Chapter 17
Proper Planting Improves Performance

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Abstract

Current procedures and guidelines, and justification for their use, are reviewed for the three major components of the planting process: environmental factors, equipment and system selection, and planting technique. Southern pines can be planted across a wide variety of weather conditions as long as seedling exposure to sun and wind, a primary factor in early mortality in plantations, is minimized. Simple planting machines and hand tools continue to be the equipment selected for virtually all planting, with choices governed by factors such as topography, soil conditions, site preparation, and costs. On sites that can be planted with either system, hand planting may be slightly less costly with fewer skipped planting spots, but may result in less uniform planting quality than machine planting. Shallow, loosely planted seedlings are the most likely to die in new plantations; however, survival or growth of seedlings whose roots are L or U shaped, but otherwise properly planted, seems relatively unaffected by root configuration. Training and supervision of planting crews are critical to preventing planting-quality problems. Contractors account for 80 to 90% of planting operations. Contracts can be written to improve planting quality and, ultimately, plantation performance, but continuous overseeing of all phases of the planting operation is crucial to assure success.

17.1 Introduction

The primary goal of the planting operation is to place seedlings into the ground in a manner that will optimize survival, growth, and stability. Methods employed in that operation will depend on the types and conditions of available seedlings, seedling handling practices, soil and site characteristics, and the intensity of site preparation, all described in previous chapters in this volume. Costs and production rates also influence operational decisions in that both landowners and tree planters seek to optimize income and costs as well as plantation performance. Successful planting requires a clear understanding of the effects of different planting practices and adherence to appropriate guidelines related to those practices.

This chapter reviews the three major components of the planting process: environmental factors, equipment and system selection, and planting technique. For each component, effects on regeneration success, current practices and their limitations, and appropriate management guidelines are discussed. Many organizations have recently developed planting guidelines for their operations. This chapter focuses on the justification and need for those guidelines, leaving it up to the reader to obtain copies of relevant brochures, reports, or manuals from local agencies or organizations.

Emphasis is on bareroot loblolly (*Pinus taeda* L.) and slash (*P. elliottii* Engelm.) pines because they represent approximately 90% of the planted seedlings in the South [5]. Guidelines for other species and stock types will be described where they differ substantially from those for loblolly and slash pines. Specific planting methods for container seedlings are also discussed in chapter 7, this volume.

17.2 Environmental Factors

Planting season, planting weather, and soil conditions are the primary environmental factors to be considered. Seedling response to each of these is a function of the physiological condition (especially level of dormancy) and morphology of the tree (see chapter 8). These two seedling characteristics are influenced by nursery practices such as irrigation, fertilization, and lifting date (see chapters 6 and 7) and by handling and storage conditions before and during planting (see chapter 16).

17.2.1 Planting Season

17.2.1.1 General considerations

The planting season for southern pines has traditionally been November through March, with extensions at both ends of this period under varying circumstances. Two major factors influence planting timing: (1) seedlings should be lifted at the nursery while they are most dormant, but while there is sufficient time for the nursery beds to be

M.L. Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 303–320.

prepared for the following crop; and (2) seedlings should be planted early enough for good root growth before budbreak and the onset of droughty conditions in the spring and summer. Planting timing is further limited by the fact that storing seedlings for more than 4 weeks is generally possible only with seedlings lifted between December and February, depending on nursery location and local weather (see chapters 6, 7, and 16, this volume).

Various advantages and disadvantages accompany planting at different times of the year. Planting early in the season (October to December) assures that all seedlings will be in the ground at a reasonable time, and that access will be possible before midwinter high water tables on wet sites. Provided that soil moisture is adequate at the time of planting, and that subsequent growing conditions are favorable, early planting may also result in more first-year growth than later planting [4]. On the other hand, seedlings planted early may face the risk of desiccation, or frost heaving in clay soils, when midwinter weather systems bring clear, cold air, or of drowning when water tables are high on poorly drained sites. Seedlings lifted from October to December generally are less resistant to cold and drought stress than those lifted later in the season.

When seedlings are lifted in January or February they are usually at the peak of dormancy, with maximum resistance to stress caused by handling, storing, and site conditions, and with the greatest root-growth potential. Planting freshly lifted seedlings during this period offers the highest likelihood of seedling survival in most of the southern states. Lifting seedlings at this time and storing them for later planting optimize survival as one moves further north.

Planting late in the season (March to May) avoids winter site and weather problems, but carries the risk of planting trees which are coming out of dormancy or have already started to grow. Root growth before budbreak may be inadequate for seedling survival during dry weather in the spring.

In a generalized diagram based on information from a number of different sources, South and Mexal [33] showed the optimum planting season to be between late December and mid-March (Fig. 17.1). The shape of these curves was originally demonstrated by Wakeley [41] for the four major southern pines with the decrease in survival for spring planting much more distinct than for fall planting (see chapter 16, Fig. 16.9).

These trends have since been supported by a number of other studies. In 1974 and 1978, Weyerhaeuser Company installed lift and planting date tests in Arkansas and Alabama [25, 26]. Survival of loblolly pine lifted and planted in October or early November was as much as 20 to 30% lower than that of trees lifted and planted later in the season. In addition, trees lifted early and stored for 8 weeks had much lower survival rates than trees not stored. In one of the studies [26], trees lifted in March and planted in April also had poor survival, indicating that seedlings had passed the period of hardiness and storability when they were lifted.

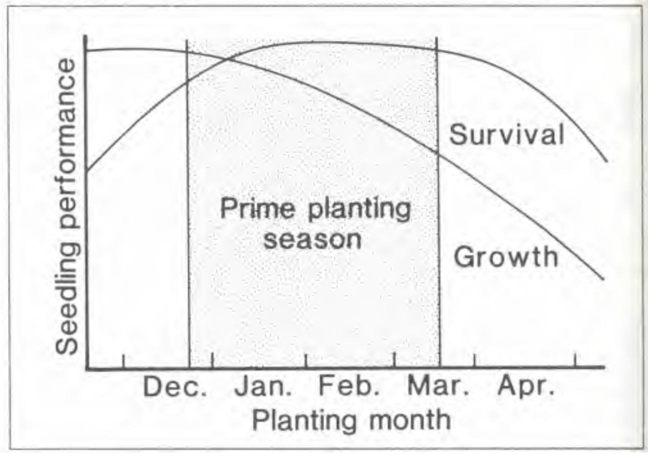

Figure 17.1. Generalized relationship between planting date and subsequent performance of bareroot seedlings (adapted from South and Mexal [33]).

In another series of tests, loblolly pine were planted in Louisiana on different dates during the 1978-79 and 1979-80 planting seasons [39, 40]. Second-year survival in both tests was strongly influenced by a prolonged dry period in the middle of 1980, but still demonstrated lower survival rates of seedlings planted early or late in the planting season compared to other times (Table 17.1). These tests also confirmed that the ideal season may vary from one year to another depending on hardiness of the seedlings at the nursery and post-planting weather conditions.

17.2.1.2 Current guidelines and modifications

Most recommendations for time of planting now concentrate on the period between mid-December and early March, with modifications based on latitude, site, and operational considerations. Generally, the earliest lifting and planting dates are delayed until after the first freeze or until there have been sufficient chilling hours at the nursery. At the more southern latitudes, the uncertainty of this date leads many landowners to begin planting in November if soil moisture is adequate, with special precautions to be sure that seedlings are planted within 2 to

Table 17.1. Effect of planting date on survival of 1 + 0 loblolly pine seedlings planted in Louisiana (adapted from Venator [39], Venator and Barnett [40]).

	Field survival, %, in		
	1978–79 test		1979–80 test
Planting date	Year 1	Year 2	Year 2
October	42	27	–
November	68	23	–
December	69	32	80
January	71	40	56
February	81	42	48
March	79	51	38
April	75	43	–

3 days of lifting. In Oklahoma and Arkansas, one recommendation has been for fewer than 7 days' storage if seedlings are lifted in November and fewer than 2 weeks if lifted in December [26]. After December, seedlings may be stored up to 12 weeks if buds are not swollen because of midwinter warm weather. These interactions between lifting date and storage are especially critical at the more southern latitudes where the "lifting window" at the nurseries may be restricted to January and February, the period of greatest seedling dormancy. Lifting and handling seedlings outside this window require great care and minimum storage [49].

Planting is increasingly delayed into late winter or early spring as latitude increases. For example, most planting in Virginia is done between mid-February and April because of frozen ground at nurseries and field sites earlier in the season and to avoid midwinter desiccation after planting. One recommendation, based on 8 years of tests, suggested that planting north of latitude 33° (approximately a line between Charleston, South Carolina, and Dallas, Texas) should be done in March and April, with cold-stored seedlings lifted in January and February [37].

