# CHAPTER 7—SEEDLING GROWTH AND DEVELOPMENT

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## TABLE OF CONTENTS



## LIST OF TABLES



## LIST OF FIGURES

## MAJOR FACTORS

Development and growth of seedlings begins with germination and continues until the seedlings are lifted. Among the multitude of factors or conditions affecting development and growth are:

A. The size and viability of the seed
B. Time and depth of sowing
C. Stratification of the seed
D. The genetic endowment of the seed
E. Condition of the seed beds
F. Characteristics of the mulch
G. Moisture and temperature conditions during germination
H. Soil chemicals
I. Soil pests (nematodes, fungi, and insects)
J. Seedbed densities
K. Soil texture and structure
L. Availability of nutrients
M. Soil moisture during the growing season
N. Competition from weeds
O. Soil and atmospheric temperatures during the growing season
P. Cultural treatments

Research results and observations over many years show:

1. For a specific species, initial development and growth follow a fixed course and maintain a characteristic form for a definite time after germination. The tendency to change when subjected to different external conditions becomes more pronounced as the seedlings become older.
2. When some species are subjected to different external conditions, they exhibit much earlier tendencies to change than do other species. This is also true for individuals within the species.
3. Fine-textured soils encourage root branching, whereas coarse-textured soils appear to stimulate the growth of longer tap roots.

This chapter discusses patterns of growth and development for southern pine seedlings. Discussions of soil moisture, nutrients and fertilization, and pest control are contained in Section III: Management Considerations.

## SEED GERMINATION

The essential event in seed germination is initiation of growth by the embryo and its development into an independent seedling. Physiological processes involved in seed germination are:

1. Absorption of water
2. Beginning of cell enlargement and cell division
3. Increase in enzyme activity
4. Assimilation of stored food
5. Translocation of food to growing regions
6. Increase in respiration and assimilation
7. Increase in cell division and cell enlargement
8. Differentiation of cells into various tissues and organs of a seedling

Germination can be regarded as complete when the seedling has produced enough photosynthetic surface to supply its own food (Kramer and Kozlowski 1960).

The first visible evidence of germination of southern pine seeds is the cracking or opening of the seed coat, followed by the emergence of the radicle, which develops into the primary root. This primary root rapidly grows down into the soil, anchoring the seedling. In normal seedbed germination, radicles emerge from the seed coat about 7 to 30 days following sowing, depending on the species, condition of the seed at the time of sowing, and microclimatic conditions surrounding the seed. As germination continues, the hypocotyl (cotyledons of longleaf pine and cotyledons and stems or epicotyl of other pine species) elongates rapidly and initially arches upward, then straightens, bringing the cotyledons (usually with the seed coat still attached) through and above the soil or mulch. Within a few days cotyledons expand, forcing the seed coat to fall to the ground. In some instances it may remain attached to a cotyledon. The seed coat still encloses the remains of the nutritional tissue. As the cotyledons spread apart, the rudimentary primary needles are revealed which are the principal photosynthetic organs. The cotyledons of the seedling may become functional needles while the primary needles are developing (figure 7-1).

## GROWTH ASSESSMENT

Following germination, seedling growth and quality are largely under the control of the nursery staff. The final products desired are seedlings suitable for outplanting, with dimensions and qualities that will ensure adequate survival and growth. Seedlings can be viewed in terms of two overall characteristics, namely:

1. Morphological measures of size and development: stem height, and diameter, root area, dry weight, percentage of needles in fascicles; terminal bud, and seedling index (table 7-1).
2. Physiological properties: Seedlings with similar morphological and internal characteristics may show differences in their ability to survive or grow, especially on adverse sites. Desirable physiological qualities include rapid initiation of root growth after planting; water intake that equals or exceeds water loss; high resistance to drought and freezing; and ability to overcome competing vegetation.

Morphological and chemical evaluations of seedlings should be a continuing function of the nursery manager

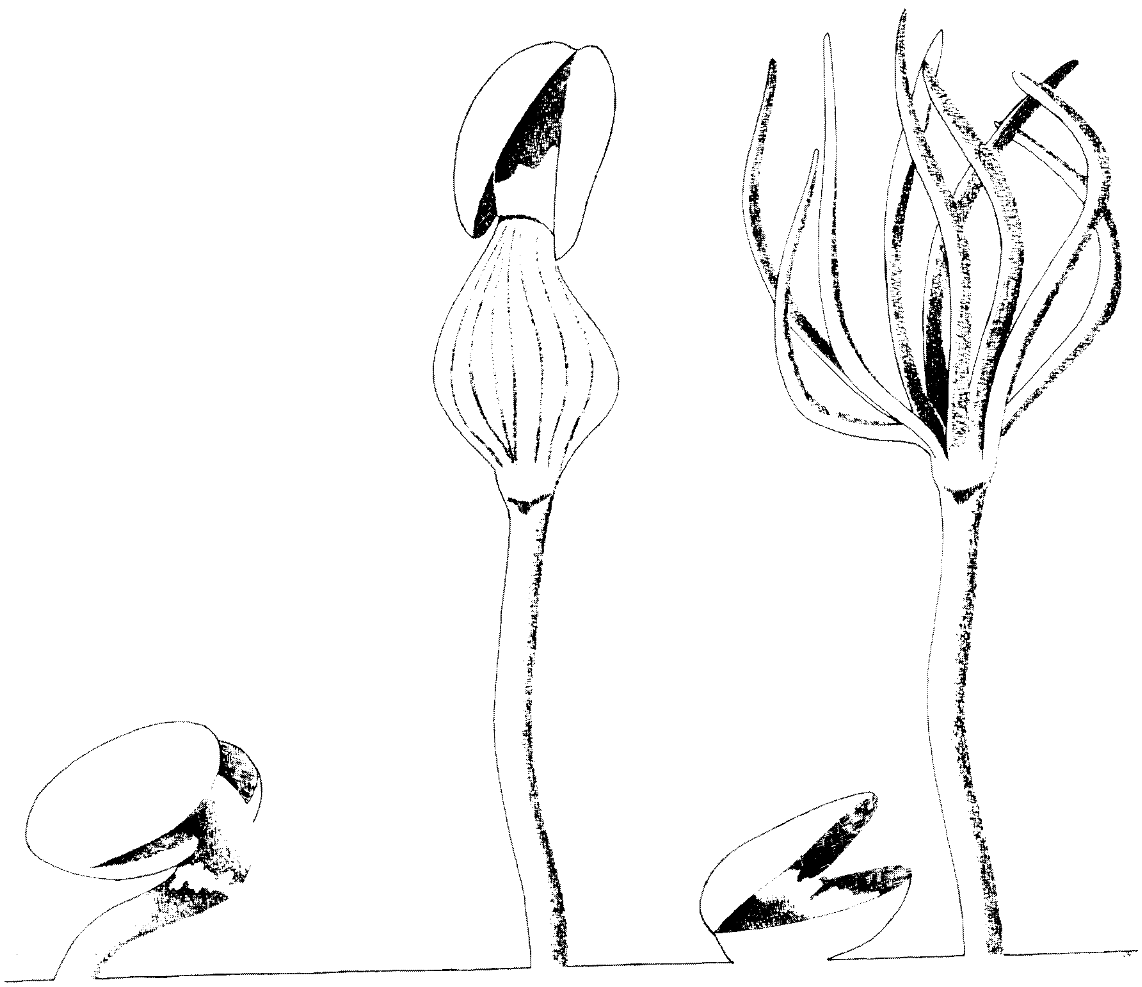

**Figure 7-1.—Germination sequence of southern pine seedlings.**

during the entire growing season. Some measurements can be made by the nursery staff, others must be done with laboratory analysis.

