The Container Tree Nursery Manual

Volume Seven

Chapter 6
Outplanting

Contents

7.6.1 Introduction

Outplanting is the final stage of the nursery process, but before we get to specific techniques, we should review some important concepts. Outplanting performance (survival and growth) depends on three factors, which are the final elements of the Target Plant Concept (fig. 7.6.1).

Limiting factors on the outplanting site. Each site is different, so it is critical to identify the environmental factors that can limit plant survival and growth. Temperature and moisture are usually the most limiting and are discussed in Section 7.6.4. Other site factors, such as aspect and soil type, must also be considered. Sites with south or southwest aspects will dry out more quickly and should therefore be planted first. In some cases, shade materials may be required. Some planting tools should not be used on fine-textured soils, such as silts and clays; this will be discussed in Section 7.6.7.

Outplanting sites must be evaluated well in advance of the actual outplanting. Although the site evaluation process will not be covered in detail here, two good resources exist. First, the Forest Service requires a detailed Reforestation Plan for each planting project (USDA Forest Service 2002). Second, a very comprehensive example of how to conduct a site evaluation on a restoration site can be found in Steinfeld and others (2007). Because of the highly disturbed nature of restoration sites, site evaluation is even more critical before planting can begin (Munshower 1994).

Timing of the outplanting window. For each site, there is an ideal time to plant, and the process for determining this "window" is discussed in Section 7.6.2.

Outplanting tools and techniques. The processes for selecting the best way to plant nursery stock are discussed in Sections 7.6.3 to 7.6.9, and Section 7.6.10 describes how to evaluate the quality of the outplanting project.

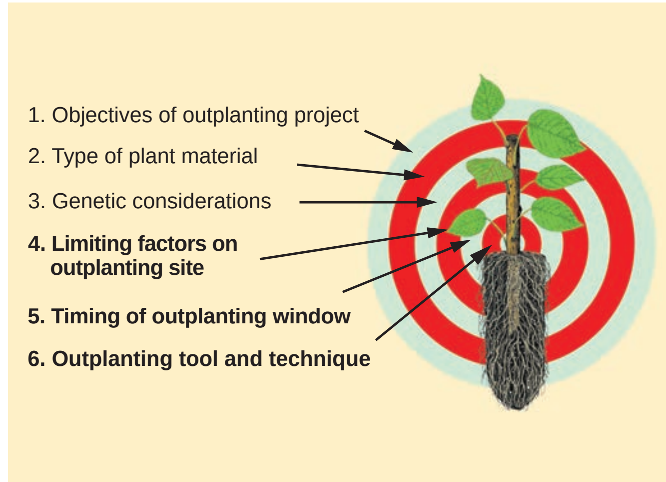


Figure 7.6.1—*The final three steps of the Target Plant Concept are critical to outplanting success and should be considered when planning and initiating outplanting projects.*

7.6.2 Outplanting Windows

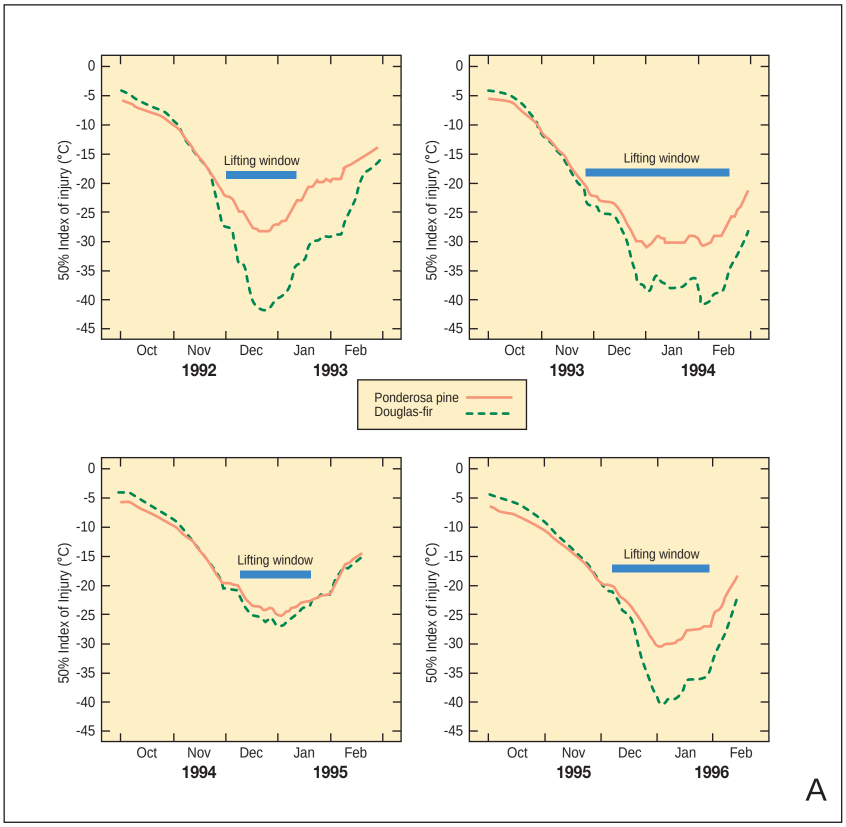
Years of experience have proved that the best time to outplant seedlings is when they are dormant and least susceptible to the stresses of harvest, storage, shipping, and planting. The outplanting window concept was introduced as a critical part of the Target Plant Concept (see Section 7.1.1.5) and is defined as the period of time during which environmental conditions on the site most favor survival and growth of nursery stock. Traditionally, outplanting windows were established by harvesting nursery stock and observing outplanting performance. Plant quality tests, such as cold hardiness, are also good ways to determine when nursery stock is most hardy and best able to survive the stresses of outplanting. For example, cold hardiness testing of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) over a 4-year period shows how the duration of outplanting windows varies from year to year (fig. 7.6.2A).

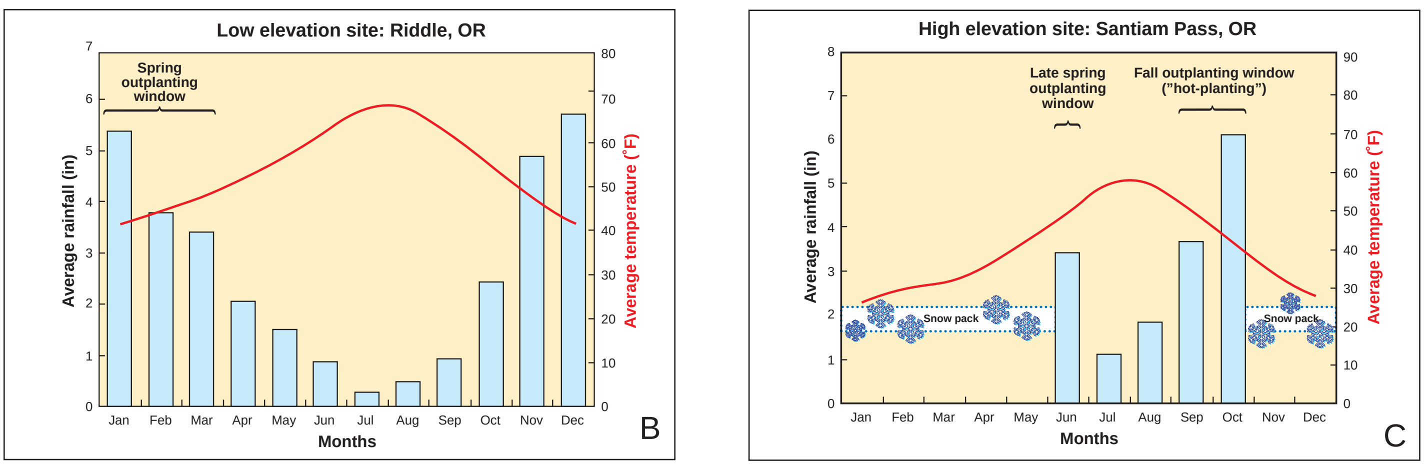
The start and end dates of an outplanting window are constrained by limiting factors on the planting site. Soil moisture and temperature are the usual constraints on most sites, but other environmental or biological factors can also limit plant survival and growth (see Section 7.1.1.4). For high-value plantings where irrigation can be supplied, container stock can be outplanted throughout the year in appropriate weather conditions and with proper handling (White 1990). Changing weather patterns have caused changes in the outplanting window. In eastern Texas, an extended drought has caused foresters to change from traditional spring outplanting with bareroot stock to fall outplanting with container stock. Tests show fall-planted container seedlings had a 93 percent survival rate compared with 67 percent for bareroot stock (Taylor 2005).

In most of the continental United States, nursery stock is outplanted during late winter or early spring, when soil moisture is high and evapotranspirational losses are low. In most of Canada and the United States, this typically occurs from January to April for lower elevations (fig. 7.6.2B). These outplantings have used dormant stock that was harvested during early winter and stored for 2 to 8 months under refrigeration or in outdoor compounds (see Chapter 4 in this volume for more information).

At high elevations and latitudes, however, it is impossible to plant during late winter or early spring, because persistent snow cover keeps soil temperatures low and limits access. This means that all nursery stock must be outplanted during a relatively short window when long days and high solar angles cause high evapotranspiration rates (fig. 7.6.2C). Therefore, some foresters in northern Canada, Scandinavia, and the northern mountains of the Western United States have outplanted container stock during early summer or even later in the fall (Luoranen and others 2004; Page-Dumroese and others 2008; Tan and others 2008). Container plants have a wider outplanting window because they suffer less transplant shock; their roots are protected in the plug and not damaged during harvesting. In addition, with modern container nursery techniques, it is possible to culture plants to better tolerate outplanting stresses. Because nursery stock outplanted during summer or fall is not dormant, this is known as "hot-planting." Hot-planted stock needs some hardening to withstand the stresses of harvesting, shipping, and outplanting; moisture stress or short-day ("blackout") treatments are most commonly used (Landis and Jacobs 2008). Finnish researchers have been conducting outplanting research on hot-planted Norway spruce (*Picea abies*) and silver birch (*Betula pendula*) for several years (Louranen and others 2005). For example, to investigate the effect of drought on outplanting performance, hot-lifted Norway spruce seedlings were subjected to up to 6 weeks of water stress in a research plot (Helenius and others 2002). They found that hot-lifted stock with wet plugs that were outplanted in July had better root egress than those planted later that year, or even those that were stored and outplanted the following spring (fig. 7.6.2D).

Therefore, many biological and operational factors must be considered when determining the best outplanting window, but nothing substitutes for actual experience, and survival and growth are always the best guides. (For more information on hot-planting see Sections 7.4.2 and 7.6.3.2.)





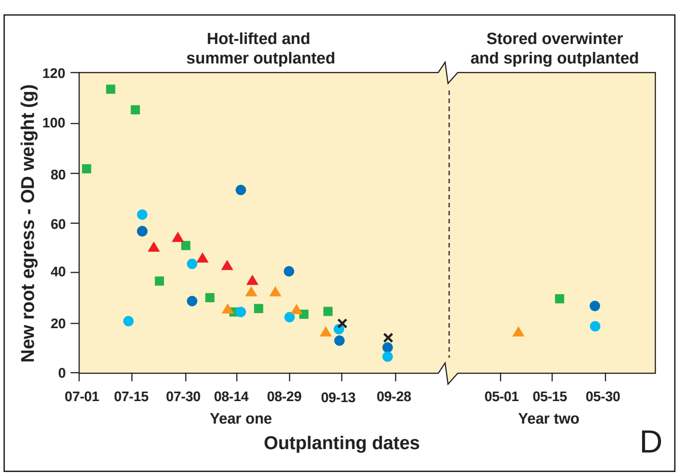


Figure 7.6.2—*Outplanting windows are established from observations of lifting and planting successes or with plant-quality testing (A). In most of the United States and Canada, the outplanting window occurs during late winter or early spring (B). At higher elevations and latitudes, however, the outplanting window is later spring or early summer due to persistent snow and cold soil temperatures (C). Hot-lifted Norway spruce outplanted in early summer had more root egress than those planted later that year, or even overwintered stock planted during the traditional spring outplanting window (D) (A, modified from Tinus 1996; B&C, courtesy of Steinfeld and others 2007; D, modified from Louranen and others 2006).*

7.6.3 Onsite Handling and Storage

Nursery stock should be outplanted as soon as it arrives on the project site, but that is often operationally impossible. Weather delays, worker scheduling, and poor communication are just a few of the reasons why onsite storage may be necessary. The duration of onsite storage should last for only a few days, although, under unanticipated weather, such as heavy snow, it can reach a week or more. Therefore, it is always wise to plan ahead. Ideally, project managers should bring only as much stock as can be planted on a given day to avoid the need for onsite storage. Distance and other logistical factors, however, may make this difficult.

Overheating and desiccation are the major stresses that can occur during onsite storage. Because of significant differences in dormancy stage and hardiness, however, nursery stock for hot-planting must be treated differently from stock that comes from refrigerated storage.

7.6.3.1 Inspecting nursery stock

As discussed in Chapter 7.5, many things can happen between the harvest and outplanting of nursery stock. Therefore, it is a good idea to conduct a thorough inspection of nursery stock when it arrives at the outplanting site. All boxes should be opened and checked for the following (Mitchell and others 1990):

- In-box temperatures of refrigerated stock should be checked upon delivery (fig. 7.6.3A) and should be cool, no warmer than 2 to 4 °C (36 to 39 °F). Stock delivered in containers or hot-plant stock should be kept as cool as possible and out of direct sunlight.
- If possible, use a pressure chamber to check plant moisture stress of a sample of plants (fig. 7.6.3B). (Target PMS values can be found in Chapter 7.2.)
- Nursery stock should not smell sour or sweet, which is evidence that the stock has been too warm or excessively wet.
- Root plugs should be moist. If the plants have foliage, most often it should be a healthy green. For species with terminal buds, those buds should still be firm.
- Check the firmness of the bark around the root collar. The bark should not easily slough off and the tissue underneath should be creamy, not brown or black, which indicates frost injury.

Figure 7.6.3— *Nursery stock should be inspected upon delivery to the outplanting site. Check in-box temperatures of boxed plants (A) and, if possible, measure the plant moisture stress with a pressure chamber (B). Storage molds can become a serious problem in onsite storage, so check for gray or colored mycelia within the foliage (C).*

- Spread the foliage to check for white or gray mycelia (fig. 7.6.3C), which is evidence of storage molds, such as *Botrytis cinerea*. In particular, check foliage at the base of the crown. If mold is present, check the firmness of the tissue underneath. Soggy or water-soaked tissue indicates serious decay and those plants should be culled. Plants with superficial mycelia without corresponding decay should be planted immediately. Fungal molds will not survive after exposure to ambient conditions on the site.

7.6.3.2 Hot-planted stock and open-stored stock

Hot-planted stock, because it is not fully dormant or hardy, should be outplanted immediately or stored on the project site for only a day or two. The key to a successful hot-planting operation is careful planning and coordination between the nursery and planting project managers. Ideally, hot-plant stock should be packed upright in cardboard boxes without plastic bag liners that can reduce air exchange and increase respirational heat buildup. If stock is pulled and wrapped, using white packing boxes will help to reflect sunlight and keep in-box temperatures lower (Kiiskila 1999).

At the outplanting site, tops of cardboard boxes containing open-stored or hot-planting stock should be opened to dissipate heat and promote good air exchange. If not already so, the plants should be set upright and placed in a shady area as soon as they arrive on site. Unfortunately, trees and other natural shade are absent on many reforestation and restoration sites, but even when natural shade is available, it can be difficult to keep plants in the shade all day (fig. 7.6.4A). Therefore, plan on erecting some type of artificial shade. Tarps or shadecloth suspended between poles is effective (fig. 7.6.4B). As shown in figure 7.5.12D in the previous chapter, dark-colored tarps absorb and reradiate solar heat (Emmingham and others 2002); therefore, canvas tarps should be suspended above the nursery stock to allow for good air circulation. Wetting the tarps regularly will keep the air cooler through evaporative cooling (Mitchell and others 1990).

Moisture stress is another concern with open-stored or hot-planted stock because plants are transpiring during delivery and onsite storage. As with respiration, the transpiration rate is a function of temperature, but sunlight intensity is equally important. Therefore, it makes sense to check that root plugs are fully charged and plants are not under any moisture stress immediately before outplanting. Irrigating container plants on the project site is not commonly done but recent research with hot-planted birch (*Betula* spp.) and spruce (*Picea* spp.) seedlings showed that water before outplanting significantly increased survival (fig. 7.6.4C). So, the best onsite storage for open-stored or hot-planted nursery stock has access to a reliable water source (fig. 7.6.4D) because frequent watering requires large volumes of water (Mitchell and others 1990).

