Outplanting

Diane L. Haase, Thomas D. Landis, and R. Kasten Dumroese

17

Survival and growth after outplanting are the ultimate tests of nursery plant quality. After the nursery plants are established in the field, they will provide many benefits to the environment by improving soil quality, enhancing biodiversity, inhibiting establishment of invasive plants, sequestering carbon, restoring native plant populations, providing windbreaks, creating wildlife habitat, and preventing soil erosion. In addition, established native and traditional plants can provide food, fuel, medicines, crafts, animal fodder, beautification, and many other benefits. Careful planning well in advance is important with attention to the eight steps of the Target Plant Concept. In addition, care with site preparation, onsite plant handling, selection of planting spots, proper planting techniques, support and protection of seedlings, and quality control during the outplanting process all help ensure the plants will have the best chance to survive. Long-term monitoring by the client and follow up with the nursery can help refine target plant requirements and improve future project successes.

Facing Page: *Native seedlings ready to be outplanted on a former pasture in Hawai'i. Photo by Douglass F. Jacobs.*

Review of the Target Plant Concept and Implications for Outplanting

Applying the target plant concept and proper crop scheduling are accomplished by working with clients to define the target plant for their outplanting site (Chapter 3, Defining the Target Plant, and Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records). The target plant is of the right species and genetic source; is of the appropriate size, age, and shape for its purpose; and is ready at the right time for outplanting with the best chance to thrive on the site. The eight steps for defining the target plant are—

Step 1—What are the outplanting objectives?

Step 2—What are the conditions of the outplanting site?

Step 3—What factors on the project site could limit success?

Step 4—How will limiting factors be mitigated?

Step 5—What species and genetic sources will meet project objectives?

Step 6—What types of plant material (stocktypes) are best suited to the project site and objectives?

Step 7—What are the best outplanting tools and techniques?

Step 8—What is the best time for outplanting?

Outplanting performance (survival and growth) depends on careful consideration of each step. To meet the project objectives (step 1), the plant material (steps 5 and 6) must be matched to the specific site conditions (steps 2 and 3). Furthermore, successful outplanting depends on optimum timing (step 8), site preparation (step 4), and proper planting techniques (step 7). A quick review of some of these key aspects of the target plant as it relates to the outplanting process follows.

The Outplanting Window

The outplanting window is defined as the period of time during which environmental conditions on the site are most favorable for survival and growth of outplanted nursery stock. Soil moisture is the primary determining factor, but other environmental or biological factors can also influence the outplanting window. On tropical sites that have wet and dry seasons, the outplanting window needs to be as soon as possible after reliable rains begin so that plants have sufficient time to develop established root systems before the dry season begins. Nursery stock is outplanted when soil moisture is high and evapotranspirational losses (from wind and sun) are low. Where a very short dry season exists, as is the case for the Caribbean side of much of Central America and in some of the wetter Caribbean islands, planting can be done throughout the year. To ensure that outplanting can commence at the optimum time, careful planning is crucial, alongside close coordination with the nursery (see Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records).

Limiting Site Conditions

It is critical to identify the outplanting site's environmental factors that may limit plant survival and growth. Temperature and moisture are usually the most limiting and are discussed in the following sections. Other site factors, such as aspect and soil type, must also be considered. Limiting conditions on each outplanting site must be evaluated well in advance of the actual outplanting to determine the optimum planting window.

Soil Moisture

Soil moisture plays a vital role in the uptake and translocation of nutrients and can have a significant influence on tropical plant survival and growth (Engelbrecht and Kursar 2003). Following outplanting, a root system must be able to take up sufficient water from the surrounding soil to meet the transpirational demands of the shoot. If soil moisture is inadequate, the newly planted seedling can become stressed, resulting in lower photosynthetic rates, reduced growth, and mortality.

Air Humidity and Wind Speed

Weather conditions at the time of outplanting have a direct effect on plant moisture stress. An increase in both air temperature and wind speed affect transpiration, especially when relative humidity is low. Relative humidity does not influence evapotranspiration rates as much as vapor pressure deficit, which is the difference between the amount of water the air can hold at a given temperature and the amount of water at saturation. Therefore, planting is best done during the early morning hours when air temperatures are cool and wind speeds are low. When weather is sunny, windy, or dry, it is necessary to take extra protective precautions to minimize plant stresses. In extreme cases, the planting operation may have to be suspended until conditions are more favorable for outplanting.

Site Aspect and Planting Sequence

Conditions can vary at different locations in the planting area, especially in mountainous terrain. Aspect, or direction of hill and mountain slopes to solar exposure, can have a strong influence on outplanting success. In the northern hemisphere, south- and west-facing aspects have a hotter, drier environment than north and east aspects while in the southern hemisphere north- and east-facing aspects have a hotter, drier environment than south and west aspects. Depending on the severity of moisture or temperature stress, shading of outplanted stock can help mitigate these stresses.

Temperature

In tropical regions, low temperatures are only an issue for mountainous planting sites and frost is rarely a consideration. Plants destined for these sites need to be adequately hardened off to minimize vulnerability to cold damage. High temperatures and solar loading are more frequently a serious concern during outplanting, especially in lowland sites. Ground temperatures in full sun are commonly much hotter than ambient temperature. Abandoned pastures and other forest restoration/rehabilitation sites are notorious for having extreme ground temperatures that can contribute to rapid soil moisture loss and even contraction and cracking of the soil. Sun scald or leaf burn on newly outplanted plants can result. Even if temperatures are high, simple cloud cover can dramatically reduce the plants' solar load and decrease ground temperatures.

Other Limiting Factors

Proper culturing of stock in the nursery can help overcome many other limiting site factors such as lack of beneficial microorganisms and low soil fertility. Other limiting site factors can be overcome by site preparation, outplanting methods, and maintenance practices, as described later in this chapter.

Species Selection

Choosing the plant species to be outplanted depends on the project objectives and needs to be tailored to meet the existing conditions at each outplanting site. If the primary objective is to restore the site to its natural condition, then selection of plant species indigenous to that area could be a logical choice. On degraded sites, such as abandoned pastures, however, climatic and edaphic conditions are highly altered and vastly different from conditions to which native species are adapted. In such cases, it is often more appropriate to plant species (noninvasive) that can withstand the extreme conditions. If the site will be managed for agroforestry, then species selection will be based on value for food or fodder production. For roadside plantings, trees must be able to handle difficult conditions and not produce messy flower or fruit that can interfere with cars or pedestrians.

The light requirements of a species are especially important to consider. Shade-intolerant species require full sunlight and tend to be "pioneer" species that can establish following disturbance. Shade-tolerant species can survive with less light and tend to grow slower than shade-intolerant species. In addition, some species are capable of fixing nitrogen from the atmosphere and can help mitigate poor soil conditions. These plant characteristics can be useful in deciding which species to use on a specific site. For instance, the use of a shade-intolerant, nitrogen-fixing pioneer species such as a noninvasive or native *Acacia* species may be ideal for "badlands," abandoned bauxite and phosphate mine sites, and pasture lands. After those are established and site conditions have improved, the site can be underplanted with native plant species. In some cases, an overstory of exotic trees is established. The canopy of these trees functions protectively over the underplanted native plant species (figure 17.1), thereby having a nurse effect (Feyera and others 2002).

Restoring abandoned pastures is common throughout the tropics. These pastures tend to be dominated by exotic, invasive species and have unique conditions that require special consideration when selecting species for outplanting. Pioneer species generally perform better when planted in former pastureland than mature forest species (Holl and Aide 2011; Hau and Corlett 2003) and using many species is preferable to using few (Van der Putten and others 2000). An additional planting at a later successional stage can be made to introduce a broader range of species to enhance diversity (Lamb and others 2005). Establishing fast-growing shrubs has also been shown to increase tree seedling survival (Holl 2002).

The project objectives will also dictate how many species to plant on a given site. A single species ("monoculture")

***Figure 17.1**—Native plant species underplanted beneath a nonnative overstory on Guam badlands. The overstory helped to improve the soil, and serves as shelter for the native plants. Photo by Ronald Overton.*

may be desirable when growing crops or tree farms. The lack of diversity in a monoculture may make the site vulnerable to disease or insects, but the temporary overstory can stabilize the microclimate, provide a forest structure, and encourage regeneration (Lugo 1997). Multiple species may be chosen based on their ability to provide multiple benefits or to create a multistoried mixture of native trees and shrubs. For instance, a mixture of shrubs and trees can provide an ideal structure for a windbreak or shelterbelt (Upton and deGroot 2008).

For any species used on a site, it is important that they meet the target size specifications suited to the particular outplanting site conditions (see Chapter 3, Defining the Target Plant). For example, smaller plants with shallow root systems are best for poorly drained sites. Smaller plants also require less water than larger plants. On the other hand, larger plants can better compete with existing vegetation. In addition, the proper genetic source should be selected (see Chapter 8, Collecting, Processing, and Storing Seeds).

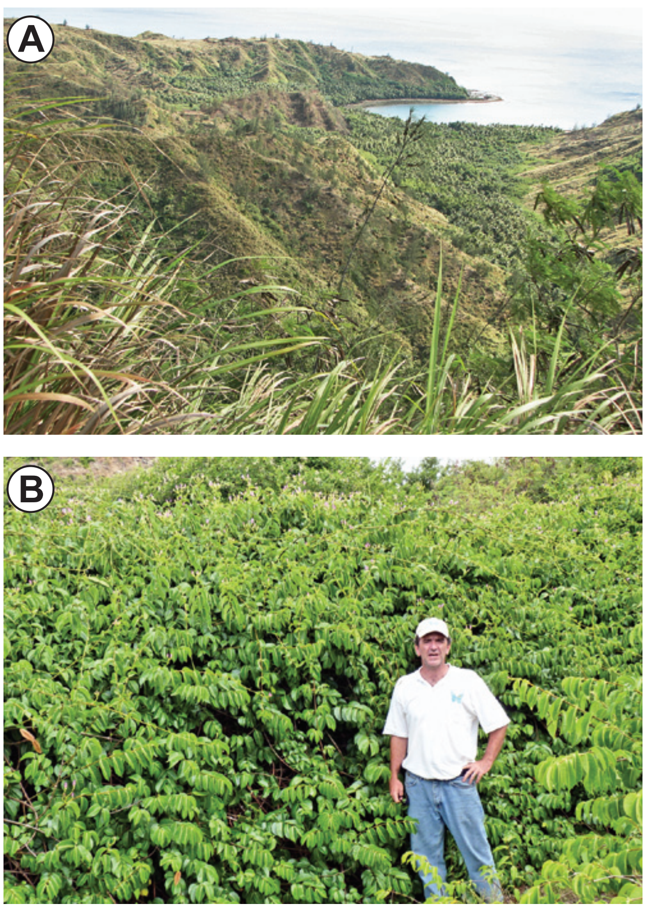


***Figure 17.2**—Existing vegetation on tropical sites often requires intensive site preparation to reduce competition with outplanted nursery stock. Shown: restoration site invaded with sword grass (*Miscanthus floridulus*) and tangantangan (*Leucaena leucocephala*) in Guam (A); an 8-ft-tall (2.4 m) wall of exotic, invasive rubber vine (*Cryptostegia grandiflora*) smothers all remaining woody plants in an abandoned pasture in coastal St. Croix, U.S. Virgin Islands (B). Photo A by Ronald Overton, and photo B by Brian F. Daley.*

Site Preparation

Many tropical sites have become overgrown with invasive plants (figure 17.2) and cannot be restored successfully without intensive site preparation (referred to as "site prep") to achieve adequate control of competing vegetation. Exotic, invasive plants aggressively compete for nutrients, water, and sunlight and can severely suppress or devastate newly planted nursery plants. In some cases, exotic, invasive plants can also pose a severe fire risk.

Removing competing vegetation has several benefits (USDA 2002), which can combine to give outplanted nursery plants a competitive advantage over exotic, invasive plants. Competitive advantage is critical in tropical sites where weed development is rapid and persistent. Site preparation is labor intensive and costly, but can be well worth the effort. Lowery and others (1993) noted that growth and survival of planted trees on tropical sites can increase by as much as 50 and 90 percent, respectively, with early control of vegetative competition.

Site prep also makes the physical process of planting easier by reducing or managing some of the surface debris on the site. Some surface debris is a valuable site resource. For example, woody material can be chipped and used on site as mulch and fallen logs or standing stumps can provide favorable microsites for planting as described later in this chapter.

Site prep can be accomplished by mechanical or chemical means. It is important to remember that site prep is a form of disturbance and exotic, invasive plants are well adapted to successfully invade freshly disturbed sites. Therefore, timely replanting of sites where vegetation has been removed is important to prevent weeds from recolonizing the cleared area.

Scalping

Scalping is the removal of grasses, forbs, small shrubs, and organic debris ("duff") around planting holes (figure 17.3A). Scalping reduces weed competition and increases soil moisture availability. Removing organic debris around the planting hole also ensures that roots are in contact with mineral soil (figure 17.3B); nursery stock planted in organic matter or duff tend to dry rapidly and often die. Scalping is ineffective against larger, woody, deep-rooted plants.