Local site and operational conditions may also require general planting-season guidelines to be modified. For example, one industrial landowner in the Lower Coastal Plain of Georgia and South Carolina plants between late October or early November and early January to be able to use planting machines on sites which have standing water later in the winter. Beds on such sites must be sufficiently high to prevent submersion of the roots of freshly planted seedlings once the water table rises. If this cannot be guaranteed, planting probably should be delayed until after water tables recede [2]. Such early-season planting depends, of course, on timely lifting schedules at local nurseries.

Other sites planted early should be those with the best drainage or those likely to dry out first in spring [49]. Roots of trees on such sites have a longer time to grow before spring drying than do those of seedlings scheduled for later planting. Sites prone to midwinter exposure and desiccation should be planted later when seedlings are more stress resistant.

17.2.1.3 Other planting-season considerations

Besides seedling dormancy and storability, and the need to plant seedlings well before the onset of dry weather in the spring, the size of a landowner's regeneration program relative to planting-system capacity and availability of contractors may influence the timing of planting. A large program with a limited supply of planting crews or machines may require planting during as long a season as possible. This will necessitate extra care in seedling handling and sequencing of planting sites, according to the principles described in this chapter. On the other hand, a small program with ready access to contractors will allow planting during the optimum months of January and February (or later in more northern states).

Container (or plug) seedlings have traditionally been viewed as a source of planting stock for summer and fall planting, when soil moisture and site conditions are favorable. However, planting plugs at that time is still largely experimental because of uncertainties about post-planting soil and weather conditions and the need for nursery schedules that produce seedlings which have set buds and whose roots are growing in midsummer. Recent, but limited, experience with longleaf pine *(P. palustris* Mill.) in Florida and North Carolina suggests that planting with plugs may be feasible in late summer after summer rains have started. Adding mycorrhizae to containers used in North Carolina has also apparently aided seedling survival. Elsewhere, container seedlings have been tested for summer planting on sites with high water tables during winter.

17.2.2 Planting Weather

17.2.2.1 Classification

Weather at the time of, and immediately after, planting can significantly affect survival, especially if seedlings are not properly handled or planted. Weather conditions must be observed and regularly monitored to be sure that they are favorable for subsequent seedling performance. Most critical for judging those conditions is their impact on seedling moisture loss, which is a function of temperature, vapor pressure deficit (relative humidity), and wind speed.

In a number of different tests, Wakeley [41] observed planting conditions ranging from sunny, dry periods to rain and found no consistent effects of weather on survival. He concluded that the southern pines can be planted within a wide range of conditions without significant mortality, although situations such as below- freezing temperatures or frozen soil may substantially decrease survival. However, other comparisons of planting weather generally are lacking in the literature.

Several southern states currently classify planting weather into normal, marginal and critical categories [1, 7, 8, 29, 38]; marginal, and critical are called critical and severe, respectively, by some organizations. Following are temperature, relative humidity, and wind limitations for each of the three categories:

	Temperature,		Relative humidity,	Wind speed,	
	°C	°F	%	kph	mph
Normal	1–23	33–75	> 50	< 16	< 10
Marginal	24–29	76–85	30–50	16–24	10–15
Critical	< 0 or > 29	< 32 or > 85	< 30	> 24	> 15

Temperature and relative humidity can easily be measured with a sling psychrometer with wet- and dry-bulb thermometers, and a conversion table that provides relative humidity as a function of wet- and dry-bulb temperatures. Sustained wind speed (not just occasional gusts) can also be quickly measured with low-cost wind gauges. Planting weather for a given day is generally classified according to the lowest rating for the three parameters described above. For example, if the temperature was 20°C but relative humidity only 40%, planting weather would be classified as marginal. In using this classification it is important to remember that, at a specified relative humidity (e.g., 60%), the vapor pressure deficit of the air increases with increasing temperature [10]. Thus, the same relative humidity at 10 and 20°C will dry out seedlings much faster at the higher temperature. Use of this classification system calls for careful judgment, especially when weather conditions are near classification boundaries.

17.2.2.2 Planting guidelines

For those organizations that use the weather classification described in 17.2.2.1, planting guidelines and precautions are increasingly restrictive for marginal and critical categories. In general, if the guidelines are followed, planting can be safely done on normal days, is still allowed on marginal days (but greater care in seedling handling is necessary), but should be suspended on critical days. One reasonable exception to these general guidelines is on days on which wind speed is considered critical but temperature is low and relative humidity high (cold, rainy days). Under such conditions planting could proceed, at least on sites where clay soils would not be compacted by tractors pulling planting machines. Similarly, at temperatures near freezing but still considered normal by the guidelines, low (critical) relative humidities actually represent a very low air vapor pressure deficit and, therefore, little moisture demand on seedlings.

Specific guidelines for lifting, handling, storage, and planting under each of these classifications can be found in the planting guidelines provided by the different organizations that use them [1, 7, 8, 29, 38]. A summary of some of the more important guidelines for planting follows.

On normal days:

(1) If roots are not already coated with a clay slurry or other moisture retardant, they should be dipped (but not left standing) in water as soon as they are removed from packing bags and before being placed in planting bags, buckets, or boxes on machines; all carrying devices for seedlings should provide root protection in the form of wet sawdust, peat moss, burlap, or a small amount of water.

(2) Planters should not carry extra seedlings in their hands. Roots rapidly dry out when seedlings are exposed to sun and wind during planting, culling, or root pruning. Such exposure should be limited to < 5 minutes, although a 1-minute limit is probably better, except on rainy days. Roots should be kept visibly moist at all times.

(3) Seedlings should be quickly, but carefully, separated to reduce both drying and breaking of roots.

(4) No more than a 2-hour supply of seedlings should be carried by tree planters or on tree planting machines.

On marginal days, all standards for normal days must be very carefully followed. In addition:

(1) Seedling shoots should be dipped in water before being placed in planting bags or boxes to reduce transpiration before planting.

(2) Seedling exposure to sun and wind should be <3 minutes, and preferably < 1 minute.

(3) Only a 1-hour supply of seedlings should be carried on machines or by planters.

(4) Planting on dry ridges, or with bareroot longleaf pine, should be suspended.

(5) Planting should be postponed if temperatures that will freeze the ground are forecast for several days immediately after planting.

Only if localized exceptions to weather and soil conditions exist can planting proceed on critical days. Decisions regarding these exceptions should be the responsibility of landowners or their representatives. If a planting contract includes clauses that guarantee certain levels of survival, then the contractor should also be involved in the decision. For example, one exception would be freezing temperatures early in the morning with a forecast of warming during the day. Planting is permissible once temperatures reach 1 °C. Another exception might be container seedlings planted during summer. In such cases, even though temperatures will often be in the critical category, planting may proceed carefully if relative humidity and soil moisture are high and seedlings are well protected.

17.2.3 Soil Conditions

Many aspects of soil effects on regeneration and planting are discussed elsewhere in this book (see chapter 10). The major concerns here are soil conditions that influence the decision about when to plant. Soil water — either "available moisture" or the level of the water table — is the most important of those conditions. Dry soils at the time of planting or during the first growing season are more often related to mortality in planted pines than any other broad soil condition [49] except perhaps water-logged soils. Mortality in young plantations is most likely during the first spring and summer after planting, when root development is minimal, especially on seedlings planted close to the time of budbreak. Other causes of mortality, such as shallow planting or poor soil packing around roots, are also related to soil water because they reduce the ability of roots to access it. On the other hand, if water is available to roots throughout the summer, where roots are located in the soil profile may be of little consequence.

Like planting weather (see 17.2.2.1), available soil water is classified as normal, marginal, and critical as follows:

	Available soil water, % of field capacity
Normal	75–100
Marginal	50–75
Critical	< 50 or > 100

As with temperature, humidity, and wind, all planting operations should be stopped when soil water conditions are critical. Planting should also be suspended if available soil water is approaching 50% of field capacity (marginal) and weather forecasts do not indicate precipitation in the near future.

In addition, seedlings should never be planted when soils are frozen because air spaces will remain around the roots after planting, and roots and stems may be damaged when frozen particles are packed against them. Planting on sites with > 5 cm of snow should also be avoided because microsite and soil conditions at each potential planting spot cannot be identified. On sites with high or perched water tables, planting should be delayed until soils dry and water tables recede. In a recent study in Arkansas, seedlings planted in February on a site with a perched water table had only 15% survival, compared to 99% for seedlings planted in May [50].

17.3 Equipment and System Selection

Southern pines are planted with a variety of tools, ranging from hand-held dibble bars to semiautomatic planting machines that selectively place seedlings in the ground. In reality, over 95% of the seedlings are planted with only a few of the most basic machines and hand tools. The equipment selected varies by site conditions, topography, costs, labor and equipment availability, and personal preference. Before describing the more common equipment and guidelines for proper use, I review some of the past and current trends in planting methods, with an emphasis on comparisons of machine and hand planting systems.

17.3.1 General Comparisons of Machine and Hand Planting Systems

17.3.1.1 Historical perspective

Tree planting in the South began in the late 1920s with several thousand hectares annually. It expanded to nearly 80,000 ha by 1940, dropped to very small areas during the Second World War, then climbed to a peak of 650,000 ha in 1959-60 [45]. In the last 10 years, annual planting has averaged around 700,000 ha.