## Stem Growth

The height growth curve for most pine seedlings is sigmoidal, and tends to vary among species, from season to season, between nurseries and sometimes within nurseries (Huberman 1940, Wakeley 1954, Walsh 1954, Johnson 1960). See figure 7-2.

Stem diameter has traditionally been used as an index of a seedling's sturdiness and quality and is usually measured directly above or at the ground line. Stem diameters increase slowly during the first few months following germination, and are inversely correlated with seedling density in the seedbed. Growth does not occur uniformly on the stem throughout the growing season. For example, the root collar diameter may not increase, but in the region of new primary needles diameter growth may be occurring.

The total dry weight of a plant is a fundamental measure of growth since it represents the net gain in photosynthate and is therefore the difference between gross metabolic production and losses due to respiration (Armson and Sadreika 1979). Unfortunately, the determination of total dry weight requires destructive sampling. However, dry weight should be used occasionally in each nursery for each major species to determine the shape of the seedling dry weight curves during the growing season. The seasonal progression of dry weight is curvilinear with time (figure 7-3). The progression of dry weight during the growing season varies with species, seedling density, climatic conditions and soil fertility. The curves for loblolly, shortleaf and Virginia pine seedlings are more similar to slash pine than longleaf pine.

The dry weight of seedling stems increases approximately 25 to 75 percent beginning about the first week in December, depending on the species and possibly soil fertility (table 7-2). Much of this increase in dry weight of tops seems attributable to carbohydrate production during the late fall and early winter. Any material not needed for active root growth is stored in stems, foliage and buds.

*Table 7-1. — Seedling characteristics of lablolly and slash pine at different growth periods.*

| Time since germination | Characteristics: Roots | Tops | Other |
|---|---|---|---|
| 0 - 30 days ± April - early May | Roots elongate rapidly; anchor seedling. | Cotyledons open; seed coats still attached; primary needles begin to form and elongate; Cotyledons may turn red or brown; stems green or greenish to reddish brown. | Tissue very succulent; Seedlings subject to damping-off, drought, heat and cold. |
| 30 to 45 ± days May - June | Elongation of primary root continues rapidly; branch or lateral roots appear; sometimes mycorrhizae appear; a corky layer begins to form on roots. | Primary needles usually well developed, and increase in size and number; flush of new growth evident; lower stem becomes woody, and dark reddish brown to chocolate brown. Stems appear wrinkled under hand lens. | Seedlings begin to harden; essentially safe from damping-off; only moderately resistant to drought or heat injury. |
| 75 to 165 ± days July - September | Primary or tap root elongation practically ceases; abundant laterals and more mycorrhizae develop; root collar diameter begins to increase. | Stems continue to elongate; secondary needles (in fasicles) increase in length and number; terminal buds begin to appear. | Seedlings well hardened except for succulent secondary growth; resistant to drought and heat, except the succulent tips of stems. |
| 165 ± days October until lifting. | Numerous growing points appear on roots; lateral roots and mycorrhizae continue to develop. | Stem growth practically ceases (unless affected by warm weather, increase in soil moisture or fertilization); fascile needles increase in number and size; terminal buds increase; nodal buds appear on many seedlings; bark is formed on lower stem. | Increase in dry weight of stems; drastic increase in dry weight of roots; increase in storage of reserve carbohydrates. |

This accumulation of food reserves has an important favorable effect on survival after planting (Barnard et al 1981).

Under optimum conditions seedling stems may lengthen continuously from the first flush of growth (after the appearance of primary needles) until the buds form in the late summer or early fall. More often, the stems lengthen at varying rates between June and September. The supply of moisture and nutrients can have a pronounced effect on both the pattern of height growth and the seedling's final development.

Flushes of rapid stem growth may be followed by short periods of no apparent change. Needles in fascicles (secondary needles) begin to appear about the middle of the summer as seedling stems become woody (figure 7-2). Terminal buds may develop on some seedlings as early as July or August. Budding at this time is usually associated with some form of seedling stress. Usually, terminal buds do not develop until early fall when soil moisture is low from lack of rain or irrigation, and mean daily temperatures decline.

Nodal buds appear in late summer or early fall. An appreciable percentage of winter buds may open just before or during the winter lifting season. Such breaking of the winter buds is not abnormal, and does not necessarily reduce survival (Wakeley 1954).

## Root Growth and Mycorrhizae

Growing roots possess four distinct regions: (1) the root cap, (2) the meristematic region, (3) the region of cell elongation, and (4) the region of differentiation and maturation. In some roots these regions are not clearly defined. The roots lengthen rapidly in young pine seedlings. Supported by the older, more rigid tissue and on the sides by the soil particles, the root tip is pushed through the soil by the elongating cells. Its course is somewhat tortuous as it follows the line of least resistance between the soil particles. This fast growth may extend straight downward 4 to 5 inches in sandy soils with little or no bending, and before there is any root hairs or lateral roots are evident. In fine-textured soils this growth is slower, and the root system reflects the influence of greater obstacles to elongation (figure 7-4).

As the newly formed cells at the base of the zone of cell enlargement lose their ability to elongate, they differentiate into the epidermis, cortex and stele. The epidermis is composed of thin-walled elongated cells that are often slightly smaller than the cortical parenchyma cells. The most distinctive characteristic of the root epidermis is the production of root hairs that usually arise as protrusions from the external lateral cell walls, or from the