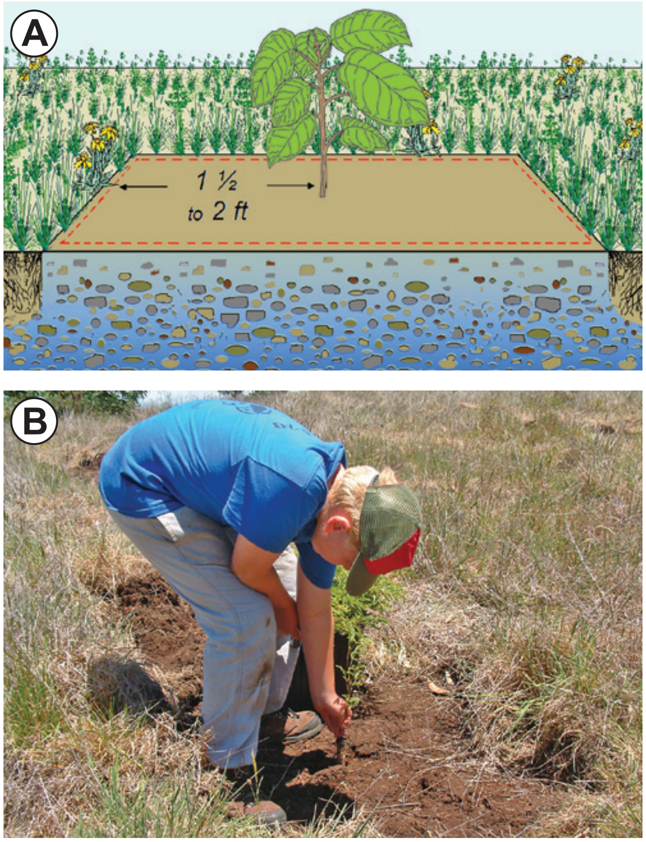


Figure 17.3*—Scalping is the physical removal of plants and organic debris from around the planting hole (A). Scalping helps to control competing vegetation and ensures that plants are planted into mineral soil (B). Illustration A by Jim Marin, modified from Rose and Haase (2006), and photo B by J.B. Friday.*

Physical Scalping

Scalping can be accomplished with planting tools such as a hoe or the side of a hoedad blade. With other planting implements, such as augers, another worker scalps beforehand. Planting contracts often contain specifications for the size and depth of scalping. For example, the Forest Service requires that all vegetation be removed from an area 12 to 24 in (30 to 60 cm) around the planting hole and 1 to 2 in (2 to 5 cm) in depth. On exposed sites, duff, litter, and decaying plant material should be placed back on the cleared surface after planting to serve as mulch (USDA 2002). In one study, increasing scalp size resulted in significant improvement in growth of planted conifer seedlings after 4 years (Rose and Rosner 2005).

Chemical Scalping (Herbicide Application)

Another site preparation option is to kill competing vegetation on the site with herbicides, especially around the planting holes,. Herbicide treatment is particularly effective against grasses and other herbaceous plants and is useful in tropical sites where plant growth is rapid (Ammondt and others 2013). A general-purpose herbicide such as glyphosate is effective against a broad spectrum of plant species. Herbicide application temporarily eliminates competition for water and also creates a mulch of dead organic matter that reduces surface evaporation. Vegetation control with herbicides has been shown to increase subsequent survival and growth of outplanted nursery stock. In a study with native tropical hardwoods in Costa Rica, tree diameter was significantly greater in plots treated with herbicide (Wightman and others 2001). An experiment evaluating three levels of vegetation control with chemical scalping significantly increased stem volume, basal diameter, and height of conifer seedlings on four of five sites with increasing area of weed control, and the magnitude of difference between treatments increased with time (Rose and Ketchum 2002). Although herbicide applications are effective in eradicating nonnative plants, they can also kill native plants so judicious and selective use is necessary.

The most appropriate herbicide application method depends on the type of project. For projects where the plants will be planted in rows, herbicides can be sprayed in rows by all-terrain vehicles (ATVs). For smaller projects, a person trained to select likely planting spots can apply herbicides with a backpack sprayer. Where the competing grasses and weeds are tall, they are first reduced mechanically, manually, or by burning before herbicides are applied to the emerging grasses and weeds. Herbicide application can be carefully timed to use the minimum amount possible for the maximum result. Never apply herbicide on the same day as planting and always follow the label instructions for application rates and time to reentry to the site after application. Quickly filling cleared areas with desirable plants is important to keep weeds from moving back in (figure 17.4).

Figure 17.4*—Competing vegetation can be killed with herbicides before planting. Quickly filling cleared areas with desirable plants is important to keep weeds from moving back in. Photo by J.B. Friday.*

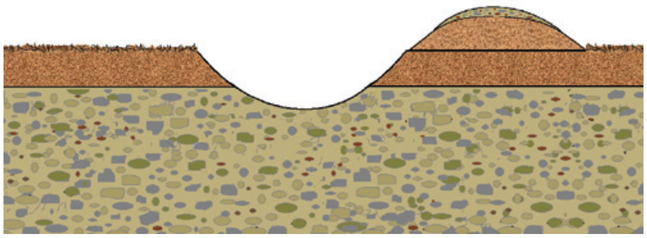


Figure 17.5*—On sites with heavy duff layers or in water-logged soils, mounding has proven to benefit plant survival and growth. Illustration from Landis and others (2010).*

Mounding

In some tropical sites, clay soils and organic matter combined with heavy rainfall can result in poor drainage and be an impediment to planted nursery stock. Mounding can be used to treat several potentially limiting factors: plant competition, poor soil aeration on wet sites, shallow soils, and nutrient deficiencies. Sutton (1993) provides a thorough discussion of mounding and how it has been used worldwide. For our purposes, we define mounding as the mechanical excavating and inverting of soil and sod to create planting spots that are higher than the existing terrain. With thick duff layers, the resulting mounds consist of a mineral soil cap over a double layer of humus (figure 17.5). The results of mounding have been generally favorable, at least in the short term. A study found that mounding was an effective alternative to herbicides for establishing pedunculate oaks (*Quercus robur*) on water-logged sites (Lof and others 2006). Mounding has been criticized from an aesthetic and ecological standpoint and can have a negative effect on other forest values such as recreation (Lof and others 2006). So, as with all site preparation treatments, mounding needs to be carefully evaluated on a site-by-site basis and compared with other site preparation options. It is generally only appropriate in areas where waterlogging and heavy rainfall are a problem.

Pit Planting (Zaï Holes)

In arid tropical soils, shallow planting pits can be prepared during the dry season (Kaboré and Reij 2004). The planting pit (zaï) dimensions vary according to soil type (8- to 16-in [20- to 40-cm] diameter and 4- to 8-in [10- to 20-cm] depth). The excavated soil is ridged around the pit to improve its water retention capacity and the pit is filled with composted organic matter. After the first rainfall, the pit is planted and covered with a layer of soil. The zaï functions to conserve water and reduce soil erosion.

Preparation of Severely Degraded Sites

Many tropical planting sites are established on degraded lands, such as abandoned pasture land, old agricultural fields, or mine land. On level, well-drained soils with heavy textures, mechanical site preparation using tractors with disc harrows can be used (Ladrach 1992). On low, wet sites, discing can help remove excess water and increase soil aeration. Subsoiling is effective for treating soils compacted from years of grazing or farming or on sites that have a natural hardpan.

On severely disturbed restoration sites, unusual site preparation to create suitable planting may be required. After the eruption of Mt. St. Helens in Washington State, the restoration of 150,000 acres (60,700 ha) of timberland posed some serious challenges (figure 17.6A). Experiments showed that seedlings must be planted in mineral soil to survive, which required digging through 1 to 2 ft (30 to 60

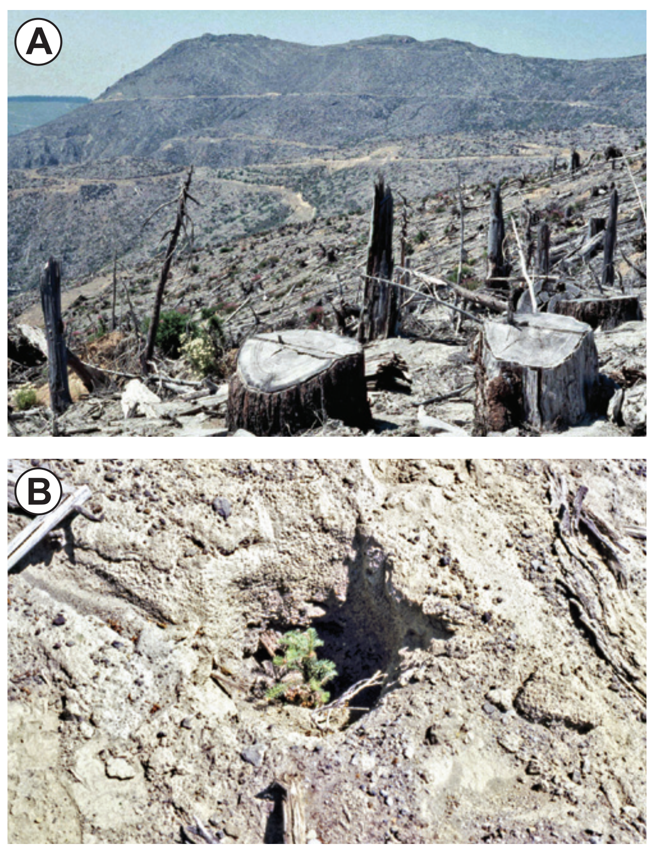


Figure 17.6*—Some restoration sites require special preparations before they can be planted. The blast zone of Mt. St. Helens in Washington State was covered with volcanic ash (A), which had to be dug away so that seedlings could be planted in mineral soil (B). Photos by Thomas D. Landis.*

cm) of volcanic ash at each planting spot (figure 17.6B).

In many cases, planting sites must undergo major stabilization before planting can occur. Because of their steep slopes and the erosive power of water, stream banks must be stabilized with bioengineering structures before they can be revegetated (figure 17.7A). Woody cuttings of many riparian species used in the structures will sprout (figure 17.7B) and provide rapid revegetation (Hoag and Landis 2001). With stabilization, careful planning, and planting quality stock, riparian areas can be restored (figure 17.7C).

In other conditions, the disturbance may be so severe that recovery has to take place in stages. For example, a strategy for addressing watershed restoration, biodiversity, invasive species, and wildfire problems in southern Guam involves a diversified landscape approach with objectives and prescriptions adapted to local site conditions which range from extremely eroded badlands to highly flammable, swordgrass-dominated grasslands. Steps include creating fuel breaks, planting nonnative *Acacia* trees to shade out sword grass and rehabilitate the soil, and ultimately planting native trees (Bell and others 2002).

Onsite Inspection, Storage, and Handling

Nursery Stock Inspection

As discussed in Chapter 16, Harvesting and Shipping, nursery plants are vulnerable to stresses from the time they are harvested at the nursery until they are outplanting. Therefore, it is a good idea to conduct a thorough inspection of nursery stock when it arrives at the outplanting site. The plants should appear green and healthy with full canopies and without signs of insect, disease, or other stresses. Nursery stock should not smell sour or sweet, which is evidence that it has been too warm or too wet. Root systems need to be moist but not saturated. The bark should not easily slough off and the tissue underneath should be creamy white, not brown or black. If white or gray mycelia (evidence of mold) are present, check the firmness of the tissue underneath. Soggy or water soaked tissue indicates serious decay and those plants need to be culled. Plants with superficial mycelia without corresponding decay need to be planted immediately. Fungal molds will not survive after exposure to ambient conditions on the site.