7.6.3.3 Stock from refrigerated storage

Nursery plants delivered from cooler or freezer storage must be treated differently than open-stored or hot-planted stock because they are still fully dormant and hardy and, ideally, should be kept that way until outplanting. So, whenever possible, refrigerated trucks ("reefers") should be used for transportation to the site as well as for onsite storage (fig. 7.6.5A). Each truck should receive a mechanical check before use, and the storage van should be precooled by operating the compressor for at least 4 to 6 hours (Paterson and others 2001). Anticipate mechanical failure by having a backup plan.

Snow caches, culvert or pole structures covered with snow and an insulating material such as sawdust or straw (fig. 7.6.5B), have been successfully used for onsite storage where conditions permit (Paterson and others 2001). In a Canadian trial, a custom-made, insulated storage building was effective in protecting container stock from both frost damage and overheating (Zalasky 1983).

Boxes or bags of stock, stored either under refrigeration or in insulated buildings, should be patched if torn during shipping and handling and kept closed. The temperature inside the boxes or bags can be much warmer than the outside temperature because plants produce heat during respiration. As the temperature increases, so does the rate of respiration, which further increases the temperature. Therefore, the temperature in boxes or bags should be monitored on delivery and daily thereafter (fig. 7.6.3A). Make sure that the in-box temperature remains above freezing but below 10 °C (50°F) (Rose and Haase 2006). If nursery stock is exposed to warm temperatures for an

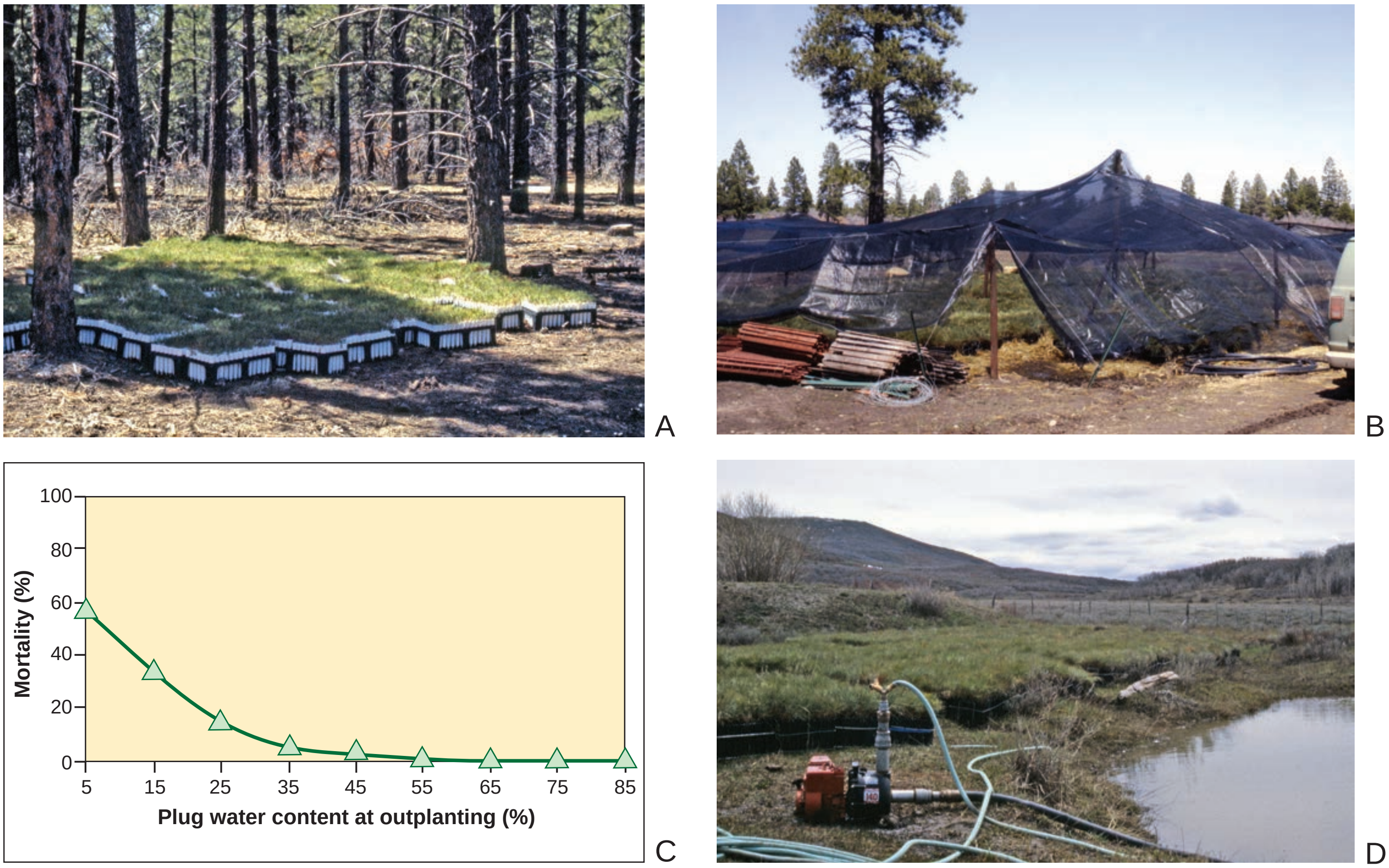


Figure 7.6.4—*All nursery stock should be kept in the shade on the outplanting site, but natural shade moves with the sun (A). Artificial shade from tarps or shadecloth is needed on many project sites (B). Watering plants immediately before outplanting has proven beneficial for hot-planted silver birch on dry sites (C), so provide for a source of irrigation water (D) (C, modified from Luoranen and others 2004).*

extended period, standard seedling quality tests (root growth potential, chlorophyll fluorescence, and cold hardiness) and in-container concentration of ethanol were shown to accurately predict seedling performance (Maki and Colombo 2001). (See Chapter 7.2 for more information on plant quality tests.)

It is also prudent to check inside a few boxes for signs of storage molds such as *Botrytis cinerea* (fig. 7.6.3C). This common nursery pest can increase rapidly after refrigerated storage, perhaps because of increased carbon dioxide levels inside boxes and bags (see Volume Five for more information).

Thawing frozen stock. Plants with root plugs frozen together must be thawed before outplanting. Some customers want their stock thawed before shipping by either “rapid” or “slow” thawing (fig. 7.6.6A). However, the definitions of “slow” and “rapid” vary considerably (table 7.6.1). Originally, slow thawing was considered best (for example, Mitchell and others 1990) and was typically done at the nursery. Recent research comparing the two thawing techniques found no differences after two growing seasons (Rose and Haase 1997). In the most comprehensive physiological research on thawing frozen stock (Camm and others 1995), cold hardiness tests showed that rapidly thawed stock was more hardy and also resumed shoot growth earlier than

A

B

Figure 7.6.5—*Nursery stock from refrigerated storage should be kept in reefer trucks (A), insulated structures, or snow caches (B) until outplanting.*

Figure 7.6.6—*Frozen nursery stock must be carefully thawed at warm temperatures for 24 to 48 hours (A). Never expose frozen plants to direct sunlight (B), but open boxes or bags (C) in a shady location (D) (A, modified from Paterson and others 2001.)*

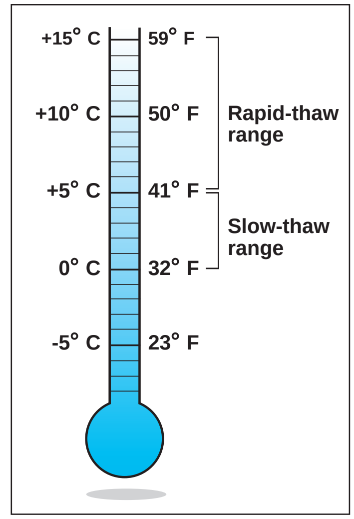


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Table 7.6.1—*Common thawing regimes for frozen container nursery stock*

Speed of thawing	Reference	Temperatures	Duration
Slow thaw	Camm and others (1995)	5 °C (41 °F)	7 days
		followed by	
		15 °C (59 °F)	2 days
	Rose and Haase (1997)	0 to 3 °C * (32 to 37 °F)	42 days
	Kooistra and Bakker (2002)	0 to 3 °C * (32 to 37 °F)	21 to 35 days
Rapid thaw	Camm and others (1995)	22 °C (72 °F)	2 to 5 hours
	Rose and Haase (1997)	7 °C (45 °F)	5 days
	Kooistra and Bakker (2002)	5 to 10 °C (41 to 50 °F)	5 to 10 days

* Operational cooler storage conditions

slowly thawed seedlings. Moreover, shoot and root growth measurements after 3 months were similar. These results suggest that a good operational procedure might be to remove bundles of frozen stock from shipping containers and lay them on the ground or to open shipping boxes or bags (fig. 7.6.6C) in a well-ventilated shady location. Never attempt to thaw frozen nursery plants by placing them in direct sunlight (fig. 7.6.6B), as this can cause serious moisture and temperature stress. Do not physically pry frozen root plugs apart because this can cause serious damage (Mitchell and others 1990). Defrost only enough stock that can be planted in a couple of days. The ideal situation is to setup a thawing operation in which frozen stock is removed from refrigerated storage and then thawed in an adjacent shade structure (fig. 7.6.6D).

Outplanting frozen stock. Outplanting nursery stock with frozen root plugs would save the time and effort needed to thaw plants. A few years ago this was not possible because root plugs were frozen together; now technology for packing singulated plants is available. Results of field trials, however, are mixed. In British Columbia, the performance of western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), and interior spruce planted frozen was not significantly different from thawed plants 2 years after outplanting (Kooistra and Bakker 2005). Other studies indicate that site conditions have an overriding effect. In an outplanting study of Norway spruce seedlings in Finland, thawed seedlings outperformed frozen stock in survival and shoot and root growth in warm and cold soils (Helenius 2005). In a more recent trial, the physiological processes of thawed and frozen Douglas-fir container seedlings that were exposed to either "cool and moist" or "warm and dry" conditions were monitored. Thawed plants had higher photosynthesis rates and more active buds and roots than plants that were planted frozen, which could affect subsequent outplanting performance (Islam and others 2008). Obviously, more research trials under a wide variety of outplanting site conditions are needed before outplanting frozen stock can be recommended.

7.6.4 Preplanting Preparations

Before the outplanting actually begins, several preparations should be made to ensure the project runs smoothly and successfully.

7.6.4.1 Check soil moisture and temperature

Soil moisture plays a vital role in the uptake and translocation of nutrients and can have a significant influence on plant survival and growth (Helenius and others 2002). 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 reduced growth and increased mortality. Lower photosynthetic rates can occur in newly planted seedlings under water stress, which results in lower root regenerating ability (Grossnickle 1993). Ideally, soil water potential in the top 25 cm (10 in) should be greater than –0.1 MPa at the time of outplanting (Cleary and others 1978; Krumlik 1984).

Soil temperature has a profound effect on root development (Balisky and Burton 1997; Domisch and others 2001; Landhäusser and others 2001). The ideal soil temperature range for root growth is 5 to 20 °C (41 to 68 °F) (fig. 7.1.5B), so planting may have to be delayed until soil temperatures increase. When transpirational demands are high but cold soils limit water uptake, plants may experience a "physiological drought" that can limit survival and growth (Mitchell and others 1990). In Ontario, planting projects are not started until soil temperatures exceed 5 °C (41 °F).

7.6.4.2 Monitor air humidity, air temperature, and wind speed

Weather conditions at the time of outplanting have a direct effect on plant moisture stress. Although an increase in both air temperature and wind speed affect transpiration, wind effects are more difficult to quantify. Conditions become critical when air temperatures exceed 25 °C (78 °F) and relative humidity is lower than 30 percent (Paterson and others 2001). 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. Sample calculations can be found in Cleary and others (1978). 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.

7.6.4.3 Site aspect and planting sequence

Conditions will vary at different locations in the planting area, especially in mountainous terrain. Aspect, or direction of solar exposure of mountain slopes, is one of the most important factors affecting outplanting success. South- and west-facing aspects have a hotter, drier environment than north and east aspects and should be planted first. Shading of outplanted stock is often required on these aspects (see following section). Deer and elk often use southern and western exposures for winter range so this impact must also be considered (USDA Forest Service 2002).

Be sure to consider access and transportation distance from the on-site storage. It is generally a good idea to start at the furthest location and plant back towards access roads.

7.6.4.4 Watering plants and root dips

The practice of dipping plant roots to protect them from stress during outplanting has been around for many years because it is intuitively attractive, especially for bareroot stock. Roots of nursery plants dry as they are exposed to the atmosphere during harvesting and handling, so it makes sense to rehydrate them or apply a coating to protect them (Chavasse 1981). Many different commercial root dips have become available and most are superabsorbent hydrogels. These crosslinked polymers can absorb and retain many times their own weight in water and are routinely applied to bareroot stock as root dips. Little research on the benefits of hydrogels to container stock has been published. However, one recent trial with Eucalyptus seedlings with root plugs dipped in a hydrogel slurry had significantly lower mortality at 5 months after outplanting compared with the controls. The author attributed this to increased soil moisture or contact between the root plug and the field soil (Thomas 2008). It would be interesting to see more research on this subject.

The plug should already be moist when it is unpacked. If not, then a quick water dip should be adequate to protect the roots from desiccation, because, as demonstrated in figure 7.6.4C, irrigating root plugs before outplanting has proved beneficial.

7.6.4.5 Site preparation

Trees and other native plants vary in their requirements for sunlight and other site resources to successfully regenerate. Site preparation (referred to as "site prep") to remove competing vegetation and site debris has several benefits (USDA Forest Service 2002). Biologically, it improves nursery stock survival and growth by reducing the competition from existing plants for nutrients, water, and sunlight. Roots from existing plants may have already occupied the soil profile and can easily reduce survival of outplanted nursery stock (fig. 7.6.7A). Operationally, site prep makes the physical process of planting easier by reducing surface debris on the site and removing the duff or sod layer. Removal of woody and herbaceous plants around Douglas-fir (*Pseudotsuga menziesii*) seedlings resulted in up to three times the stem volume after 8 years as compared with seedlings without vegetation control (Rose and Rosner 2005).

Site prep done at the time of outplanting can be accomplished by mechanical (scalping or mounding) or chemical (see Section 7.6.4.6) means.

Scalping. Scalping is the physical removal of grasses, forbs, small shrubs, and organic debris around planting holes (fig. 7.6.7B)—it is ineffective against larger woody plants that are too difficult to remove. Removing organic debris around the planting hole ensures that roots are in contact with mineral soil. Nursery stock planted in organic matter or duff dry out rapidly and often die (Grossnickle 2000). Scalping can also reduce the frequency of drought damage because of the reduction in competition (Barnard and others 1995; Nilsson and Orlander 1995). When light is the limiting factor, however, scalping can reduce growth because of reduced moisture and available nutrients (Miller and Brewer 1984).

Scalping can be accomplished with some planting tools such as the side of a hoedad blade (fig. 7.6.7C). With other planting implements such as augers, scalping is done beforehand by another worker. 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 30 to 60 cm (12 to 24 in) around the planting hole and 2 to 5 cm (1 to 2 in) in depth. On dry exposed sites, duff, litter, and rotten wood should be placed back on the cleared surface to serve as mulch (USDA Forest Service 2002). Scalping can definitely slow down planting productivity, but operational experience in Oregon found that a good hoedad planter can still scalp and plant 850 trees/day in Oregon (Henneman 2007).

Continuous scalping ("discing" or "scarifying") is done with tractor-drawn or self-powered equipment. The Bräcke Scarifier is mounted on the front of a prime mover on a three-point hitch allowing the operator to select individual spots. Two side-by-side scalps are about 2.5 m (8 ft) apart with about 2 m (6.5 ft) spacing between rows. Depending on terrain and desired density of the scalps, production varies from 0.5 to 2.0 ha (1.2 to 4.8 acres) per hour (Converse 1999). Discing, which produces a shallow furrow about 0.6 to 0.9 m (2 to 3 ft) and 5 to 10 cm (2 to 4 in) deep, has proved essential for establishment of longleaf pine (*Pinus palustris*) on abandoned farmland in the Southeastern United States (Shoulders 1958). Barnard and others (1995) found continuous scalping to be beneficial for these reasons:

- Reduced weed competition.
- Improved soil moisture availability.
- Less damage by root pathogens and insects.
- Increased planting efficiency.

The beneficial effects of scalping will vary on a site-by-site basis, and whether or not to scalp should be determined during the planning phase of any outplanting project. On grass-dominated sites in interior British Columbia, scalping was found to reduce evapotranspiration and increase soil moisture, which yielded better survival and growth of conifer seedlings (fig. 7.6.7D). In Oregon, increasing scalp size resulted in significant improvement in stem volume after 4 years (Rose and Rosner 2005). On the other hand, on boreal reforestation sites in northern British Columbia where plant competition is not severe, the additional time and expense of scalping failed to improve outplanting performance (Campbell and others 2006).