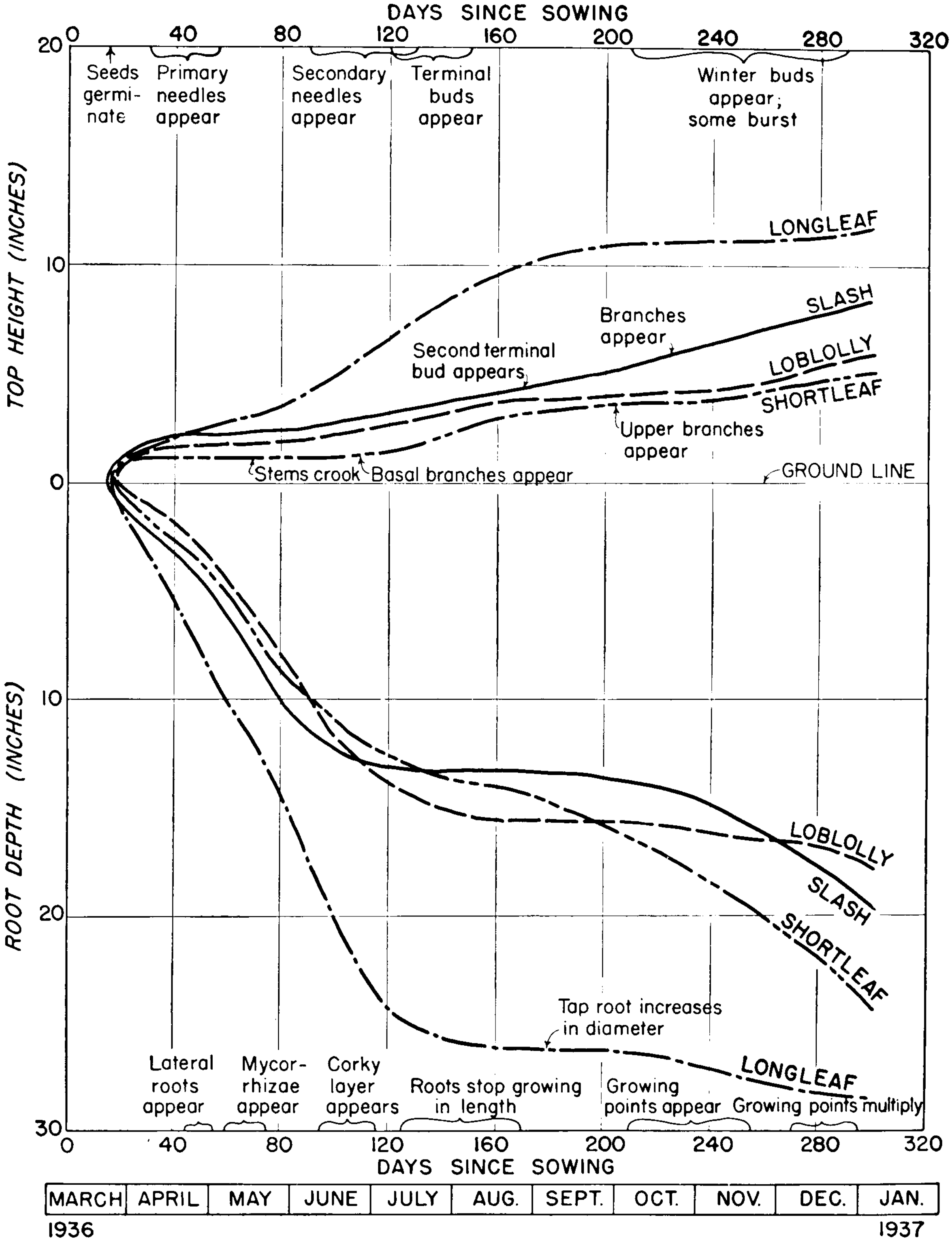


**Figure 7-2.—Normal developmental sequence of southern pine seedlings. (from Wakeley)**

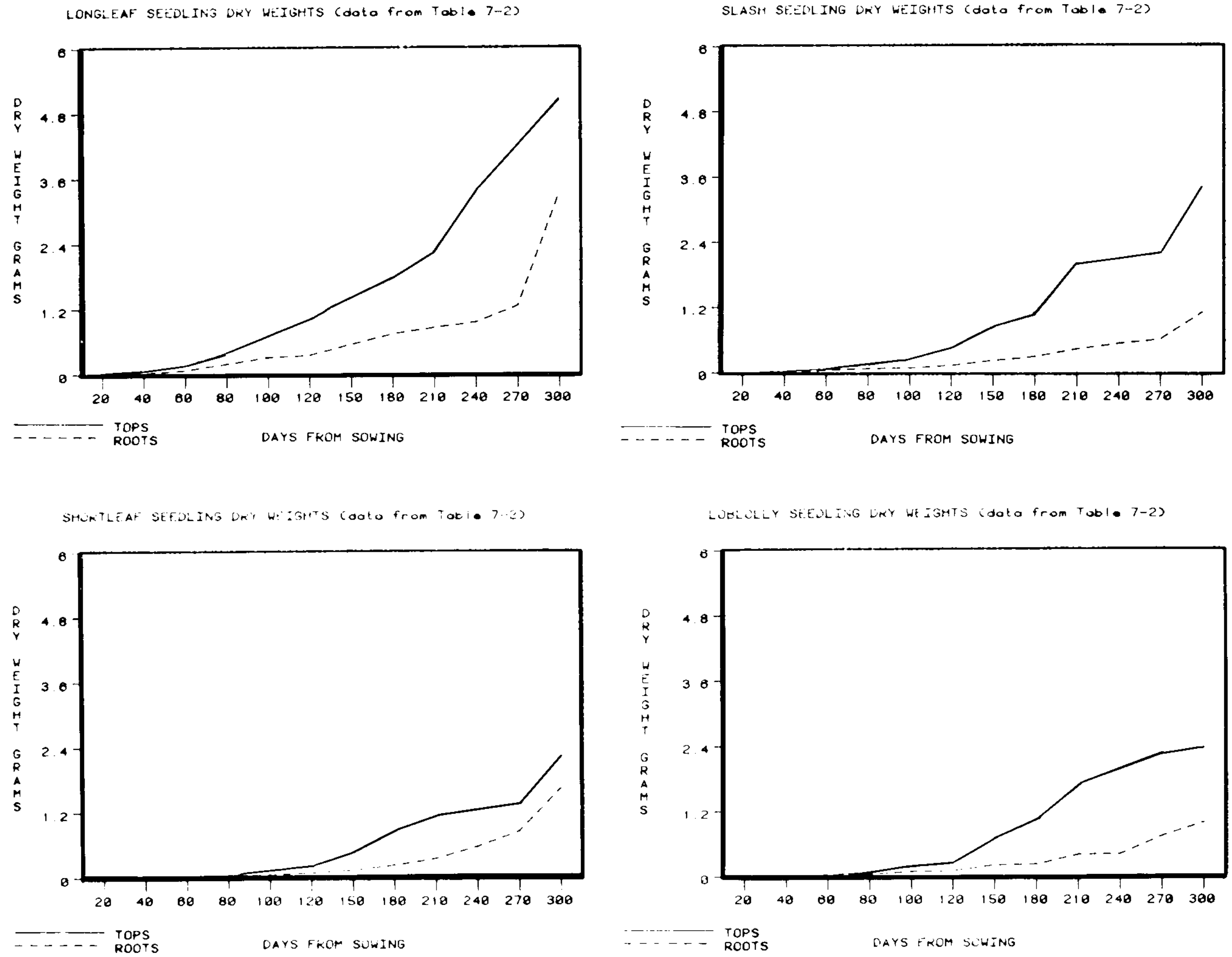


**Figure 7-3. — Top and root growth of southern pine seedlings (dry weight).**

cortical cells one or two cell layers beneath the epidermis. In a fertile soil in a greenhouse, roots of 7-week-old loblolly pine seedlings had 217 root hairs per square centimeter (Kozlowski and Scholtes 1948). These hairs are probably being destroyed in a few days or weeks by the changes associated with secondary thickening of the epidermis or hypodermis. Root hairs are rarely observed on the roots of pine seedlings in southern nurseries possibly because of extensive development of mycorrhizae.

As the primary or tap root continues to lengthen, lateral roots arise. Laterals first appear as little bumps on the roots of young pine seedlings. They may continue to lengthen and branch, resulting in primary, secondary, tertiary, etc., lateral roots or they may develop a mycorrhizae-like structure. Occasionally, the hypodermal cells produce secondary root hairs, lenticels and absorbing areas consisting of groups of thin-walled, radially elongated cells. Lenticels may be numerous, sparse or absent on seedling roots.

The most efficient zone of water and nutrient absorption is usually near the root tip. Thus, the number of growing root tips is an important factor in absorption. Because capillary movement of water in soils below field capacity is very slow (or almost absent in sandy soils) continual extension of roots through the soil is essential. Those seedlings that develop the most extensively branched and the most penetrating root systems will use soil water and minerals most effectively. A major reason for the ability of pine seedlings to grow rapidly and vigorously is the presence of so many lateral roots, or root branches and tips in the form of mycorrhizae (figure 7-5).