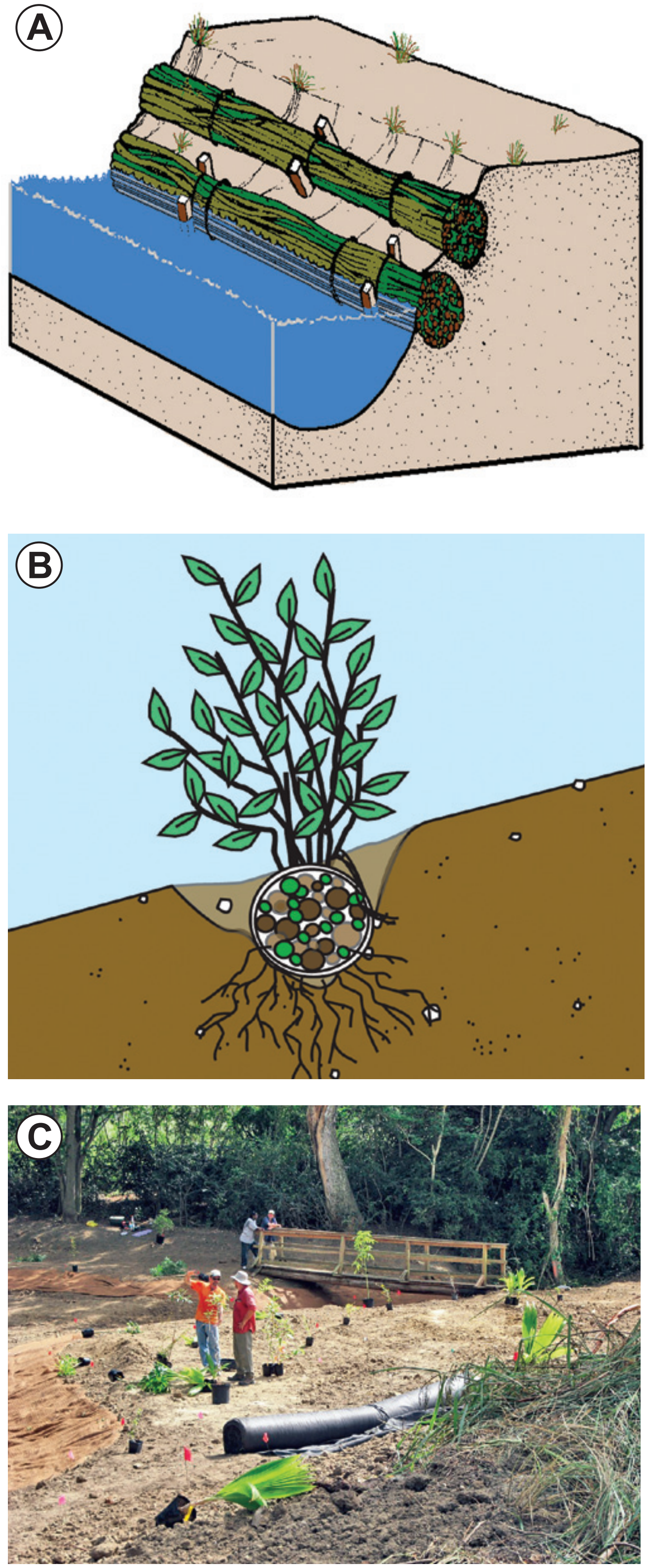


***Figure 17.7**—Stream banks often require bioengineering structures (A) for stabilization. When cuttings of certain species are used, they can sprout quickly (B). Careful planning and quality planting stock help ensure restoration success (C). Illustration A from Hoag and Landis (2001), illustration B from Steinfeld and others (2008), and photo C by Brian F. Daley.*

Onsite Storage

Nursery stock need to be outplanted upon arrival to the project site. Therefore, it is always wise to plan ahead. Bring only as much stock as can be planted on a given day. Weather delays, distance, worker scheduling, poor communication, or other logistical issues can make it operationally impossible to complete planting in a single day, however, and therefore short-term onsite storage may be needed. The duration of onsite storage should last for only a day or two.

Whether for a couple hours or a couple days, overheating and desiccation are the major stresses that can occur during onsite storage. To dissipate heat and promote good air exchange, the plants need to be set upright and placed in a shady area as soon as they arrive on site. Plants should never be left in a closed vehicle. Trees and other natural shade are often absent on many restoration sites, but even when natural shade is available, it can be difficult to keep plants in the shade all day. Therefore, plan on erecting some type of artificial shade. Tarps or shadecloth suspended between poles is effective. Light-colored tarps are preferred. As shown in Figure 16.9B, dark-colored tarps absorb and reradiate solar heat (Emmingham and others 2002) and need to be suspended above the nursery stock for good air circulation.

Plant respiration and transpiration rates are a function of temperature, which is influenced by sunlight intensity. Therefore, check that root plugs are kept moist and plants are not under any moisture stress. Irrigating plants on the project site is not commonly done but can increase survival when site conditions may dry stock. So, the best onsite storage has access to a reliable water source.

On mountainous sites, the plants need to be covered to protect the roots from excessive cold if frost is anticipated during onsite storage.

Plant Handling

During the planting process, plants should always be handled with utmost care. Plants must be protected at all times from desiccation, temperature extremes, and physical damage. The same principles of careful handling described for harvesting and shipping (see Chapter 16, Harvesting and Shipping) need to be applied to the planting operation. Crews need to be instructed to never toss or drop plants. Research shows that dropping seedlings from various heights can result in growth reductions after planting (Sharpe and others 1990, McKay and others 1993). Larger plants need to be carried by the container or the rootball, never by their stems. Planters should never shake or beat plants to remove excess growing medium. Each planter should carry only as many plants as can be planted in 1 or 2 hours. On larger reforestation and restoration projects, it is most efficient to use runners that carry batches of nursery stock from onsite storage to planters.

All planters need to be thoroughly trained in gentle handling and planting procedures. Even high-quality nursery stock will die if improperly outplanted. Training is particularly important with volunteers or other inexperienced planters. Many of these people lack the skill or strength necessary to properly plant on wildland sites. One option is to have an experienced planter create the planting holes just ahead of the volunteer crew, and let the volunteers place and tamp plants into position. This technique ensures that the experienced planter chooses the proper planting spot, creates the desired planting pattern, and makes certain that the planting hole is large and deep enough so that plants can be situated properly.

Selecting Planting Spots

Pattern and Spacing

The selected pattern and spacing of outplanted plants reflects the project objectives. Most planting projects specify a desired number of established plants per area (table 17.1). These density targets need to be considered general guidelines and should never override the selection of planting spots in biologically suitable areas. Trees grown for timber or fruit production are often planted with uniform spacing in rows (figure 17.8A). Trees planted for windbreaks are planted in staggered rows positioned perpendicular to the prevailing winds. Where ecological restoration is the objective, however, planting distribution and spacing will be more representative of natural vegetation patterns based on reference sites (see Chapter 3, Defining the Target Plant). For aesthetics and a more natural look, other projects may choose random outplanting of individual plants (figure 17.8B) or outplanting in random groups (figure 17.8C).

When planting with larger tree species, proper spacing is of utmost importance to minimize competition after the trees reach maturity. This spacing is generally achieved by assigning minimum distances between plants (table 17.1). It can be advantageous to plant at a higher density than the final target density to avoid the need to replant after some plants die. In fact, denser planting can promote plant growth by forming a thicket to protect against animals, wind, and competing vegetation and by promoting mycorrhizal development (Upton and deGroot 2008). If necessary, plants can be thinned out as they mature.

Microsites

Choosing the best planting spots is critical and more important than exact spacing. Planting in favorable microsites protects nursery stock and greatly improves the probability of survival. Examples of unfavorable planting spots include depressions with standing water, rocky spots, deep duff, and compacted soils. Plants shaded by a stump, log, or large rock tend to grow well, especially on hot, dry sites (figures 17.9A, 17.9B). High sunlight on plant foliage causes moisture stress and direct sunlight can cause ground temperatures lethal to the seedling. Planting around physical

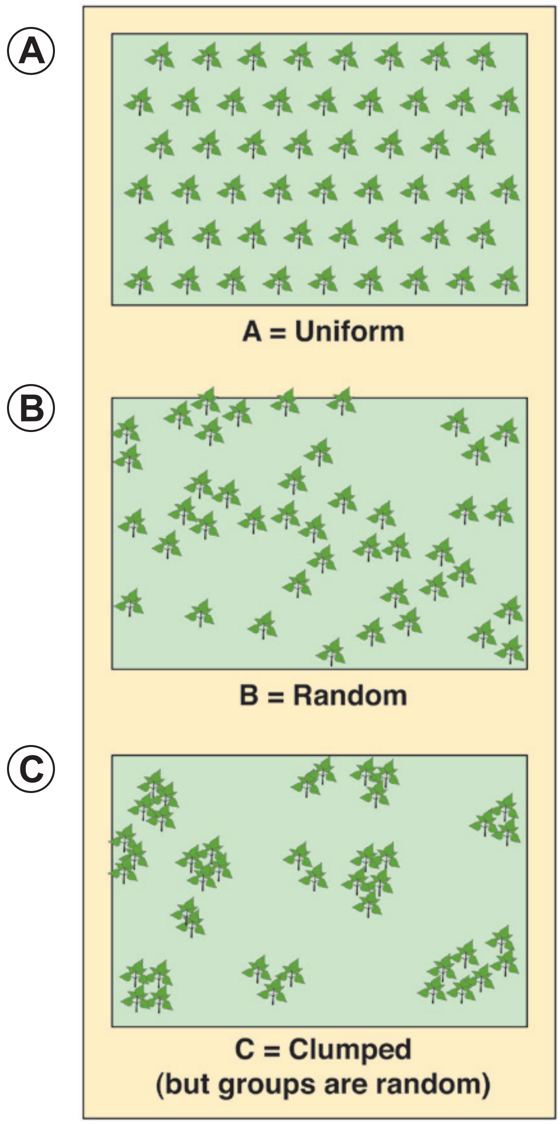


Figure 17.8*—In addition to target plant specifications, the objectives of the outplanting project also affect planting patterns. If the objective is timber or agroforestry, then plants are often regularly spaced (A). Most restoration projects are spaced in a more random pattern to mimic natural conditions (B) or in a random clumped pattern where different species are planted in groups (C). Illustrations adapted from Landis and others (2010).*

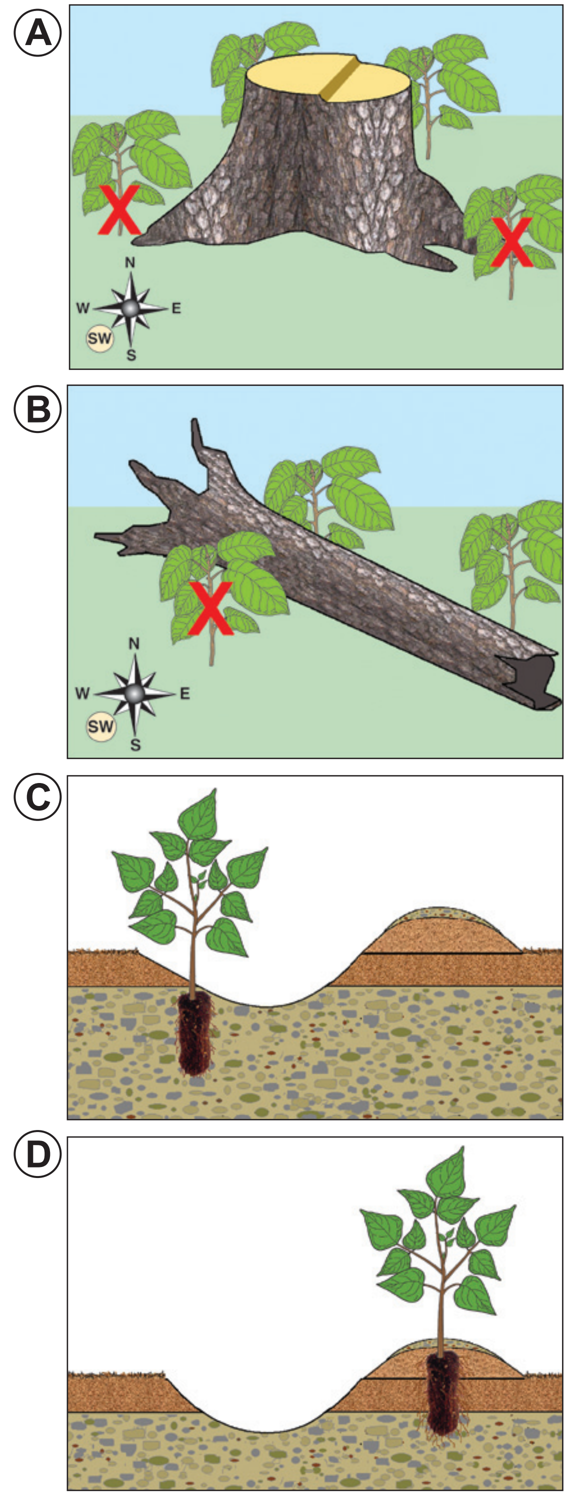


Figure 17.9*—On sites with uneven terrain with physical obstructions, the best planting spots are in microsites in the shade of stumps (A) or other debris (B). Compass designations in A and B are for the northern hemisphere; planting orientation is the opposite for the southern hemisphere. Specific planting spots are also prescribed on sites that have been prepared by discing (C) or mounding (D). Illustrations A and B adapted from Rose and Haase (2006), and illustrations C and D adapted from Heiskanen and Viiri (2005).*

Table 17.1—Plant spacing based on regular grids with resultant densities. Adapted from Cleary and others (1978).