Before 1946, virtually all planting was done by hand. The development and improvement of planting machines and tractors after 1945 encouraged the use of mechanical systems, especially on cutover longleaf pine land [41] and on the old fields and abandoned farmlands that characterized planting in the Soil Bank program of the late 1950s. In the last 20 to 25 years, machines have also been widely used wherever intensive site preparation has involved mechanical operations such as land clearing, harrowing, and bedding.

17.3.1.2 Current uses and trends

Mechanical planting systems still predominate in some areas of the South, and the Conservation Reserve Program is providing a new source of ground appropriate for their use. Machine planting is primarily used on sites with gentle slopes (< 15%) and where surface debris will not result in a poor planting job with a high rate of skips. It is most efficient on large areas where the cost of moving equipment can be spread over many hectares, and least expensive on flat, clean sites where small machines and tractors can be used. On the Lower Coastal Plain, especially on sandy soils and beds on other light-textured soils, machines are used for at least 70% of the planting on forest industry land [18]; some landowners use machines on at least 90 to 95% of their new plantations.

Other opportunities for the continued use of planting machines include: harvested areas that were originally machine planted on old agricultural land, many of which are at, or approaching, rotation age; areas planted with either bareroot or container longleaf pine; and less intensively prepared sites on which a V-blade mounted on the front of the tractor is used to move debris out of the path of the planter [44].

Hand tools are generally used for planting on steep slopes, broken topography, and sites where heavy residual vegetation or debris are not removed with mechanical site preparation or burning. They are also desirable on flat bedded sites where water tables and heavy clay or organic soils restrict tractor mobility, on portions of machine-planted units with incomplete site preparation or difficult maneuvering for machines, and on small plantations where the cost of moving heavy equipment to the site is expensive.

Over the last 5 to 10 years, the general trend has been away from machine planting and toward more hand planting. Many regeneration units have been on cutover sites with steep or rough terrain where heavy equipment operations are both difficult and costly. On these and other sites, mechanical site preparation and planting programs have been reduced because of rising equipment costs. Herbicides are also replacing mechanical site-preparation treatments in some areas, leaving residual vegetative material that creates access and safety problems for small planting machines. Safety concerns, high insurance costs, and accident rates have increasingly limited the use of small open planting machines to only old field and debris-free planting sites. High purchase cost for large planting machines and reduced availability of maintenance service and parts supply for other types of machines have strengthened this trend. Finally, there has been a significant increase in availability and quality of hand planting crews, creating the opportunity to plant many areas by hand that might previously have been done with machines.

17.3.1.3 Productivity and quality

Productivity rates (trees planted per day per crew member) will almost always be considerably higher for machines than hand planters on a site that can support either method. They will also be higher on old fields than on cutover sites. Estimates of daily production for machine crews generally average from 8,000 to 12,000 trees, with the highest rates on open, debris-free sites. Considering that most machine crews have two people, daily production under average conditions would probably be 4,000 to 6,000 trees per person. In comparison, most hand planters average 800 to 2,000 trees per day, although some contractors claim daily rates as high as 3,000 trees per person under the very best conditions. However, the higher rates are probably accompanied by less attention to planting quality.

Despite these large differences in production rates, the actual cost per hectare has, in recent years, been very similar for machine and hand planting systems across the South [12, 43]. In fact, on sites where both systems could be used and where hand planting contractors are available, hand planting will often cost slightly less than machine planting.

In addition to cost, planting quality has been an important point of concern, although quality is often more a function of site conditions than the system selected. Despite an abundance of experience and anecdotal information, few definitive studies have compared machine and hand systems. Wakeley [41] summarized a number of early studies by stating that survival with machine planting should be as good as, or better than, that with hand planting, provided that seedlings are set at the right depth. In the early years of machine planting, there was considerable concern that survival rates would be lower with machine than with hand planting; in the last 10 to 15 years, however, the concern seems to have been the reverse, although full-time forestry services contract crews are changing that situation.

In a more recent comparison of machine and hand planting of sand pine *[P. clausa* (Chapm. ex Engelm) Vasey ex Sarg.], where both types of planting were done by the same person, seedling survival rates were 20% lower with hand than machine planting [24]. However, Xydias et al.

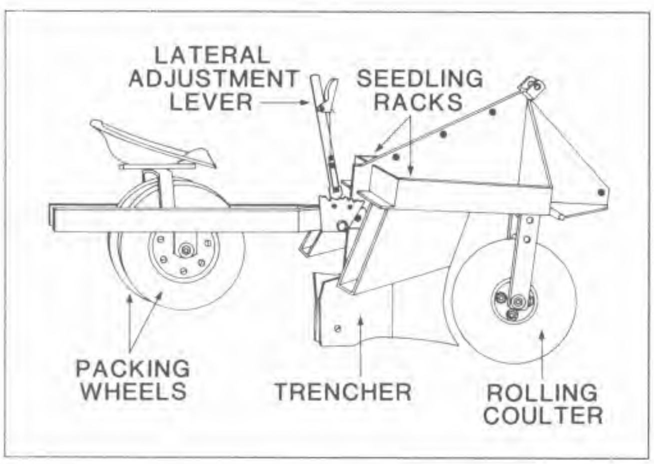

Figure 17.2. Simple, continuous-furrow, mechanical tree planter, attached to a farm tractor through a 3-point hitch. Seedlings carried in the racks are manually placed in the planting slit by the operator (adapted from Slusher [32]).

[49] observed that hand and machine planting on similar sites usually results in the same survival for slash pine. Current experience tends to favor the opinion that survival rates will be slightly higher with machines, perhaps because of more uniformity in the depth of the planting hole, seedling placement, and soil packing [33]. Those slightly higher rates may be offset by the greater percentage of skipped planting spots with machine planters; skips can average 10% and range as high as 20 to 30% on some units [9, 44, 47].

Site conditions, in conjunction with planting method, can also affect planting quality — for example, where seedlings are planted by machine on heavy clay soils, especially when ripping or subsoiling precedes planting. During dry weather, clays may shrink and crack, creating fissures that follow the line created by the coulter on the planting machine. High seedling mortality is common in such situations.

17.3.2 Planting Machines

17.3.2.1 Types of equipment

Virtually all machines must be pulled by a prime mover (such as a farm tractor, skidder, or bulldozer), whose size depends on the size and weight of the planting machine and the site conditions. The prime mover may be attached through a 3-point hitch, which allows it to hydraulically lift the planter off the ground for transport or maneuvering, or a tow-type hitch, through which it may support some of the weight of the planter depending on the arrangement of axles and wheels under the planter [32]. Axle structures which support planters may also be equipped with hydraulic systems to raise and lower the planter.

Planting machines and operators perform the same three functions as a person hand planting a tree: they create an opening in the soil, insert the seedling, and pack soil around the root system. Designs for carrying out these functions vary widely, and site conditions and economics are the major factors influencing equipment selection.

In the simplest form (Fig. 17.2), planting machines include a rolling coulter which opens a continuous furrow for planting, a trencher which spreads the soil and provides space for the tree to be placed in the slit, and packing wheels for closing the furrow and firming the soil around the seedling. The coulter slices through debris and old roots and helps the planter to roll over rocks and logs. An operator riding on the planter manually places the seedling into the slit in the middle of the trencher and provides much of the weight for the packing function. Adjustments on the machine or hitch control the depth of the coulter and the orientation of the packing wheels. These lightweight (200 to 500 kg) manual planters, generally pulled by farm tractors or small, tracked machines, are used in old fields or on clean sites. Sites must be free of brush and litter, which could injure the machine operator. On very heavy clay soils or old fields with shallow plow pans, these machines may have difficulty maintaining the right depth for planting and