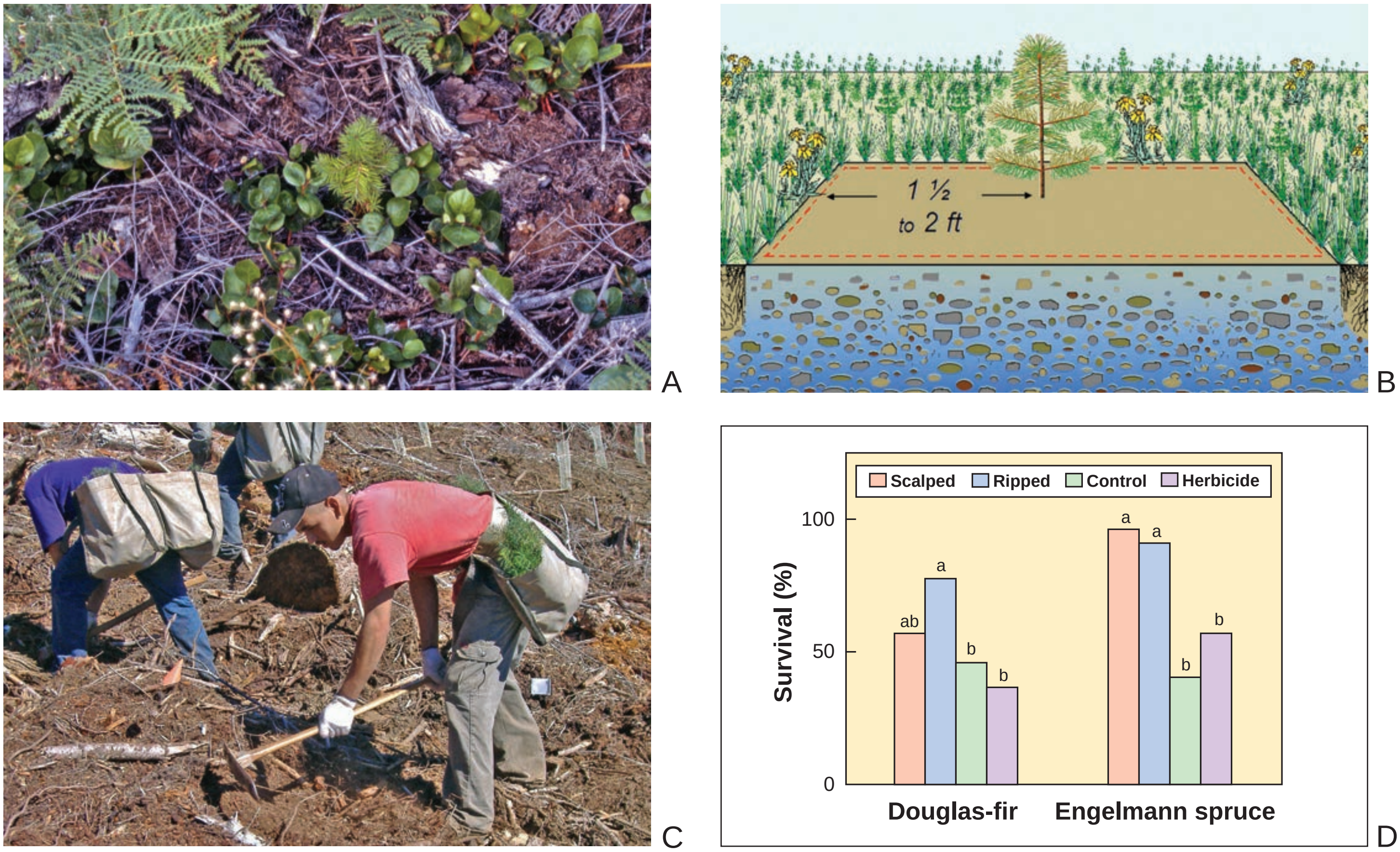
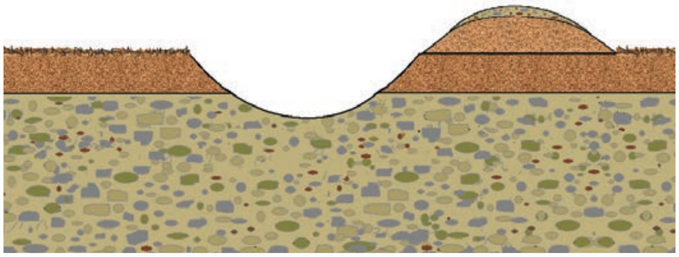


Figure 7.6.7—*Existing plants compete with outplanted nursery stock for moisture (A); scalping is the physical removal of plants and organic debris from around the planting hole (B). Spot scalping can be done with a planting tool, such as this hoedad (C). On a grass-dominated reforestation site, scalping improved conifer seedling survival compared with ripping, herbicide, or the no-treatment control (D) (D, modified from Fleming and others 1998).*

Mounding. On boreal and other cool-temperate planting sites, slow organic matter decomposition creates a heavy surface layer of duff that can be an impediment to planting nursery stock. "Mounding" is a general term for a type of site preparation that can treat several potentially limiting factors: plant competition, cold soil temperatures, poor aeration on wet sites, and nutrient deficiencies. The term mounding has been, however, applied to a variety of mechanical site treatments that can have widely different biological consequences. 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 separate piles that are higher than the existing terrain. With thick duff layers, the resulting mounds consists of a mineral soil cap over a double layer of humus (fig. 7.6.8A). While mounding was originally done by hand; a number of mechanical implements have been developed to speed up the process. For example, the Bräcke Mounder is a scarifier featuring a hydraulically operated entrenching spade followed by a mounding tool that uses soil from the scalped area. Widely used in Canada and Scandinavia, this machine produces mounds 16 to 26 cm (6 to 10 in) high with 3 to 19 cm (1 to 7 in) caps of mineral soil. Other studies have used modified mouldboard plows to generate a continuous mounded ridge (Sutton 1993).

The results of mounding have been generally favorable, at least in the short term. For example, compared with scarification and herbicide treatments, mounding produced



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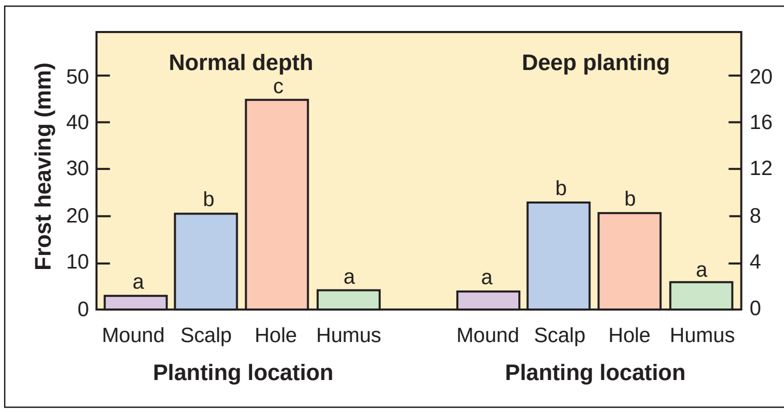

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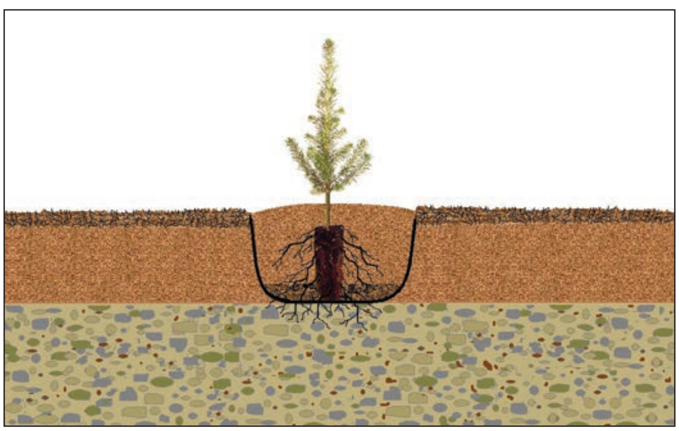


E

Figure 7.6.8—*On boreal sites with heavy duff layers or in waterlogged soils, mounding has proven to benefit plant survival and growth (A). Plants that can rapidly grow new roots (B) will be less susceptible to frost heaving (C). Mounding has also proven effective when the plants are positioned on top of the mound and not in the hole (D). Inverting achieves some of the same benefits as mounding but has a much more acceptable appearance (E) (B, courtesy of Cheryl Talbert; D, modified from Sahlen and Goulet 2002).*

strong, consistent, positive results for jack pine (*Pinus banksiana*) on grass-dominated sites (Sutton and Weldon 1993). Most research involved conifers, but a recent study found that mounding was an effective alternative to herbicides for establishing pedunculate oaks (*Quercus robur*) on waterlogged sites (Lof and others 2006). Conversely, Sutherland and Foreman (2000) found that mound planting resulted in less growth of black spruce (*Picea mariana*) compared with repeated herbicide treatments. Mounding has also been shown to help reduce injury by the European pine weevil (*Hylobius abietis*), which is the major regeneration pest in northern European forests. Because it reduces feeding damage by the weevil, mounding is common on 20 percent of Norway spruce plantations in Finland (Heiskanen and Viiri 2005).

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.

Inverting. This relatively new mechanical site preparation method uses an excavator to create planting spots containing inverted humus covered by loose mineral soil

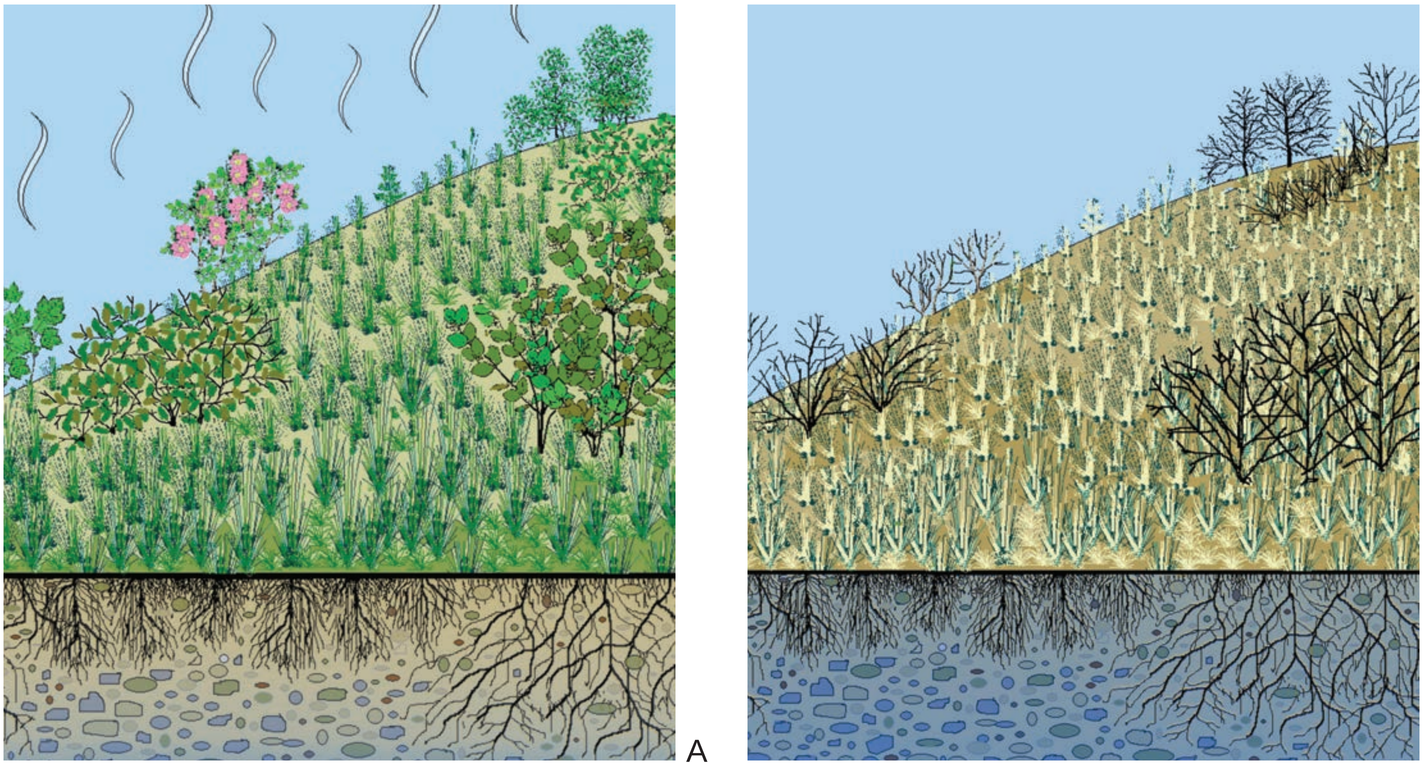


Figure 7.6.9—*When competing vegetation is killed with herbicides prior to planting (A), the soil moisture that would have been lost to transpiration is conserved on the site (B).*

without making large mounds or ridges (fig. 7.6.8E). Research in Sweden with Norway spruce and lodgepole pine found that inverting produced significantly greater survival and stem volume growth after 10 years compared with plowing, mounding, disc trenching, or no scarification (Orlander and others 1998). A subsequent research trial with Norway spruce confirmed that inverting produced increased seedling survival compared with mounding or unscarified controls. Appearance and environmental effects were also measured and, compared with mounding, inverting reduced the alteration of the ground contour from 40 to 15 percent (Hallsby and Orlander 2004).

Site preparation and frost heaving. Frost heaving of recently outplanted nursery stock is a major problem on sites subject to repeated cycles of freezing and thawing. Heaving is a purely mechanical process whereby plants or other objects are slowly racheted out of the soil by repeated freezing and thawing (Goulet 1995). All nursery plants can be frost heaved, but, because of their smooth-walled root plugs, container plants are particularly susceptible.

Sites prone to frost heaving have high soil moisture and soil textures with good hydraulic conductivity (Bergsten and others 2001). The tendency to frost heave increases as pore size decreases, so silt and clay soils are most problematic. Southerly or southwesterly sites have more of a problem with frost heaving because the high solar exposure intensifies the freeze-thaw cycle.

The physiological condition of stock at outplanting can have a significant effect on frost heaving. Plants that have rapid root egress (fig. 7.6.8B) will become physically anchored into the soil and therefore less susceptible. Fear of frost heaving is a major reason why late fall outplanting is discouraged. Nursery stock that is outplanted so late that new roots cannot anchor the plant will be vulnerable to frost heaving (fig. 7.6.8C). In one study, however, stock outplanted later did not suffer more damage than stock outplanted earlier (Sahlen and Goulet 2002).

Site preparation treatments have a significant effect on frost heaving. Scarifying the planting spot increases potential for heaving, because the insulating humus layer and surrounding vegetation are removed, allowing diurnal temperatures to fluctuate more widely. On the other hand, mounding should reduce frost heaving because it provides better drainage and reduces capillary water rise (Bergsten and others 2001). Research on the effect of planting position on frost heaving showed that heaving was considerably higher in the hole where water migrated to the surface and froze into layers that attached to the plant. On top of mounds, frost heaving was as low as in the nontreated humus layer (fig. 7.6.8D). Although deep planting has been suggested as a way to provide better anchorage, it was ineffective in this study (Sahlen and Goulet 2002).

7.6.4.6 Application of herbicides ("chemical scalping")

Mechanical scalping is a time-consuming and therefore expensive site-preparation treatment. Another option is to kill competing vegetation around planting spots with herbicides in advance of the actual outplanting. A general-purpose herbicide like glyphosate (Roundup®) kills all types of plants in the treated area but has very low environmental effects and no residual activity. By killing competing plants before the planting project begins, soil moisture that would otherwise be lost by their transpiration (fig. 7.6.9A) is conserved onsite and will be readily available to the outplanted nursery stock (fig. 7.6.9B). On reforestation sites in Northern California mountains, hexazinone (Velpar®) herbicide is applied 1 to 2 years before the planting project to kill brush and other competing vegetation (Fredrickson 2003). Two years of intensive vegetative control was essential to successful reforestation on Weyerhaeuser lands in Washington State (Talbert 2008).

Concerns about phytotoxicity of sulfometuron methyl (Oust XP®) were addressed for Douglas-fir, western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) container seedlings in coastal Oregon. Although root egress was initially restricted due to the herbicide, no significant effects were observed after 9 to 21 months, showing that any phytotoxicity was short lived (Burney and Jacobs 2009).

Herbicides not only eliminate transpirational water loss, but create 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. An experiment evaluating three levels of vegetation control with chemical scalping significantly increased stem volume, basal diameter, and height of 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). Herbicide applications can also be effective in reducing fire hazards and eradicating non-native plants.

