, specific concentrations can be formulated at the nursery, and they can be stored for longer periods under the right conditions. Some growers believe that liquid solutions are more accurate than powders regarding the amount of rooting hormone entering the stem tissue. The most common procedure for treating cuttings with liquid products is the quick-dip method in which the base of the cutting is dipped into the solution for 3 to 10 seconds. Whole bundles of cuttings can be treated at once (figure 10.16). An alternate method is to soak cuttings for a longer time in a more dilute hormone solution. When using liquid rooting hormones, it is important to—

Figure 10.16*—Using the liquid hormone "quick dip" method is preferred by many growers because bundles of cuttings can be treated at the same time with consistent uniformity of application. Photo by Tara Luna.*

- Wear gloves during mixing, preparation, and application.
- Make certain that the solution was precisely diluted to the correct concentration.
- Place the solution in a clean jar.
- Ensure that the treatment time is constant for a uniform application rate and to avoid damaging the plant tissue.
- Make certain that the basal ends are even to obtain uniform depth of dipping in the solution if bundles of cuttings are dipped.
- Allow the alcohol to evaporate from the stem of the cutting before striking cuttings into the propagation bed, a process that usually takes only a couple of minutes.
- Properly discard any remaining solution, because it is contaminated with plant material.

The optimum auxin rate for cuttings varies by plant species. A good starting rate is a 0.25-0.5 percent (2,500-5,000 ppm). With trial and error, this rate can be increased or decreased until optimum rooting occurs for a particular species. Longman (1993) listed rates of IBA for the following tropical species:

- 0.2 percent for *Triplochiton scleroxylon*, *Tripvochysia hondurensis*, and several other tropical tree species.
- A range of 0.05 to 0.4 percent for *Albizia guachapele*.
- 0.4 percent for *Cordia alliodora*.
- 1.0 percent for *Khaya ivorensis*.

Striking, Monitoring, and Growing Cuttings

Direct striking into containers is more efficient and therefore more economical than striking into a special rooting environment because the cuttings are handled only once and expensive transplanting is avoided. Easy-to-root hardwood cuttings, such as many *Erythrina* species, *Gliricidia sepium* (known locally as "quick stick" in much of the world), and mangrove propagules should always be direct struck (figure 10.17). Often, a dibble of the same diameter as the stem of the cutting is a useful tool for making openings in the medium into which the cutting can be struck. For striking several small cuttings, a template for the holes can be created by driving nails through a piece of plywood at the correct spacing and

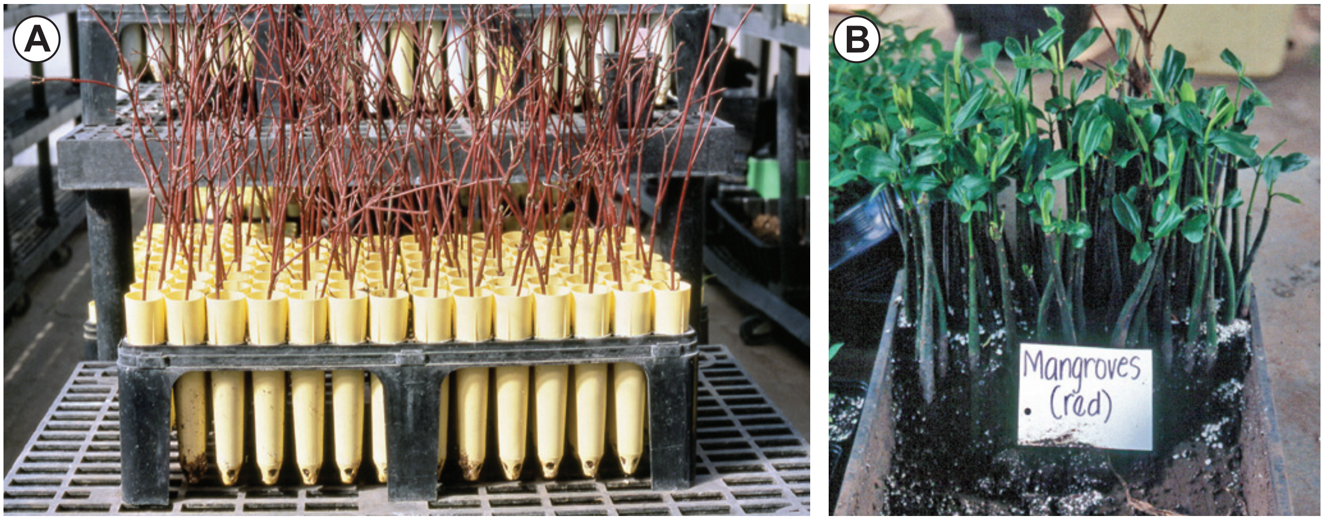

Figure 10.17*—Easy-to-root hardwood cuttings (A) or mangrove propagules (B) can be directly stuck into containers for rooting and is the most economical way of producing cuttings. Photo A by Tara Luna, and photo B by Thomas D. Landis.*

depth. If using powdered rooting hormones, this practice of creating holes ahead of time will help keep the hormone from being brushed off. The following practices need to be encouraged when striking cuttings:

- Wear gloves if the cuttings were treated with rooting hormones.
- Maintain polarity (keep the correct end of the cutting up).
- When using stem cuttings, make certain that at least two nodes are below the surface of the rooting medium.
- If cuttings were wounded, make certain that wounded tissue is adequately covered with rooting hormone and is below the surface of the rooting medium.
- Strike cuttings firmly in the rooting medium. Make certain to avoid air pockets around the base of the stem.
- Try to strike cuttings within 1 to 2 days so that all the plants will have the same level of root development and thus can be hardened off properly before harvesting.
- Place labels before the first cutting and after the final cutting of a particular clone or batch of cuttings.