Spacing (m)	Plants per hectare	Plants per acre	Spacing (ft)
6.4 by 6.4	247	100	20.9 by 20.9
14.8 by 14.8	494	200	4.5 by 4.5
3.7 by 3.7	741	300	12.0 by 12.0
3.2 by 3.2	988	400	10.4 by 10.4
2.8 by 2.8	1,236	500	9.3 by 9.3
2.6 by 2.6	1,483	600	8.5 by 8.5
2.4 by 2.4	1,730	700	7.9 by 7.9
2.2 by 2.2	1,977	800	7.4 by 7.4
2.1 by 2.1	2,224	900	7.0 by 7.0
2.0 by 2.0	2,471	1,000	6.6 by 6.6

obstructions also provides protection from animal damage. Where planting sites have been mechanically prepared with disc scarifiers, nursery stock need to be planted on the side of the hole in mineral soil (figure 17.9C). On mounds, the best planting spot is on the top (figure 17.9D).

Proper Planting Technique

Planting Hole

Good root-to-soil contact is necessary for nursery stock to become established on the site and be able to readily access water and mineral nutrients. The planting hole needs to be made deep enough so that, when filled, the soil is up to the plant's root collar. For container plants, the root plug needs to be completely covered with mineral soil (figure 17.10A). "J-rooting" and unnecessary exposure of the root plug are avoided when the planting hole is sufficiently deep (figure 17.10B), but the plant should not be planted too deep (figure 17.10C). Burying foliage should be avoided. According to Forest Service specifications, the minimum-size hole for container stock is 1 in (2.5 cm) deeper than the plug length, and at least 3 in (7 cm) wider than the plug at top of the hole and 1 in (2 cm) wider at bottom (USDA 2002). By making the hole larger than the root system, the planter can break up any compacted soil around the root system, thereby creating more favorable soil conditions for roots to grow.

The planters need to be instructed to plant at the correct depth and not to pull up on the plant to adjust depth or straightness. Plants should not be oriented more than 30 degrees from the vertical plane (figure 17.10D); this configuration seems obvious on level ground, but the steeper the slope, the more important this orientation becomes. Planting holes need to be backfilled with mineral soil without grass, sticks, or rocks (figure 17.10E). It is important to firmly tamp the soil around the root plug to remove air pockets (figure 17.10F), but refrain from stomping around plants to avoid excessive soil compaction or stem injury.

Planting Tools

Although the choice of the proper planting tool is important, experienced planters can achieve success with a variety of implements and may choose to use a combination of tools

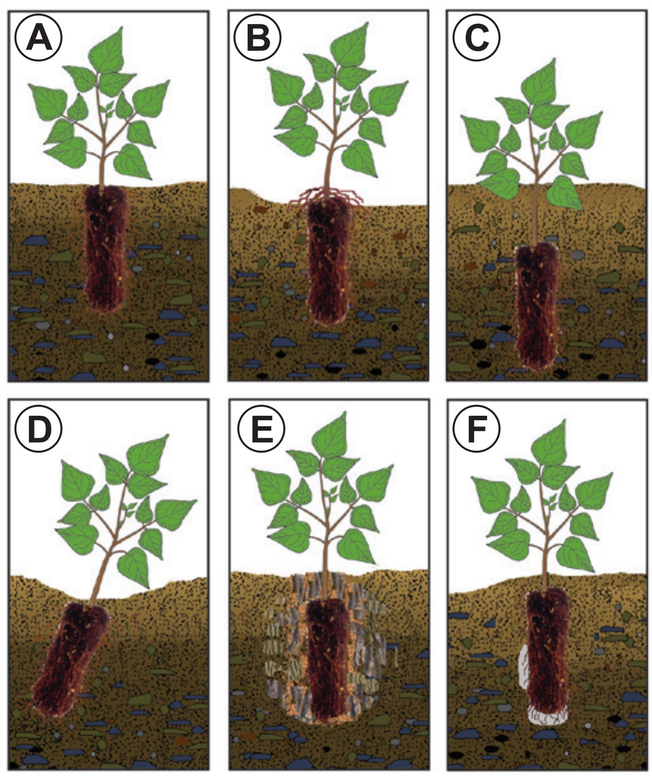


Figure 17.10—Nursery stock should be planted properly (A). Common problems include planting too shallow (B), planting too deep (C), not placing vertically (D), filling the hole with debris (E), or allowing air pockets around the roots (F). Adapted from Rose and Haase 2006.

depending on site conditions. Planting failures are often more attributable to improper technique or handling rather than choice of planting tool (Adams and Patterson 2004). Appropriate planting tools and techniques can mean the difference between a live or dead plant, and an on-budget or over-budget project (Kloetzel 2004). Hand-planting methods provide maximum flexibility in plant placement and distribution. A well-trained and experienced hand planter can surpass the planting quality and generally match the speed of many automated methods, especially over rough terrain. Hand planting is especially recommended for placing plants into microsites, and when planting a mixture of species or stock types. Motorized auger planting may be useful for larger stock sizes, especially on open, flat sites with deep soil and few rocks or roots.

Dibbles

Dibbles or dibble sticks were among the first tools used to plant small container stock, primarily because they are easy to use (figure 17.11A). Dibbles are custom-made probes that create a planting hole specific to one container type and size. Most designs have one or two metal foot pedals for forcing the point into the soil (figure 17.11B). After making the hole, the planter simply inserts the container plant and moves to the next hole. One drawback is the lack of loose soil to cover the top of the plug and prevent possible desiccation of the medium. Dibbles are most appropriate for lighter textured upland soils or alluvial bottomland soils in wetland restoration projects. Dibbles should be avoided on heavier textured clay soils because they can compact soil and form a glaze around the planting hole that can restrict root egress (figure 17.11C). Hollow dibbles are a recent modification that extract a core of soil and therefore reduce soil compaction (figure 17.11D). The hollow dibble heads are interchangeable to provide the correct dibble for different container sizes (Trent 1999). Commercially produced dibbles are available for specific container types and sizes, including Ray Leach Cone-tainer™ cells and several cavity sizes of Styrofoam® block containers (Kloetzel 2004). The ‘o’o bar (Hawaiian name) or oso planting stick (Samoan name) is a traditional planting tool similar to a dibble stick and is useful for breaking through layers of lava to help tree roots reach mineral soil (figure 17.12).

Bars

Planting bars originated with bareroot stock, but this tool is also used for smaller container plants. Bars are typically cylindrical with a wedge-shaped blade welded on the tip, and side pedals to help force the blade into the soil. Like dibbles, planting bars require little experience or training. The bar is dropped and forced into the ground with the side pedals (figure 17.13A), and by working the bar back and forth the planting hole is formed. The nursery plant is vertically positioned along one cut face (figure 17.13B), and then the hole is closed by reinserting the bar into the soil on the opposite side of the planting hole and rocking the bar back and forth (figure 17.13C). The final step is to finish tamping any loose soil around the plant to remove any air pockets (figure 17.13D). Planting bars are often preferred for rocky soils but should not be used in heavier textured clays where they cause excessive compaction. They are also popular on reforestation sites with sandy soils. Planting bars are durable and simple to maintain, with only occasional blade sharpening required (Kloetzel 2004).

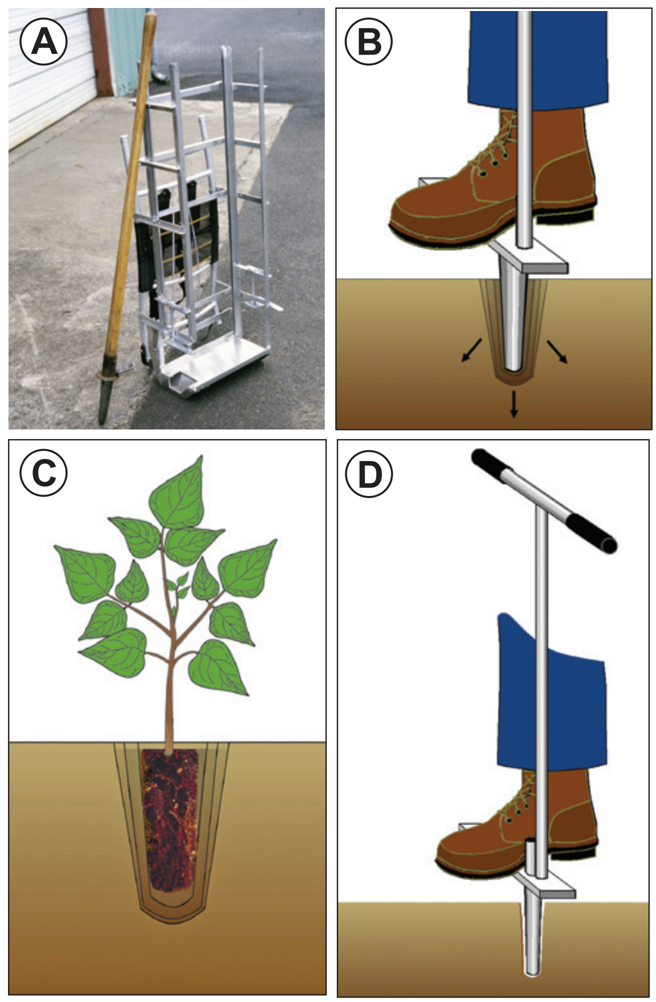


Figure 17.11*—Dibbles are a useful tool for hand planting container nursery stock (A). Because they displace soil to form the planting hole (B), compaction can be severe enough to restrict root egress (C). Hollow dibbles are an improvement because they remove a core of soil to create a planting hole (D). Photo A by Thomas D. Landis, and illustrations B, C, and D by Steve Morrison, modified by Jim Marin.*

Figure 17.12—'O'o bars or oso digging sticks are traditional planting tools useful for digging through lava to plant seedlings in mineral soil. Photo by Diane L. Haase.

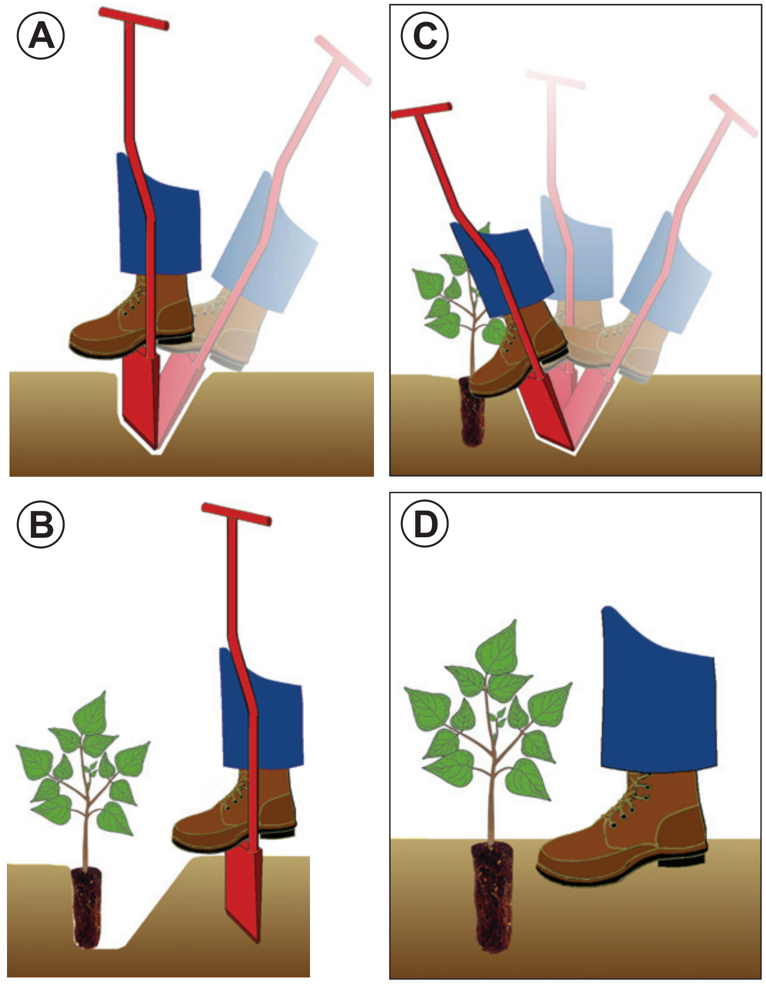


Figure 17.13—Bars are planting tools that create a planting hole by lateral movement (A). The plant is positioned along one side of the planting hole (B), and soil is backfilled by leverage from the other side (C). Soil should be gently compacted around the plant with hand or foot (D). Illustrations by Steve Morrison, modified by Jim Marin.