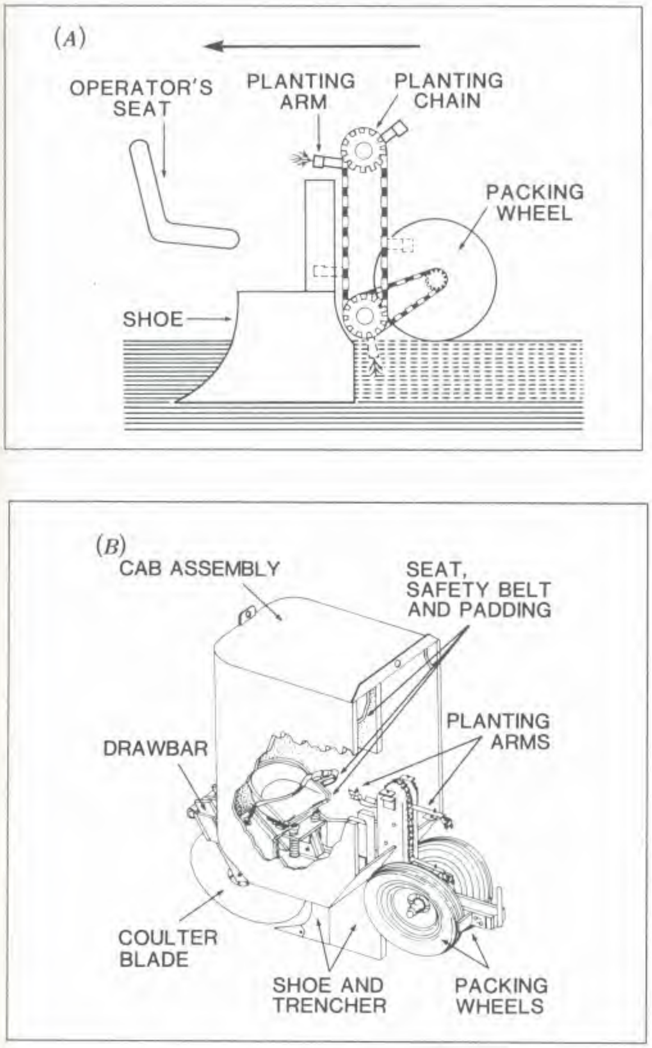

Figure 17.3. Continuous-furrow mechanical tree planter, with (A) a semiautomatic device which sets seedlings in the planting slit after the operator has placed them in the fingers of the device, and (B) a cab assembly for safety. (Design by Whitfield Manufacturing Co.)

enough pressure for packing unless additional weight is added over the coulter and/or trencher or a ripper is used before planting.

The seedling placement function on some machines is handled by a semiautomatic device which requires only that the operator place the seedling in a rotating set of rubber "fingers" or "hands" rather than stooping to place the tree directly in the ground (Fig. 17.3A). The fingers hold the seedling stem just until soil begins to pack around the roots immediately behind the trencher. The speed of the rotating mechanism is generally controlled through a chain drive or other linkage between the device and the packing wheels or coulter. Although this semiautomatic system does not significantly alter the rate of planting, it is substantially easier for operators because they do not have to continually stoop over. These machines usually are 300 to 400 kg heavier and have a purchase cost several thousand dollars higher than the standard manual models described previously. Because of the additional weight, they may be used on heavier soils than manual equipment but, without additional safety protection, are usually limited to very clean sites.

Both manual and semiautomatic models are available with cab structures (Fig. 17.3B) and other safety features which allow them to be used on sites with debris or standing brush. Depending on design modifications and materials, these safety features may add 100 to 300 kg or more in weight and $200 to $800 in purchase cost. Additional weight can be added to most machines, primarily over the coulter but also over packing wheels, to facilitate planting in heavier soils or cutting through debris. As planting machines become larger and heavier, they require larger prime movers to pull them, increasing planting costs.

The largest continuous-furrow planting machines currently in use weigh 1500 to 2500 kg and include safety cabs, storage compartments for seedlings, and crank axle systems for transporting the planter. Coulters and packing wheels are usually larger and heavier than on smaller models. These machines can be operated on a wide variety of soils, including rocky soils and heavy, wet clays, and under various site-preparation conditions. With heavy, wet clays, caution must be exercised to avoid soil damage caused by the large prime movers. Large planting machines may also be useful on abandoned agricultural land where shallow plow pans cannot be penetrated by small machines, coulters, or hand tools. Ripping soils before planting should be considered on such sites.

On sites with debris, rocks, or stumps, machine planting could be facilitated if planting holes were created intermittently at favorable spots rather than as a continuous furrow. Several machines, designed and built in the last decade, have this capability [34]. In principle, most of the machines operate similarly. The operator places a seedling in a dibble or planting foot which, when actuated hydraulically, is driven into the ground in a spot or short furrow. The seedling is released at the correct depth, and packing wheels are lowered to firm the soil. On some models, packing wheels are continuously in contact with the ground. Although such machines are designed to automate the hand planting procedure, their high purchase price makes them uncompetitive with hand planting on the types of sites (little or no site preparation) where they would be most useful. On sites more intensively prepared, continuous-furrow machines are more economical than intermittent planters because of the lower purchase price of the former.

Planting machines or their prime movers can be equipped with additional implements to enhance planting or complete other silvicultural operations at the same time as planting. V-blades mounted on the front of tractors pulling planters may be used for site preparation and debris clearing directly before planting. This procedure is increasingly being used in the South [44] for sites which previously received herbicide applications or had no site preparation. Sod scalpers, usually mounted on the planting machine, are used to plant seedlings in mineral soil on sites with a heavy grass cover. Use of both V-blades and sod scalpers should be carefully supervised to avoid displacement of top soil from the planting row. Spray booms may also be mounted on the front or back of either the tractor or planter for applying herbicides on both sides or over the top of the planting row.

17.3.2.2 Operating logistics

Nearly all planting on nonindustrial and public forestland is done by contractors. In the early 1960s, 70% of the planting by the forest products industry was conducted with company crews; this decreased to < 40% by 1978 [44]. Recent information suggests that contractors now account for 95% of the hand planting and 86% of the machine planting in the South [43]. (See 17.5, this chapter, for some important aspects of contracting for planting.)

Machine planting obviously requires operators for both the prime mover and planter. Many crews will also have a third person who does one or more of the following: handles seedlings at roadside and supplies them to the planter; checks on planting quality; replants errors or plants skips; and trades jobs with the planter operator to reduce boredom and physical fatigue. If a planting operation includes more than one machine, the third person may cover these functions for two or more planters. Having more than one planting machine operating on a given site also means that the second prime mover can be used for assistance when the other planting machine (primarily the coulter) becomes stuck in a stump or there is other mechanical breakdown. Lightweight planting machines are especially prone to being lodged in stumps when the stumps are buried in beds.

Quality control is as critical with machine as with hand planting. Although machines may be expected to plant seedlings with considerable uniformity, planting quality will only be acceptable if factors such as depth, firmness, and root straightness are correct. These factors must be constantly checked by the contractor, landowner, or both. Such monitoring is most important when there are changes in slope, soil texture, moisture, or amount of litter and debris on the planting site. Adjustments to the machine to accommodate these changes may include adding or removing extra weight placed over the coulter, vertical alignment of the coulter, trencher, and packing wheels, and angles of the packing wheels. Packing wheels are available as inflatable rubber, solid rubber, and solid metal, depending on the amount of weight needed. Larger or smaller coulters can be used as needed. For example, it is generally recommended that the depth of the planting slit be at least 25 to 30 cm for longleaf pine, slightly deeper than for most other species. Coulters must be changed if an old one is too worn to maintain proper depth.

Correct spacing between and within rows must also be maintained (for more information on spacing, see chapter 15, this volume). Creation of beds during site preparation will help spacing, at least between rows. Otherwise, this spacing will depend on the tractor operator's judgment or use of various marking devices attached to the equipment. Spacing within rows is most uniform with semiautomatic planters because planting rate is directly linked to the packing wheels. For manual planters, spacing will again depend on the planter operator's judgment and rhythm or on bells or other devices mounted on tractor wheels. The tractor must be able to pull steadily at slow speeds to give the planter operator sufficient time to place the seedling in the ground at a uniform rate and to avoid skips. Additional suggestions for correcting planting problems and regular maintenance of planting machines can be found in Slusher [32] and Balmer and Williston [3].

As with any forestry equipment operations, safety is of utmost concern with planting machines. The importance of cab structures for preventing debris and brush from hitting the planter operator has already been discussed. Other equipment safety features should include a rearview mirror for the tractor operator and/or a bell, horn, or earphone system for communication between the tractor and planter operators. Planter operators should not wear loose clothing that might get caught in moving parts, should wear eye protection, and should be careful with their hands near the packing wheels. Tractor operators must be cautious in making turns to avoid tipping the planting machine with the wheels of the tractor.

17.3.2.3 Guidelines

As mentioned previously, guidelines for planting are available in a variety of forms from many different public and private forestry organizations [1, 7, 8, 29, 38]. Following is a summary of some of the more important ones.

(1) All planter operators and checkers should receive training at the beginning of the planting season for technique and quality. Monitoring planting quality should be more intense early in the season so that problems can be corrected before they become set patterns.

(2) Seedlings stored and carried on the planter must be protected from desiccation. Roots should be kept moist, and seedlings should be covered with wet material such as burlap. Ideally, the operator should take only one seedling at a time from the seedling storage trays although, in practice, this may not be possible because of the speed of the planter. Under normal weather conditions, the planter may be able to take 5 to 10 trees from the tray at a time; however, under marginal conditions, the planter should take no more than 5.

(3) The furrow must be deep enough to place seedlings in it without curling, twisting, or balling the roots. Coulters should be replaced when periodic checking indicates they are too worn to maintain proper furrow depth.

(4) When planting with manual machines, the operator should place a seedling at the proper depth in the

Table 17.2. Dimensions of common hand-planting tools.