The best herbicide application method depends on the type of project. Aerial application with helicopters is efficient and cost effective for large reforestation or restoration projects. For forest plantation projects, herbicides can be sprayed in rows by all-terrain vehicles (ATVs) or by sprayers attached to ripping equipment. For smaller projects, herbicides can be applied with a backpack sprayer by a person trained in the selection of likely planting spots.

7.6.4.7 Site preparation for restoration plantings

On restoration planting sites, severe disturbance may require unusual site preparation to create suitable planting spots. After the eruption of Mount St. Helens in Washington State, the restoration of 60,700 ha (150,000 acres) of timberland posed some serious challenges (fig. 7.6.10A). Experiments showed that seedlings must be planted in mineral soil to survive, which required digging through 30 to 60 cm (1 to 2 ft) of volcanic ash at each planting spot (fig. 7.6.10B). 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 (fig. 7.6.10C). Woody cuttings of willows or other riparian species used in the structures will sprout (fig. 7.6.10D) and provide rapid revegetation (Hoag and Landis 2001).

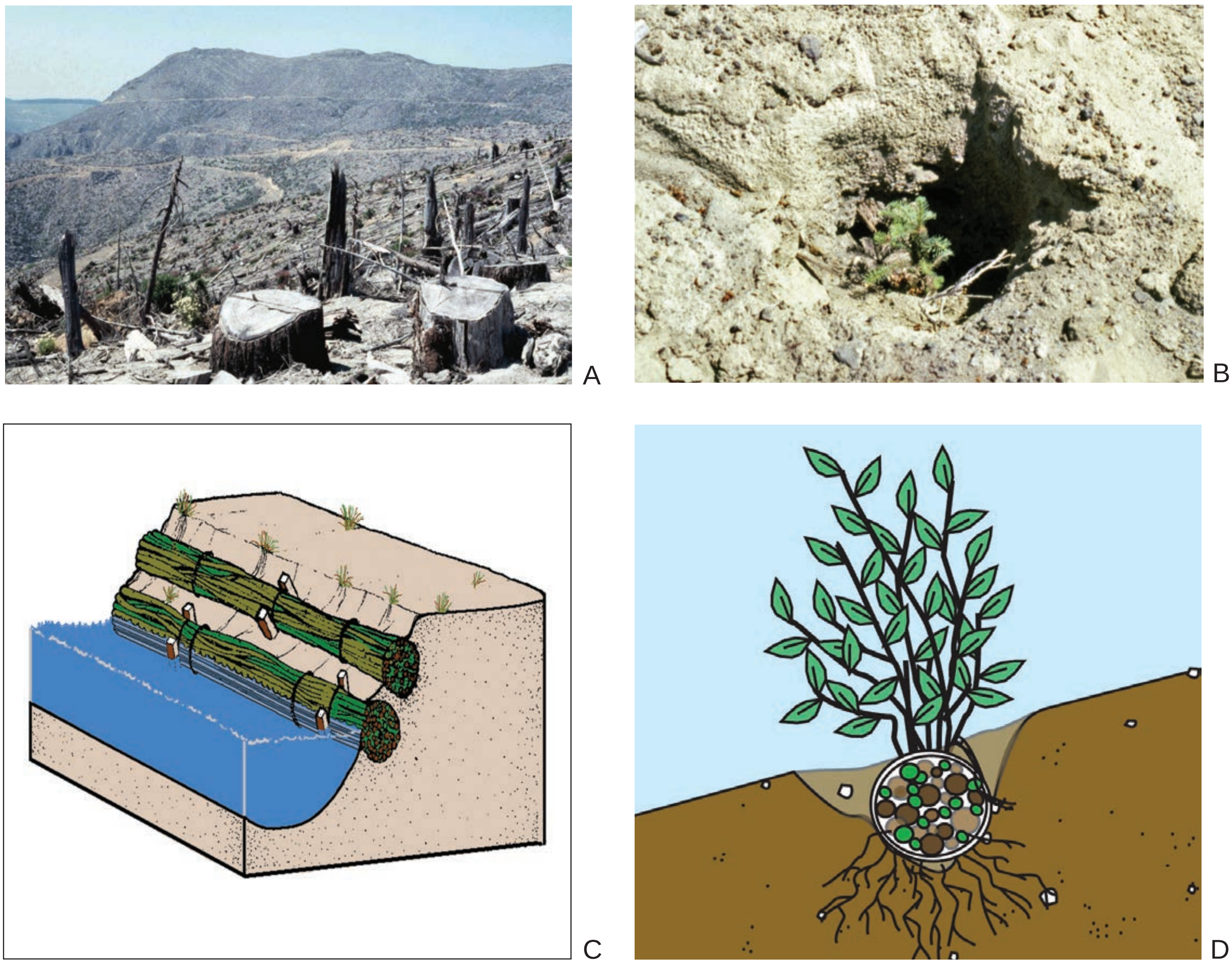


Figure 7.6.10—*Restoration sites require special and sometimes extreme preparation before they can be planted. The blast zone of Mount St. Helens in Washington State was covered with volcanic ash (A), which had to be dug away so that seedlings could be planted in mineral soil (B). Stream banks often require bioengineering structures (C) for stabilization; when willow cuttings are used, they can sprout quickly (D) (D, courtesty of Steinfeld and others 2008).*

7.6.5 Selecting Plant Spacing and Pattern

The pattern and spacing of outplanted plants is also a reflection of project objectives. Industrial forestry projects, where timber production is the primary objective, dictate a specific number of seedlings per area in a regularly spaced pattern (fig. 7.6.11A) based on expected survival rates and laws governing the number of free-to-grow plants required after a specified period of time. Most planting projects will specify a certain desired number of established plants per area (table 7.6.2). These density targets should be considered general guidelines and should never override the selection of planting spots in biologically desirable areas (Paterson and others 2001).

Where ecological restoration is the objective, however, random outplanting of individual plants (fig. 7.6.11B) or outplanting in random groups (fig. 7.6.11C) is more representative of natural vegetation patterns.

The best place to plant nursery stock depends greatly on site conditions. When reforesting a level farm field with relatively uniform terrain, proper spacing is of utmost importance to minimize competition after the seedlings reach pole size. In this situation, then, the choice of planting spots is very mechanical; planters work in parallel lines and plant at the prescribed distance between spots (table 7.6.2). The same goes for using mechanized planters that plant seedlings at regular intervals.

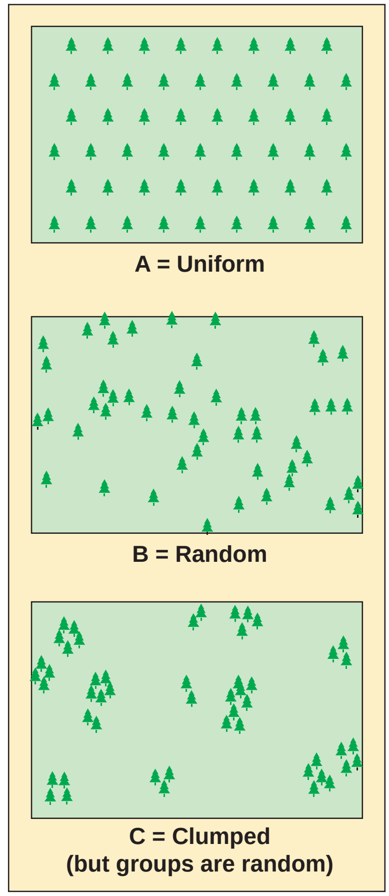


Figure 7.6.11—*In addition to target plant specifications, the objectives of the outplanting project affect planting patterns. If the objective is rapid growth or Christmas trees, then plants can be regularly spaced (A). Most restoration projects do not want the "cornfield look," however, so plants are spaced in a more random pattern to mimic natural conditions (B). The most natural outplanting look uses the random clumped pattern, where different species are planted in groups (C).*

7.6.5.1 Selecting planting spots

Microsites. When hand-planting in mountainous sites with old stumps and other woody debris, 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. Seedlings shaded by a stump, log, or large rock tend to grow well, especially on hot, dry sites (fig. 7.6.12A&B). High sunlight on plant foliage causes moisture stress, and direct sunlight can cause lethal temperatures to the seedling stem at the ground line. Planting around physical obstructions also provides protection from cattle damage and large-game browsing (USDA Forest Service 2002). In the southern Rocky Mountains, planting in microsites shaded by dead woody material doubled the survival of ponderosa pine seedlings. This improved performance was attributed to better moisture and temperature and protection against animal browsing (Nelson 1984).

Where planting sites have been mechanically prepared with disc scarifiers, nursery stock should be planted on the side of the hole in mineral soil (fig. 7.6.12C). On mounds, the best planting spot is on the top (fig. 7.6.12D). Advance planning, crew training, and good supervision are essential to achieving good outplanting success.

Table 7.6.2—*Plant spacing based on regular grids with resultant stocking densities (modified 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

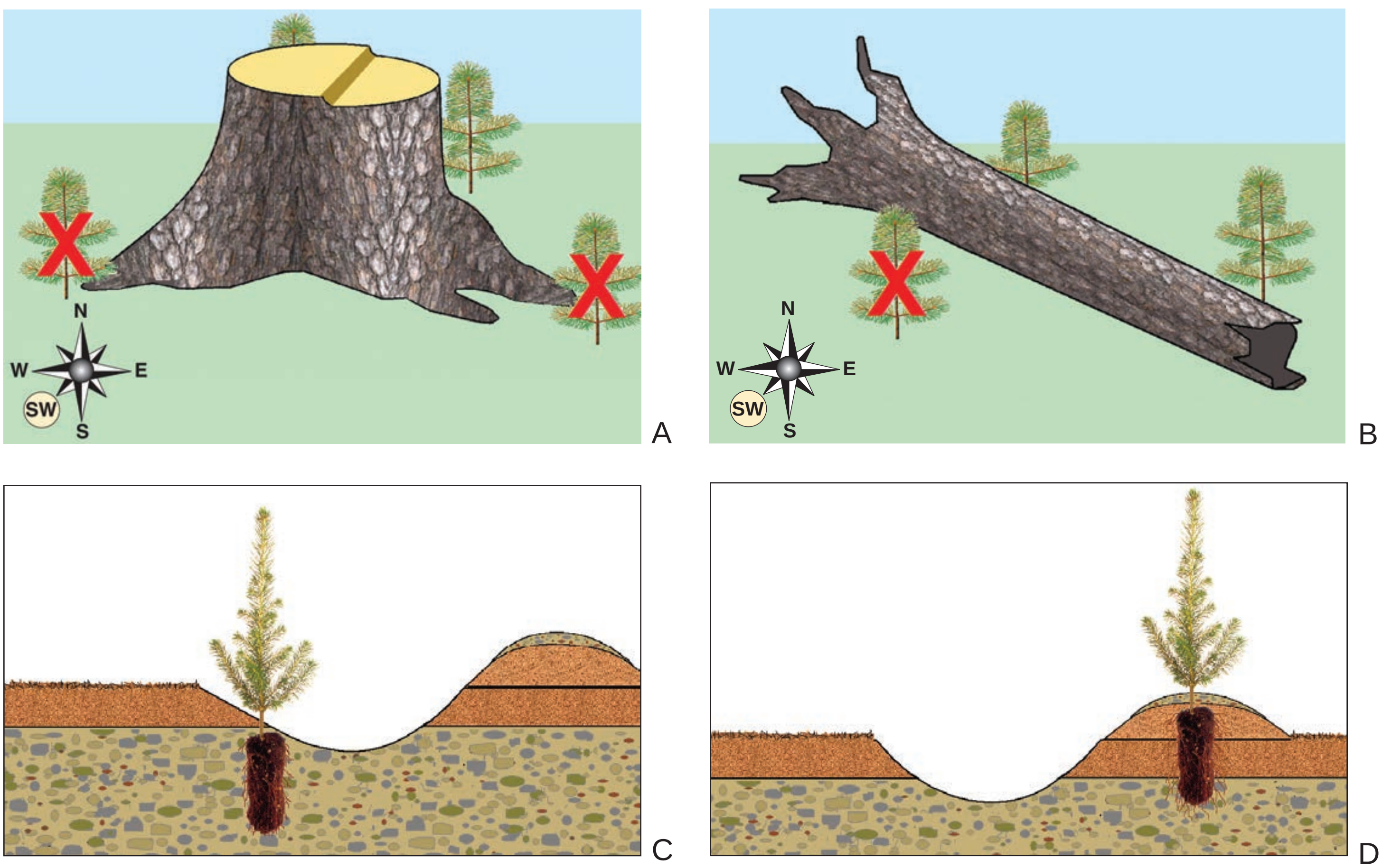


Figure 7.6.12—*On sites with uneven terrain or physical obstructions, the best planting spots are in microsites in the shade of stumps (A) or other debris (B). Specific planting spots are also prescribed where sites have been prepared by discing (C) or mounding (D) (A&B, from Rose and Haase 2006; C&D, from Heiskanen and Viiri 2005).*

7.6.6 Crew Training and Supervision

7.6.6.1 Plant handling

During the planting process, plants should always be handled with extreme care. Crews should be instructed never to toss or drop boxes of plants from the truck. Research shows that dropping seedlings from various heights can result in growth reductions after outplanting (fig. 7.5.5) (McKay and others 1993; Sharpe and others 1990; Tabbush 1986). Planters should never shake or beat plants to remove excess media. Deans and others (1990) found that height growth of Sitka spruce (*Picea sitchensis*) seedlings was negatively affected by beating them against boots at time of outplanting.

Each planter should carry only as many plants as can be planted in an hour or two. On larger reforestation and restoration projects, it is most efficient to use runners that carry batches of nursery stock on all-terrain vehicles (ATVs) from onsite storage to planters (fig. 7.6.13A). Planting bags must not be overfilled to avoid crushing plants (fig. 7.6.13B); loose plants are easier to remove without damage. After a planting hole has been prepared, only one plant should be pulled gently from the bag to avoid root stripping and stem damage (fig. 7.6.13C&D). One mistake inexperienced planters make is to take a handful of plants from the bag and then carry them from one planting hole to the next, increasing the risk of physical damage or desiccation.

The critical concepts are to handle plants gently and to minimize root exposure during the entire planting process. Although it is difficult to actually measure stresses during the shipping, handling, and outplanting process, comparison of outplanting performance between operational projects and research trials proves that the additional care afforded plants in trials pays off.


A


B


C


D

Figure 7.6.13—*All-terrain vehicles are handy for ferrying boxes of plants from onsite storage to planters (A). Planting bags should never be overfilled (B), and plants should be carefully removed one at a time from the container (C) or planting bag (D) and only after the planting hole has been dug (A, courtesy of Risto Rikala; B, courtesy of Mark Hainds; C, courtesy of J.D. Irving, Ltd).*

7.6.6.2 Proper planting technique

The retention of experienced tree planters from year to year appears to be declining (Betts 2008). Moreover, planting crews are often prone to high turnover rates during planting season, with members of the crew changing week to week. Nonetheless, it is crucial that all planters be thoroughly trained in planting procedures. Even a plant with the best quality will die if improperly outplanted. Good training, close supervision, and regular inspection are important in order to optimize outplanting quality.

Somewhat surprisingly, very little is published on proper planting depths for container plants, although the advantages of "deep planting" bareroot stock are many (Stroempl 1990):

1. Improved stem stability against wind and snow pressure.

2. Insurance against root exposure from soil settling or washing away.

3. Protection of the "root collar" against heat injury.

4. Roots situated deeper in the soil profile have better access to soil moisture.

Therefore, on appropriate sites, the planting hole should be deep enough to bury the plug 2.5 to 5 cm (1 to 2 in)—about up to the cotyledon scar (Londo and Dicke 2006; USDA Forest Service 2002). This can vary with plant species; for example, in the Southeastern United States, longleaf pine seedlings that have their apical buds near the plug surface are planted with 0.6 to 1.3 cm (0.25 to 0.50 in) of the container plug exposed (Hainds 2003); this probably holds true for other species that have apical meristems near the plug surface. Because new photosynthates are required for new root growth after outplanting (van den Driessche 1987), burying foliage should probably be avoided.

The most important training concept is that good root-to-soil contact is necessary before nursery stock can become established on the site and quickly access water and mineral nutrients. The planting hole should be made deep enough so that, for most species, the root plug can be completely covered with mineral soil (fig. 7.6.14A) and "J-rooting" and unnecessary exposure of the root plug are avoided (fig. 7.6.14B), but the plug is not planted too deep (fig. 7.6.14C). According to Forest Service specifications, the minimum-size hole for container stock is 2.5 cm (1 in) deeper than plug length, and at least 7 cm (3 in) wider than the plug at top of the hole and 2 cm (1 in) at bottom (USDA Forest Service 2002). The planters should 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 (fig. 7.6.14D); this seems obvious on level ground, but the steeper the slope, the more important this becomes. Planting holes should be backfilled with mineral soil without grass, sticks, rocks, or snow (fig. 7.6.14E). It is important to firmly tamp the soil around the root plug to remove air pockets (fig. 7.6.14F), but refrain from stomping around plants to avoid excessive soil compaction or stem injury.