Mycorrhizae or fungus-roots are the normal feeder roots of many seedlings, at least in some stage of seedling growth and development. The ectomycorrhizal formulation mechanisms on roots of pine seedlings are extremely complex and still not thoroughly understood. Most of the fungi that form ectomycorrhizae are Basidiomycetes, which produce mushrooms or puffballs. *Thelephora terrestris* is the most common, naturally-occurring fungus

*Table 7-2. — Mean dry weights of southern pine seedlings throughout the growing season (at about 30 per sq. ft.).*

| Approx. number of days after sowing | Longleaf | | Slash | | Loblolly | | Shortleaf | |
|---|---|---|---|---|---|---|---|---|
| | Tops | Roots | Tops | Roots | Tops | Roots | Tops | Roots |
| | | | | Grams | | | | |
| 20 | .03 | .00 | .01 | .00 | .01 | .00 | .01 | .00 |
| 40 | .07 | .03 | .03 | .01 | .01 | .01 | .01 | .01 |
| 60 | .17 | .08 | .08 | .05 | .04 | .03 | .03 | .03 |
| 80 | .41 | .20 | .14 | .08 | .09 | .05 | .05 | .05 |
| 100 | .73 | .32 | .25 | .09 | .21 | .10 | .16 | .06 |
| 120 | 1.03 | .36 | .46 | .14 | .26 | .11 | .22 | .10 |
| 150 | 1.41 | .56 | .85 | .23 | .71 | .22 | .49 | .15 |
| 180 | 1.76 | .75 | 1.06 | .30 | 1.06 | .23 | .88 | .24 |
| 210 | 2.23 | .86 | 2.00 | .44 | 1.70 | .41 | 1.14 | .36 |
| 240 | 3.36 | .96 | -- | .54 | -- | .42 | -- | .58 |
| 270 | -- | 1.26 | 2.19 | .62 | 2.25 | .75 | 1.36 | .86 |
| 300 | 5.03 | 3.33 | 3.41 | 1.11 | 2.36 | 1.00 | 2.24 | 1.65 |

1/ These values may vary 100± percent depending on the nursery, growing season, seedling density and soil fertility.

From Huberman, 1940 and other sources.

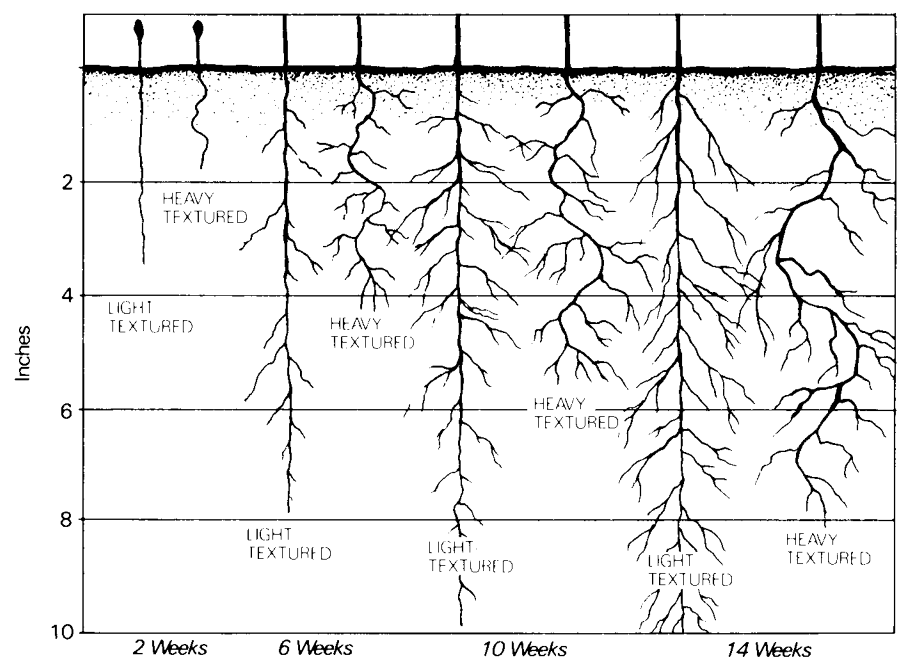


**Figure 7-4. — Loblolly pine seedling root systems in coarse and fine-textured soils.**

Figure 7-5. — Mycorrhizal associations on pine seedling roots.

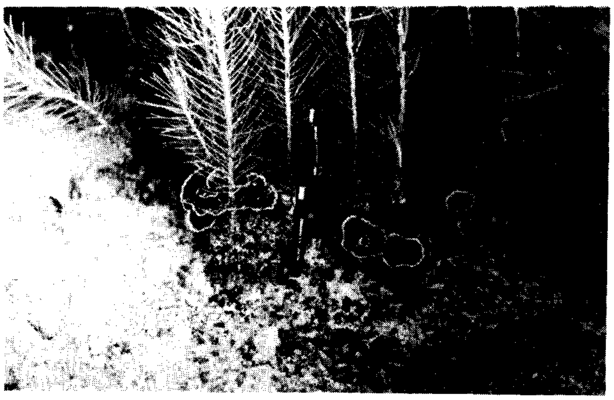

Figure 7-6. — Ectomycorrhizal fungi: fruiting bodies.

that forms ectomycorrhizae on pine seedlings in southern nurseries. Fruiting bodies (basidiocarps) are produced which surround the stems of seedlings (figure 7-6). While these growths appear to be pathogenic and have often caused concern among nursery workers and planters, they are beneficial fungi. Many other mycorrhizal-forming fungi, including *Pisolithus tinctorius* (Pt) have been found in southern nurseries. Spores produced by the fruiting bodies of these fungi are easily spread by the wind. Many of the mycorrhizae will not become established except in a selective micro-environment as they are not competitive under nursery conditions. Thus only one to four genera usually occur in any one nursery. Mycorrhizae are discussed further in chapters 1 and 13.

## Type of Root System

The pattern of seedling root development and growth is determined by the inherent genetic characteristics of the species or race, texture and structure of the soil, soil moisture and certain cultural practices. Three distinct types of root systems are preferred for southern pines:

1. Long taproots (7 to 9 inches) with numerous first and second order laterals for machine planting on deep, coarse soils.
2. Medium-length taproots (±6 inches) with several first- and second-order laterals for hand planting on deep, medium- to fine-textured soils.
3. Short tap roots (±4 inches) with many fibrous, lateral roots for hand- or machine-planting on shallow soils.

Length of tap roots and number or abundance of laterals are used widely to describe seedlings because they are simple measurements. However, the measurement of roots is time-consuming and these measurements may not estimate seedling survival and growth potentials.

Oven-dry weights of all roots have been used widely with shoot dry-weight, to express the seedling balance and a shoot:root ratio (table 7-2). One major limitation of this method is the nature of the root system. For example, two seedlings may have the same dry weight, yet one seedling may possess a few larger-diameter roots and the other mainly medium and fine roots—with consequent differences in absorbing-surface areas. Root volumes suffer the same disadvantages as root dry-weight: A seedling with one large-diameter root will have a larger, cubic root-volume than another seedling with a mass of small, fibrous roots. In this case the latter seedling may actually have a larger, absorbing root-surface area. Some Canadian nurseries use the Root Area Index as a standard measure for root systems. This index is the photometrically measured silhouette of the root surface of a seedling, expressed in the number of square centimeters of light blocked by the root surface (Morrison and Armson 1968). This procedure could be useful in southern pine nurseries.