Hoedads

Hoedads are one of the more popular and versatile tools for outplanting reforestation and restoration stock. Brackets, holding the wooden handle to the desired blade, are typically brass for extra weight and penetration, or tin alloy ("Tinselite") for lighter applications. Brackets can be found in two blade angle configurations: 100° angle for applications on gently sloped or flat areas and 90° angle for steep ground planting. It is a good idea to purchase and keep handy spare blades, handles, and nuts and bolts with matching socket or box wrenches. Blades should also be regularly sharpened with a metal file or electric grinding wheel (Kloetzel 2004). Hoedads are particularly useful on steep sites, and on rocky and compacted sites. They are swung much like a pick, and it may take several swings to create a proper planting hole. With each swing, the planter lifts up and back with the butt of the handle to open the planting hole (figure 17.14A). After a proper hole is opened, the planter uses the tip of the hoedad to gently loosen soil on the sides of the planting hole to avoid any compaction effects. Then, the plant is inserted and positioned to the proper depth (figure 17.14B). While holding the plant, the planter uses the hoedad blade to backfill the soil around the plug (figure 17.14C). Finally, the planter gently tamps the soil around the plant (figure 17.14D) and moves to the next planting spot. If plant competition is a problem, or a planting basin is required, the back and side of the hoedad's blade is a useful scalping tool. Some compaction in the planting hole can occur from the backside of the hoedad's blade, but compaction is typically less than with other methods. Planting rates vary with container size, planter skill, and terrain. Kloetzel (2004) reported that beginning planters can install 20 plants per hour while

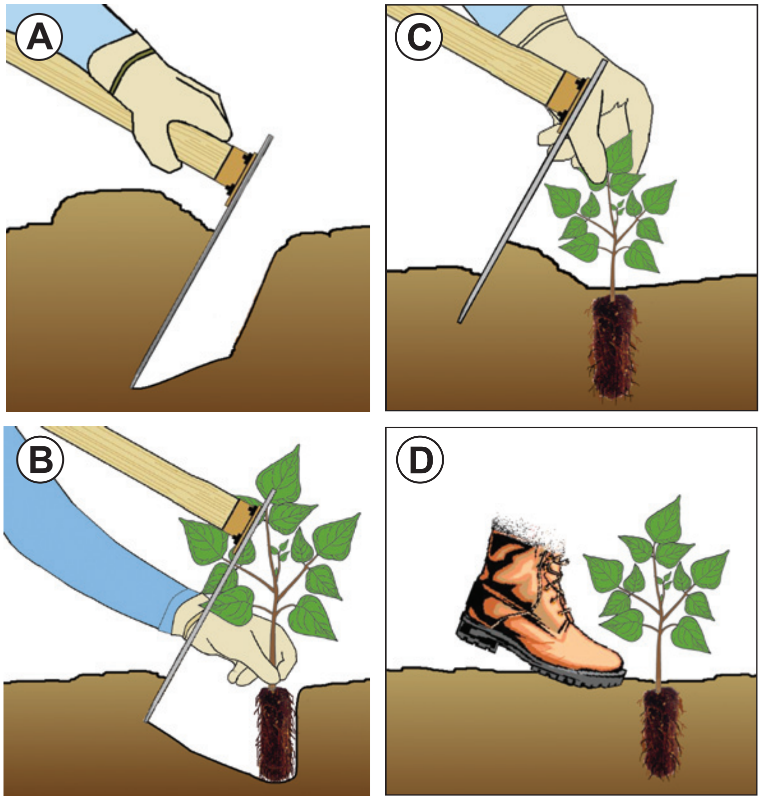
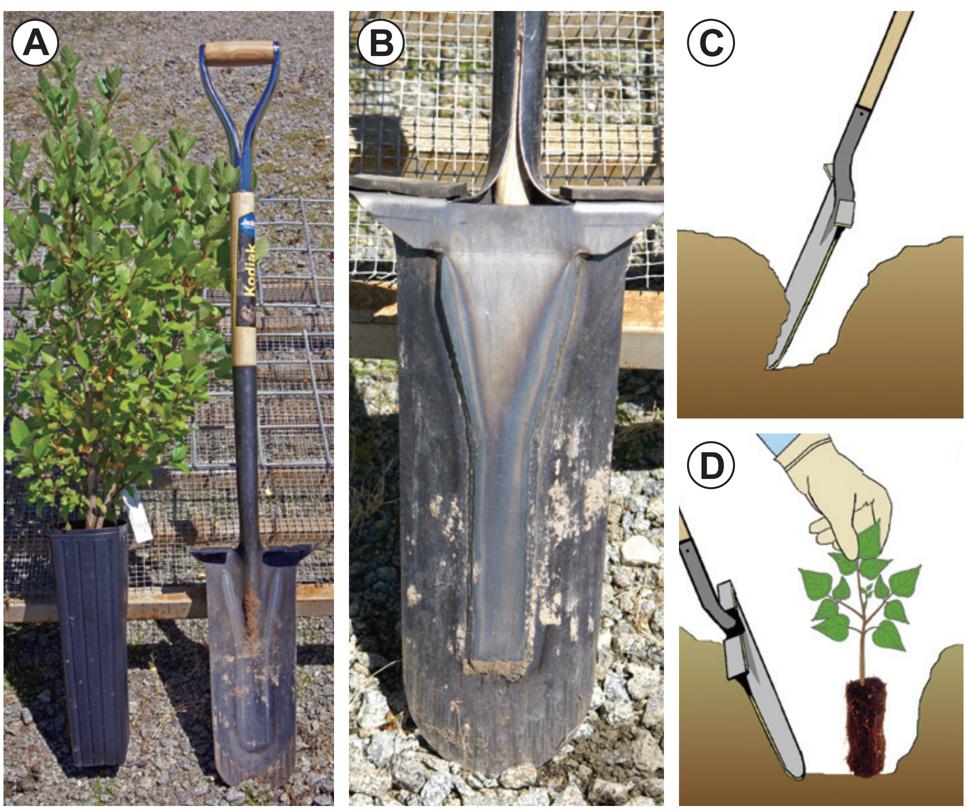


Figure 17.14—After several swings with the hoedad to create a deep enough planting hole (A), the plant is positioned and held (B) while backfilling with soil (C). The final step is to gently tamp the soil around the plant to remove any air pockets (D). Illustrations by Steve Morrison, modified by Jim Marin.

experienced planters may reach up to 100 plants per hour, and that on wetland planting projects with small stock and favorable soil conditions, production reached 240 plants per hour.

Shovels

Although standard garden tile spades can be used, professional planters use customized shovels with blades long enough to accommodate large containers (figure 17.15A). Wooden handles are standard but fiberglass models are lighter, and reinforced blades (figure 17.15B) can endure the vigorous prying action used to open planting holes (figure 17.15C). Although not as difficult to learn to use as hoedads, planters need to be trained to use tree-planting shovels efficiently. After the hole is excavated to the proper size and depth, the nursery plant is placed in the hole and held in a vertical position (figure 17.15D) while the planter backfills around the root plug (figure 17.15E). Soil amendments, fertilizers, and other such in-soil treatments are easily applied with planting shovels. When using planting shovels, keep some spare handles and footpads on hand, along with tools for installing parts and sharpening blades (Kloetzel 2004).



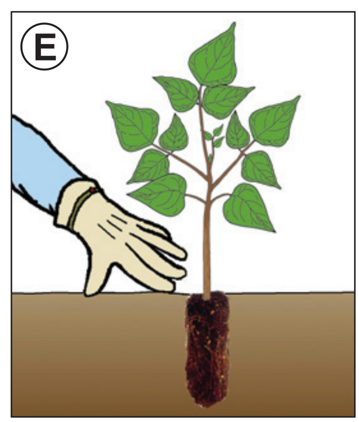


Figure 17.15—Shovels are very versatile planting tools and are ideal for large and deep container plants (A). Specialized shovels have reinforced blades (B) that open deep planting holes without soil compaction (C). While holding the plant vertical in the middle of the hole (D), soil is backfilled and tamped around the root plug (E). Photos A and B by Thomas D. Landis, and illustrations C, D, and E by Steve Morrison, modified by Jim Marin.

Mattocks

The mattock ("talacho") is a versatile tool used for digging and chopping (figure 17.16). It is especially useful for cutting through overstory tree roots when doing enrichment plantings under native tropical forests. In a comparison of three planting tools used for establishing tropical hardwood seedlings, no difference existed in seedling performance attributable to the type of tool but workers preferred the talacho because it was easy to use, it cut roots even better than a machete, and soil did not adhere to it as readily as on the other tools (Mexal and others 2005). Planting technique with a mattock is very similar to the hoedad (figures 17.14, 17.16) but the sharp axe-like end can be used to clear roots and other barriers.

Figure 17.16*—Mattocks (left) are versatile tools useful for digging and chopping through roots. They are similar to the hoedad (on the right) but have a sharp axe-like end for clearing roots and other barriers. Photo adapted from Forestry Suppliers, Inc., (2013) by Jim Marin.*

Mechanized Dibbles (Planting Tubes)

Mechanized dibbles create a planting hole by compressing soil to the sides and bottom with a pointed pair of hinged jaws. The jaws are switched open with a foot lever, and a container plant is dropped through the hollow stem tube into the hole (figure 17.17). The Pottiputki planting tube is the most popular brand and is available in several models with different tube diameters. In some models, the planting depth is adjustable, which would be necessary for stocktypes with longer plugs. One attractive benefit of planting tubes is less worker fatigue because the operator does not have to bend over. Planting tubes are popular in the Northeastern United States and Canada, although they are considered expensive to purchase and maintain. In one comparison, planting tubes were as effective as dibbles or planting bars (Jones and Alm 1989).

Motorized Augers

Power augers have been used in reforestation for decades and are becoming popular for restoration projects (figure 17.18A). Augers work best in deep soils without too many large rocks or roots, and are the best planting

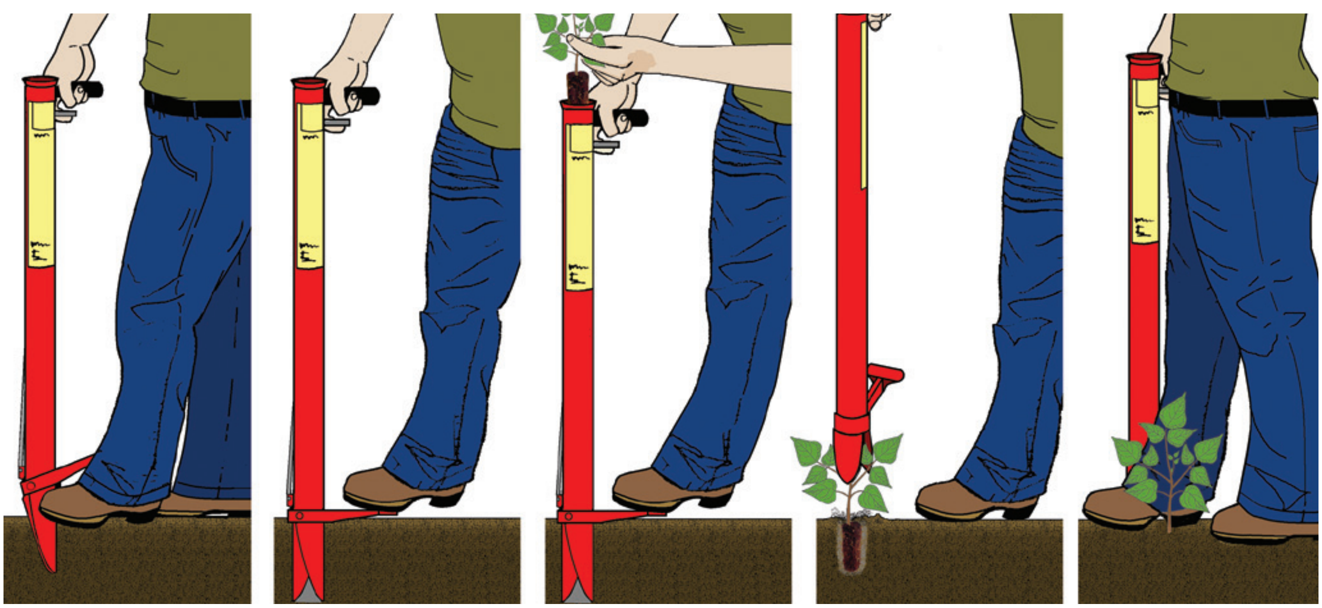


Figure 17.17*—Planting tubes have pointed jaws that open the planting hole. The plant is then dropped down into the hole through the hollow stem. Original illustration by Steve Morrison, and modified by Jim Marin.*

tool to use for larger, taller stocktypes. One concern has been compaction or glazing on the sides of augered holes that occurs under some soil conditions (Lowman 1999); this effect can be minimized by rocking the auger bit slightly. A gasoline-powered hand drill can be used with auger bits from 1 to 4 in (2.5 to 10.0 cm) diameter, and the reversible transmission helps when the bit becomes stuck (Trent 1999). Larger augers (10 to 16 in [25 to 40 cm] in diameter) mounted on a skid steer can also be used depending on soil type and terrain (figure 17.18B).

One benefit of auger planting projects is that the operator selects the location of planting spots and also controls the quality of the planting holes (figure 17.18C). One operator can drill enough holes for several planters to follow and plant the nursery stock (figure 17.18D). When scalping is required, the scalper will select the planting spots and create the scalp in advance of the auger operator. In some soil types, the operator will have to excavate extra mineral soil near each hole to ensure proper planting. When possible, it is best to rotate the auger operator to reduce fatigue.

