learning objectives
- Define the major systems for seedling production.
- Describe the procedures for direct-seeding crops.
- Describe the procedures for seedling production in temporary nursery beds.
- Describe the procedures for producing transplants under protected culture.
- Define the procedures for transplanting to permanent locations.

INTRODUCTION
Producing plants from seeds is the most important propagation method for agronomic, forestry, vegetable, and flowering bedding plants. These methods vary from field seeding operations to very sophisticated greenhouse transplant production systems. For example, vegetables may be started by direct field seeding or from transplants. Bedding plants and herbaceous perennials are started primarily as transplants grown in small transplant containers called plugs. Woody seedlings are usually started from field transplant beds at close spacing to produce bare-root liners for nursery production or understocks for grafting.

Seedling propagation involves careful management of germination conditions and knowledge of the requirements of individual kinds of seeds. Success depends on fulfilling the conditions detailed in the previous chapters on seeds. These include:

1. Using seeds of proper genetic characteristics to produce the cultivar, species, or provenance desired. This can be accomplished by obtaining seeds from a reliable dealer, buying certified seed, or—if producing one’s own—following the principles of seed selection described in Chapter 5.
2. Using good-quality seeds. Seeds should germinate rapidly to withstand possible adverse conditions in the seed bed and provide a high percentage of usable seedlings.
3. Manipulating seed dormancy. This is accomplished by applying pregermination treatments or by properly timing planting.
4. Supplying proper environment to the seeds and resulting seedlings, including supplying sufficient water, proper temperature, adequate oxygen, and either light or darkness (depending on the kind of seed) to the seeds and resulting seedlings until they are well established. A proper environment also includes control of diseases and insects and prevention of excess salinity.

SEEDLING PRODUCTION SYSTEMS
Although many horticultural production systems rely on seedling propagation, these systems can vary depending on the crop being produced. Therefore, there are three basic systems that are relied upon to produce seedlings:

1. Field seeding at relatively low density in the location where the plant is to remain during the production cycle.
2. Seeding in field nurseries at relatively high density to produce seedlings that will be transplanted to a permanent location.
3. Seeding in protected conditions, as in a greenhouse, cold frame, or similar structure, and then transplanting to the permanent location.

Field Seeding

Direct field seeding is used for commercial field planting of agronomic crops (grains, legumes, forages, fiber crops, oil crops), lawn grasses, many vegetable crops, and some woody perennials (Fig. 8–1). The method may also be used by hobbyists for home vegetable and flower gardens. Compared to transplants, directly seeded plants are less expensive and can grow continuously without the check in growth often seen by transplanting (53). Frequently, direct-field-seeded vegetables and other crops are precontracted for processing, whereas the more expensive transplants are targeted as a fresh market crop. On the other hand, there are many potential field problems that must be overcome to provide the proper environmental conditions for good uniform germination. Likewise, cold weather may decrease growth. Seeding rates are critical to providing proper plant spacing for optimum development of the crop. If the final plant density is too low, yields will be reduced because the number of plants per unit area is low; if too high, the size and quality of the finished plants may be reduced by competition among plants for available space, sunlight, water, and nutrients.

The following factors maximize direct-seeding success:
1. Good site selection and seed bed preparation
2. Using high-quality seed
3. Planting at the correct time
4. Seed treatments to facilitate sowing or to relieve dormancy
5. Selecting an appropriate mechanical seeder
6. Using the correct sowing depth
7. Sowing seed at an appropriate rate
8. Applying proper postsowing care

Field Seeding for Vegetable Crops

Direct field seeding is a common propagation method for many vegetable crops including corn, peas, beans, and spinach.