After cuttings are struck, maintain a clean rooting environment (figure 10.18); routinely inspect cuttings for proper temperature, humidity, and moisture levels and adjust as necessary. Check to ensure that all equipment (including bottom heat) is working properly.

Environmental Conditions for Direct Struck Cuttings

In general, easy-to-root hardwood cuttings directly struck into containers can be treated similar to seedlings.

Environmental Conditions in Special Rooting Environments

Achieving successful rooting requires attention to sanitation, relative humidity, temperature, light, rooting medium, and sometimes mycorrhizae and dilute fertilization. See Chapter 5, Propagation Environments, for information about equipment necessary to regulate humidity, temperature, and light.

Sanitation

Always keep the propagation environment as clean as possible. Strike cuttings into a sterilized rooting medium. Routinely inspect for and remove dead leaves or cuttings that could be a source of disease infection.

Figure 10.18*—The propagation environment must be carefully maintained to ensure that the mist system, the timers that control the frequency of mist, and other equipment are working properly. Keeping the rooting environment as clean as possible during rooting is crucial for producing healthy plants. Photo by Tara Luna.*

Humidity

Until the root system forms, high relative humidity must be maintained in the propagation environment to slow the rate of water loss from the cutting. Placing cuttings under an automatic misting or fogging system is often effective. Another method is to place the cuttings within a frame covered in clear or white polyethylene sheeting with a reserve of water below a moist rooting medium (Longman 1993). Cuttings in this "polypropagator" need to also be irrigated with a fine spray of water in late afternoon and early morning, especially when the weather is hot and dry. If possible, water temperature should not be significantly cooler or warmer than the rooting medium to avoid damaging the young roots from sudden changes in temperature. Achieving optimum humidity and medium moisture can be one of the most challenging aspects of successful propagation with cuttings. Too much moisture can encourage fungal pathogens and rotting, whereas too little moisture can result in lethal desiccation. Daily monitoring is important.

Light and Temperature

Providing light for photosynthesis is necessary so that cuttings can continue to manufacture food during rooting, but too much sunlight can cause high temperatures. Shadecloths of 30 to 50 percent shade cover are most effective to reduce air temperature while providing sufficient light. Shadecloth can also serve to reduce the effect of rain when propagating outdoors. The optimum air temperature for rooting cuttings is 68 to 80 °F (20 to 28 °C)—manage with shade so the air temperature does not exceed 91 °F (33 °C) maximum. Optimum temperatures of the rooting medium needs to be about 5 °F cooler [63 to 75 °F (17 to 24 °C)] than optimum air temperatures.

Rooting Medium

A good rooting medium provides aeration and moisture, physically supports the cuttings, and promotes the development of fibrous root systems. A pH of 5.5 to 6.5 is optimum for most plants, but acid-loving plants prefer 4.0 to 5.0. Some common components of rooting media generally include a combination of two or more of the following: large-grade perlite, pumice, *Sphagnum* peat moss, sawdust, sand, coir, grit, or fine bark chips. The ideal rooting medium drains freely and does not become waterlogged from misting. Different rooting media components are used depending on the species being propagated. Selection of the rooting medium components influences rooting percentages and the quality of roots produced. Using very fine-grade or very coarse-grade sands tends to discourage the development of secondary roots. Roots that do form tend to be brittle and break off during transplanting. See Chapter 6, Growing Media, for more details on developing a good growing medium.

Mycorrhizal Fungi

Some growers inoculate the rooting medium with mycorrhizal fungi or other symbiotic organisms, which has improved rooting results with some species (Scagel and others 2003). See Chapter 13, Beneficial Microorganisms, for more information on mycorrhizae.

Nutrient Mist

Some difficult-to-root cuttings may remain in a special rooting environment for a long period of time. Over time, nutrients can be leached from the leaves by the long exposure to overhead misting, resulting in yellowing of the leaves or leaf and needle drop. In these cases, the application of a dilute, complete foliar fertilizer through the mist line can improve cutting vigor and may aid in rooting. Because some species respond favorably to nutrient mist while others are adversely affected, you will need to do some preliminary trials before treating all the cuttings. Also, be aware that excessive nutrients can encourage unwanted growth of mosses and algae on the medium surface.

Transplanting Cuttings From Special Rooting Environments

A few weeks after striking cuttings into the rooting environment, they should be inspected for root development. Using a trowel, carefully dig well below the end of the cutting and excavate it to examine for rooting. When cuttings have developed adequate root systems, they need to be hardened for transplanting outside the rooting environment. See Chapter 15, Hardening, for more information. The goal is to condition stem and leaf tissues and promote secondary root development before transplanting. Following these guidelines can harden cuttings:

- Gradually reduce the misting frequency over a period of 3 to 4 weeks.
- Increase the frequency and duration of ventilation in enclosed propagation systems.
- Do not let the rooting medium dry out completely.