Digging auger holes deeper than the depth of the container reduces compaction and can promote downward root growth. This approach leaves the planter to support the plant at the proper depth in the hole, while filling with soil from the bottom up (figures 17.8D, 17.8E). Soil settling can be a problem with auger planting so it is a good idea to mound soil around the base of the plant. A wide variety of augers are commercially available for rent or sale. When doing large-scale reforestation or restoration projects, it is more cost effective to purchase one. If you are inexperienced with their operation, however, it is a good idea to rent first to ensure that you have the correct machine for the project. Augers are high maintenance planting tools, so have an extra one handy, as well as extra parts and bits. Well-organized auger teams can reach production rates ranging from 30 to 70 plants per person/hour (Kloetzel 2004). In some parts of Hawaiʻi, the auger has become the ideal planting tool when volunteers or other nonprofessional planters are involved, because the planting rate is 2.5 times that of standard hand tools (Jeffrey and Horiuchi 2003).

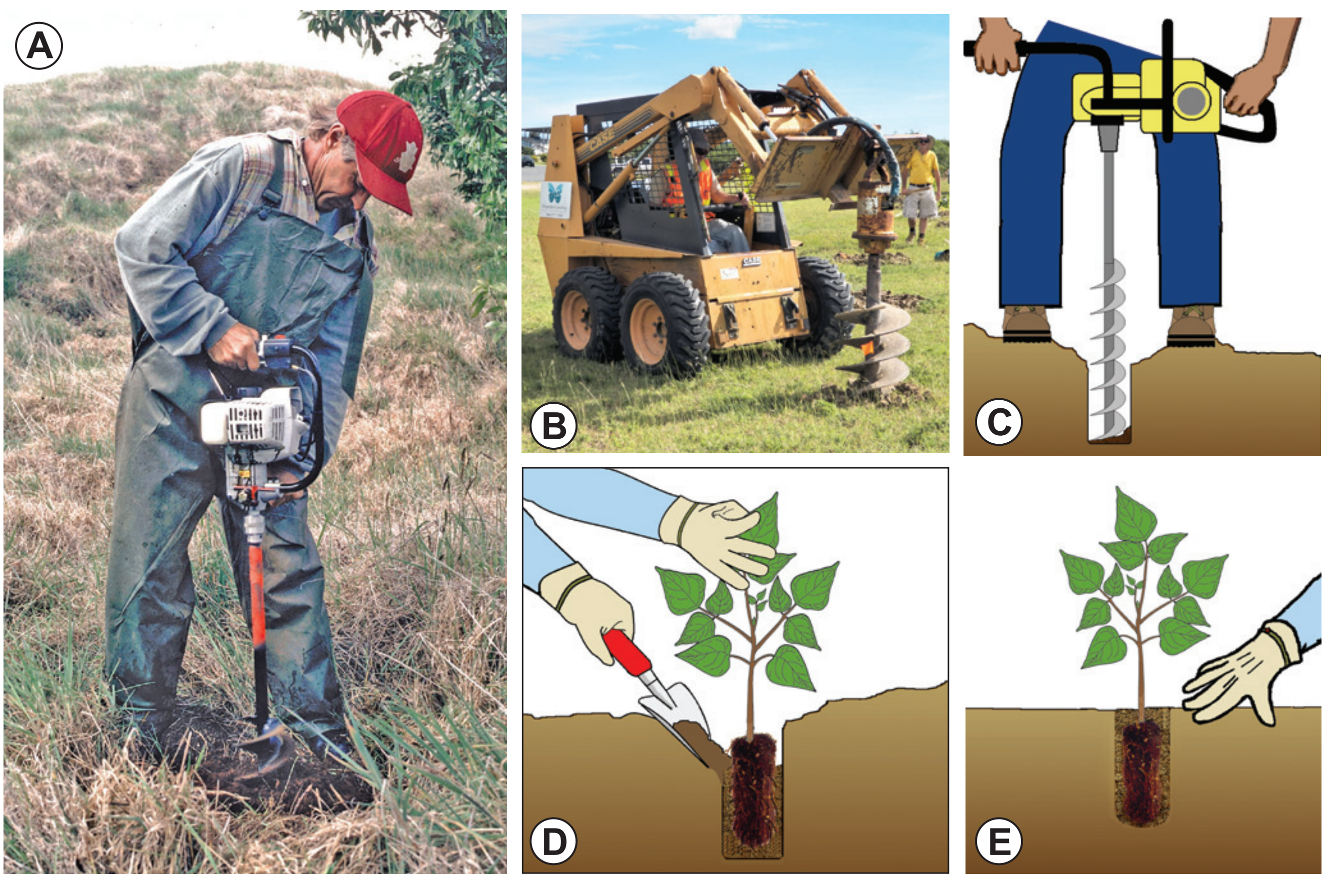


Figure 17.18*—Augers are effective planting tools and are available in handheld (A) or tractor-mounted (B). One skilled operator can create planting holes (C) while other workers plant the stock and fill the holes by hand (D and E). Photo A by ©Jack Jeffrey Photography, photo B by Brian F. Daley, and illustrations C, D, and E by Steve Morrison, modified by Jim Marin.*

Worker Protection

Planting nursery stock can be strenuous. Encourage workers to wear hard hats, safety glasses, and sturdy footwear to protect them from sun, insects, and site hazards. If possible, workers need to rotate with each other for carrying, digging, planting, and other tasks. Workers need to have plenty of fluids available to drink and need to take adequate breaks to avoid exhaustion. The time and resources spent on worker protection will be offset by potential downtime and workers' compensation claims (Kloetzel 2004).

Treatments at the Time of Planting

In addition to site preparation to control competing vegetation on tropical reforestation or restoration sites, other treatments may be applied to plants at the time of outplanting to improve survival and growth. These solutions to potential limiting factors need to be identified during the site evaluation and planning process.

Dipping Roots

The seedling root system or container plug needs to be moist when it is placed in the planting hole. The practice of dipping plant roots in water or a clay slurry to protect them from desiccation during outplanting has been used for many years, especially for bareroot stock, and has proven beneficial on dry sites. Roots of nursery plants dry as they are exposed to the atmosphere during harvesting and handling and so it makes sense to rehydrate them or apply a coating to protect them. Simply dipping the root systems in a bucket of clean water to saturate them before outplanting is beneficial. Wetting some of the soil and using it to "muddy-in" the hole with wet soil and water also helps ensure that no air pockets exist around the plant's roots.

Many commercial root dips are available and most are hydrogels, which can absorb and retain many times their own weight in water. Little published research exists on hydrogels and the results are mixed (Landis and Haase 2012). In a trial with Eucalyptus root plugs dipped in a hydrogel slurry, significantly lower mortality rates emerged 5 months after outplanting compared with the controls. The author attributed this outcome to increased soil moisture or contact between the root plug and the field soil (Thomas 2008).

Water Catchment

When filling the planting hole, a small bund (embankment) can be made around the base of individual trees or blocks of trees to prevent runoff of rainwater and direct it to the roots (Upton and deGroot 2008). This method can be vital during the dry season when plants are becoming established. The raised bund can be made on the downhill side of the tree and a trench or small swale is made on the uphill side to encourage water to infiltrate into the root zone.

Protection From Animal Damage

Compared with wild plants, fertilized nursery stock has higher levels of mineral nutrients and is therefore preferred browse by many animals. In many tropical areas, introduced pigs, goats, cattle, sheep, horses, deer, and other animals severely damage or destroy plantings by grazing, browsing, rooting, and trampling (figure 17.19). If the outplanting area is known to have a problem with animal damage, then control measures will be necessary. Physical barriers installed immediately after planting such as netting, rigid mesh tubing, bud capping, and fencing can be helpful to protect plants long enough for them to grow large enough to resist animal damage. Most mesh tubes and netting are designed to biodegrade over time. Even still, periodic maintenance is usually required because shoots can get tangled in the mesh and deform the stem. After plants grow out of the netting or tube, they are again vulnerable to browsing damage.

Fencing is expensive but in areas with dense animal populations, exclusion via fencing is often the most effective method. In Hawai'i, an intensive restoration program to rebuild functional ecosystems in the Auwahi forest of Maui includes installation of a 7 ft (2 m) tall fence to exclude ungulates, application of a 1- to 2-percent concentration of

Figure 17.19*—Animals can cause significant damage to outplanted nursery stock such as the browse damage on this seedling planted in Guam. Photo by Ronald Overton.*

Figure 17.20*—This intensive restoration project by the Leeward Haleakala Watershed Restoration Partnership to rebuild functional ecosystems in the Auwahi forest of Maui includes fencing to exclude ungulates and can be seen by satellite imagery. Source: "Maui Restoration." 20°38.627' N 156° 20.519' W. Google Earth. March 20, 2011. Accessed March 2013.*

glyphosate to kill exotic grasses, outplant of quick-growing native shrubs, and public involvement (Medeiros and vonAllmen 2006). Within 10 years, the results were dramatic and could be seen in satellite photos (figure 17.20). Weller and others (2011) concluded that effective conservation of native tropical forests requires ungulate exclusion, removal of invasive exotic plant species, and proactive restoration programs for native species without natural sources of propagules. In some instances, "live fencing," made of species that grow densely and have thorns that will keep animals (and people) away from the newly planted nursery stock, can be used. This approach requires advanced planning, however, because it may take 2 to 3 years before the live fence is sufficiently developed.

Chemical repellents are another option to protect from animal damage. These repellents are less costly than physical barriers but their efficacy can be shorter lived. A variety of products are available that have an odor (often from predators) or taste that is repugnant to wildlife.

Fertilization

Mineral nutrition is a key component of plant performance after outplanting. Studies have shown a positive field response to fertilizer applied at the time of planting or incorporated into the growing medium of container seedlings (Haase and others 2006). Fertilizer efficacy, however, varies with site conditions (Rose and Ketchum 2002). On moisture-limited sites, fertilizer salts can build up to toxic levels resulting in a negative effect on survival and growth (Jacobs and others 2004). Before applying any fertilizer, it is crucial to consider the formulation, application rate, placement, solubility/release rate, and existing nutrient levels on the site.

Phosphorus is quite often deficient for tree growth in tropical soils. Boron can also be deficient in tropical soils, particularly in volcanic ash soils and soils of basaltic origin. Applications of these elements are routinely made at the time of planting and can produce dramatic growth responses on nutrient-deficient tropical soils (Ladrach 1992). Fertilizer responses are often not realized where high competition exists from surrounding vegetation. In plots treated with herbicide, fertilizer increased height and diameter of tropical hardwood seedlings in Costa Rica by 19 and 31 percent, respectively, but no response occurred from the fertilizer used in manually weeded plots (Wightman and others 2001). When soil pH is too high or too low, nutrient availability is reduced; combined applications of mulch, lime, and fertilizer to highly acidic soils in Palau resulted in dramatic growth responses of planted trees (Gavenda and Nemesek 2008, Dendy 2011).

Mulches

Mulching with organic or inorganic materials can reduce recurrence of vegetative competition for a longer duration than initial site preparation. Mulch mats made from materials such as plastic, fabric, sod, or paper are held in place with rocks, branches, or stakes. Mulching can also be accomplished with a thick layer of loose organic matter such as corncobs, coconut fiber, pine straw, sawdust, or bark chips (figure 17.21). In addition to inhibiting growth of competing vegetation, mulch insulates soil from temperature extremes, helps maintain soil moisture by reducing surface evaporation, and provides protection against soil erosion. Organic mulches also have the benefit of providing nutrients to the soil and improving soil structure as they decompose.

Although purchase and installation of mulch materials can be costly, mulches can significantly improve plant survival and growth on droughty sites. In a study to examine the effects of mulches on the survival and relative growth rate of three species in a degraded seasonally dry tropical forest, soil water content and sapling growth and survival were higher in plots mulched with polyethylene than in bare soil plots. Sapling survival under organic mulches (alfalfa straw and forest litter) were similar, and lowest in bare soil (Barajas-Guzmán and others 2006).

Figure 17.21—Mulching can reduce competing vegetation around the outplanted seedling. Photo by Ronald Overton.

Shelters

Tree shelters (figure 17.22A) can protect plants from animal damage and can limit the intensity of UV light and drying winds that cause damage by desiccation and sunscald. Engelmann spruce (*Picea engelmannii*) seedling survival after 11 growing seasons increased from 35 percent to 78 percent when shelters were installed (Jacobs 2011). Tree shelters are available in a variety of sizes and colors (allowing varying amounts of solar radiation to penetrate) and with or without venting. Selection of a specific shelter is based on expected site conditions and the growth habit of the species. In a comparison of ventilated and nonventilated shelters, ventilation consistently reduced inside shelter temperatures by about 5 °F (2.7 °C) (Swistock and others 1999). Plants kept in tall, rigid shelters for a long period of time can become spindly (reduced stem diameter relative to height) and incapable of standing upright after shelter removal (Burger and others 1996). Management considerations for using tree shelters need to include the costs of purchase, assembly, installation, and annual maintenance. Nevertheless the increased cost may be offset by increased survival, thereby reducing the need to replant at a later date when competing vegetation is established.