Studies and observations of southern pine seedling growth in nurseries reveal that root growth increases about the time active stem-height growth decreases in the fall. Root growth can occur throughout the lifting season and into the planting season whenever the soil temperature is above 40 °F.

## SEEDLING DORMANCY

Conifer seedlings generally do not grow continuously through the year, but alternate between flushes or periods of active growth and periods of inactivity or dormancy. Often this fact is obscured because growth data usually represent averages of a number of trees which grow at different times in contrast to individual seedling growth which may start or stop several times during the growing season. In the winter, growth often stops because of low temperature. However, the growth of many conifer seedlings will normally cease long before these temperatures are reached.

Two types of dormancy may develop in southern pine seedlings. One type is a temporary summer dormancy which occurs between flushes of growth, lasts a few days to a few weeks, and is broken spontaneously. The other type is semi-permanent or permanent dormancy which may last for several weeks or months and usually is not broken until the seedlings have been exposed to low temperatures for a few weeks, followed by higher temperatures. Garber and Mexal (1980) estimated that loblolly pine seedlings from southeastern Oklahoma need about 7 weeks of cold temperatures to satisfy their cold requirements. Cessation of visible growth caused by internal factors is called "rest" (Samish 1954). This "rest" is also called internal dormancy.

Unfavorable conditions such as drought, nutrient deficiency, or a severe shock will sometimes stop seedling growth in the middle of the season. If the water supply is restored, nutrients are replaced, or the shock is overcome, growth resumes. Hot weather of midsummer, by creating a physiological stress, may cause the beginning of quiescence or rest. Lateral root pruning, wrenching or top pruning may stop growth. A sudden drop in air temperatures to freezing or below will stop stem growth. Wakeley (1954) states that dormancy or near dormancy of southern pine seedlings seems to result from a combination of temperature, length of day and stage of seedling development.

Kramer and Kozlowski (1960) suggest that perhaps growth itself produces the conditions which stop growth and the formation of buds. Development of dormancy can be due to the accumulation of a single inhibitor, or it may be correlated with a change in relative proportions of growth-promoting and growth-inhibiting substances. Growth hormones or retardents (e.g. Maintain) applied before or after bud break can cause plants to remain quiescent for several months (Gill and Newbold 1979).

### Dormancy Measurement

There is a need for a simple method to measure dormancy in seedlings, as lifting dates, storage techniques and seedling survival are closely dependent on seedling dormancy. Electrical characteristics of seedlings have been used to predict or measure dormancy in a number of forest tree species (Askren and Hermann 1979, Glerum 1980, Reitveld and Williams 1977, Jaramillo 1981). The electrical resistance (ER) in a pine seedling may be correlated with:

1. Season or time of the year.
2. Seedling temperature. Sharp increases or decreases in temperature indirectly affect resistance through their effect on the seedling's physiological processes or metabolic activity.
3. Degree of hydration or water potential. ER is inversely correlated with percent moisture content above the fiber saturation point.
4. Concentration of cations. ER decreases as the concentration of cations increases.
5. Size of seedlings. Larger caliper seedlings tend to have lower resistance readings.
6. Position in the plant. ER appears to be higher at the terminal bud than at the root collar.

The possibility of determining dormancy or degree of metabolic activity can have a far-reaching effect on some of the cultural practices in nursery management—especially fertility levels, irrigation regimes, undercutting and wrenching, lateral root pruning and top pruning. The oscilloscope technique (Ferguson et. al. 1975) and the Shigometer technique (Reitveld and Williams 1977) have been used with limited success on southern species (figure 7-7). The dormancy meter is an improvement on the oscilloscope design and was developed by Missoula Equipment Development Center of the USDA Forest Service. This instrument has the potential of providing useful dormancy predictions. This meter has been tested on a number of forest tree species and has been used operationally in some western nurseries.

## ROOT PRUNING, CUTTING AND AERATION

The term root pruning has been applied to at least four distinct operations.

1. The trimming of laterals and the tap root after lifting. This is done mainly for more efficient packing and planting.
2. Undercutting before lifting: The cutting of roots in the nursery seedbed by means of a cutting blade drawn horizontally through the soil at a predetermined depth. The blade may be reciprocating or fixed (figure 7-8).
3. Wrenching. A modified form of undercutting in which seedbeds are undercut periodically at different depths during the growing season, using a tilted blade. Either fixed or reciprocating blades may be used (Edgren 1975).
4. Lateral root pruning. The cutting of lateral roots in place in the nursery seedbeds by means of rolling coulters or knife blades drawn between drills or rows of seedlings (figure 7-9).

Trimming of excessively long laterals and tap roots before baling or bagging is a standard practice in some nurseries. Roots may be cut with a hatchet or machette and chopping block, or with a band saw on a grading table. When carefully done, this practice should not affect survival or growth of seedlings in the field. This operation makes planting easier and may have a beneficial effect on field survival because the root system is more likely to be contained within the planting hole or trench.

Undercutting and wrenching are used to:

1. Prevent excessive height growth of larger seedlings in the seedbed.
2. Create a more fibrous root system to increase the water-absorbing surface area of the seedling root.
3. Improve the shoot:root ratio of seedlings by reducing the shoot height, stem diameter and weight while increasing the size of the root system.
4. Accelerate dormancy.
5. Increase the yield of plantable seedlings.
6. Increase the ease of planting.
7. Increase the survival of outplanted seedlings.

Research shows that undercutting or wrenching has consistently fulfilled one or more of these objectives (Shoulders 1959, 1972; Davey 1964; Sutton 1967; Dykstra 1974; Edgren 1975; Tanaka et al, 1976; Koon and O'Dell 1977; Bacon and Hawkins 1979).

### Undercutting

Undercutting has been a standard operation in many southern nurseries to restrict the growth of large seedlings, sever long taproots, loosen the soil to improve aeration and infiltration and possibly stimulate growth of small seedlings. Beds are undercut at a depth of 6 to 7 inches when the majority of the seedlings reach the desired height for planting, i.e., usually in late August to October. One pruning during the season, regardless of when it is done, is not adequate to significantly increase the uniformity of the stock at the time of lifting. Two or more undercuttings give better control of shoot growth than one.

### Wrenching

Wrenching is an operational procedure in some New Zealand and Australian nurseries and has been tested in nurseries in the United States. The major use of wrenching in southern nurseries may be to: (1) hasten dormancy,