Tool	Length, cm		Blade width, cm	Blade (top) thickness, cm	Weight, kg
	Blade	Total			
OST bar	23–27	94	8	2–3	3.6–4.1
KBC bar	28–36	105	8–10	3	4.5–5.5
Hoedad	38–44	91	10	–	2.9–3.4
Plughoe	33–38	91	8	–	2.7

middle of the trench and hold it until soil falls back around the roots. Alternatively, the operator should place the seedling deeper than normal, then lift it to the right depth to straighten the roots as soils close on them. The operator's hand should move backward with the seedling to keep the tree in one position to avoid dragging it through the soil. Each seedling should be checked for firmness by gently tugging upward on the needles as the packing wheels begin to close the furrow on the roots.

(5) Planting on slopes > 5% should be done on the contour if at all possible to avoid creating potential erosion channels with the tractor or along the furrow.

17.3.3 Hand Tools

17.3.3.1 Types of equipment

Two general types of hand-held tools are used for most hand planting in the South: the dibble bar and hoedad (Fig. 17.4). Dibble bars (planting bars, planting dibbles), used in some form since the early days of planting, are basically a straight metal shaft about 70 cm (27 in.) long, with a welded or formed metal handle and a shaped blade with a step plate [19]. The Old Standard (OST) bar has a wedge-shaped blade that is uniformly wide and tapers to a straight edge at the bottom (Table 17.2). Though widely used on most soils, it may require more than one shove to penetrate heavy clay or rocky soils to the proper depth. For such conditions, the KBC bar may be more effective with its pointed blade, triangular cross section and extra weight. Planting bars are suitable for use with most bareroot and containerized seedlings, except those with large root systems. They can be easily maneuvered in slash and brush, but mineral soil should be fairly accessible because planting bars are not practical for scalping litter and debris from the planting spot. In creating the planting hole, the operator can basically stand in an upright rather than stooped position.

In contrast, a planter must stoop to create a hole with the hoedad because the blade is nearly perpendicular to the handle. Widely used on steep slopes in the West, this tool is increasingly being used in the South, especially by contract crews who plant in different parts of the country. Planting on flat ground may be facilitated by a bracket which connects handle and blade at greater than a right angle (Fig. 17.4). With either version of the tool, special care is necessary to obtain a vertical, rather than slanted, planting hole. Blades are rounded at the end and straight or curved

Figure 17.4. Hand tools commonly used for planting in the South: (from left to right) hoedad with concave blade and regular bracket, cylindrical dibble for container seedlings, KBC dibble bar, double planting bag with belt, OST dibble bar, long-handled planting shovel, and hoedad with flat blade and Earp bracket. (Tools provided for photograph courtesy of Forestry Suppliers Inc.)

slightly in both length and width. Hoedads can be used for scalping planting spots, but their use is limited in heavy brush and slash where they cannot be swung freely. They work well on rootbound sites and a variety of soils, including heavy clays; however, they may be difficult on rocky soils. Hoedads create a larger planting hole than dibble bars because of their longer, wider blades. A narrow version of this tool, the plughoe, is available for planting container seedlings.

Shovels of various sizes are a third major hand tool in some parts of the South, especially in Oklahoma and Arkansas. They are most practical for deep, loose soils, soils that have been ripped, heavy slash and brush, and planting quality inspection. Shovels should be the only hand tool used for planting seedlings with large root systems, but the large planting hole they create is well suited for any seedling size.

Most other tools available for hand planting are only for special situations [19]. Mattocks, or hazel hoes, were commonly used in the past; they have a shorter, broader blade than the hoedad, but otherwise function similarly. Planting dibbles with cylindrical blades (Fig. 17.4) are frequently used for planting container seedlings and work well when the blade dimensions are nearly the same as those of the root plug so that the planting hole needs only minimum filling. They are best on light or rocky soils; on heavy clay soils, compaction and glazing of the hole wall may impede root development. Several other hand-held tools allow the tree planter to create a hole and place the seedling in it without stooping over [19]; most are for container seedlings but at least one can supposedly be used with bareroot seedlings. None are operationally employed for planting in the South.

Augers are occasionally utilized for research planting and for some operational planting on rocky soils. Lacking the simplicity of a planting bar or hoedad, augers probably will never be widely adopted, although the cost of planting can be comparable with that of other hand systems on stony sites [14].

Equipment for carrying seedlings during the planting operation is critically important to keep seedlings from becoming desiccated. Various types of trays and bags have been used in the past. Trays provide less protection for the whole seedling than most types of bags, but have been convenient where two people work together planting. Bags belted around the waist are currently most common and provide adequate protection to both seedling stems and roots, if the seedlings are moist before being placed in the bags.

Few studies have been done to compare the production rates and subsequent performance of seedlings planted with different hand tools. Trees planted with dibble bars or mattocks in the 1920s showed no differences in size at age 30 [42]. With little additional information, most decisions on tool selection are based on personal preference and the types of site conditions for which each tool may be more or less practical.

17.3.3.2 Operating logistics

Unlike machine planting, hand planting can be done under all types of site conditions. Although intensive site preparation treatments often facilitate machine planting, they also generally improve hand planting operations. For example, a number of industrial landowners in the Lower Coastal Plain prefer local hand-planting crews on bedded sites because of both lower per-hectare costs and greater accessibility during the winter when water tables are high. Moreover, on bedded sites, planting crew members do not have to concentrate on staying in line and on spacing between rows, only on spacing within rows.

Hand planting can also be facilitated by preplanting ripping of soils which are very stony or compacted, or which have a shallow pan layer. Not only will ripping make planting easier, but it should also encourage earlier, faster tree growth. Soil should be ripped when it is sufficiently dry to fracture, with ample time for the slit to refill before planting.

Most hand-planting crews are organized with 8 to 12 people, although some crews may be much larger, especially on flat, bedded sites. Each crew should have a nonplanting crew leader or foreman who is responsible for maintaining quality procedures for seedling handling, regular monitoring of planting quality, and training and advice for planters on technique and quality. During planting, most crews are spread out diagonal to the direction of planting, with the fastest planters in the front positions to set the pace for the rest of the crew. On sites with variable soils and debris, crews should either have a versatile tool, such as a hoedad or wide dibble bar, or have several different tools available for use. In addition to the planting-crew foreman, landowners or their representatives should continually monitor progress and communicate with the foreman about spacing, quality, problems, or other logistics. The importance of supervision and monitoring of progress and quality cannot be overemphasized.

Most crews today operate with each planter carrying and planting his or her own seedlings. Although this is generally faster than the two-person crews commonly used in the past, it may tire crew members earlier in the day, resulting in less attention to proper planting techniques. At least one large industrial landowner still prefers to use two-person crews on some sites, with one person opening and closing the planting hole with a dibble bar and the other person carrying seedlings. Planting quality is further assured with this system in that the person with the seedlings places a tree in the planting slit with a pair of tongs which grasps the seedling at the bottom of the root system. Caution is necessary on clay soils; if clay becomes attached to the tongs, it may cause the roots to stick to the tongs and be pulled into a J or U shape. Daily planting rates with this two-person system average 1,000 to 1,200 trees per person.

Daily productivity for most hand planting averages 800 to 1,200 seedlings per person, with high rates of 2,000 to 2,500 per person. Major factors influencing these rates - and therefore planting costs - include topography, intensity of site preparation, soil type, size of the area to be planted, and type of landowner and contractor [11]. Small units are often planted with local contractors who add crew members, and therefore raise costs, as unit size increases. Larger units (> 60 to 80 ha) are usually planted by regional contractors with large crews; costs per hectare may actually decrease as unit size increases.

It is important to recognize that there is an interaction between what a landowner is willing to pay for planting and the rate and quality of planting that will be obtained. Because contractors now handle most hand planting, compensation is often based on hectares planted rather than hours worked. However, contractors tend to base their operations on assumed levels of necessary income per hour or day. Therefore, if a landowner is willing to pay more per hectare for a planting job, the contractor will probably slow the rate of planting, giving greater assurance of quality planting. It is likely that the highest reported rates of planting are achieved under contracts with a low per-hectare pay schedule; in such operations, the percentages of poorly planted trees probably are higher than in units planted more slowly. If payments are based on number of trees, rather than hectares planted, the landowner needs a good monitoring system to be sure that seedlings delivered to the contractor match with the actual number of hectares and trees planted per hectare.