After cuttings have hardened, transplant them into containers and transfer them to the nursery for additional growth (figure 10.19). Because cuttings are more expensive to produce than seedlings, it is important to handle them

Figure 10.19—Cuttings can be transplanted into containers and moved to the nursery for hardening. Photo by Tara Luna.

carefully at this stage. It is essential to avoid root damage by following these guidelines:

- Examine each cutting to ensure it has a root system capable of sustaining the cutting after transplanting. Cuttings with only a few slender roots or very short roots need to remain in the propagation bed for further root development (figure 10.20A).
- Transplant only on cool, overcast days or during early morning hours to avoid transplant shock.
- Transplant cuttings in an area of the nursery protected from wind and sunlight.
- Prepare containers, medium, labels, and transplanting tools before transplanting cuttings.
- Moisten the growing medium before transplanting to prevent tender roots from drying out.
- Remove cuttings from the rooting medium carefully and remove only a few at a time so roots will not dry out. Loosely wrap a moist paper towel around the root systems until they are transplanted.
- Handle cuttings carefully by holding the cutting by the stem and by leaving any rooting medium still attached to the root mass. Do not shake medium off the root system.
- Partially fill the container with moistened medium before inserting the cutting. Then add additional moistened medium and gently firm the medium with fingers without breaking the roots (figure 10.20B).
- Do not transplant the cuttings too deep or too shallow.

After transplanting the cuttings, they need to be placed in a shadehouse or protected from full sun and wind for at least 2 weeks. When the cuttings appear to be well established, gradually increase the level of sunlight by moving them to a different area of the nursery or by exchanging the shadecloth for one with a more open weave. After a couple of weeks, move sun-requiring species into full sun. Cuttings need to be closely monitored for any sign of stress. Adequate sunlight is needed for new shoot growth and adequate accumulation of carbohydrates before outplanting.

Other Methods of Vegetative Propagation

Besides stems and roots, several other portions of mother plants can be used to vegetatively propagate new daughters, and stems can be used in ways other than the traditional rooted cuttings.

Layering

Layering is a technique by which adventitious roots are formed on a stem while still attached to the plant.

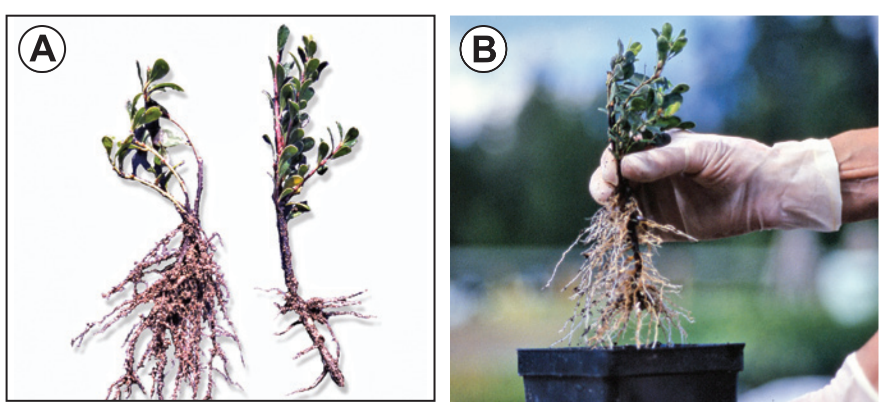

Figure 10.20—Cuttings need to have enough developed roots that can support the cutting after it is lifted and transplanted outside the mist chamber or polypropagator (A). Cuttings with under-developed roots need to be left in the propagation bed longer to develop an adequate root mass (B). Photos by Tara Luna.

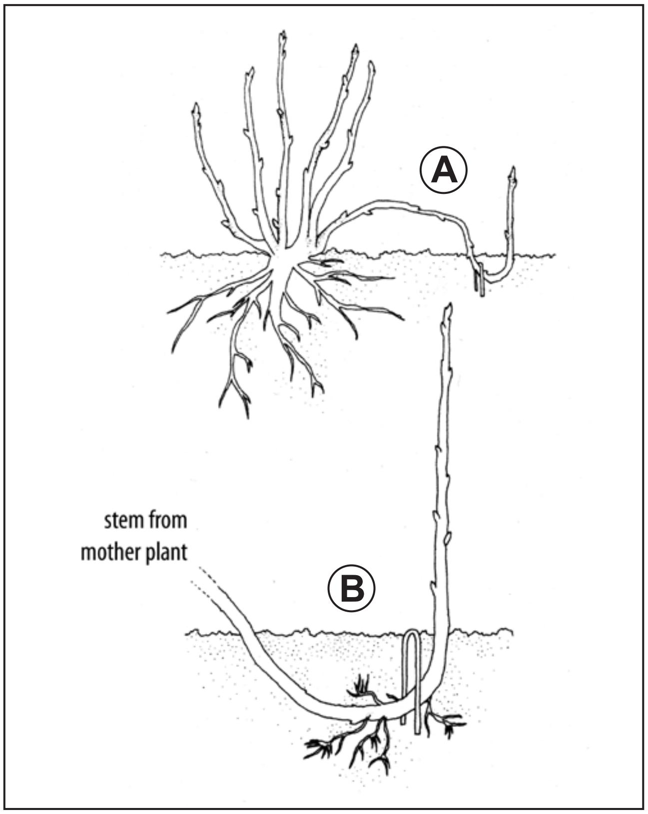

Figure 10.21—In simple layering, the stem from a mother plant is pinned down and covered with soil or an organic mulch (A). New plants can be severed after there is sufficient shoot and root development (B). Graphic courtesy of Bruce McDonald and Timber Press, Inc.