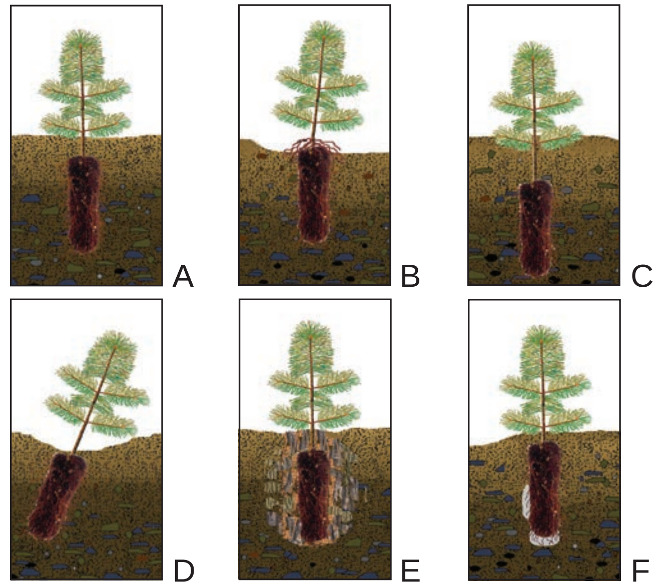


Figure 7.6.14—*Nursery stock should be planted properly (A). Common problems include planting too shallow (B), planting too deep (C), improper vertical placement (D), filling the hole with debris (E), or poor compaction that leaves air pockets around the root plug (F) (modified from Rose and Haase 2006).*

Crew 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 a professional create the planting holes with a machine auger and let the volunteers place and tamp plants into position. This technique has several benefits: the professional chooses the proper planting spot, creates the desired pattern, and makes certain that the planting hole is large and deep enough so that plants can be situated without "J-roots." Several studies have found that mechanical outplanting is more successful when working with private landowners who may not plant nursery stock properly (Davis and others 2004).

Although the choice of the proper planting tool is important, experienced planters can achieve success with a variety of implements. Planting failures are often more attributable to improper technique or handling rather than choice of planting tool (Adams and Patterson 2004).

Tree planting is strenuous work, and the swinging, bending, and lifting can quickly lead to worker injuries, especially early in the season. Back problems and carpal tunnel syndrome are common complaints. Crews should have sturdy boots, safety glasses, and hard hats and do strengthening and stretching exercises each day before starting to plant. The time and resources spent on worker protection will be offset by potential downtime and worker's compensation claims (Kloetzel 2004).

7.6.7 Hand-Planting Equipment

Root plugs on nursery stock used for reforestation or restoration are longer and narrower than plant materials used for landscaping and gardening, so specialty tools are necessary. Appropriate planting tools and technique can mean the difference between a live or dead plant, and between 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 stocktypes. The most common types of hand-planting equipment are discussed in the following sections, but new equipment is continually being developed (Trent 1999).

7.6.7.1 Dibbles

Dibbles or dibble sticks were among the first tools used to plant container stock, primarily because they are easy to use (fig. 7.6.15A). 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 (fig. 7.6.15BA). 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 (fig. 7.6.15C).

Hollow dibbles are a more recent modification that extract a core of soil and, therefore, do not cause soil compaction (fig. 7.6.15D). The hollow dibble heads are interchangeable, allowing use for different container sizes (Trent 1999). A slide hammer soil extractor can also remove a core of soil and, although one study found that it was more effective on rockier and compacted soils, it was also considered very strenuous to use because of its weight (Trent 1999).

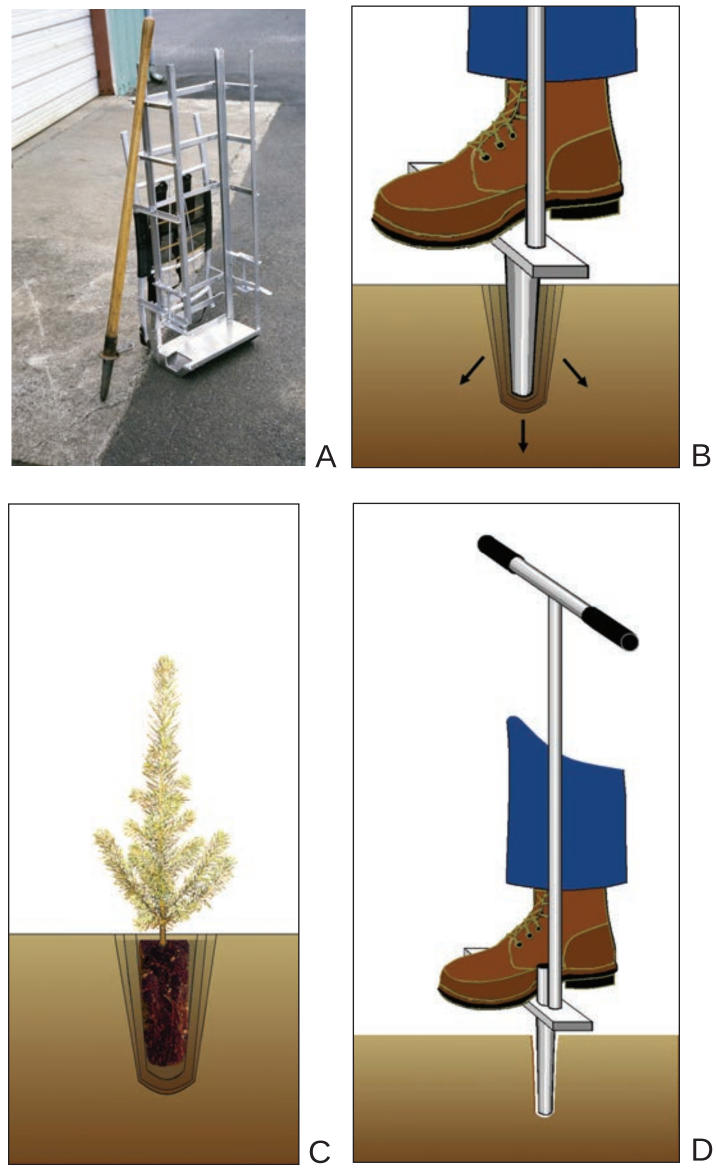


Figure 7.6.15—*Dibbles were among the first hand-planting tools developed for container nursery stock (A). Because they displace soil to form the planting hole (B), compaction can be severe enough to restrict root egress (C). Hollow dibbles are an improvement because they remove a core of soil to create a planting hole (D).*

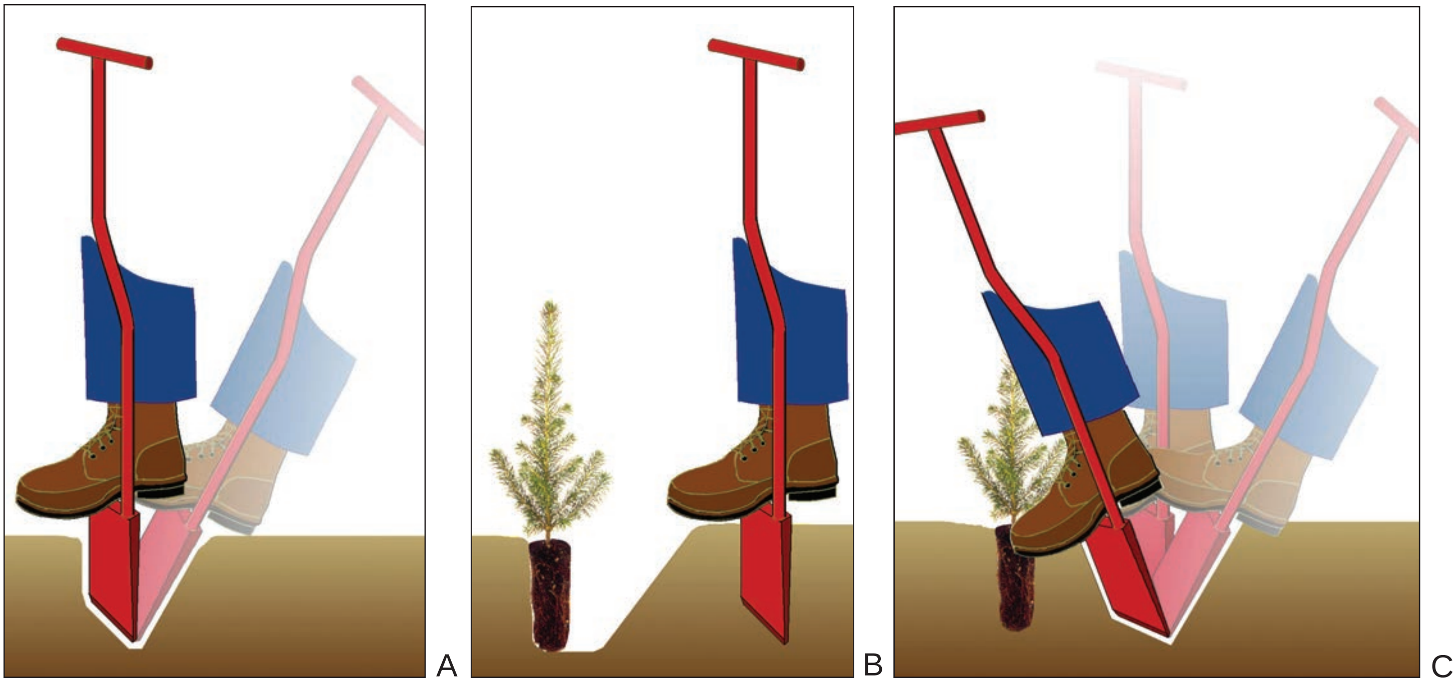


Figure 7.6.16—*Bars are easy-to-use planting tools that create a planting hole by lateral movement (A). The plant is positioned along one side of the planting hole (B), and soil is backfilled by leverage from the other side (C). Soil should be gently compacted around the plant with hand or foot (D).*

Commercially produced dibbles are available for specific container types and sizes, including Ray Leach Conetainers™ and several cavity sizes of Styrofoam™ block containers (Kloetzel 2004). Dibbles have been used on shallow soils in Ontario but not on sites prone to frost heaving (Paterson and others 2001).

7.6.7.2 Bars

Planting bars originated with bareroot stock and are still used for smaller container plants. Bars are typically fabricated from a cylindrical bar 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 (fig. 7.6.16A), and the planting hole is formed by working the bar back and forth. The nursery plant is positioned vertically along one cut face (fig. 7.6.16B), 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 (fig. 7.6.16C). The final step is tamping any loose soil around the plant with the fist or boot to remove any air pockets (fig. 7.6.16D). In the Pacific Northwest, planting bars are often preferred for rocky soils but should not be used in heavier textured clays, where they cause excessive compaction (Cleary and others 1978). They also are popular on reforestation sites with sandy soils in the Southeastern United States. Planting bars are durable and simple to maintain, with only occasional blade sharpening required (Kloetzel 2004).

7.6.7.3 Hoedads

Hoedads, also known as planting hoes or mattocks, were developed specifically for planting bareroot conifer seedlings for reforestation and have since been adapted for container applications (fig. 7.6.17A). They are probably the most common handtool used in the United States, especially in the Pacific Northwest (Lowman 1999). Hoedads come in a variety of sizes and shapes and are one of the most versatile tools available. Special "plug hoes" for various sizes of container stock are available. Brackets, holding the hickory 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 be regularly sharpened with a metal file or electric grinding wheel (Kloetzel 2004).

Hoedads are particularly useful on steep reforestation sites, and even on rocky and compacted restoration projects. 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 (fig. 7.6.17B). After a proper hole is complete, the planter uses the tip of the hoedad to gently loosen soil on the sides of the planting hole in order to avoid any compaction effects. Then, the plant is inserted and positioned to the proper depth (fig. 7.6.17C). While holding the plant, the planter used the hoedad blade to backfill the soil around the plug (fig. 7.6.17D). Finally, the planter gently tamps the soil around the plant (fig. 7.6.17E) and moves to the next planting spot. If plant competition is a problem, or if a planting basin is required, the back and side of the planting blade is a useful scalping tool (fig. 7.6.7C). Some compaction in the planting hole can occur on the backside of the blade with this tool, but compaction is typically less than with other methods.

Planting rates vary with container size, planter's skill, and terrain. Kloetzel (2004) reported that beginning planters can install 20 plants/hr while experienced planters may reach up to 100 plants/hr; on wetland planting projects

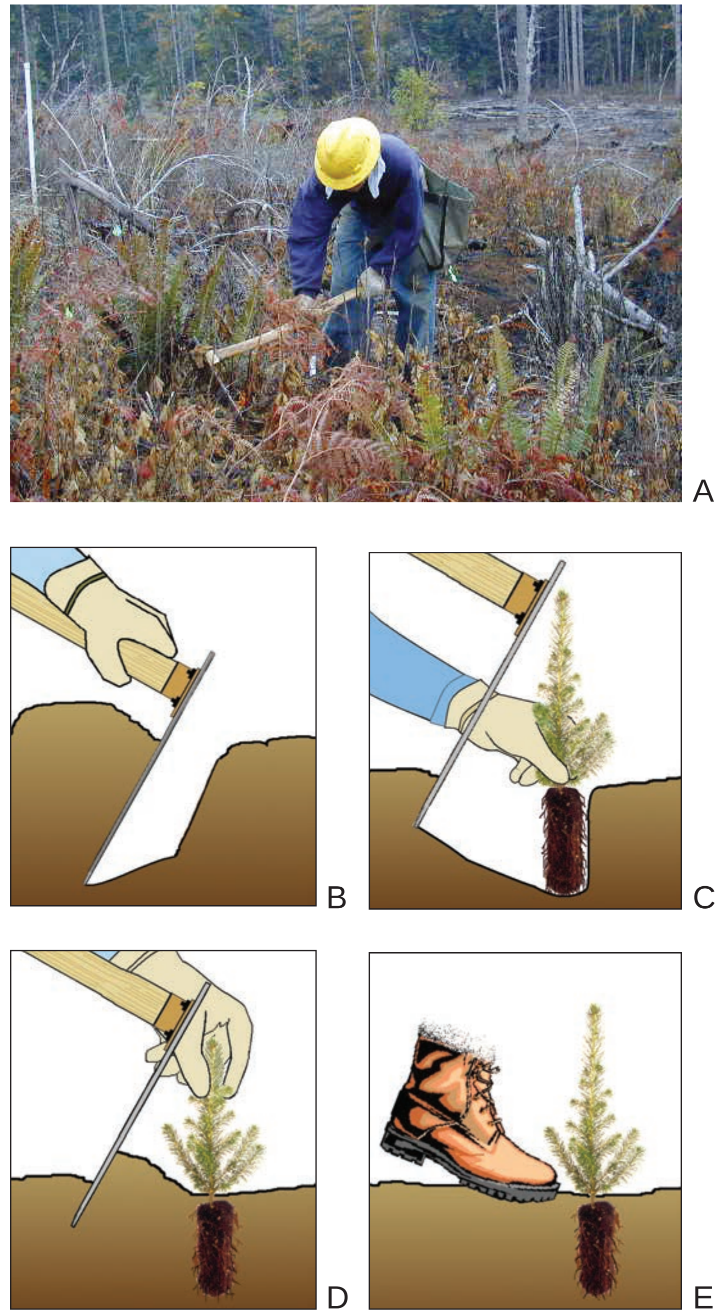


Figure 7.6.17—*Hoedads are one of the most popular planting tools in the mountains of the Western United States and Western Canada (A). After several swings to create a deep enough planting hole (B), the plant is positioned and held (C) while backfilling with soil (D). The final step is to gently compact the soil around the plant to remove any air pockets (E).*

with small stock and favorable soil conditions, production reached 240 plants/hr. For small-volume containers (66 cm^3 [4 in^3]), Meikle (2008) reports planting rates of 600 to 800 trees and shrubs per day on mineland reclamation sites, but the rate dropped to 400 to 600 plants when container volume increased to 164 cm^3 (10 in^3). Adding Vexar tubes to prevent herbivory dropped the planting rate by one-half (Meikle 2008).

7.6.7.4 Shovels

Although standard garden tile spades can be used, professional planters use customized shovels (fig. 7.6.18A) with blades long enough to accommodate large containers (fig. 7.6.18B). Wooden handles are standard, but fiberglass models are lighter, and reinforced blades (fig. 7.6.18C) can endure the vigorous prying action used to open planting holes (fig. 7.6.18D). Although shovels are not as difficult to learn to use as hoedads, planters should be trained to use tree-planting shovels efficiently. After the hole is excavated to the proper size and depth, the nursery plant is installed and held in a vertical position (fig. 7.6.18E) while the planter backfills around the root plug (fig. 7.6.18F). Tree-planting shovels are the tools of choice for some tree planters in the Western United States and are considered the most versatile planting tool in British Columbia (Mitchell and others 1990), as well as by reforestation crews in the Southeastern United States. Soil amendments, fertilizers, and other such in-soil treatments are easily installed with planting shovels. Sites requiring scalping require a two-person team with the scalper preparing the site beforehand. When using planting shovels, keep some spare handles and footpads on hand, along with tools for installing parts and sharpening blades (Kloetzel 2004).