Despite varied opinions and numerous practical observations, few definitive studies document the differences in planting quality and subsequent plantation performance due to differences in planting rate and crew type. In one comparison among types of planting crews, first-year seedling survival averaged 92% where planting care was maximal, 87% for company crews paid by the hour, and

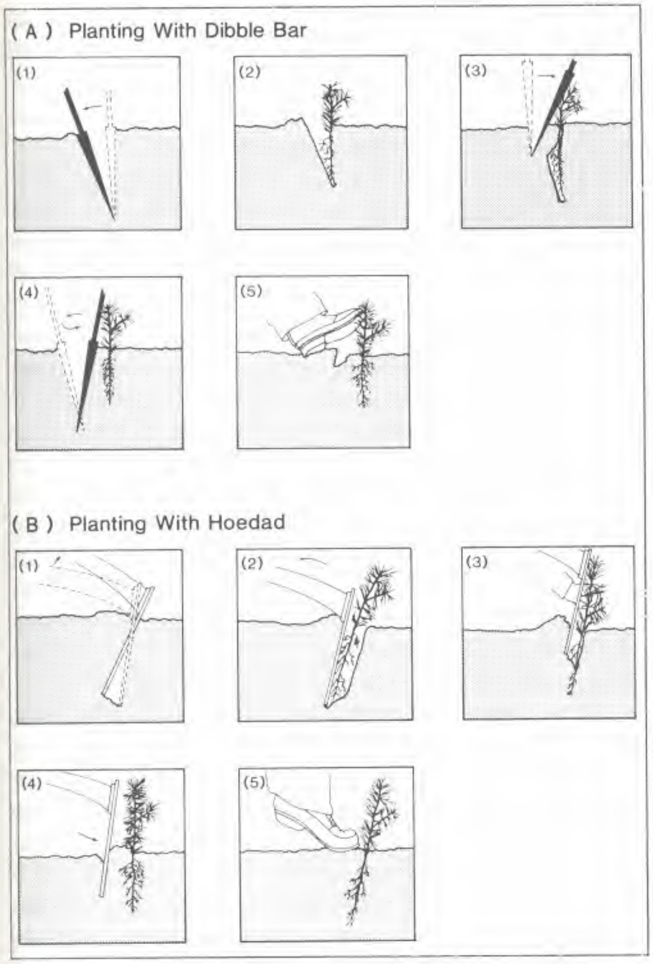

Figure 17.5. General planting procedures for (A) dibble bars and (B) hoedads. For each tool, the planter: (1) creates a planting hole using the full length of the blade; (2) places the seedling deep in the hole, then lifts it to the proper depth to straighten the roots; (3) holds the seedling in place by hand or with loose soil; (4) closes the hole firmly, first at the bottom, then the top; (5) packs the top of the soil around the seedling without stepping on or bruising the seedling.

81% for contract crews paid by the tree [28]. Although the differences in seedling survival were not large, survival rates tended to be higher when crews emphasized quality and de-emphasized production. The balancing of quality and production must be handled through proper guidelines, contract terms (see 17.5), and appropriate pay schedules.

17.3.3.3 Guidelines

Schematic drawings and descriptions of planting procedures are available as brochures, pamphlets, and guidelines from many different agencies and organizations [for example, 1, 7, 8, 29, 38]. In general, the hand planter must select the appropriate microsite for the planting spot, create an opening large enough to accommodate the seedling's root system, place the seedling in the opening without deforming the roots, and firmly pack soil back around the roots (Fig. 17.5).

When placed into the planting slit, the seedling generally should be gently pushed to the bottom of the slit, then raised back to the proper depth (see 17.4.1.2). This assures that the roots are completely within the slit, and straight, before the hole is closed. Of course, if the slit is not large enough to accommodate the root system, roots may never be restraightened or planted deep enough, emphasizing the importance of a sufficiently wide and deep planting hole. Soil must also be packed firmly around the roots at the bottom of the hole. Simply closing the hole at the top may leave an air pocket around the roots, which will deter root contact with the soil and subsequent root growth. This care in packing is most critical in heavy, clay soils where pushing soil in at the top of the hole is far less likely to pack it around roots than in sandy and loamy soils. Tree planters should wear boots or other footwear heavy enough for packing soil around seedlings.

Following is a summary of some other important guidelines for hand planting.

(1) Blades of dibbles and hoedads must be long enough and wide enough to create the proper opening. If worn, and < 20 to 25 cm long or < 7 to 8 cm wide, they must be replaced.
(2) Planting holes (and planted trees) should be perpendicular to the soil surface; this also applies on slopes, where planting perpendicular to the surface will permit the roots to be as deep as possible to prevent desiccation as soils dry out. Before the hole is dug, the soil surface should be cleared of litter that might fall in the hole.
(3) Planters should not remove more than one seedling at a time from their bags or trays, and should never carry seedlings between planting spots. Extra seedlings carried in a hand tend to dry out and may be damaged as they are swung about during the planting operation. Seedlings should not be removed from the planting bag or tray until the planting hole is ready.
(4) If seedlings were not well separated before being placed in the planting bag or tray, planters should be careful not to strip roots when removing seedlings for planting.

17.4 Planting Technique

Planting technique has received far more attention and study than either environmental factors or equipment selection. Seedling depth and root deformation are most widely discussed, but other aspects of planting technique are equally important for plantation success.

17.4.1 Seedling Placement

17.4.1.1 Microsite selection

Most of the available information on acceptable and unfavorable planting spots comes from experience and post-planting observation rather than designed studies. In an extensive post-mortem study, one industrial landowner found that planting spots in the middle of, or surrounded

Table 17.3. Effect of planting depth on first-year survival of hand-planted slash and longleaf pine (adapted from Wakeley [411).

Planting depth, cm	Survival, % (test 1)		Survival, % (test 2)	
	Slash	Longleaf	Slash	Longleaf
Deeper than nursery				
5	83	80	95	82
4	80	70	98	83
3	80	82	96	95
1	81	83	96	90
Same as nursery	83	73	92	74
Shallower than nursery				
1	58	44	91	59
3	35	34	78	56
4	23	10	56	40
5	26	7	59	30

by, coarse debris tended to have lower seedling survival than better prepared spots [48]. Other microsite conditions often recognized as high risk include: low-lying areas on flat terrain; soils compacted by heavy equipment; berms or beds created with loose soil, litter, and air pockets; dense sod; thick piles of ash; and proximity to hardwood stumps and brush sprouts. On the other hand, the best planting conditions are characterized by: deep, loose mineral soil; a light coating of ash, which can indicate a potential source of nutrients for early growth; and high spots and beds on wet sites (also see chapters 12 and 13, this volume).

Tree planters on machines generally do not have the opportunity to watch for, and select, the most favorable planting spot in a given area. However, hand planters do, and should be encouraged through training and planting specifications to select the best planting spot within a certain spacing. Planting contracts can define acceptable planting spots as, for example, an area of mineral soil at least 30 cm in diameter, where a seedling can be expected to have satisfactory survival and growth. Other specific guidelines could include: not planting on the types of microsites previously described; planting near conifer stumps or slash that can provide some shade during the first growing season; and planting close to windrows so that seedlings will have access to nutrients in the topsoil that is usually pushed into the windrows.

17.4.1.2 Depth, orientation and root placement

The importance of planting depth has long been recognized, as shown by Wakeley's statement [41] that:

> "Setting southern pine seedlings at the wrong depth probably reduces initial survival more often and more seriously than any and all other errors in planting technique combined."

He supported his statement with results from two tests of planting depth with slash and longleaf pine (Table 17.3). When seedlings were planted at the same depth as grown in the nursery or deeper, survival of slash pine was unaffected; that of longleaf pine was somewhat improved with deeper placement. However, when seedlings were planted shallower than at the nursery, first-year survival declined, most noticeably with the shallowest placement.

Subsequent studies [31, 36] and monitoring of forest industry plantations [47] have clearly shown that shallow planting is a leading cause of mortality in new plantations, probably because water is lost through exposed roots and from roots in soil layers that dry out quickly. Growth of survivors also tends to be slower than that of trees planted deeply or at the same depth as grown in the nursery. Deep planting, on the other hand, has generally maintained or improved survival on well-drained soils [23, 31], but decreased it on poorly drained sites [35]. McGee and Hatcher [23] suggested that, in very dry soils, trees might be planted as deep as the terminal bud, and that such planting would be especially beneficial for small seedlings. The various reports on the benefits of deep planting have included all the major southern pine species. In those tests on well-drained soils, up to three-quarters of the stem has been buried without noticeable effects on survival.

If seedlings are planted deeper than grown in the nursery, it is important that the planting hole be deep enough to accommodate them without deforming the roots. Where roots have been properly placed in deep holes, lower roots have not died nor have new roots formed above the root collar [23, 31]. However, deep planting operationally is probably not always accompanied by equally deep planting slits or holes. Deep planting has been positively correlated with taproot deformation in 3- to 5-year-old loblolly pine planted operationally in Oklahoma and Arkansas [27].

The most common planting problems relative to root placement and deep planting are: (1) L-shaped roots, usually resulting from machine planters dragging the seedling slightly before soil closes around it; (2) J- and U-shaped roots, caused by hand planters pushing seedlings into planting slits and not lifting them up enough to straighten the roots, or by having too shallow a planting slit; (3) twisted roots, resulting from hand planters twirling seedlings to facilitate placing them in the planting hole; and (4) balled roots, generally caused by jamming trees into shallow holes. The frequency and long-term impacts of these problems, and the errors that cause them, have been the subject of many studies and much debate. However, it is important to recognize that when poor survival in the field is related to root deformities, shallow planting is often the real cause of mortality. In the following tests, root deformities were generally evaluated independent of planting depth.