Layering often occurs naturally without the assistance of a propagator. It is mostly used on those species that fail to root from stem or root cuttings. Four types of layering are commonly used in tropical nurseries: simple, French, air, and mound. In addition, drop and stack are two other layering techniques that could be used.

Simple Layering

Simple layering is used on species that produce many shoots annually. Long, low-growing flexible shoots are pegged down 6 to 9 in (15 to 23 cm) from the shoot tip, forming a "U" (figure 10.21A). The bottom of the U stem is girdled with a sharp knife and is covered with soil, sawdust, or other organic mulch, leaving the tip exposed. After a sufficient root system is formed, the new plant can be severed from the donor plant (figure 10.21B).

French Layering

French layering is similar to simple layering but uses a long, single branch that is pegged down to the soil surface (figure 10.22A). After a period of time, the pegs are removed and the branch is laid into a trench and buried up to the tips of the shoots with well-aerated soil and sawdust or mulch (figure 10.22B). After burying repeatedly, each shoot along the stem will form roots by the second year (figure 10.22C) and can be severed from the mother plant (figure 10.22 D).

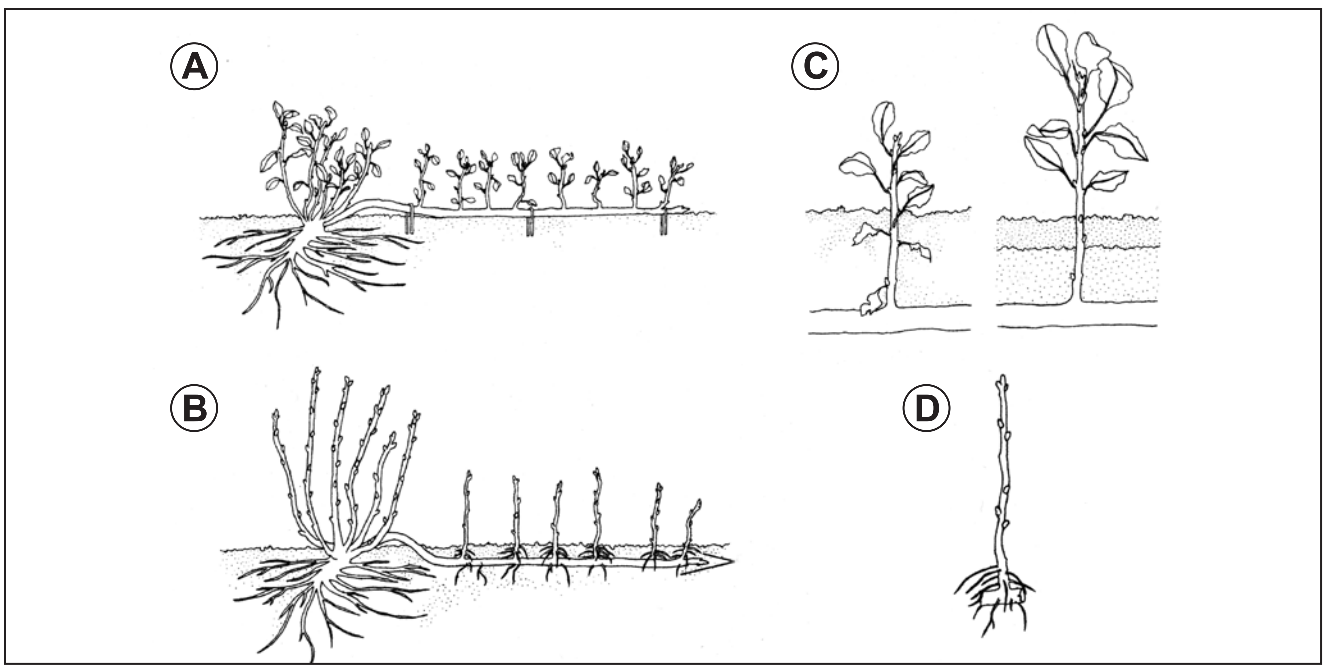

Figure 10.22—French layering consists of pegging a long branch to the soil surface and allowing for new shoots to develop (A). After a period of time, the branch is buried in a deeper trench to encourage root development on each new shoot (B). Repeated burying (C) results in sufficient root development for plants to be severed from the mother plant (D). Graphic courtesy of Bruce McDonald and Timber Press, Inc.

***Figure 10.23**—After wounding the stem, an air layer is created by wrapping the area with peat moss (A), then enclosing this stem area in plastic wrap (B), and sealing the ends (C). After the layer has rooted (D), it can be severed from the stem and potted. Photos by Thomas D. Landis.*

Air Layering

Air layering is useful for producing a few plants of relatively large size. An advantage of air layering is that the rooted layer will be physiologically similar in age to the parent plant and will therefore flower and fruit sooner than a seedling or cutting. Air layering is used mostly on tropical fruit species, such as lychee, and to propagate rare and endangered tropical species. For optimum rooting, air layers are made on shoots produced during the previous season or during the mid- to late-active growing season on shoots from the current season's growth (figure 10.23). For woody plants, stems of pencil-size diameter or larger are best. An area directly below a node is chosen, normally about 1 ft (30 cm) from the tip. Leaves and twigs on the stem are removed 3 to 4 in (7 to 10 cm) above and below this point. Air layering techniques differ slightly depending on whether the species is a monocot or a dicot.