Site Selection and Seed Bed Preparation. The ideal site for vegetable production is relatively flat with good soil water drainage. High production areas such as California and Texas often use laser-assisted grading to produce a level seed bed (Fig. 8–2a, page 252). A good seed bed should have a loose but fine physical texture that produces close contact between seed and soil so that moisture can be supplied continuously to the seed. Such a soil should provide good aeration, but not too much or it dries too rapidly. The surface soil should be free of clods and of a texture that will not form a crust (Fig. 8–2b). Soil impedance due to crusts from an improperly prepared seed bed or adverse environmental conditions during seeding can substantially...
reduce seedling emergence (61). Several materials, including organic polymers and phosphorus-containing compounds, have been developed to reduce soil crusting and to aid in seedling emergence (53, 55). The subsoil should be permeable to air and water with good drainage and aeration. Adequate soil moisture should be available to carry the seeds through germination and early seedling growth stages, but the soil should not be waterlogged or anaerobic (without oxygen). A medium loam texture, not too sandy and not too fine, is best. A good seed bed is one in which three-fourths of the soil particles (aggregates) range from 1 to 12 mm in diameter (39).

Seed bed preparation requires special machinery for field operations, and spading and raking or rototilling equipment for small plots (Fig. 8–2). Adding organic or soil amendments may be helpful, but these should be thoroughly incorporated and have time to decompose. Seed bed preparation may include soil treatments to control harmful insects, nematodes, disease organisms, and weed seeds. Weed control can be facilitated by careful seed bed preparation, cultivation, and may include chemical herbicide application (see Chapter 3). Three types of chemical controls are available:

1. Preplant fumigation is effective and also kills disease organisms and nematodes.
2. Pre-emergence herbicides can be applied before the weed seeds emerge but can reduce germination of the desired species.
3. Post-emergence herbicides can be applied as soon as the weed seedlings emerge.

Wide ranges of selective and nonselective commercial products are available. Such materials should be used with caution, however, since improper use can cause injury to the young nursery plants. Not only should the manufacturers’ directions be followed, but also preliminary trials should be made before large-scale use.

Select High-Quality Seed. Quality is based on seed testing data, as discussed in Chapter 7. A low sowing rate requires high-quality seeds that produce not only high germination percentages but also vigorous, uniform, healthy seedlings.

Choose Correct Planting Times. Planting time is determined by the germination temperature requirements of the seed, available soil moisture, and the need to meet production schedules. These are determined according to the individual crop and vary with the particular kind of seed. Early season sowing of seeds that require warm soil temperatures can result in slow and uneven germination, disease problems, and “chilling” injury to seedlings of some species, causing growth abnormalities. High soil temperatures can result in excessive drying, injury, or death to seedlings, or induction of thermudormancy in the case of heat-sensitive seeds such as lettuce, celery, and various flower seeds (see Chapter 21).

Seed Treatments to Facilitate Sowing. It is often desirable to use seeds that have been pretreated for protection with a pesticide (fungicide and/or insecticide)
or enhanced for germination by a seed coating or priming treatment (see Chapter 6). These treatments can speed up germination, increase uniformity, and offset some environmental hazards in the seed bed. Coated seeds have improved flowability, and uniform size can improve the seeding precision of mechanical planters.

Choose the Proper Mechanical Seeder for Outdoor Planting. The first mechanical seed drill was developed by Henry Smith in 1850 (37). Today, most field-sown crops are seeded mechanically. Selection of a seeder is determined by the following:

1. Size and shape of the seed
2. Soil characteristics
3. Total acreage to be planted
4. Need for precision placement of the seed in the row

Mechanical seeders contain three basic components: a seed hopper for holding seeds and a metering system to deliver seeds to the drill. A drill opens the furrow for planting the seed. The drill controls seeding depth and must provide good seed-to-soil contact while minimizing soil compaction that might impede seedling emergence. The most common type of drill is a simple “Coulter” drill that places seeds into an open furrow. “Dibber” drills that punch individual holes to place seed have also shown good seeding performance (21, 27). In some cases, a press wheel may be used to help cover the seed, and attachments to the seeder may supply fertilizer, pesticides, or antircrusting agents before or after depositing the seed.

Mechanical seeders (Fig. 8–3) are available as either random or precision seeders (9, 53).

Random seeders meter seed in the row without exact spacing. They are less complex than precision seeders and are useful when spacing between plants in the row is not critical, and thinning is not applied to achieve final plant stand as in many agronomic crops. Random seeders use gravity to drop seeds through holes located at the bottom of the hopper. The size of these holes and tractor’s speed determine the seeding rate.