Shelters can also be used to protect newly planted plants from frost at high elevations (figure 17.22B).

Shading

Ideally, an outplanting site provides adequate materials such as stumps, logs, rocks, or remnant vegetation to provide microsites for planting. It is sometimes useful, however, to install artificial shade to protect plants from damaging heat. Resistance to heat damage increases with plant size as the ability of the plant to shade itself increases. Shading only the basal portion of the stem can be as effective in preventing heat damage as shading the entire stem and some foliage, which can also reduce transpiration (Helgerson 1989). Artificial shade materials include cardboard, shingles, rigid shade cloth, or other

*Figure 17.22—Tree shelters can provide favorable microsites to improve seedling growth and establishment on hot, dry sites (A). Frost shelters can be used to help decrease heat loss to the night sky and protect plants from frost at high elevations. At 6,500 ft (1,980 m), the Hakalau Forest National Wildlife Reserve on the Big Island of Hawai'i is high enough that frost can kill seedlings during the winter months; this frost shelter can help keep this 'akala (*Rubus hawaiensis*) seedling safe (B). Photo A by Diane L. Haase, and photo B by J.B. Friday.*

materials and need to be installed on the "sun" side of the seedling (south or southwest side for sites north of the equator or north or northeast side for sites south of the equator).

Monitoring Planting Quality

The best way to determine if planting has been done correctly is to conduct an inspection during or immediately after planting. With contract planting jobs, these inspections certify whether the work meets specifications, and the results are used to calculate payment. A typical planting inspection consists of determination of the number and distribution of plants and examination of aboveground and belowground planting quality. These quality control checks during outplanting help ensure that each plant was installed properly and has the best chance of survival possible.

Determination of the Number and Spatial Distribution of Planted Plants

Plots are established to determine whether the correct number of plants was installed in a given area, whether good planting spots were selected, and whether plants were properly spaced. See Survey Types section later in this chapter for descriptions of plot establishment.

Aboveground Inspection

A representative sample of plants is examined to check the quality of the scalping, stem orientation, and planting depth. Planting depth is one of the most critical details to check and is usually specified in relation to top of the root plug or the root collar.

Belowground Inspection

A hole is dug with a planting shovel alongside the planted plant to check for proper root orientation, loose soil, air pockets, foreign material in the hole, and so on. Begin digging the hole far enough away from the main stem (10 in [25 cm]) so that the shovel does not disturb the roots. Then, gently clear soil away while digging toward the plug so that the plug can be inspected in the position it was planted. The plant's root system must be in a vertical plane and not twisted, compressed, or jammed and the hole should not contain large rocks, sticks, litter, or other foreign debris. Soil needs to be nearly as firm as the undisturbed surrounding soil with no air pockets. In auger plantings, be sure to check soil firmness near the bottom of the holes (USDA 2002).

Monitoring Outplanting Performance

Reforestation and restoration outplantings can be an expensive investment so it makes sense to conduct surveys to track outplanting success over time. An excellent guide on how to evaluate restoration plantings is available in chapter 12 of Steinfeld and others (2008). Quality control during or immediately after outplanting ensures plants are installed correctly. Longer term monitoring provides feedback to the nursery and the client, which can lead to improved seedling quality and increased outplanting success in subsequent projects.

When and What To Monitor

Plots of seedlings should be monitored for growth and survival during the first month or two after outplanting and again at the end of the first year. Growth can be measured as height growth and stem diameter growth (figure 17.23). Subsequent checks after 3- and 5-year periods will give a good indication of plant growth and survival rates. Survival can be expressed in percentages; if the client planted 100 trees, but after 2 months, 20 were dead, the survival is 80 percent at that point in time.

Some projects define measurable goals within specified time frames as part of their objectives. These goals are sometimes called "success criteria" or "desired future conditions." For example, a reforestation project might set a goal of 400 living trees per acre 2 years after outplanting. A native plant project might have a goal to reach a certain percentage of native groundcover or species composition within the first year after outplanting. Monitoring is then conducted to measure if these goals were achieved.

The client and the nursery manager then use this performance information to refine the target plant specifications for the next crop. The client may also alter his or her outplanting and management practices to achieve better survival and growth based on this information.

Survey Types

Two types of surveys, circular plots and stake rows, have traditionally been performed, and each has its own advantages.

Circular Plots

The traditional method to determine planting density is to measure 1/100 acre (40 m^2) plots that are evenly distributed throughout the planting site. An adequate sample is about one plot per acre (2.5 plots per hectare),

Figure 17.23*—Yard or meter sticks can be used to monitor height growth of planted trees as seen here with* Senna polyphylla *(A) and* Cordia rickseckeri *(B) in a forest enrichment project in the U.S. Virgin Islands. Photos by Brian F. Daley.*

with usually no more than 30 plots evenly distributed throughout the planted area. A 1/100 acre plot has a radius of approximately 12 ft (3.6 m), which is established with a center stake and a piece of string or twine cut to this length (Londo and Dicke 2006). All planted plants within the plot are counted, and their tops examined and measured. The root system of the plant closest to the center is excavated to evaluate planting technique. Record each plot separately on a survey form (figure 17.24) using the examination criteria shown in figure 17.10.

Stake Rows

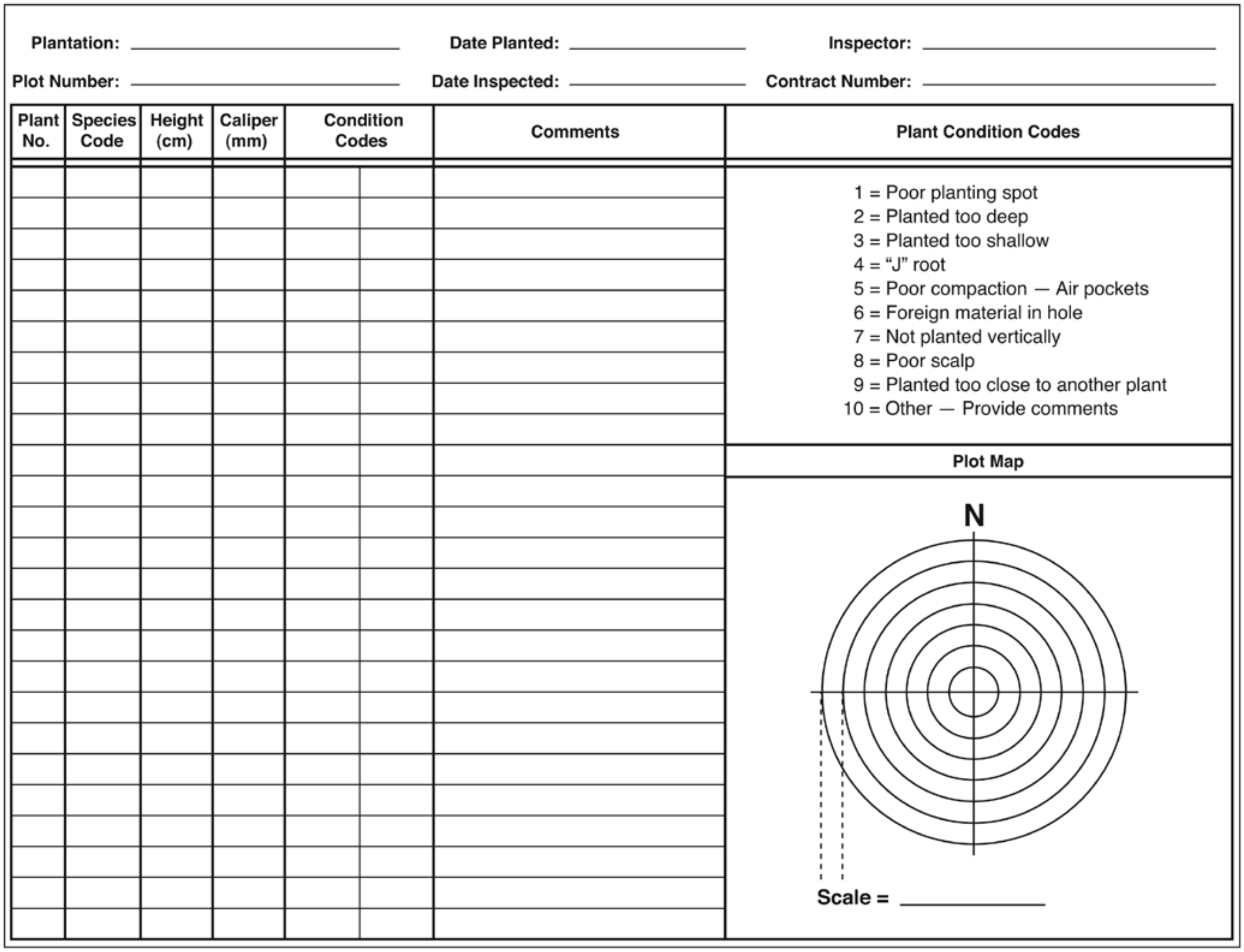
Because it is hard to relocate plants on sites with rapid weed growth, 10-plant stake rows can be used to make plants easier to find in subsequent evaluations. One row plot consists of a starting point that can easily be relocated and 10 plants staked along a compass bearing. Height, diameter, and plant condition are recorded on the data form, along with average spacing between plants. Stake row data is typically used to determine survival, growth rates, and plants per area (Londo and Dicke 2006).

Sampling Design

Systematic, stratified sampling is often recommended because plots are located at standard predetermined distances and are therefore easy to establish and relocate. Stratification means that the entire population of plants in the outplanting area is subdivided into homogeneous units before sampling begins. First, strata of uniform conditions are identified, and then sample plots are located systematically within these areas (Pearce 1990). These strata could be based on species, nursery of origin, planting crew, or any other factor that could introduce serious variation. Machine-planted stock on abandoned farmland would have less variability because conditions are relatively uniform and planter-to-planter variation is not an issue. In contrast, considerable variability exists on hand-planted projects in mountainous terrain because of differences in aspect, soil, and planting technique.

Number of Plots

The number of plots to establish is generally a function of two factors: (1) available resources (time and money),



Plantation: ______ Date Planted: ______ Inspector: ______

Plot Number: ______ Date Inspected: ______ Contract Number: ______

Plant No.	Species Code	Height (cm)	Caliper (mm)	Condition Codes		Comments

Plant Condition Codes

1 = Poor planting spot
2 = Planted too deep
3 = Planted too shallow
4 = "J" root
5 = Poor compaction — Air pockets
6 = Foreign material in hole
7 = Not planted vertically
8 = Poor scalp
9 = Planted too close to another plant
10 = Other — Provide comments

Plot Map

N

Scale = ______

Figure 17.24*—Using a standard survey form will ensure that the same information is collected at each plot. Figure by Jim Marin.*

and (2) variability of the attributes that will be measured. In calculating an appropriate number of plots, statisticians are interested in some measure of variability, such as the standard deviation of plant heights in the outplanting. For example, if a quick check of plant heights shows great variability within the site to be sampled, then more plots should be added. On the other hand, if the heights appear to be very uniform, then fewer plots will be sufficient. If you want statistical significance, more complex calculations are available to compute appropriate number of plots using an estimate of the variability of the attribute and the degree of statistical accuracy desired (Stein 1992). Determining the number of plots based on variability is often a judgment call but, in most cases, a 1- to 2-percent sampling intensity is sufficient (Neumann and Landis 1995).

Post-Planting Maintenance

The most significant threat to success of planted seedlings on tropical sites is competing vegetation and animal damage. In addition to preventative measures performed by site preparation and treatments at the time of planting, post-planting treatments may be required to ensure the early growth and survival of seedlings.

Weed Control

Aggressive growth of grasses and weeds makes post-planting vegetation control an absolute necessity for the successful establishment of nursery plants on tropical project sites. Climbing vines can severely damage young trees and must be cut several times a year during the first years to keep them from shading, deforming, or even toppling young trees. Many field sites are infested with exotic grasses, such as the kikuyu grass (*Pennisetum clandestinum*) from Africa, which was introduced into many tropical areas a century ago and has effectively colonized expansive areas (figure 17.25). This grass has large roots, is a fierce competitor for soil moisture and nutrients, and is allelopathic (produces growth inhibitors to other

***Figure 17.25**—Kikuyu grass has formed a thick, dense cover across vast areas in Hawai'i and must be controlled to enable establishment and long-term growth and survival of desirable plant species. Photo by Diane L. Haase.*

vegetation). Tree growth is severely inhibited if this grass is not completely controlled around young trees. Herbicides have been found to be more effective than manual weed control because they kill the allelopathic roots as well as the tops (Ladrach 1992). In a planting of bluegum eucalyptus (*Eucalyptus globulus*) in Colombia, glyphosate was applied to kikuyu grass in a 3 ft (1 m) diameter along with hoed planting scalps at the time of planting and again 7 months later. After 2 years, tree volumes increased by more than 250 percent by the use of herbicide, compared with trees in plots where weeds were controlled by hoeing (Lambeth 1986).