The following steps describe air layering of monocots:

- Make an upward 1.0- to 1.5-in (2- to 4-cm) cut about one-third through the stem.
- Hold the cut open with a toothpick or wooden matchstick.
- Surround the wound with moist, unmilled *Sphagnum* moss (about a handful) that has been soaked in water and squeezed to remove excess moisture.
- Wrap the moss with plastic and hold in place with twist ties or electrician's tape. No moss should extend beyond the ends of the plastic.
- Fasten each end of the plastic securely, to retain moisture and to prevent water from entering. If it will be exposed to the sun, the plastic needs to be shaded.

The following steps describe air layering of dicots:

- With a sharp knife, make two parallel cuts about 1 in (2.5 cm) apart around the stem and through the bark and cambium layer.
- Connect the two parallel cuts with one long cut.
- Remove the ring of bark, leaving the inner woody tissue exposed.
- Scrape the newly bared ring to remove the cambial tissue to prevent a bridge of callus tissue from forming.
- Application of a root-promoting substance to the exposed wound is sometimes beneficial.
- Wrap and cover using the same procedure as that described for monocots.

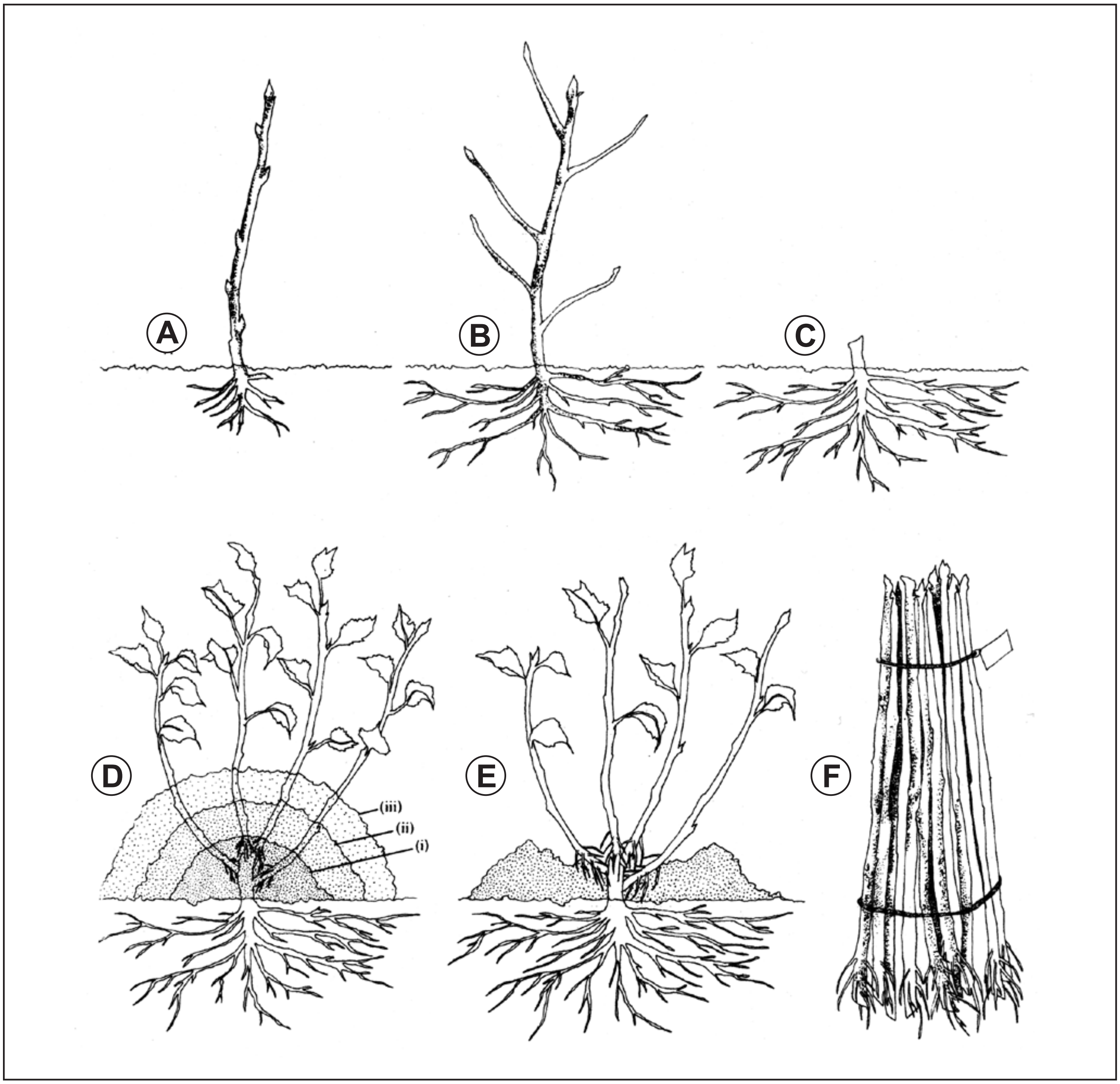

Figure 10.24*—Mound layering or stooling involves selecting a young stock plant (A, B) and cutting back its shoots (C). After new shoots develop, they are covered to one-half of their height with soil, sawdust, or other organic mulch; this procedure is repeated three times (D), encouraging root development on the new shoots (E). After 2 or 3 growing seasons, the well-rooted shoots are ready to plant as individuals (F). Graphic courtesy of Bruce McDonald and Timber Press, Inc.*

For both monocots and dicots, the stem is severed below the medium after the rooting medium is filled with roots (figure 10.23D). The layer is then potted and needs to be kept shaded with adequate moisture until the root system becomes more developed.