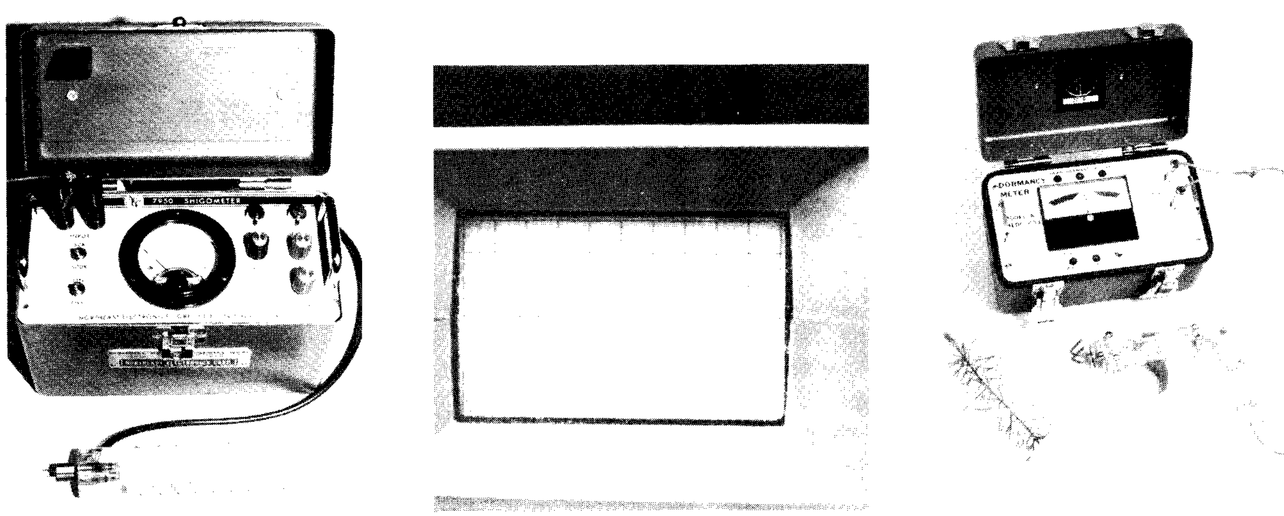

**Figure 7-7. —Shigometer, oscilloscope and dormancy meter. (left to right)**

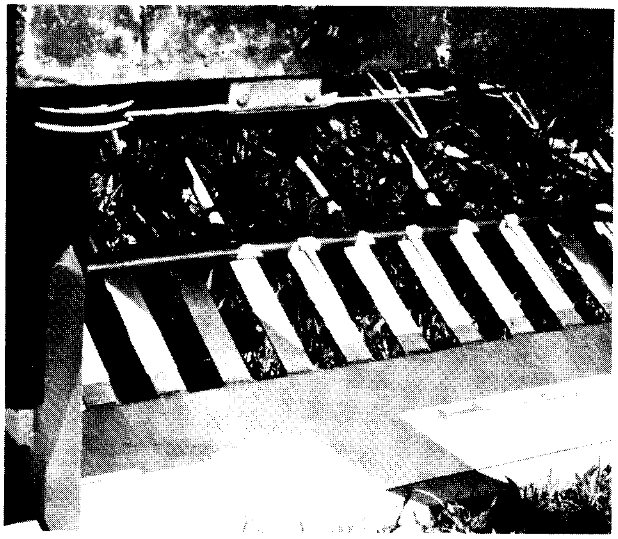
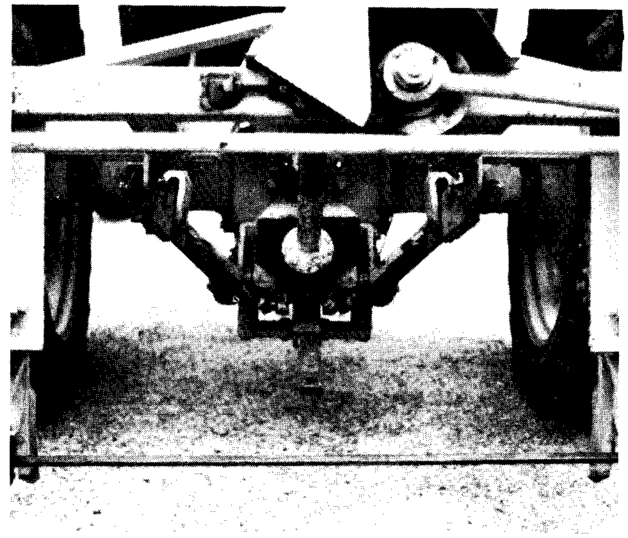

**Figure 7-8.—Undercutting blade (left) and reciprocating wrencher (right). (Right photo—Whitfield Mfg. Co.)**

i.e., create a dormant condition as early as October or November, and (2) develop a mass of short, fibrous roots on seedlings to be planted in shallow mountain soils. The depth of the first wrench is 3 to 4 inches. Wrenching at either weekly or biweekly intervals has produced similar results. Wrenching can kill many seedlings, especially if seedbeds are permited to become dry. Seedbeds should not be watered until at least 30 percent of the seedlings wilt however.

Seedbeds should not be watered immediately before cutting. In wet soils, the pressure of the blade loosens the root ends and pushes them forward rather than cutting them. These treatments may create a physiological shock from which the seedling may not recover for several weeks or months. More studies are needed before wrenching is adopted as a standard cultural treatment in the South.

Both undercutting and wrenching may create a thin compact layer (pan) at the interface of the soil and the cutting blade. This layer may form an impermeable barrier to the movement of water and air through the soil, especially in fine-textured soils such as loams, clay loams and silt loams. This impervious layer may become a habitat for active soil pathogens. Tap and lateral roots near this layer may turn black and die. The second- and third-order laterals and mycorrhizal roots may disappear.

A tractor used for undercutting should be powerful enough to maintain a constant speed and should be equipped to accurately maintain the depth of the blade in the soil. The blade should be rigid, thin, sharp and absolutely horizontal at the cutting depth so that it will cut the roots cleanly with a minimum of disturbance to the soil. Frequently sharpening of the blade is mandatory with both undercutting and wrenching.

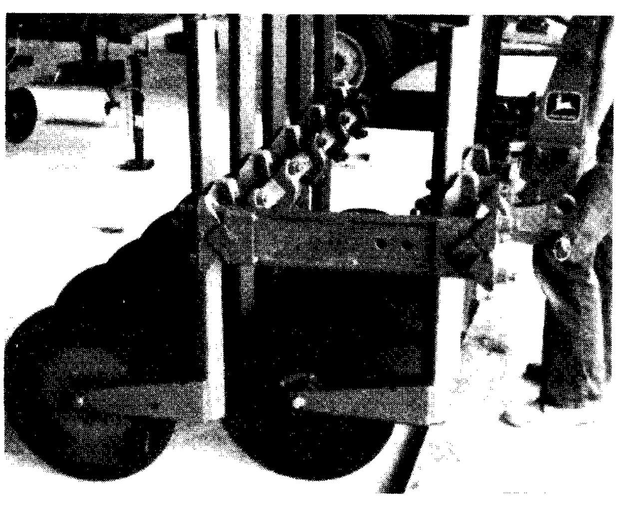
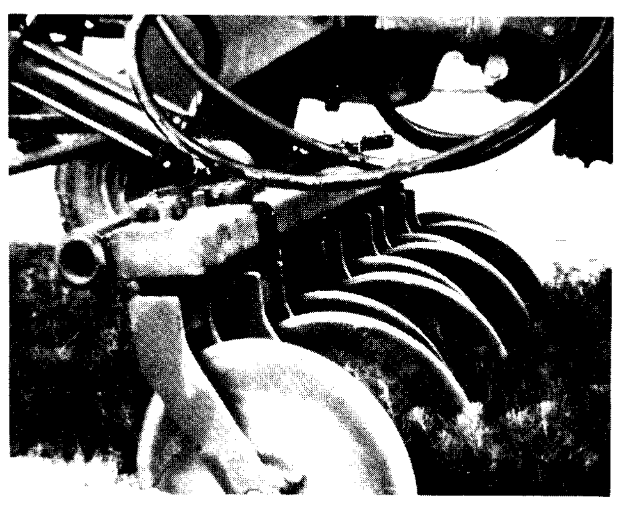

**Figure 7-9. — Lateral root pruners.**

## Lateral Root Pruning

Lateral root pruning is not a new practice, but its increased use in recent years was brought about by the use of mechanical seedling harvesters. The one- or two-row belt lifters pull seedlings from the soil without undercutting. Many lateral roots occupy the space between the rows of seedlings, particularly with loblolly seedlings. These roots of adjacent seedlings tend to intertwine. As the belt pulls the seedlings from the soil the intertwined roots strip and break, causing an excessive loss of lateral and mycorrhizal roots. Measurements before and after such lifting reveal that from ⅓ to ½ of the lateral roots remain in the soil. Lateral root pruning cuts the intertwined roots from adjacent drills and allows lifting without stripping, this reduces the loss of lateral roots during lifting.