In Ontario, experienced planters started the season by planting approximately 1,800 seedlings (100 cm^3 [6 in^3]) per day with shovels, while rookie planters managed only about 900. After about 6 weeks of planting, however, both groups were able to plant substantially more plants: 2,500 per day for experienced planters and 1,800 for rookies (Colombo 2008). In Washington State, larger stocktypes (250 cm^3 [15 in^3]) are planted west of the Cascade Mountains, and this is reflected in the planting rate. Only 900 larger seedlings can be planted per day compared to 1,000 of the smaller stocktype (Khadduri 2008).

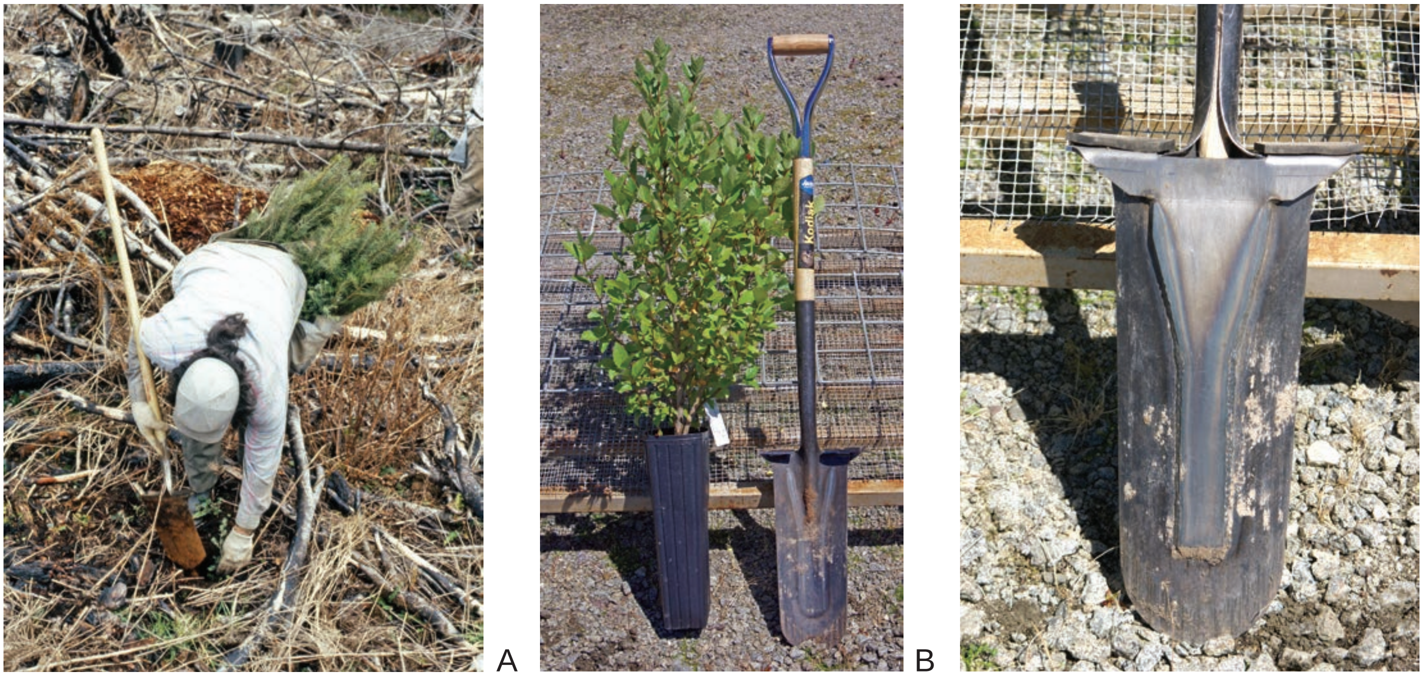
7.6.7.5 Tubes

Planting tubes are mechanized dibbles that create a planting hole by compressing soil to the sides and bottom with a pointed pair of hinged jaws (fig. 7.6.19A). The jaws are switched open with a foot lever, and a container plant is dropped though the hollow stem tube into the hole (fig. 7.6.19B). 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 Eastern Canada. Although popular in Ontario, they are considered expensive to purchase and maintain (Paterson and others 2001). In one comparison, planting tubes were just as effective as dibbles or planting bars (Jones and Alm 1989).

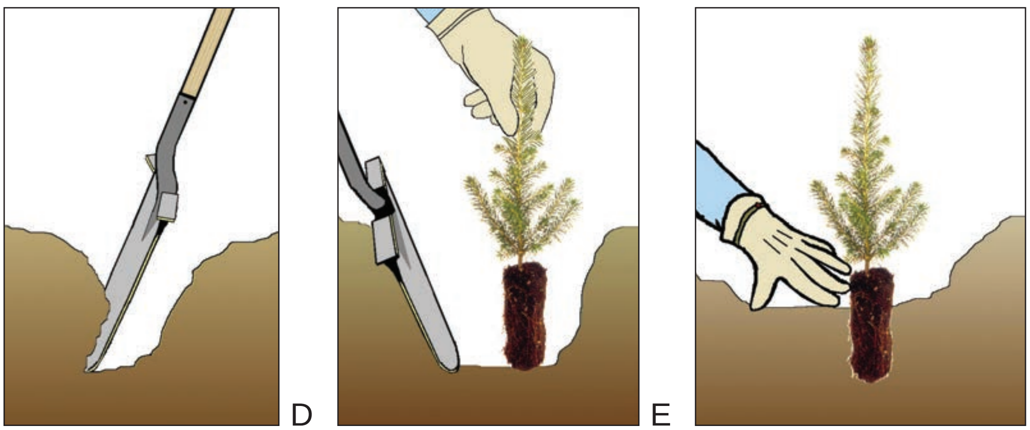
7.6.7.6 Motorized Augers

Power augers have been used in reforestation for decades and are becoming popular for restoration projects (fig. 7.6.20A). Augers work best in deep soils without too many large rocks or roots and are the best planting tool to use for larger, taller stocktypes. One concern has been compaction or glazing on the sides of the auger holes under some soil conditions (Lowman 1999), but this can be minimized by rocking the bit slightly. In Quebec and Nova Scotia, large-container seedlings are preferred because of heavy brush competition and a gasoline-powered auger was considered a better planting tool than spades or soil extractors in all soil types (St-Amour 1998). A gasoline-powered hand drill can be used with auger bits from 2.5 to 10 cm (1 to 4 in) in diameter, and the reversible transmission helps if the bit becomes stuck (Trent 1999).

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 (fig. 7.6 20B). One operator can drill enough holes for several planters to follow and plant the nursery stock (fig. 7.6.20C). 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. Digging



A B C

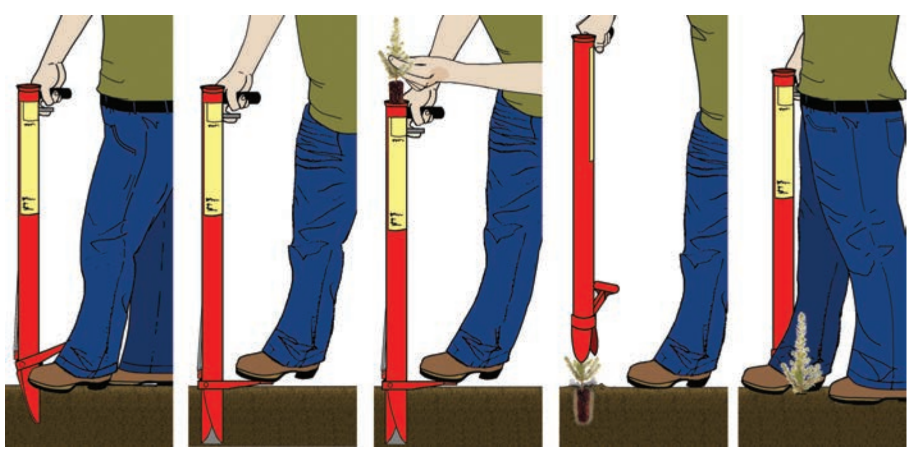


D E F

Figure 7.6.18—*Shovels are very versatile planting tools (A) and are ideal for large and deep container plants (B). Specialized shovels have reinforced blades (C) that open deep planting holes without soil compaction (D). While holding the plant vertical in the middle of the hole (E), firm the soil around the root plug as the hole is backfilled (F).*

A

Figure 7.6.19—*Planting tubes have pointed jaws that open the planting hole (A). The plant is dropped down into the hole through the hollow stem (B).*



B

auger holes deeper than the depth of the container plug reduces compaction and can promote downward root growth. This means that the planter has to support the plant at the proper depth in the hole, while filling with soil from the bottom up (fig. 7.6.20D). Soil settling can be a problem with auger planting so it is a good idea to mound soil around the base of the plant. When more than one auger operator is available, it is best for them to take turns in order to reduce fatigue (Cleary and others 1978).

A wide variety of augers are commercially available for rent or sale: chainsaw-head, one-person, two-person, and tractor-mounted augers (fig. 7.6.20E). Most small planting projects can rent power augers at any commercial rental agency. 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 probably a good idea to rent first to make sure that you have the correct machine for the project. Augers are high-maintenance planting tools so keep a spare one available as well as extra parts and bits (Kloetzel 2004).

Well-organized auger teams can reach production rates ranging from 30 to 70 plants per person/hr (Kloetzel 2004). In Hawai‘i, using an auger has become the ideal planting tool when volunteers or other non-professional planters are involved because the planting rate in order is 2.5 times that of standard hand tools (Jeffrey and Horiuchi 2003).

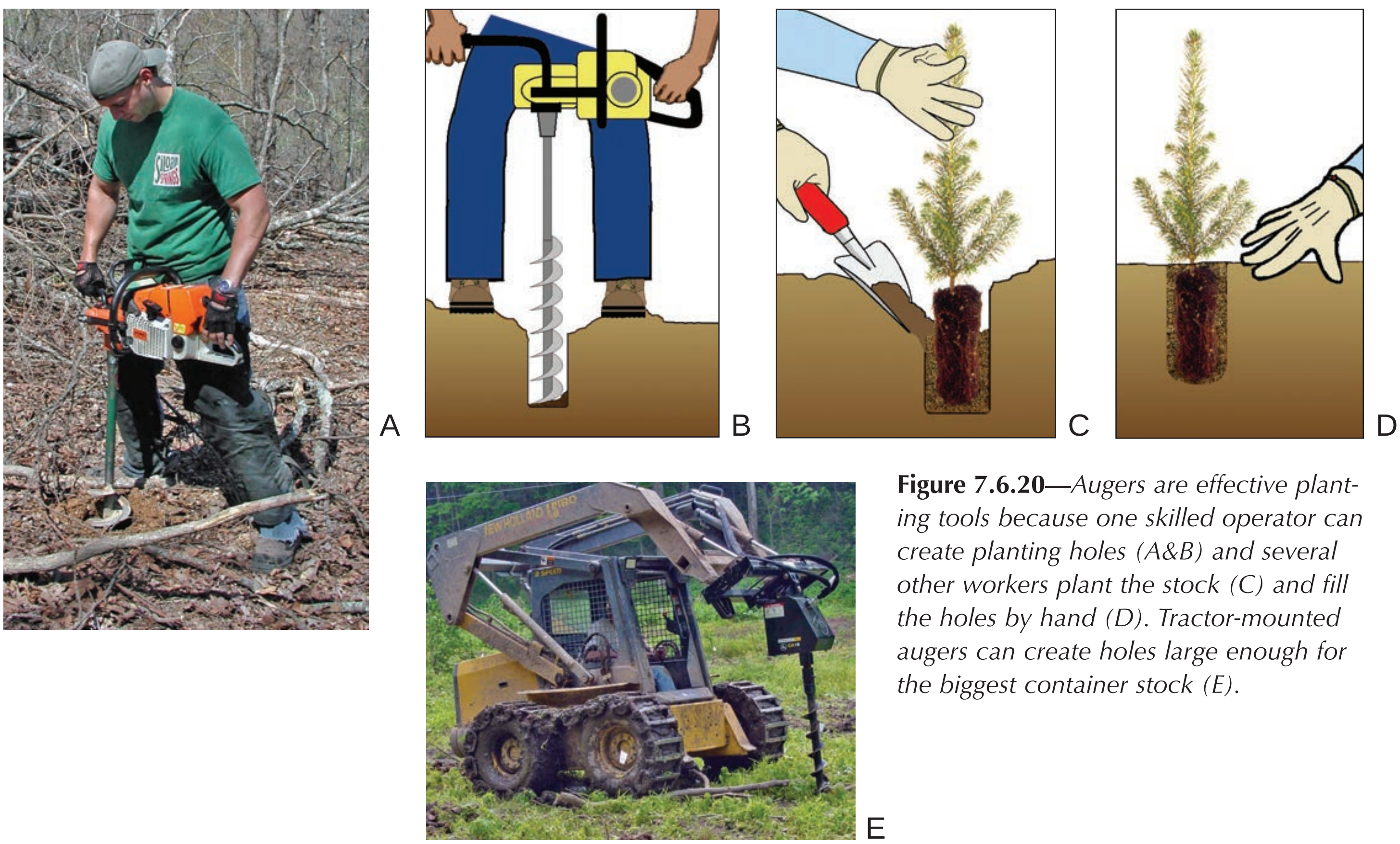


Figure 7.6.20—*Augers are effective planting tools because one skilled operator can create planting holes (A&B) and several other workers plant the stock (C) and fill the holes by hand (D). Tractor-mounted augers can create holes large enough for the biggest container stock (E).*

7.6.8 Machine-Planting

Planting machines have been used for forest tree seedlings for more than 100 years, and container plants are ideal for machine-planting because of their compact root systems and uniformity. Steadily increasing labor costs and difficulty in finding skilled planters has motivated many reforestation and restoration specialists to look at machine-planting (Hallonborg 1997). Foresters in British Columbia conducted trials with planting machines and found that the cost of machine-planting was comparable to hand-planting but was possible only on relatively flat, easily accessible sites. Many mountainous reforestation sites are steep, rocky, and covered with stumps and slash, factors that favor trained hand-planters (Mitchell and others 1990). Likewise, mechanical tree-planters are not used widely in Ontario because of site restrictions, high initial investment, and greater maintenance costs (Paterson and others 2001). Machine-planting has been more popular on the more gentle terrain of the Central, Northeastern, and Southern United States, and in Scandinavia.

Two basic types of planting machines, towed and self-propelled, are used and will be discussed separately (table 7.6.3).

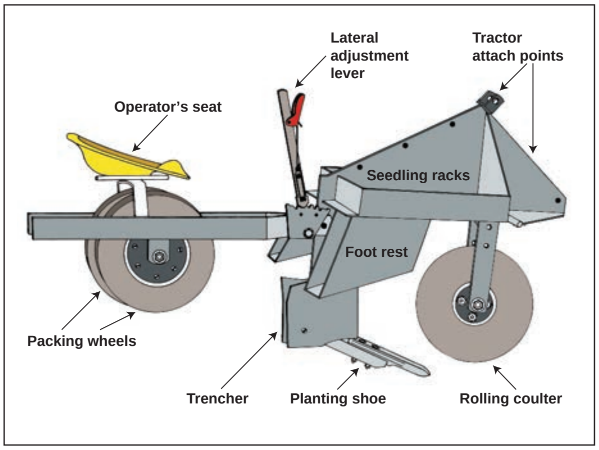
7.6.8.1 Machines towed behind tractors

Many mechanical tree-planters are commercially available and consist of a rolling coulter, a trencher, an operator's seat, and packing wheels that are mounted on a sturdy frame (fig. 7.6.21A). Machine-planters for open fields feature a three-point hitch and are towed behind a tractor with the operator facing forward. The coulter cuts through the sod and any roots, and the trencher opens a narrow furrow (fig. 7.6.21B) in which the stock is hand-planted by the operator. Packing wheels on the back of the machine close the furrow and firm the soil around each plant. For planting in open fields, planting machines can also be equipped with a tank for applying herbicides (fig. 7.6.21C).