Mound Layering

Mound layering or stooling involves selecting a young stock plant (figures 10.24A, 10.24B) and cutting back shoots to 2 to 4 in (5 to 10 cm) above ground level (figure 10.24C). Numerous shoots develop in consecutive growing seasons and are covered to one-half of their height with soil, sawdust, or other organic mulch (figure 10.24D). This procedure is repeated three times as the shoots grow so that, by the end of the second or third growing season, the well-rooted shoots are unburied and are ready to plant as individuals (figures 10.24E, 10.24F).

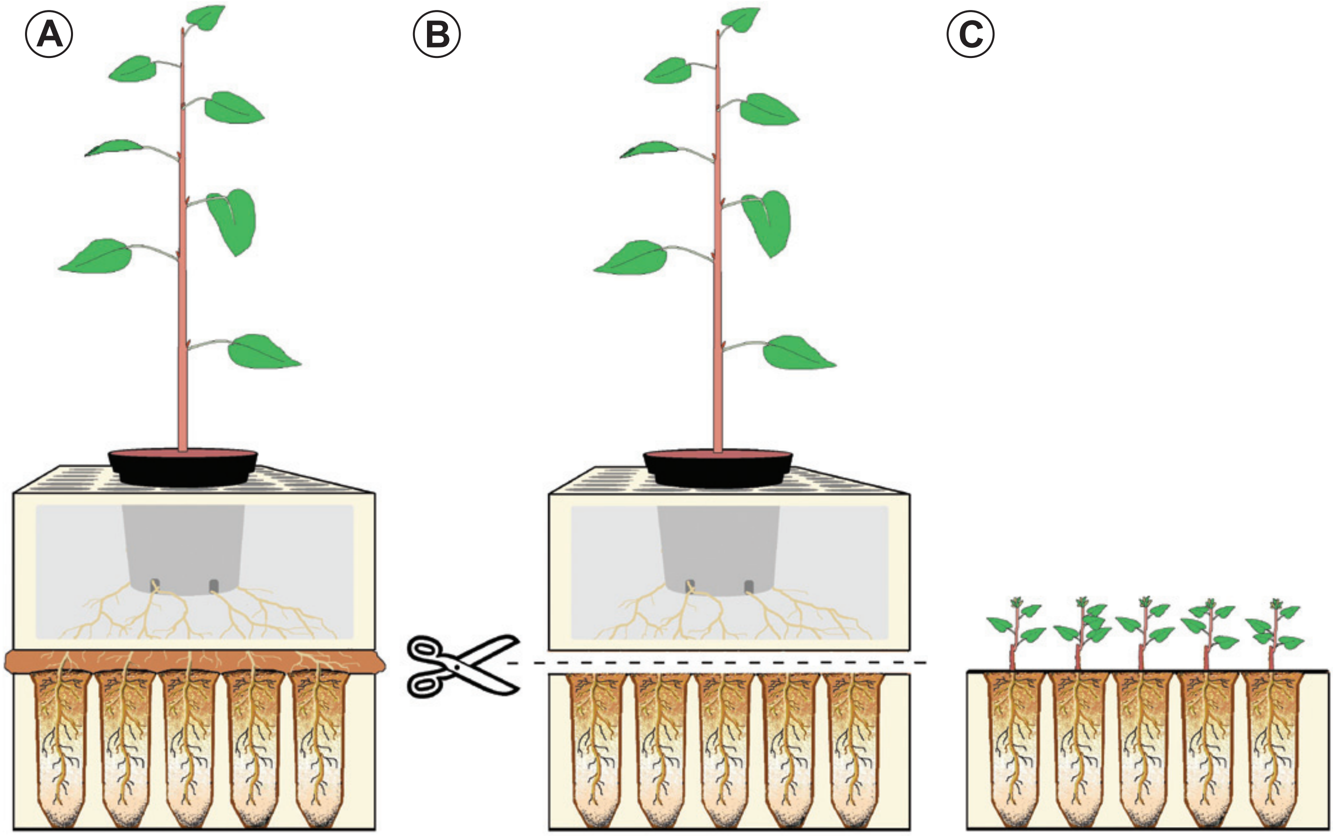

Figure 10.25—Roots from the mother plant grow downward through the cavities of stacked Styrofoam™ containers (A). The roots are then severed (B), after which they develop new shoots (C). Adapted from Landis and others (2006).

Drop Layering

Drop layering is very similar to mounding. Drop layering involves planting well-branched container plants deeply in the ground with only the tips of the branches exposed. New growth forms from the exposed branch tips, but the buried portions of the stems form roots along the stems.