In a study of 3- to 8-year-old shortleaf (*P. echinata* Mill.) and loblolly pine that developed from seeding, nearly three-quarters of the trees had normal taproot development (Table 17.4) [13]. However, even under these "natural" conditions, some roots were deformed. Of the naturally developed root systems, 9 to 14% were characterized by horizontal taproots or laterals without a taproot. These

Table 17.4. Root-system configuration for 3- to 8-year-old loblolly and shortleaf pine seeded or planted in Oklahoma, Arkansas, and Texas (adapted from Harrington et al. [13]).

	Percentage of trees with		
Seedling type	Single vertical taproot	Multiple vertical roots	Horizontal taproot or lateral roots
Seeded			
Loblolly	79	12	9
Shortleaf	68	18	14
Planted			
Loblolly	38	36	26
Shortleaf	43	28	30

deformities were most prevalent in soils which were heavy or rocky, or which contained a hard spodic or pan layer. In contrast, only about 40% of the planted loblolly and shortleaf seedlings had normal taproots; 28 to 36% had vertically oriented systems with multiple lateral roots or taproots (Table 17.4). Planting increased the amount of horizontal (or abnormal) root systems by only 16 to 17%. Although trees with horizontal root systems tended to have slightly slower growth than trees with vertical systems, average growth of all seeded and planted trees was comparable [13].

In a similar study with excavated loblolly pine in Oklahoma and Arkansas, over 60% of 3- to 5-year-old planted trees did not have a normal taproot [27]. Although top growth was not correlated with amount of root deformity, it was positively related to the number of lateral roots and their distribution. These results, which supplemented other observations in 5- to 10-year-old plantations, led to the conclusion that root stripping before planting, or poor lateral root development in the nursery, might contribute to sparse root systems and reduced tree growth [27]. Marx and Hatchell [22] also showed that root stripping decreased survival, especially because mycorrhizae are removed.

Operationally planted slash pine in Florida were excavated 5 and 12 years after planting [30]. Over 50% of the lateral roots and about 40% of the taproots were deformed to some extent. There was no apparent difference in deformity due to hand or machine planting, and no indication that early growth was inhibited by poor planting. By age 12 much of the root deformity (except taproot bending at spodic layers) was masked by root growth and expansion.

In North Carolina, a sampling of 4- to 6-year-old hand-planted loblolly pine showed a positive correlation between tree size and amount of taproot deformity [15]. The authors hypothesized that either large seedlings are more likely to be poorly planted or that deformities may actually encourage lateral root development in upper soil horizons, thereby stimulating shoot growth.

Other studies have focused on deliberately planting trees with different root deformities to assess effects on performance. One of the oldest of these was in the North Carolina Piedmont, where seedlings were planted with roots straight or deliberately curled in a U shape [17]. After 24 years, survival, height, and diameter were similar for the two treatments. Root excavations at age 7 on a small sample of the trees did not indicate any differences in weight for major components of the root systems. Although root balling was not included as a treatment in this test, the authors did suggest that such a root deformity could contribute to windthrow in 3- to 5-year-old plantations, after which lateral root development would increase wind firmness.

Survival, height growth, and diameter of loblolly pine planted in Tennessee with roots in straight, slanted, L-shaped, P-shaped, or balled configurations also did not differ significantly 7 years after planting [46]. Survival of trees with the most severe deformities (P shape and balled) averaged 4 to 6% lower than that of trees in the other treatments. Excavation revealed that root systems in each treatment generally retained the configuration initially imposed on them.

Studies with younger trees also confirm the generalization that root deformities (of otherwise properly planted trees) do not strongly affect survival or growth [16, 20, 21, 36]. Excavations in each of these tests indicated that J- or U-shaped roots often turned down or became anchored with growth of new vertical laterals from the deformed taproot. When roots were not planted straight, their lateral root development in the upper soil horizons also seemed to be greater than when roots were planted straight.

In summary, the major root depth and configuration problems are shallow planting under all soil conditions, deep planting on poorly drained sites, and the most extreme deformities such as balling. Current evidence suggests that other root deformities, such as J, L, and U shapes, do not have a major impact on plantation performance. With or without root deformities, many planted trees tend to produce root systems that are not uniformly distributed around a central axis, but rather are concentrated in the plane of the planting slit or furrow. It is not likely that this will have significant long-term impacts on wind firmness or total stand production. Reduced survival attributed to these deformities has probably resulted from shallow planting rather than the deformity itself. Despite these general conclusions, relaxation of planting standards would undoubtedly lead to indifference regarding planting quality. Planting guidelines (see 17.4.1.4 for summary) should continue to emphasize careful seedling placement.

17.4.1.3 Soil packing after planting

The final step in the planting operation is to be sure that good root-soil contact is established and that seedlings are firmly in place. Next to improper depth of planting, loose planting of seedlings is probably the most important cause of early mortality. Air pockets around roots prevent absorption of available soil water and may cause root tips to dry out. Loosely planted seedlings are also prone to desiccate more rapidly than firmly packed trees, and can be more easily damaged by wind and animals.

The major cause of loose planting is usually the failure to firmly close the top of the planting hole [41]. Correctly weighted packing wheels on planting machines and proper technique with a dibble bar or hoedad are necessary for packing soil into the planting hole as well as closing the top of the hole. When seedlings are checked for firmness after planting, needles of a correctly planted tree should pull away from the seedling rather than moving it. Planters should be careful that tools, heels of shoes, and packing wheels do not scrape or break seedling stems when they close the planting hole.

17.4.1.4 Summary of planting guidelines

(1) Planting spots should be cleared of litter, rotten wood, and leaves that might fall into the planting hole.

(2) Planting holes and slits should be perpendicular to the soil surface, and must be large enough so that when the seedling is placed in the opening the roots do not get caught on the sides of the hole. Planting tools should not be used to maneuver the roots or seedling into the hole.

(3) Seedlings should be placed as deep in the hole as possible without damaging roots, then lifted back to the correct depth and gently shaken to loosen and spread the roots; seedlings should not be twirled nor roots twisted.

(4) On well-drained sites, seedling root collars (groundline in the nursery) can be 5 to 7 cm below the groundline at the planting spot; on deep, dry sands, seedlings can be planted even deeper; small seedlings should also generally be planted deeper than 5 to 7 cm. Longleaf pine can be hand planted to about the same depth as in the nursery, but machine planting should cover the seedling almost to the bud (soil settling will lower the berm around the seedling).

(5) On poorly drained sites (including many beds), seedlings should be planted no more than 2 cm deeper than they were grown in the nursery.

(6) Seedlings should never be planted shallower than they were grown in the nursery.

(7) Container seedlings should always be planted deep enough to completely cover the root plug to avoid desiccation.

(8) Seedling placement in the hole or slit should avoid leaving roots that are J, L, or U shaped, balled, or twisted.

(9) When the planting hole is closed, all roots should be in the hole, and soil should be firmly pressed around both roots and the base of the stem.

17.4.2 Post-planting Treatments

The most widely used post-planting treatments with southern pines are replanting after survival problems or failure (see chapter 18, this volume), and weed, insect, and disease control (see chapters 19 and 20). If replanting is necessary because of site conditions (for example, heavy vegetation), those conditions will need to be ameliorated before further planting. If necessary because of poor seedling quality, replanting may still be done early in the first growing season; beyond that time, additional site treatments such as weed control may be required for seedling establishment. Obviously, causes and timing of mortality must be identified as soon as possible. Generally, replanted seedlings have fared poorly unless in large openings with good weed control. Seedlings replanted under or beside older pines have seldom developed into dominants or codominants in the canopy. Measures that might improve this performance include special nursery sorting for seedlings with large root systems, planting with shovels, and spot control of herbaceous weeds. In lieu of replanting, naturally regenerated seedlings might be released if site assessment indicates that enough natural seedlings are available.

Other possible treatments include devices or sprays to protect seedlings from animal browsing, mulching for water conservation and weed control, and devices for shading. Some highly eroded soils and spoil banks have also been mulched to hold soil in place. Although each of these treatments is frequently used in other parts of the country, they are only rarely applied operationally in the South. They require extra treatments in the nursery or extra passes through the plantation, and are not likely to be included in regeneration programs until there is an obvious benefit from them.

17.4.3 Organizational Considerations

17.4.3.1 Crew training

Training of planters, whether for hand or machine operations, should be a continual function of supervisors and contractors. Even people with substantial experience can benefit from periodic review of techniques and effects of planting methods. Contractors or supervisors of company crews must be certain that all new crew members receive adequate instruction before they begin planting. Followup throughout the planting season is based on monitoring and observation, and should be regular and timely so that crew members do not form bad habits or become careless. If potential crew members cannot adapt to training and proper procedures, they should not be retained.

A number of states now require that planting contractors and/or crews be certified before they operate in the state. When only contractors are certified, it is assumed that they will properly train their crews. In some states the requirement is limited to those who will be working on federal or state cost-sharing jobs. Certification usually includes several days of class and field training before the planting season. Several states offer voluntary certification; and a number of large contractors have asked other states to develop certification programs to upgrade the quality of tree planting. As long as certification includes both training and recognition of continuing acceptable crew performance, it should be implemented by all states.