Some models, such as the Whitfield Tree Planting Machine, are popular for reforestation sites that have a lot of woody slash. They are safer because the operator rides backward in a protective cage and cannot be hit by debris thrown up by the tractor (fig. 7.6.21D) . The operator places plants in a clip on a revolving chain assembly (fig. 7.6.21E) that carries the plant around until it is positioned in the furrow. The clips open mechanically and the plant is placed in the

Table 7.6.3—*Characteristics of the two types of tree-planting machines (modified from Landis 1999)*

				Planting stock characteristics		
Type of propulsion	**Planting method**	**Plant placement**	**Plant spacing**	**Plug length determined by**	**Firm root plugs required**	**Stem rigidity required**
Towed behind tractor	Furrow with closing wheels	Manual	Fixed in row	Depth of opening shoe	No	Yes
Self-propelled: mounted on excavator or harvester	Scarifying, mounding, and hole-making heads	Automated: hydraulic or pneumatic	Variable	Depth of planting head	Yes	Yes



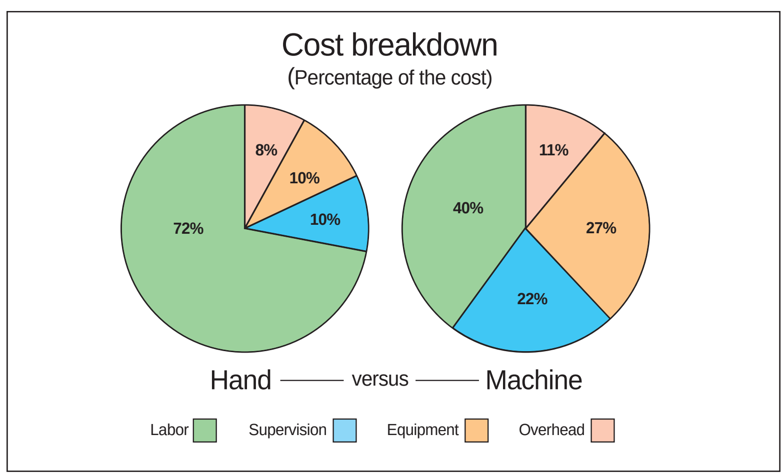
A

B

C

D

E



F

Figure 7.6.21—*A traditional type of planting machine (A) is towed behind a tractor, and the plants are spaced evenly in straight rows (B). Some models feature a herbicide sprayer for weed control (C). With the Whitfield planter, the operator rides backward and places seedlings in clips in a revolving chain (D) that carries them to the bottom of the furrow, which is closed by packing wheels (E). Economic comparisons have shown that machine-planting can be much more economical than hand-planting (F).*

furrow that is closed by the packing wheels (fig. 7.6.21E). The Taylor Tree Planting Machine is attached to the prime mover with a three-point hitch that allows down pressure to maintain planting depth; it also features a water tank on top to cool the stock (Converse 1999). Some machine-planters are equipped with furrowing attachments to scalp the planting spot, while others have spray attachments for applying herbicides to control unwanted vegetation. Planting speed varies with the ground conditions, size of the nursery stock, and experience and skill of the planting crew. Planting rates of 400 to 1,000 trees/hr have been reported (Slusher 1993), and in the Southeastern United States, 1,100 longleaf pine seedlings can be planted per hour at a within-row spacing of 4 m (12 ft) (South 2008).

Machine-planting must be evaluated on a site-by-site basis and is not effective on slopes greater than 35 percent. To offset the considerable transportation, operation, and maintenance costs, planting projects must be relatively large and accessible. A comparison of hand-planting versus machine-planting showed that labor savings can be considerable (fig. 7.6.21F). For example, in Southeastern Alaska, reforestation costs ranged from $247 to $321/ha ($100 to $130/ac), which was 18 percent less than hand-planting (Peterson and Charton 1999).

One consideration with towed planting machines is that plants are spaced regularly along the furrows. This is beneficial when a grid-like planting pattern is desired, such as in commercial forest or Christmas tree plantations (fig. 7.6.11A). Equal plant spacing is a drawback, however, when a more natural-appearing planting is desired (fig. 7.6.11B&C).

7.6.8.2 Self-propelled planting machines

Because of the high cost and unreliability of skilled planters, several models of self-propelled planters have been developed for container stock in Scandinavia (fig. 7.6.22A). These all-purpose planting machines have multiple benefits (Drake-Brockman 1998):

- Scarifying, mounding, and planting can be accomplished in a single operation.
- Planting spots are selected by the operator, which results in a more natural-looking plantation (fig. 7.6.11B&C).
- Fewer worker injuries as the machine does the physical work.
- Operators protected from inclement weather.
- Consistent quality of planting.
- Less contact with chemically-treated nursery stock.
- Reduced management planning and supervision.

Each planting machine has a different mechanism, but all have remote heads that scarify, mound, and plant seedlings in specific spots selected by the operator.

Bräcke planting machine. Developed in Sweden, this machine has been the most popular of the self-propelled planting machines (fig. 7.6.22A) and has been used in the United Kingdom and throughout Scandinavia. More than 30 Bräcke planting machines are being used in Finland due to a shortage of hand-planters. The quality of work has been equal to manual planting, but planting costs have been slightly higher (Harstela and others 2007). The planting head is mounted on the hydraulically controlled arm of an excavator or harvester (fig. 7.6.22B) and contains a circular magazine containing 60 to 88 plants (fig. 7.6.22C). It can create mounds and plant seedlings in the same operation (fig. 7.6.22D); production rates have varied from 140 to 250 seedlings/hr, depending on site conditions.

M-Planter. This Finnish planting machine is also mounted on a harvester or excavator boom, but it can create and plant two mounds without relocating (fig. 7.6.22E-F). The M-Planter features a larger seedling cassette that contains 242 seedlings and, in a recent comparison, outplanted the Bräcke by 24 to 38 percent over a variety of site conditions. Research is currently under way on an improved model of the M-Planter (Harstela and others 2007).

Ecoplanter. This Swedish planting machine is also mounted on a harvester or excavator boom, but it can create and plant two mounds at a time. The Ecoplanter has a capacity of 240 plants and can plant 220 to 250 seedlings/hr (Saarinen 2007).

Several comparisons of self-propelled planting machines were done in northern Europe. In Finland, the Bräcke and Ecoplanter had similar planting rates of 200 to 250 seedlings/hr. The planting quality of the Bräcke machine was comparable with hand-planting and better than the

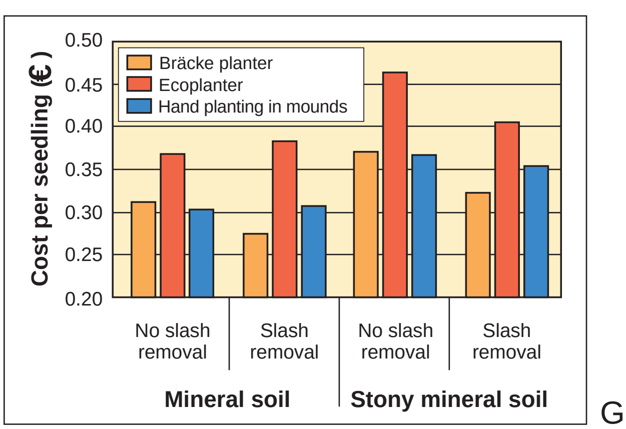


Figure 7.6.22—*A number of self-propelled planting machines have been developed in Scandinavia for planting container stock. The Bräcke planting machine (A) has been used the longest and consists of a planting head (B) with a magazine of seedlings (C), which is mounted on the arm of an excavator. The planting head hydraulically creates a mound and plants a seedling on top (D). The newest machines, such as the M-Planter (E), can plant two seedlings without moving the excavator, and tamp the soil around each (F). Planting trials have shown that machine-planters can compare favorably with hand-planting (G) (E, courtesy of Pekka Helenius; F, courtesy of Leo Tervo).*

Ecoplanter (fig. 7.6.22G), which caused stem deformation and had more weakened or dead trees after 2 years (Saarinen 2007). In a test of the Bräcke in Ireland, planting quality was well within planting quality specifications, but not as good as hand-planting. However, no overall significant differences in height growth and root-collar diameter increment were found after the first growing season (Nieuwenhuis and Egan 2002). In the United Kingdom, the Bräcke machine produced acceptable planting of container conifers on upland reforestation sites (Drake-Brockman 1998).

7.6.9 Planting Equipment for Large Stock

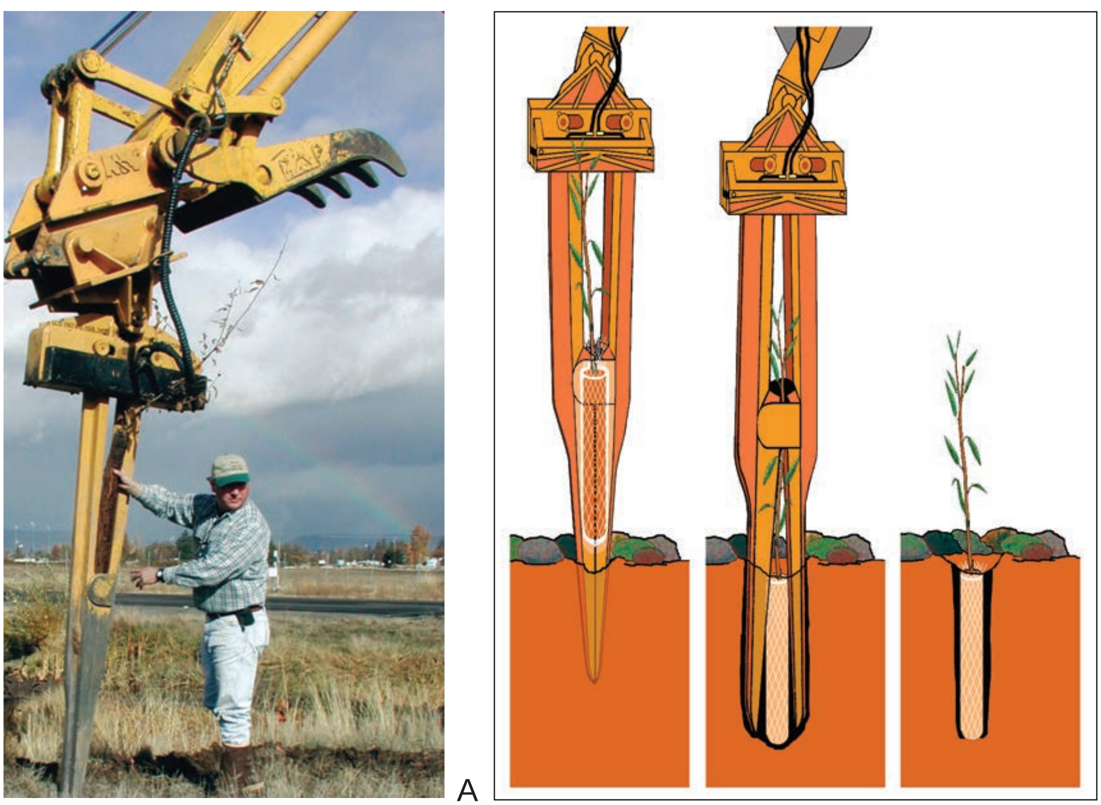
Large container stock and nonrooted cuttings are difficult to plant effectively, so special equipment has been developed. Note that good access is essential and, in the case of the pot planter, a source of water must be available.

7.6.9.1 Expandable stinger

The expandable stinger is a recently developed planting machine attached to the arm of an excavator (fig. 7.6.23A) that creates a hole and plants nursery stock in one operation. The planting head is composed of two parallel steel shafts, which are hinged in the middle to open and close in a scissor-like manner. Each shaft is constructed to create a long, hollow chamber between them when closed. The opening and closing of the shafts are hydraulically driven. When the shafts are closed, the stinger comes to a point and is pushed into the soil by the force of the excavator arm. A long hardwood cutting or container plant is placed into the chamber. The expandable stinger is maneuvered to the planting spot, where the beak is inserted into the soil. When the beak opens, the plant drops to the bottom of the hole (fig. 7.6.23B).

Two expandable stinger models, single-shot and 50-shot, are currently in use. The single-shot model holds only one plant at a time and averages 50 to 80 plants/hr. The rotary magazine of the 50-shot model holds 50 plants of up to three different species and can double the planting rate of the single-shot model (Kloetzel 2004). The expandable stinger can reach sites that are inaccessible by other planting equipment. The arms on smaller excavators can reach 7.5 m (25 ft), while those on larger machines extend out to a 15-m (50-ft) radius. This equipment can also plant in very rocky soil conditions, including rip-rap and gabions, and can penetrate very compacted soils making it ideal for restoration projects. It is a good idea to have someone follow the stinger and fill in around the plants with mineral soil.

The major drawback to the expandable stinger is its expense. In addition to hourly operating costs, mobilization costs can be very high, although these costs should be amortized across the entire project. As the number of plants installed by the expandable stinger on a project increases, the cost per established plant decreases. In a well-planned operation, the expandable stinger can achieve a production rate of 200 plants/hr.



A B

Figure 7.6.23—*The expandable stinger is a specialized planting machine for harsh sites, including compacted soil and rip-rap (A). The long scissor-like planting head creates a planting hole where a tall pot container or nonrooted cutting can be installed (B).*

7.6.9.2 Pot planter

The pot planter was developed for riparian restoration projects (Hoag 2006) and uses high-pressure water to create planting holes for large container stock. Water from a lake, stream, or tank is pumped into a compressor (fig. 7.6.24A) and then forced through the tip of a high pressure nozzle (fig. 7.6.24B). The pot planter has 7.6-cm (3-in) vanes attached to the sides of the nozzle, which create holes large enough for containers up to 3.8 L (1 gal) (fig. 7.6.24C). The hole that is created by the pot planter is filled with a soil slurry that is displaced when the root plug of the container plant is inserted to the desired planting depth. After the water drains from the slurry into the surrounding soil, the soil settles in around the root plug, assuring good soil-to-root contact. The water also thoroughly wets the root plugs and seeps into the surrounding soil. Operational trials have shown that large container stock can be planted at a rate of approximately 60 plants/hr (Hoag 2006).

A

Figure 7.6.24 —*The pot planter uses high-pressure water pumped from a compressor (A) through holes in a specialized nozzle (B) to create planting holes for large container stock (C).*

B

C

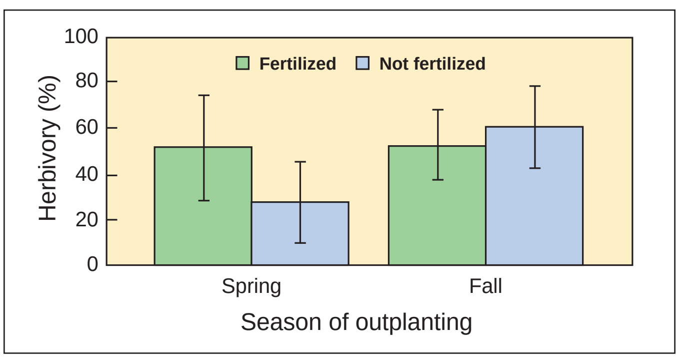
7.6.10 Treatments at Time of Planting

Depending on the site, several other treatments may be applied to plants at the time of outplanting to improve survival and growth. These solutions to potential limiting factors would have been identified during the site evaluation (see Section 7.6.1).

7.6.10.1 Protection from animal damage

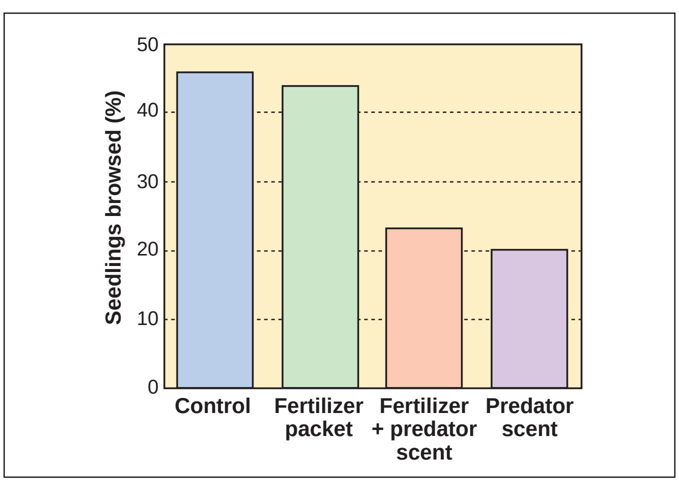
Compared with wild plants, fertilized nursery stock has higher levels of mineral nutrients and is therefore preferred browse by deer, elk, and other animals (Fredrickson 2003). Plants (especially the terminal shoots) are eaten by deer, elk, gophers, and other animals, although the rate of browsing can vary by season (Kaye 2001) (fig. 7.6.25A). If the outplanting area is known to have a problem with animal damage, then control measures may be necessary. Physical barriers installed immediately after planting, such as netting, rigid mesh tubing (fig. 7.6.25B), bud capping, and fencing, can help protect plants long enough for them to grow large enough to resist animal damage. Troy and others (2006) found that 95 percent of nonprotected oak (*Quercus* spp.) seedlings were browsed, compared with only 4 percent of those in protective shelters. Johnson and Okula (2006) concluded that browse protection increased both survival and growth of outplanted antelope bitterbrush (*Purshia tridentata*) seedlings.