Stacked Layering

Stacked layering is a new vegetative propagation method for rhizomatous species (Landis and others 2006). This technique takes advantage of the rapid and extensive root growth of seedlings and the fact that severed roots will form new shoots. In the spring, a stack of Styrofoam™ containers is created with a 1-gallon pot containing a seedling inserted in the top block. The lower Styrofoam™ containers are filled with growing medium with a thin layer of medium sandwiched between the blocks (figure 10.25A). After several months, the roots of the mother plant will have grown down through and colonized the cavities in the lower blocks. Running a sharp knife between the Styrofoam™ containers severs the roots, which then form new shoots (figure 10.25B). After a few months, the new plants can be transplanted into larger pots. Another set of filled Styrofoam™ containers can be situated below the block with the mother plant to start another propagation cycle.

Tuberous Roots, Tubers, Rhizomes, and Crown Division

Tuberous roots, tubers, and rhizomes are specialized plant structures that function in the storage of food, nutrients, and water. Many culturally important tropical species, which are not easily grown from seeds, have these structures.

Tuberous roots are swollen secondary roots. Separating each tuberous root that has a section of the crown bearing a shoot bud produces new plants. Cassava, yams, and sweet potatoes, that are widely cultivated throughout Polynesia, produce tuberous roots.

Tubers are swollen modified stems that serve as underground storage organs. One well-known common tuber is the white potato. "Eyes" in white potatoes are actually nodes containing buds. Propagation by tubers involves planting the entire tuber or dividing it into sections containing at least one eye or bud. Pia, taro, wapato, and elephant taro are examples of tropical species that produce tubers.

Rhizomes are specialized stems in which the main axis of the plant grows horizontally or vertically at or below the soil surface. Many native tropical species, such as native begonias, reproduce by rhizomes and are easily propagated into larger numbers from a few nursery plants by divisions. Rhizomes vary in length and size according to species. Rhizomes are cut into sections with each containing at least one shoot bud or active shoot; some roots are attached to the bottoms of the rhizomes and are planted into containers individually. Rhizomes can also be planted in nursery beds and used as a source for bareroot stock for planting or for cultural uses such as basketry.

Crown division is an important method for propagating many native herbaceous perennials that produce multiple offshoots from the crown. Crown divisions are usually done just before active growth and flowering. Plants are dug up and cut into sections with a sharp knife, each with a substantial portion of the root system, and transplanted individually.

Stolons, Runners, and Offsets

Stolons, runners, and offsets are specialized plant structures that facilitate propagation by layering. Stolons are modified stems that grow horizontally above the soil line and produce a mass of stems. Runners are specialized stems that arise from the crown of the plant and grow horizontally along the ground and produce a plantlet at one of the nodes. Raised beds planted with species with stolons or runners can be an endless source of propagation material, and plants can be dug and potted individually or transplanted as bareroot stock.

Plants with rosettes often reproduce by forming new shoots, called offsets, at the base of the main stem or in the leaf axils. Offsets are cut close to the main stem of the plant with a sharp knife. If well rooted, an offset can be potted individually. Plantain and banana are often propagated with offsets (figure 10.26). Sever the new shoots from the mother plant after they have developed their own root systems. Nonrooted offsets of some species may be removed and placed in a rooting medium. Some of these offsets must be cut off, while others may simply be lifted from the parent stem.

Grafting and Budding

Grafting is the art of connecting two pieces of living plant tissues, the scion and the rootstock, together in such a manner that they will unite and grow as one plant. Grafting is used primarily in the tropics for mango, citrus, other tropical fruits, and forest tree seed orchards. In Hawai‘i, grafting has been used to propagate the highly endangered species, *Kokia cookei* (figure 10.27). It is also used to repair or to top-work existing trees to change varieties, as well as to produce new plants.

Figure 10.26*—Plantain and banana are often propagated with offsets. Photo by Ronald Overton.*

The scion is a short piece of shoot including several shoot buds, which, when united with the rootstock, forms the upper portion of the plant. The rootstock is the lower portion of the graft, which develops into the root system. If grafting is done high in the tree, the rootstock includes the roots, main trunk, and scaffold branches. The rootstock may be a seedling, rooted cutting, or an older tree.

Budding is grafting using a scion with only a single bud attached to a piece of bark. It may or may not include a thin sliver of wood under the bark. Budding is the most commonly used technique for propagating new plants, but it is also used to top-work existing trees to a new variety.

The rootstock and the scion must be compatible for successful grafting. Compatibility is never a problem when grafting within a clone. Grafting between clones within a species is usually successful. Grafting between species in a genus is sometimes successful and is most often seen in the genus *Citrus*. Grafting between genera within a plant family is rarely done and the chances of success are slim. Grafting between plant families is impossible for woody plants.

In addition to compatibility, a number of factors exist that contribute to a successful graft or bud union. Vascular cambium of the scion must be placed and held in intimate contact with the vascular cambium of the rootstock. The grafting operation must be done at a time when both the rootstock and the scion are in the correct physiological stage. Immediately after grafting, all cut surfaces must be protected from desiccation. Breaking of the union between the scion and the rootstock will usually manifest failed grafts. Grafts can fail because the rootstock and scion are not compatible, the rootstock and scion are not properly united, either the rootstock or the scion are not in the proper physiological state, or the grafted tissues dry out before the tissues grow together.