The problem is slightly different with the 8-row belt lifters and the full-bed (Grayco) lifters. Much of the root system is removed from the soil in the initial lifting, but many of the small roots are removed by the root beaters. However, the intertwined roots that remain still hold many seedlings together. As the seedlings are pulled apart for packaging and planting many of the laterals are lost or damaged.

## Timing of Root Pruning

Timing may greatly influence root regeneration. Severed roots will decompose and the ends of cut roots will form callouses. New roots will develop on the laterals and occasionally on the main or tap root. Budlike root primordia may develop near the callous tip. A June or July lateral pruning may affect only 10 to 15 percent of the seedlings. By August, more than 50 percent of the seedlings should be affected by pruning on two sides. New roots may form slowly after early summer pruning, but growth of existing roots may be stimulated. Seedlings pruned in early fall will form new roots near the point of severance. Seedlings pruned on both sides respond better than ones pruned on one side at a time.

Pruning of lateral roots in October or 2 to 3 months before lifting is better than pruning immediately before the lifting operation. The stimulation of lateral root formation during the 2 to 3 months before lifting can have the beneficial effect of increasing field survival.

Seedlings with poorly developed root systems may respond better to root pruning and replace the severed roots more abundantly than those with good root systems.

Two types of lateral root pruners are: (1) tractor-mounted, vertical knife blades that are adjustable to a maximum depth of 8 inches, and (2) rolling coulters mounted on a single axle or alternately on tandem axles (figure 7-9). The rolling coulter-type, lateral root pruners are more effective than the knife-type pruners. A new lateral pruner is available which can be steered from the pruner frame, allowing precise alignment with the seedling drills.

# TOP PRUNING OR CLIPPING

Pruning of seedling stems in conifer nurseries has been practiced intermittently since the mid-1930's. The objectives have been to improve the shoot:root ratio, stop height growth of large seedlings, obtain more uniform planting stock and increase field survival. Results have varied between and within nurseries and between and within species. The best response has been obtained by clipping needles of longleaf pine seedlings. Even this has created occasional problems such as infection of brown spot needle blight on the clipped needles (Allen and Maki 1951, Allen 1955, Mullin 1957, Stoeckeler and Jones 1957, Lanquist 1966, Dierauf 1976, and Kais 1978). Top pruning has been done with rotary mowers, sickle-bar mowers and a reel-type cutter designed by Hammermill Paper Company personnel (figure 7-10). Plans for the Hammermill top pruner are available from the USDA Forest Service's Equipment Development Center, Missoula, Montana 59801.

Top pruning of succulent stems of southern pine seedlings has an effect similar to top-moth attack on the terminal shoot. Stem elongation is stopped until the shoot can form new buds and resume growth. Diameter growth of clipped seedlings is reduced slightly or not at all (Dierauf 1976 and Dierauf and Olinger 1982), but top clipping does not seem to have a significant effect on the size of the root system (Dierauf 1976). Current information on top pruning or clipping indicates:

1. Clipping or top pruning can increase survival of field planted seedlings without affecting future height growth of planted seedlings.
2. Clipping should be limited to the succulent part of the shoot.
3. Clipping of woody stems can be harmful. The adverse effects increase with age and size of the seedlings.
4. September clipping has been better than August or October clipping although the dates differ in different sections of the region. Best results have been obtained in Alabama by clipping twice at about a 1-month interval (August-September).
5. Clipping stops height growth for about 3 weeks. Buds develop just below the cut. Height growth resumes when these buds begin to lengthen.
6. Clipping produces seedlings of a more uniform height. Clipping may release shorter, nonclipped seedlings which continue to grow and compete with the clipped seedlings. These seedlings may have been slow to germinate or possibly slow in their early

growth. As a rule the smaller seeds are slower to germinate and produce seedlings with a slower early-growth rate than do larger seeds.

7. The rate of diameter growth of shorter, non-clipped seedlings is greater than that of clipped seedlings.
8. Top:root ratios are improved by clipping.
9. Clipping may result in fewer small seedlings or culls.
10. Clipping before October 1 does not result in forking of the field-planted seedlings (Dierauf 1976).

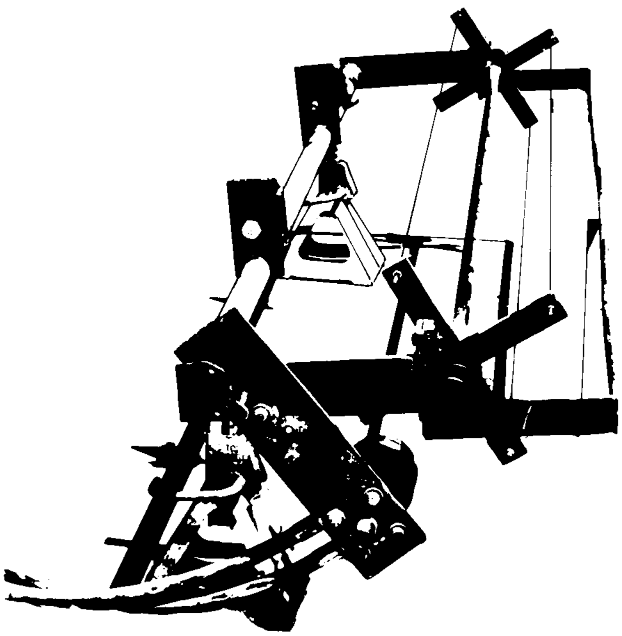

**Figure 7-10. — Hammermill top pruner.**

## GROWTH REGULATORS

The growth of plants is affected by a number of substances in addition to nutrients, minerals and water. Some of these promote vegetative growth and others inhibit it. Growth regulators or growth substances are general terms which include all organic compounds other than nutrients which, at very low concentrations, promote, inhibit or qualitatively modify growth. These substances have been of interest to nursery managers because they could modify nursery operations. Surplus seedlings left in the nursery beds after the normal planting season might be treated to inhibit growth so that they could be planted later in the year or held as 2-0 stock until the following winter. Major advantages of extending the planting season are that (1) it would be possible to plant more acres with fewer persons or machines, but over a longer period of time; and (2) would allow more choice of times for planting critical sites. Occasionally excess seedlings have been carried as 2-0 stock by using periodic top and/or root pruning. Even then, southern pine seedlings usually get too big for economical handling.