A variety of solid-walled and mesh tree shelters is available, and the environment and plant response can vary considerably. Western redcedar and Oregon white oak (*Quercus garryana*) container stock was outplanted in fine-mesh fabric shelters; solid-walled white shelters with and without vent holes; and solid-walled, blue, nonvented shelters. One year after outplanting, height and diameter growth of the western redcedar were significantly increased in all shelter types, with blue solid-walled shelters resulting in the greatest height growth. In blue, solid-walled shelters, however, photosynthesis and stem diameter growth of Oregon white oak seedlings, which are less tolerant of shade, were significantly reduced compared with nonsheltered seedlings (Devine and Harrington 2008).



A

B



C

Figure 7.6.25—*Browsing damage to outplanted seedlings can be very high on some sites (A). Options for protecting plants from animal damage include plastic mesh tubing (B), or an application of predator scent repellent (C).*

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 that have an odor or taste that is repugnant to wildlife is available. Treating plants with these products can result in significant reductions in browsing (Frank 1992; MacGowan and others 2004) (fig. 7.6.25C).

7.6.10.2 Fertilization

Mineral nutrition is a key component of plant performance after outplanting, and most outplanting sites are limiting for many essential nutrients, especially nitrogen. Agriform® tablets are made of ureaformaldehyde, which provides slow release of nitrogen, as well as phosphorus, potassium, and other secondary and minor elements (Scotts 2007). Although commonly used in ornamental plantings, Agriform® tablets have yet to find wide use in forestry, conservation, or native plant outplantings.

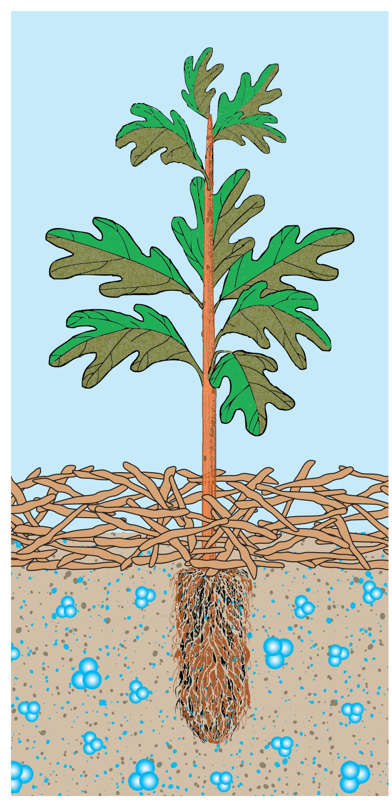
Instead, polymer-coated controlled-release fertilizers (Osmocote®, Apex®, Multicote®, Nutricote®, Diffusion®) have become the most popular method of fertilizing at the time of outplanting (Jacobs and others 2003); they feature nutrient release rates up to 18 months. Fertilizer prills are incorporated into the growing medium during sowing (Moore and Fan 2002; Haase and others 2006) or added to the bottom of the planting hole (Arnott and Burdett 1988; van den Driessche 1988). Other applications include applying the fertilizer prills in a dibbled hole alongside the plant or broadcasting it around its base. To minimize the possibility of fertilizer burn to roots and to prevent the nutrients from being "stolen" by competing vegetation, the side application makes the most sense (Landis and Dumroese 2009).

Fertilizer efficacy, however, varies with site conditions (Rose and Ketchum 2002, Everett and others 2007). On moisture-limiting sites, fertilizer salts can buildup to toxic levels, resulting in a negative effect on survival and


A


B

Figure 7.6.26—*Mulching with paper mats (A&B) or loose materials (C) can reduce competing vegetation around the planted seedling.*


C

growth (Jacobs and others 2004). For fall outplanting in Northern California, the initial growth benefits of controlled-release fertilization did not hold up over time (Fredrickson 2003). Before applying any fertilizer, it is crucial to consider the formulation, application rate, placement, solubility/release rate, and existing nutrient levels on the site.

7.6.10.3 Mulches

In addition to site prep practices that minimize effects of competing vegetation (see Section 7.6.4.5), mulching 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 (fig. 7.6.26A&B) are held in place with rocks, branches, or stakes. Mulching plants can also be accomplished with a thick layer of loose organic matter, such as corn cobs, coconut fiber, pine straw, sawdust, or bark chips (fig. 7.6.26C). In addition to inhibiting growth of competing vegetation, mulch insulates soil from temperature extremes and helps maintain soil moisture by reducing surface evaporation. Although purchase and installation of mulch materials can be costly, mulches can significantly improve plant survival and growth on droughty sites. McDonald and others (1994) found that large (3 m x 3 m [9 ft x 9 ft]), long-lasting (5 years) mulch mats effectively enabled ponderosa pine seedlings to become established on the site unimpeded by competing plants and significantly increasing height and diameter growth compared with controls. Similarly, bur oak (*Quercus macrocarpa*) and white ash (*Fraxinus americana*) had a significant positive response to mulch treatments (Truax and Gagnon 1993). On dry restoration sites, mulches can be particularly effective. Plastic mulches of only 122 cm (48 in) in diameter significantly increased soil water content and subsequent growth of Oregon white oak container seedlings; even post-planting irrigation was effective only under mulches (Devine and others 2007).

7.6.10.4 Shelters

As mentioned previously, tree shelters (fig. 7.6.27A) can protect plants from animal damage. Another important benefit is that shelters limit the intensity of UV light and drying winds that cause damage by desiccation and sun scald (fig. 7.6.27B). Engelmann spruce (*Picea engelmannii*) seedling survival increased from 58 percent to more than 95 percent when shelters were installed (Jacobs and Steinbeck 2001). Tree shelters are available in a variety of sizes and colors (allowing varying amounts of solar radiation to penetrate), as well as with or without venting. Selection of a specific shelter should be made 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

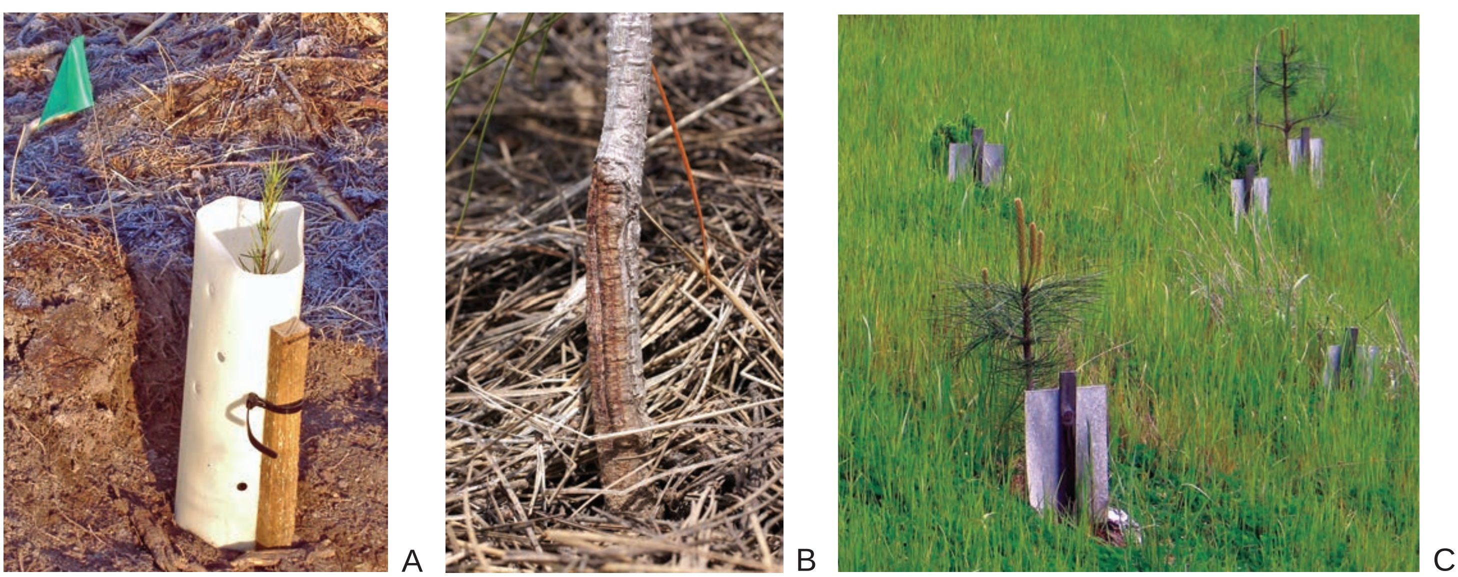


Figure 7.6.27—*Tree shelters (A) protect plants from animal damage and sunscald (B); shading is also effective against sun damage but must be installed on the southwestern side of the plant (C).*

temperatures by about 2.7 °C (5 °F) (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 should include the costs of purchase, assembly, and installation as well as annual maintenance following winter snow pack that can crush the shelters and cause plant damage. 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.

7.6.10.5 Shading

Ideally, an outplanting site provides adequate materials, such as stumps or logs, to provide microsites for planting (see Section 7.6.5.1). It is sometimes useful, however, to install artificial shade to protect plants from damaging heat. Resistance to heat damage increases with plant size because the ability of the plant to shade itself increases. Heat damage usually occurs on flat or south-facing sites in regions with hot, dry summers and clear skies, but it can also occur in wetter regions under dry, clear conditions (fig. 7.6.27B). Shading only the basal portion of the stem appears to be as effective in preventing heat damage as shading the entire stem and some foliage, which can also reduce transpiration (Helgerson 1989a). Five-year survival of Douglas-fir seedlings was increased with shading on two south-facing sites in Southwest Oregon (Helgerson 1989b). In another study, artificial shading significantly increased seedling survival on four of six harsh sites west of the Cascade Mountains (Peterson 1982). Artificial shade materials, which include cardboard, shingles, rigid shade cloth, and other materials should be installed on the south or southwest side of the seedling (fig. 7.6.27C).

7.6.10.6 Irrigation

Although irrigation is impossible on typical reforestation sites, watering after outplanting is sometimes needed on severe restoration sites and special techniques are employed. For example, on a Sonoran Desert site, honey mesquite (*Prosopis glandulosa*) seedlings were irrigated through plastic pipes to ensure that the water reached the root zone without loss to evaporation. Four years later, plants that had been deep watered had three times better survival and were significantly taller than surface-watered plants. More information on deep watering and other irrigation techniques can be found in Bainbridge (2007) and Steinfeld and others (2007).

7.6.11 Monitoring Outplanting Performance

Reforestation and restoration outplantings are an expensive investment, so it makes sense to conduct surveys to evaluate their need, monitor performance, and track outplanting success over time. Many different types of reforestation surveys have been well covered in the literature (Pearce 1990; Stein 1992); and an excellent guide on how to evaluate restoration plantings can be found in chapter 12 of Steinfeld and others (2007).

The following discussion deals with monitoring planting quality during the project. The only way to determine if planting is being done correctly is to conduct an inspection right behind the planting crew (Neumann and Landis 1995). With contract planting jobs, these inspections certify whether the work meets specifications, and the results are used to calculate payment. Prompt and thorough inspections can also lead to increased outplanting success in subsequent projects. In Texas, for example, the incidence of plantation failure was more than cut in half (from 40 percent to about 16 percent) after an inspection program was initiated (Boggus 1994).

A typical plantation inspection consists of the following three steps (Rose 1992).

Check the number and spatial distribution of 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. New technology may make this job easier. In a recent research trial, a tree-planting dibble was outfitted with an accelerometer, a Global Positioning System (GPS) unit, and a data logger to map the locations of seedlings as they were planted. Results showed that the equipment accurately (±7 percent) counted the number of seedlings planted. Although the GPS system was not sensitive enough to identify individual plants, this may be resolved with increased sensitivity of newer equipment (McDonald and others 2008).

Aboveground inspection. A representative sample of plants is examined to see if the planting spot was selected properly and to check the quality of the scalping, stem orientation, planting depth, and use of natural or artificial shade. Planting depth, which is one of the most critical things to check, is usually specified in relation to top of the root plug (fig. 7.6.28A; see Section 7.6.6.2).

Belowground inspection. A hole is dug with a planting shovel (fig. 7.6.18C) 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 (25 cm [10 in]) so that roots are not disturbed in the process of inserting the shovel. Then, gently clear soil away while digging toward the plug so that the plug can finally be inspected in the position it was planted (fig. 7.6.28B). The plug must be in a vertical plane and not twisted, compressed, or jammed and the hole should not contain large rocks, sticks, litter, cones, or other foreign debris. Soil should 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 Forest Service 2002).

7.6.11.1 What type of survey is best?

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

Circular plots. The traditional method for determining planting density is to measure 40-m² (1/100-acre) plots that are evenly distributed throughout the plantation. An adequate sample is about 2.5 plots per hectare (one plot per acre), with usually no more than 30 plots evenly distributed throughout the planted area. A 100th acre plot has a radius of 3.6 m (11 ft, 9.3 in), which is established with a center stake and a piece of string or twine cut to this length (Londo and Dicke 2006). Seedlings outplanted 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 (fig. 7.6.28C) using the examination criteria shown in figure 7.6.14.

Stake rows. Rapid weed growth makes it surprisingly hard to locate desired plants, so 10-plant stake rows are used to make plants easier to find in subsequent evaluations. Establish a starting point that can be easily located and stake 10 plants along a compass bearing. Height, diameter, and plant condition are recorded on the data form, along with average spacing between plants. Stake row data are typically used to determine survival and growth rates and, with average spacing between plants, can also be used to calculate plants per area (Londo and Dicke 2006).

A

B

Figure 7.6.28—*It is best to inspect right after the planting crew (A). Dig a vertical hole alongside the seedling (B) to check for proper depth and alignment of the root plug. Using a standard survey form (C) will ensure that the same information is collected at each plot.*

Plantation: ______________ **Date Planted:** ______________ **Inspector:** ______________

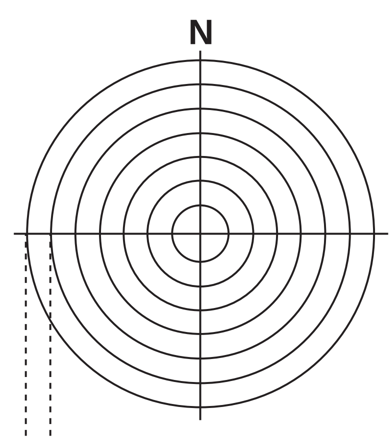
Plot Number: ______________ **Date Inspected:** ______________ **Contract Number:** ______________

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



Scale = ______________

C

7.6.11.2 What sampling design is best?

Systematic stratified sampling is often recommended, because plots are located at standard predetermined distances and are therefore easy to establish and locate again at a later time. 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, where differences in aspect, soil, and planting technique occur (Neumann and Landis 1995).

7.6.11.3 How many plots are necessary?

The number of plots to establish is generally a function of two factors: (1) available resources (time and money); 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. Using this example, if a quick check of height varies greatly within the plantation to be sampled, then more plots should be taken. On the other hand, if the heights appear to be very uniform, then fewer plots will be sufficient. If you want statistical significance, more complicated 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).

7.6.12 Conclusions and Recommendations

Outplanting is the final stage in the nursery process, and survival and growth are the ultimate tests of plant quality. The final three steps of the Target Plant Concept are critical to outplanting success and should be considered when plannning and initiating outplanting projects. Each outplanting site is unique and should be evaluated to identify critical limiting factors as well as the best season for outplanting during the planning process. The best outplanting tool and technique must also be specified during planning, because that decision will have a major effect on the best stocktype to produce. A wide variety of hand- and machine-planting options are available, but each tool or technique is best suited to particular stocktypes and outplanting site conditions. All this information is traditionally included in the site prescription which will guide the entire nursery-to-outplanting process.

Stock-handling during transport and on the planting site has a critical effect on outplanting performance. Nursery stock should be outplanted as soon as it arrives, but often a day or two of onsite storage is necessary. It is wise to plan for contingencies, such as bad weather, crew problems, or equipment breakdown. A representative sample of the nursery stock should be inspected as soon as it arrives on the planting site to identify possible problems and make adjustments. At the same time, a survey of the planting site itself should be conducted and plans made for which areas should be planted first.

Site preparation treatments, which are also part of the site prescription, will ensure that the proper supplies and equipment are available ahead of time. Plant spacing and pattern should be specified in the prescription so this critical information is part of crew training. Other treatments, such as plastic netting, tree shelters, and mulches, may need to be applied to plants at the time of outplanting to ameliorate potentially limiting site factors.

The final step in the process is to conduct surveys during and immediately after outplanting to evaluate planting, monitor plant performance, and track outplanting success over time. The best type and intensity of sampling will depend on project objectives and should be designed as part of the site prescription. Successful outplanting projects are the result of good planning and timely execution. Often, adjustments need to be made onsite but most of these contingencies can be anticipated in the site prescription.

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