Figure 10.27—*Grafting has been used to propagate highly endangered species in Hawai'i. Shown:* Kokia cookei *scion grafted onto the rootstock of* Kokia drynarioides*. Photo by Tara Luna.*

Some grafted species show excessive sap flow (bleeding) at certain times of the year. Excessive bleeding from the rootstock usually causes graft failure. Keeping recently performed grafts at 90 °F (32 °C) or lower with high humidity is essential. The graft union must also be protected from excessive drying or winds. In general, the more experienced the grafter, the better the success rate.

Grafting Tools

Sharp knives, sharpening stones, pruning shears, and saws are tools needed for grafting. These tools need to be kept very clean and only used for grafting. Knives need to be kept very sharp to minimize injury to the scion or rootstock. Dull knives strip and tear wood, leaving cuts that do not heal properly. Materials such as paraffin wax, budding rubber, and grafting tape can protect grafted tissues and seal cut surfaces of the graft. Aluminum foil wraps and plastic bags with twist ties are used in drier climates to protect the graft and provide a little extra humidity around the graft during union.

Collecting Scion Material

Budding is usually the preferred grafting method. For success, it is important to collect scion material with leaf buds and not flower buds. A small branch containing several buds suitable for grafting is called a bud stick. Bud sticks need to be collected when trees have well-developed buds. If buds have begun to swell or grow, the wood cannot be used successfully. Select parent trees of the desired variety that are disease free. Select straight, smooth bud sticks from 1-year-old wood that have 0.25- to 0.50-in (6- to 13-mm) diameters and contain at least three buds or nodes. The best bud sticks usually come from the inside canopy of the tree. Seal about 6 mm of the end of each bud stick with melted wax or grafting paint. When the seal is dry, tie the bud sticks into small bundles and surround each bundle with moist paper towels or moist wood shavings to prevent desiccation. Label each bundle. The bundles and wrapping material can be kept inside plastic bags. Keep the bundles as cool as possible and do not allow them to dry out.

Types of Budding

Chip budding works well and can be done whenever mature buds are available. Chip budding is widely used for citrus propagation. The cuts on the scion and the rootstock must be exactly the same. The first cut on the scion

***Figure 10.28**—Species like taro have been micropropagated to perpetuate certain clones and supply disease-free nursery stock. Photo by Tara Luna.*

and the rootstock is made below a bud and downward at a 45-degree angle to a depth of about 0.12 in (3 mm). The second cut is started about the same distance above the bud and the knife is drawn downward to meet the first cut. If the bud scion happens to be narrower than the rootstock hole, line up one side of the bud scion tightly against the cut on the rootstock. The exact distances above and below the scion bud will depend on species. The entire graft needs to be wrapped with very thin (2-mil), clear polyethylene tape to prevent desiccation. If clear tape is unavailable, the graft can be wrapped with budding rubber and kept in a cool, shady location with high humidity. The key is to not let the bud dry out.

Slip budding is usually done during active growth. Like chip budding, mature buds must be available on the scion and the wood must have bark that will "slip." Bark that "slips" will easily peel in one uniform layer, without tearing, from the underlying wood. The appropriate time to do this step depends on the species and local climate. The first cut on the rootstock is horizontal. The second cut, about twice as long as the first, is vertical, originating near the midpoint of the horizontal cut. Where the cuts meet, gently use the knife to slightly flare open flaps of bark. On the scion, detach the leaf below the bud but retain some of the petiole. Make the first cut about 0.5 in (12 mm) below the bud and draw the knife upward just under the bark to a point about 0.25 in (6 mm) above the bud. Grasp the petiole and make a second cut horizontally across the bud stick so that it intersects with the first cut. The bud and its accompanying wood, termed a bud shield, is then inserted under the "flaps" on the rootstock, and slid down to ensure that the scion makes intimate contact with the rootstock. Use a budding rubber to hold the stem, flaps, and bud shield firmly together. Do not cover the bud.

Finishing the Graft

Grafted surfaces must be held tightly in place using a budding rubber or grafting tape. This wrap must either breakdown by weathering (as budding rubbers do) or must be removed in 2 to 3 weeks after the union has healed. If the material does not break down and is not removed, it will girdle the rootstock. After the union has healed, the portion of the rootstock above the graft must be cut away to force the scion bud to grow. Remove any unwanted sprouts as soon as they are visible. Unwanted sprouts can be easily rubbed off with fingers.

Micropropagation

Micropropagation is a process used to propagate plants using very specialized tissue culture techniques. Tissue culture is the procedure for maintaining and growing plant tissues and organs in an aseptic culture in which the environment, nutrient, and hormone levels are tightly controlled. A small piece of vegetative material called the explant is used to create a new, entire plant. Rare or greatly endangered tropical native species have been micropropagated to increase the number of individuals for restoration projects when other methods of propagation have been limiting or failed. Micropropagation has also been used as a method to offer plants in the nursery trade in order to preserve them from poaching and eventual extirpation from wild populations (figure 10.28). Micropropagation works well for some species and poorly for others. For some native plants, such as orchids, it is one of the only options for successful propagation. Most native plant nurseries do not have an elaborate tissue culture facility because of the high cost, although small-scale micropropagation can be done with minimal equipment in a clean room.

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