Paul (1966) and Mizell (1964) discussed trials of chemical growth substances on southern pine seedlings. Intensive testing of the growth inhibitor Maintain-CF125 began in 1971. This material has been used in trials reported by Gill and Newbold (1979). This compound interferes with the development of the early stages of growth and acts systemically, i.e., is translocated from the needles to the meristematic tissue. Information to date on the use of Maintain indicates:

1. Maintain should be applied when the buds break in the spring.
2. Buds turn brown and die on seedlings treated after the buds elongate. The plant will develop new buds but will remain quiescent until about August.
3. Seedlings treated before bud break will have to be retreated.
4. Once Maintain is successfully applied, no additional treatment is required.
5. Height growth is retarded, but the diameter growth continues. Stems tend to grow pear-shaped or cone-shaped as a layer of wood resembling summerwood is built up.
6. Root systems become more fibrous.
7. Shoot:root ratios are lower.
8. The Maintain treatment is no longer noticeable 2 to 3 years after planting.
9. Maintain or other growth inhibitors may be more effective than cold storage in extending the length of the planting season.

## SUMMARY

Growth and development of seedlings begins with germination and continues until the seedlings become dormant. As seeds germinate, the radicle emerges and develops into the primary root. The root elongates rapidly and grows downward into the soil, anchoring the plant. As germination continues, the hypocotyl lengthens rapidly, arches upward and straightens out. The seed coat sheds, spreading the cotyledons apart into a rosette, revealing the primary needles.

After the primary needles are established, growth of the seedlings depends on soil fertility, soil moisture and temperature. The curve for height growth of pine seedlings is sigmoidal, showing a rapid growth rate followed by a slower rate. Stem diameters increase slowly during the first few months and this increase is negatively correlated with seedling density in the seedbeds. Periods of slow growth or quiescence, followed by periods of rapid growth, may occur several times during the growing season.

Stems should be 6 to 12 inches in length by early September depending on species, soil fertility and effects of cultural treatments. Mycorrhizal development should be noticeable by mid-summer and fruiting bodies should appear in late fall. Some seedlings may develop terminal buds in August, others later; some may not develop terminal buds before lifting. Top pruning, undercutting or wrenching may be used to retard growth and develop more uniformity of size of seedlings in the seedbeds.

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# APPENDIX 7-1—METHODS FOR ESTIMATION OF ROOT VOLUME

Austin (1965) devised a procedure for measuring root volumes using two Lucite tubes (figure 7-11). One end of the smaller tube is cemented to the larger tube and the other end is sealed. The smaller tube is calibrated in cubic centimeters to 110 cc. The open end of the larger tube is fitted with a collar that has been threaded to take a plastic screwcap. The screwcap has a 1/8-inch thick polyurethane liner to make a watertight seal. To calibrate, the device is oriented

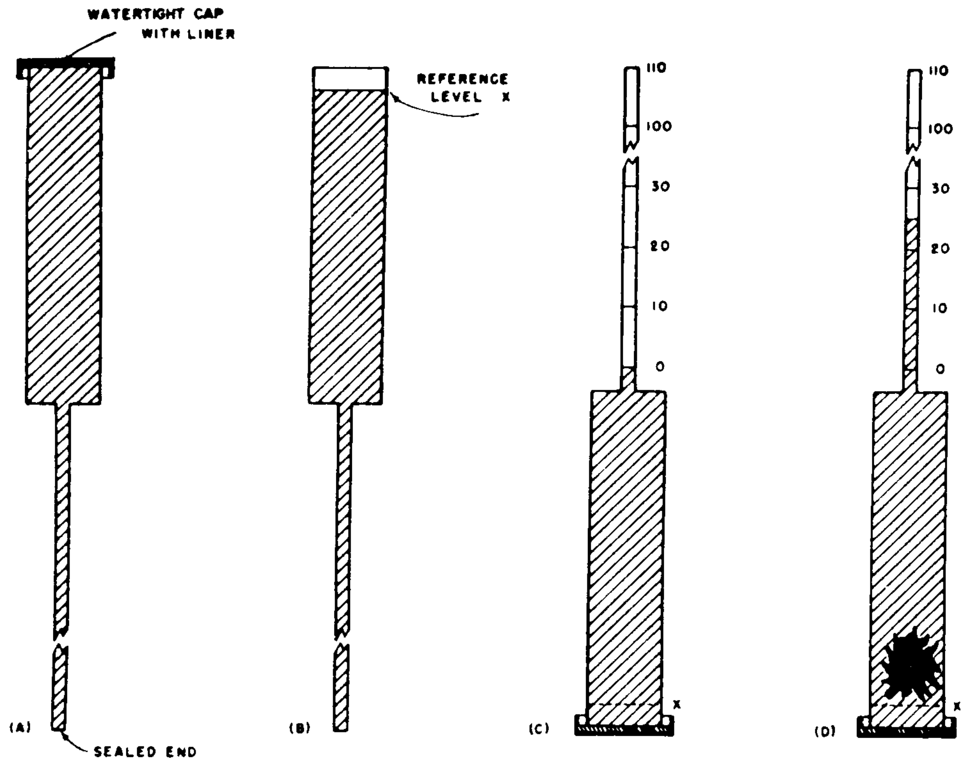


**Figure 7-11. — Root volume measuring cylinder.**

as in figure 7-11(b). The tube is completely filled with water, and then 110 cc are withdrawn figure 7-11 (C). Thus, when the device is inverted, the water level reaches a point marked zero (figure 7-11 (d)) on the calibrated tube. In use, the device is filled with water to reference level X (figure 7-11 (C)). The roots are placed in the large-diameter tube, the device inverted, and the volume of root read from the calibrated tube (figure 7-11 (C)).

Edgren and Iyer (1979) describe a simpler method of volumetric ratio determination. The analytical equipment includes a metal or plastic container large enough to accommodate either roots or stems of seedlings to be analyzed. A piece of lead weighing about 200 or 250 grams serves as a sinker. In most cases, a container 7 inches in diameter and about 18 inches high with a volume of about 2½ gallons or 10 liters, is sufficient. Near its top, the container is provided with a faucet-shaped discharge tube (figure 7-12). The sinker has a hole or an eye for attachment of a clamp or a hook and a 2-foot long string. For the sake of convenience, the sinker should be cut so its volume, together with the clamp, attains a round shape, about 20 or 30 centimeters. The number of seedlings used in each analysis varies from 10 to 20, depending on their size. Wash the seedlings in a stream of water to remove any soil and preclude a

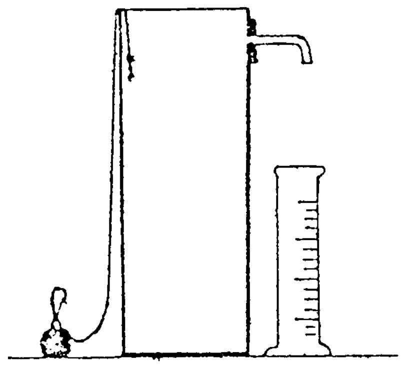

**Figure 7-12. — Immersion system for root-shoot determinations.**

decrease of the container's water by its absorption into dry tissues. Remove excess water by shaking or blotting the seedlings. For maximum accuracy, separate the roots from the tops at the ground line. Fill the container with water until the excess flows out the discharge tube. Tie roots near their thick ends with a string, attach the sinker with the long string, and immerse the root bundle in the water. Collect the discharge water in a graduated cylinder, and record the volume of the roots minus the volume of the sinker as cubic centimeters of water in the graduated cylinder. Follow the same procedure in the analysis of the tops. The method can be modified by using the entire seedling; simply make successive hand immersions of roots and tops. (The addition of a household detergent (1 gram per liter) to the water would minimize the entrapment of air bubbles).