17.4.3.2 Supervision and quality control

All planting operations require constant supervision and monitoring of planting quality and spacing. Many industrial and contracting organizations agree that operations may become inefficient, or at least difficult to control, with large crews. Thus, most try to keep one nonplanting supervisor with, at the most, 12 to 15 individual planters, 8 to 12 two-person crews, or 3 to 5 planting machines. These supervisors should constantly monitor performance of all crew members by measuring spacing of trees between and within rows or beds, gently pulling needles of seedlings to check for firmness, inspecting for leaning trees and proper planting depth, and carefully excavating sample trees to check for root placement and deformation. These assessments can be done randomly across the whole planting unit; or they might be done in combination with establishment of semipermanent plots used for determining contract payments and first-year (or longer) plantation performance (see chapter 18, this volume).

Landowners or their representatives should also inspect for spacing, quality, and/or survival and, on the basis of that inspection, rate contract performance and determine payment. They may not be able to take as large a sample as the crew supervisor because they may need to oversee more than one crew each day. The sampling method and measurements, and the use of the results for determining contract payments, should be clearly defined in each contract.

Landowners should also realize that this quality control extends through all steps in the planting operation. In several studies of the effects of care in different stages of seedling handling and planting, no single factor was found to consistently relate to survival [9, 47]. Quality control is essential throughout the entire regeneration process.

17.4.3.3 Seedling supply and protection

Previous sections and chapters have emphasized the necessity of protecting seedlings from overheating and desiccation from the time they arrive at the planting site to the time they are planted. Although guidelines for this protection may seem rigid, a number of research studies support its value.

Average survival of loblolly pine seedlings exposed to ambient conditions in Virginia decreased 7% for each 10 minutes of exposure, with the most dramatic decreases after 30 minutes; height growth and root-growth potential decreased similarly [6]. An earlier study with loblolly in Mississippi evaluated the effects on seedlings of only 5 and 10 minutes of exposure to ambient February conditions (sun, temperature 18°C, relative humidity 56%, wind 5 kph). With no exposure, seedling survival was 90%; it dropped 13 to 18% with 5 minutes of exposure, and another 13 to 14% with 10 minutes [35].

Seedling exposure can be minimized by opening only one bundle or bag at a time, and being sure that seedlings in that bag are kept moist if all are not used immediately. Seedlings should also be kept moist in carrying bags, trays, or buckets. Planting crews should always (except during rain) have a supply of water at the planting site for such purposes. Keeping roots moist does not require leaving them in water. In fact, Ursic [36] suggested that prolonged soaking in water (4 hours, for example) may be detrimental to root vigor.

Tree planters frequently root prune and cull nonplantable seedlings in the field. This not only extends the period of seedling exposure, but significantly increases the likelihood of seedling damage before planting. Neither of these activities should be done by tree planters. If necessary, they should be done at the nursery before shipping, or at another protected site, by a well-trained person before delivery to planters. Roots should be pruned with minimum exposure to avoid drying and with a sharp tool for cutting them to a uniform length; only the minimum amount of roots to make seedlings plantable should be removed. Guidelines for minimum root length as a function of seedling size can be found in most planting manuals. One justification for root pruning has been to avoid L-shaped roots in planting; as suggested in 17.4.1.2, this may not necessarily be important.

17.5 Contracts

Contractual arrangements between a landowner and planting contractor can be simple or complex. But if not thorough and well understood, they can be costly for either party. Assistance in developing contracts is usually obtained from public forestry agencies or consulting foresters; and legal advice is highly recommended, at least until parties to the contract are familiar with all terms in the agreements.

17.5.1 Contract Terms

Whichever party takes the responsibility for drafting a contract, both parties should be sure it includes certain items:

(1) A description of the project (size, location and map of area, method of determining area, rate of payment, types of trees, spacing, planting method, responsibilities for tools and equipment);

(2) Starting and ending dates of the project and provisions for contractor to notify landowner when operations begin and end;

(3) Planting guidelines and specifications (acceptable weather and soil conditions, handling and storage, root dips and pruning, protection of trees in planting bags or on machines, hand-tool procedures, machine adjustments, planting-spot selection, depth of planting, post-planting or other seedling treatments);

(4) Responsibility and conditions for procurement, transport, delivery, and storage of seedlings;

(5) Provisions for contractor to use roads or trails for access to the site, and responsibilities for maintaining those in the same condition as they were found;
(6) Inspection procedures for spacing and quality and terms of acceptance of completed work; this may include various guarantees for performance and contractor liability should performance fall below expectations (discussed more fully in 17.5.2); planting operations must pass inspection for most state and federal cost-sharing programs;
(7) Time and method of payment;
(8) Provision for settlement of disputes;
(9) Right (if any) of contractor to subcontract;
(10) Insurance (if any) and other legal or financial liabilities and responsibilities of contractor; and
(11) Conditions for cancellation or delay of project.

17.5.2 Quality Control and Guarantees of Performance

Although all the items listed in 17.5.1 are important for avoiding misunderstandings and lawsuits, special emphasis is placed here on contract arrangements to improve or insure the quality of the planting job. Quality-control measures in a contract can be implemented by adjusting payment schedules, requiring performance bonds, or specifying liabilities for replanting part or all of the project. Such measures should always be included in contracts.

A prerequisite for enforcing these procedures is an assessment of the quality and spacing of the plantation relative to standards specified in the contract. This may be as simple as a walk through the project area if expectations for performance are not very high. However, landowners and contractors can be more demanding. Standards can include proper spacing, percentage of planting spots filled, aspects of quality such as leaning or loosely planted trees, root deformity as determined by excavating a sample of trees, and survival after some period of time (such as 3 months or the first growing season). Adherence to these standards must be determined by sample plots (temporary or permanent) or other satisfactory sampling procedures conducted by the contractor, landowner, both parties, or a third party, and acceptable to all concerned. Some sampling, such as for planting quality, should be done regularly throughout the project to correct problems as they occur. If the standards and assessment procedures are clearly defined in the contract, then adjustments and liabilities can also be stated and, if necessary, implemented.

Adjustments to payments are generally flat-rate deductions for failing to meet contract specifications, or graduated deductions depending on the amount of failure. As an example of a flat-rate deduction, if a contract calls for 1,500 trees/ha, it may also specify that if stocking exceeds or falls short of that level by more than 5%, payment will be reduced by a certain amount per hectare. As an example of a graduated deduction, a landowner may specify that 90% of the planting spots be filled with well-planted trees (e.g., no shallow or loose trees); for every percent that actual planting falls below that standard, payment is reduced by a percent. If 90% or more of the planting spots have well-planted trees, payment could be either at the contract rate only or graduated so that the contractor receives an extra percent of the payment rate for every percent that the plantation exceeds the 90% standard. Though uncommon, the latter procedure does provide an incentive for good planting, rather than just a penalty for poor planting. Incentives need to be more widely adopted in contract negotiations as a means of improving planting quality.

The contractor can also be required by the contract to replant if performance does not reach specifications. Depending on the standard for assessment, replanting may be done during or immediately after the project, or at some date after survival has been measured. For example, if stocking levels are < 90% of the required standard, the contractor may need to replant enough trees to correct the stocking. Withholding a progress payment or a portion of all payments (e.g., 10%) or requiring a performance bond may provide some insurance that the replanting will be completed. There should be no additional cost to the landowner for such replanting, unless poor survival can be attributed to a condition outside the contractor's control, such as poor seedling quality upon delivery to the contractor, prolonged drought, or fire. These conditions should also be clearly specified in the contract.

A number of larger contractors now offer guaranteed survival or quality clauses in contracts, which specify that they will replant if standards are not satisfied. For reasons discussed earlier in this chapter, contracts that have such guarantees often require slightly higher payment rates, so that both contractor and landowner are compensated for their concern for quality and performance.

17.6 Summary

Although planting conditions are diverse, the procedures and guidelines that have evolved for planting the southern pines are generally flexible. Guidelines followed in many states become fairly rigid only when planting weather and soil conditions are marginal. Simple machines and hand tools are used for virtually all planting; the choice of system is a function of site conditions and preparation, local preferences, labor or equipment availability, and cost. On sites where either system could be used, average costs of the two are nearly the same.

Substantial research into the effects of planting quality has shown that shallow or loose planting of seedlings poses the greatest threat to their survival. On the other hand, deep planting, even when seedlings suffer common types of root deformity, either does not affect or may even benefit seedling survival or growth. Nonetheless, adherence to planting standards and guidelines, which are available in many different formats, will guarantee plantation establishment given adequate seedling quality and post-planting weather conditions. Continual supervision of all phases of the planting operation, with emphasis on avoiding seedling exposure, shallow or loose planting, and missed planting spots, will substantially improve plantation survival.

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