Weed control during the first 2 years after planting helps the nursery stock to become established and controls the undesired species until they can be outcompeted or shaded out. As with site prep, weed maintenance after outplanting can be accomplished by mechanical or chemical means. Care must be taken not to damage the planted nursery stock, however. Intensive weed management and planting desired species eventually will increase the site's resistance to further weed invasion by favoring the growth and establishment of the desired species.

Animal Control

As with weed control, continued protection against animal damage after outplanting can be pivotal to ensuring the project's success. Periodic monitoring and maintenance needs to be done for installed mesh tubing to ensure that the plant is not tangled in the mesh and that it is still providing adequate protection; sometimes the tube can be slid upward as the plant grows for continued protection of the top. Fences need to be examined regularly and mended as needed for continued exclusion of animals.

Long-Term Followup: Refining Target Plant Specifications

Both the nursery manager and the client learn from the outplanting experiences and monitoring results. Checking in with clients for the first few years (or longer) after outplanting is valuable for improving nursery practices, outplanting techniques, and overall project successes. As described in Chapter 3, Defining the Target Plant, and Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records, the client and the nursery manager must work together from the outset to define target morphological and physiological specifications for the plants based on the assessment of site conditions, limiting factors, outplanting windows, and so on. Working together to assess what worked and what can be improved helps refine the target plant for similar conditions and improve results in the future. Chapter 18, Working With People, shows how to create clear agreements and responsibilities so the client and the nursery manager can enjoy an ongoing cooperative relationship. See Chapter 20, Discovering Ways to Improve Nursery Practices and Plant Quality, for more information on capturing lessons learned from clients and outplanting experiences.

References

Adams, J.C.; Patterson, W.B. 2004. Comparison of planting bar and hoedad planted seedlings for survival and growth in a controlled environment. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 423–424.

Ammondt, S.A.; Litton, C.M.; Ellsworth, L.M.; Leary, J.K. 2013. Restoration of native plant communities in a Hawaiian dry lowland ecosystem dominated by the invasive grass Megathyrsus maximus. Applied Vegetation Science. 16: 29–39.

Barajas-Guzmán, A.E.; Campo, J.; Barradas, V.L. 2006. Soil water, nutrient availability and sapling survival under organic and polyethylene mulch in a seasonally dry tropical forest. Plant and Soil. 287: 347–357.

Bell, F.; Falanruw, M.; Lawrence, B.; Limtiaco, D.; Nelson, D. 2002. Draft vegetation strategy for southern Guam. Honolulu, HI: U.S. Department of Agriculture, Forest Service and Natural Resources Conservation Service; Government of Guam Division of Forestry. 11 p.

Burger, D.W.; Forister, G.W.; Kiehl, P.A. 1996. Height, caliper growth and biomass response of ten shade tree species to tree shelters. Journal of Agriculture. 22(4): 161–166.

Cleary, B.D.; Greaves, R.D.; Hermann, R.K. 1978. Regenerating Oregon's Forests. Corvallis, OR: Oregon State University Extension Service. 286 p.

Dendy, J. 2011. Low input methods of forest restoration and observations of native birds and flying foxes in savanna habitat in the Lake Ngardok Nature Reserve, Palau. MS Thesis, University of Hawai'i at Hilo.

Emmingham, W.H.; Cleary, B.C.; DeYoe, D.R. 2002. Seedling care and handling. In: Oregon State University Extension Service: The woodland workbook: forest protection. Corvallis, OR: Oregon State University Extension Service. 4p.

Engelbrecht, B.M.J.; Kursar, T.A. 2003. Comparative drought-resistance of seedlings of 28 species of co-occurring tropical woody plants. Oecologia. 136: 383–393.

Feyera, S.; Beck, E.; Lüttge, U. 2002. Exotic trees as nurse-trees for the regeneration of natural tropical forests. Trees. 16: 245–249.

Forestry Suppliers Inc. 2013. Forestry Suppliers website. http://www.forestry-suppliers.com/. (March 2013).

Gavenda B.; Nemesek J. 2008. Soil quality and land use changes on a humid tropical island-Palau. USDA Natural Resource Conservation Service, Pacific Islands Area, Mongmong, Guam, USA.

Haase, D.L.; Rose, R.W.; Trobaugh, J. 2006. Field performance of three stock sizes of Douglas-fir container seedlings grown with slow-release fertilizer in the nursery growing medium. New Forests. 31: 1–24.

Hau, B.C.H.; Corlett, R.T. 2003. Factors affecting the early survival and growth of native tree seedlings planted on a degraded hillside grassland in Hong Kong, China. Restoration Ecology. 11: 483–488.

Heiskanen, J.; Viiri, H. 2005. Effects of mounding on damage by the European pine weevil in planted Norway spruce seedlings. Northern Journal of Applied Forestry. 22(3): 154–161.

Helgerson, O.T. 1989. Heat damage in tree seedlings and its prevention. New Forests. 3: 333–358.

Hoag, J.C.; Landis, T.D. 2001. Riparian zone restoration: field requirements and nursery opportunities. Native Plants Journal. 2: 30–35.

Holl, K.D. 2002. Effect of shrubs on tree seedling establishment in an abandoned tropical pasture. Journal of Ecology. 90: 179–187.

Holl, K.D.; Aide, T.M. 2011. When and where to actively restore ecosystems? Forest Ecology and Management. 261(10): 1558–1563.

Jacobs, D.F. 2011. Reforestation of a salvage-logged high-elevation clearcut: Engelmann spruce seedling response to tree shelters after eleven growing seasons. Western Journal of Applied Forestry. 26:53-56.

Jacobs, D.F.; Rose, R.; Haase, D.L.; Alzugaray, P.O. 2004. Fertilization at planting inhibits root system development and drought avoidance of Douglas-fir (*Pseudotsuga menziesii*) seedlings. Annals of Forest Science. 61: 643–651.

Jeffrey, J.; Horiuchi, B. 2003. Tree planting at Hakalau National Wildlife Refuge—the right tool for the right stock type. Native Plants Journal. 4: 30–31.

Jones, B.; Alm, A.A. 1989. Comparison of planting tools for containerized seedlings: two-year results. Tree Planters' Notes. 40): 22–24.

Kaboré, D.; Reij, C. 2004. The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso. Paper 114. IFPRI. Washington, DC: International Food Policy Research Institute, Environment and Production Technology Division. 43 p.

Kloetzel, S. 2004. Revegetation and restoration planting tools: an in-the-field perspective. Native Plants Journal. 5: 34–42.

Ladrach, W.E. 1992. Plantation establishment techniques in tropical America. Tree Planters' Notes. 43: 125–132.

Lamb, D.; Erskine, D.P.; Parrotta, A.J. 2005. Restoration of degraded tropical forest landscapes. Science. 310: 1628–1632.

Lambeth, C.C. 1986. Grass control with the herbicide Roundup increases yield of *Eucalyptus globulus* in Salinas. Res. Rep. 108. Cali, Colombia: Carton de Colombia, S.A. 5 p.

Landis, T.D.; Dumroese, R.K.; Haase, D.L. 2010. The container tree nursery manual: volume 7, seedling processing, storage, and outplanting. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 200 p.

Landis, T.D.; Haase, D.L. 2012. Applications of hydrogels in the nursery and during outplanting. In: Haase, D.L.; Pinto, J.R.; Riley, L.E., tech coords. National proceedings: forest and conservation nursery associations—2011. Proceedings RMRS-P-68. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 53–58.

Lof, M.; Rydberg, D.; Bolte, A. 2006. Mounding site preparation for forest restoration: survival and short term growth response in *Quercus robur* L. seedlings. Forest Ecology and Management. 232: 19–25.

Londo, A.J.; Dicke, S.G. 2006. Measuring survival and planting quality in new pine plantations. Tech. Bull. SREF-FM-001. Athens, GA: University of Georgia, Southern Regional Extension Forestry. 5 p.

Lowery, R.F.; Lambeth, C.C.; Endo, M.; Kane, M. 1993. Vegetation management in tropical forest plantations. Canadian Journal of Forest Research. 23: 2006–2014.

Lowman, B. 1999. Tree planting equipment. In: Alden J., ed. Stocking standards and reforestation methods for Alaska. Misc. Pub. 99-8. Fairbanks, AK: University of Alaska Fairbanks, Agricultural and Forestry Experiment Station: 74–77.

Lugo, A.E. 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. Forest Ecology and Management. 99: 9–19.

McKay, H.M.; Gardiner, B.A.; Mason, W.L.; Nelson, D.G.; Hollingsworth, M.K. 1993. The gravitational forces generated by dropping plants and the response of Sitka spruce seedlings to dropping. Canadian Journal of Forestry Research. 23: 2443–2451.

Medeiros, A.C.; vonAllmen, E. 2006. Restoration of native Hawaiian dryland forest at Auwahi, Maui. Fact Sheet 2006–3035. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 4 p.

Mexal, J.G.; Negreros-Castillo, P.; Rangel, R.A.C.; Moreno, R. 2005. Evaluation of seedling quality and planting tools for successful establishment of tropical hardwoods. International Plant Propagators Society, Combined Proceedings. 55: 524–530.

Neumann, R.W.; Landis, T.D. 1995. Benefits and techniques for evaluating outplanting success. In: Landis, T.D.; Cregg, B., tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. PNW-GTR-365. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 36–43.

Pearce, C. 1990. Monitoring regeneration programs. In: Lavender, D.P.; Parish, R.; Johnson, C.M.; Montgomery, G.; Vyse, A.; Willis, R.A.; Winston, D. Regenerating British Columbia's forests. Vancouver, BC, Canada: University of British Columbia Press: 98–116.

Rose, R.; Haase, D.L. 2006. Guide to reforestation in Oregon. Corvallis, OR: Oregon State University, College of Forestry. 48 p.

Rose, R.; Ketchum, J.S. 2002. Interaction of vegetation control and fertilization on conifer species across the Pacific Northwest. Canadian Journal of Forest Research. 32: 136–152.

Rose, R.; Rosner, L.S. 2005. Eighth-year response of Douglas-fir seedlings to area of weed control and herbaceous versus woody weed control. Annals of Forest Science 62: 481-492.

Sharpe, A.L.; Mason, W.L.; Howes, R.E.J. 1990. Early forest performance of roughly handled Sitka spruce and Douglas-fir of different plant types. Scottish Forestry. 44: 257–265.

Stein, W.I. 1992. Regeneration surveys and evaluation. In: Hobbs, S.D.; Tesch, S.D.; Owston, P.W.; Stewart, R.E.; Tappeiner, J.C.; Wells, G.E., eds. Reforestation practices in southwestern Oregon and northern California. Corvallis, OR: Oregon State University, Forest Research Laboratory: 346–382.

Steinfeld, D.E.; Riley, S.A.; Wilkinson, K.M.; Landis, T.D.; Riley, L.E. 2008. Roadside revegetation: an integrated approach to establishing native plants. Vancouver, WA: U.S. Department of Transportation, Federal Highway Administration. 413 p.

Sutton, R.F. 1993. Mounding site preparation: a review of European and North American experience. New Forests. 7: 151–192.

Swistock, B.R.; Mecum, K.A.; Sharpe, W.E. 1999. Summer temperatures inside ventilated and unventilated brown plastic treeshelters in Pennsylvania. Northern Journal of Applied Forestry. 16: 7–10.

Thomas, D.S. 2008. Hydrogel applied to the root plug of subtropical eucalypt seedlings halves transplant death following planting. Forest Ecology and Management. 255: 1305–1314.

Trent, A. 1999. Improved tree-planting tools. Timber Tech Tips 9924-2316-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 6 p.

Upton, D.; de Groot, P. 2008. Planting and establishment of tropical trees. Propagation and Planting Manuals. Vol. 5. London, United Kingdom: Commonwealth Secretariat. 142 p.

U.S. Department of Agriculture (USDA). 2002. Silvicultural practices handbook (2409.17): chapter 2—reforestation. Missoula, MT: U.S. Department of Agriculture, Forest Service. 106 p.

Van der Putten, W.H.; Mortimer, S.R.; Hedlund, K.; Van Dijk, C.; Brown, V.K.; Leps, J.; Rodriguez-Barrueco, C.; Roy, J.; Len, T.A.D.; Gormsen, D.; Korthals, G.W.; Lavorel, S.; Regina, I.S.; Smilauer, P. 2000. Plant species diversity as a driver of early succession in abandoned fields: a multi-site approach. Oecologia. 124: 91–99.

Weller, S.G.; Cabin, R.J.; Lorence, D.H.; Perlman, S.; Wood, K.; Flynn, T.; Sakai, A.K. 2011. Alien plant invasions, introduced ungulates, and alternative states in a mesic forest in Hawaii. Restoration Ecology. 19: 671–680.

Wightman, K.E.; Shear, T.; Goldfarb, B.; Haggar, J. 2001. Nursery and field establishment techniques to improve seedling growth of three Costa Rican hardwoods. New Forests. 22: 75–96.