Precision seeders selectively meter seed from the hopper to maintain a preset spacing in the row, and can greatly reduce the number of seeds required to seed an acre compared to random seeding. For example, to achieve the same stand for California lettuce, seeding rates were reduced by

![Figure 8-3](image-url) Examples of field seeding machinery. (a) A single row  Planet Junior. (b) A row crop seeder used for crops such as corn. (c) A multiple row seeder for drilling grasses. (d) A precision row seeder for vegetable crops.

coated seeds  Seeds with an altered shape that makes them easier to sow with precision seeding machines. The coating may also improve flowability, which is the ability for seeds to flow out of the seeder.
84 percent using precision, compared with random seeders (40). Precision seeders use a separate power take-off on the tractor drive to power the planter and control seeding rate. Several types of precision seeders are available. These include belt, plate, wheel, and vacuum seeders (9).

The belt seeder uses a continuously cycling belt that moves under the seed supply. Holes in the belt at specified intervals determine seed spacing. When operating correctly, one seed will move by gravity to occupy one hole on the belt and be released as it passes over the furrow.

The plate seeder also uses gravity to fill holes in a metal plate rotating horizontally through the seed hopper. The number of holes in the plate and the speed of plate rotation determine seed spacing.

The wheel seeder employs a rotating wheel oriented in a vertical position at a right angle to the bottom of the seed hopper. Seed fills the opening at the top of the wheel (bottom of the hopper) by gravity and is carried 180 degrees where it is deposited into the furrow opening.

Vacuum seeders (Fig. 8–4) are replacing gravity seeders in the vegetable industry because they can more precisely deliver single seeds at a specified row spacing, especially small seeds (like tomato), irregularly shaped seeds (like lettuce), or uncoated seeds (41). In a comparison of vacuum and belt seeders using several different vegetable seeds (56), no difference was observed for seed placement for carrot or onion seeds. The belt seeder performed better for cabbage seed, while the vacuum seeder was more precise for cucumber seed placement. The vacuum seeder utilizes a vertical rotating plate in the hopper with cells under vacuum that pick up a single seed. Seeds are released into the planting furrow by removing the vacuum in the cell as it rotates above the seed drop tube or planting shoe (54). A “singulator device” helps displace extra seeds prior to planting. Some vacuum seeders use a burst of air to clean the cell after the seed has been dropped to avoid skips from a clogged seed hole.

For all precision seeders, different sized holes in belts or plates can be used for seeds of different species that are different sizes. In many cases, uniform seed size or pelleted seeds improve the precision of in-row spacing. However, because of seed quality, environmental factors, insect, disease, or animal predation, seeds are usually spaced at a higher density than is optimum for a final stand, and the grower must physically thin seedlings to the desired plant density following emergence. Most direct-seeded vegetable crops are planted with precision seeders.

Seeders have also been adapted for direct-seeding vegetable crops in no-till production systems (52, 76). The challenge in reduced tillage systems is planting through existing crop residue or covercrops to establish an adequate plant stand.

In addition to conventional seeders, gel seeders used for fluid drilling have been developed to deliver pregerminated seeds (see pregermination, page 188). Pregerminated seeds are incorporated into a gel and extruded or fed into the furrow via a pumping system or by having the seed tank under pressure using compressed air (53). Although this method can improve seedling
emergence (especially under adverse environmental conditions), gel seeding is still only a minor planting system compared with conventional seeding of dry seeds because of the cost and complexity of the operation (41).

**Use Correct Sowing Depth.** Depth of planting is a critical factor that determines the rate of emergence and stand density. If too shallow, the seed may be in the upper surface that dries out rapidly; if too deep, emergence of the seedling is delayed. Depth varies with the kind and size of seed and, to some extent, the condition of the seed bed and the environment at the time of planting. When exposure to light is necessary, seeds should be planted shallowly. A rule of thumb is to plant seeds to a depth that approximates three to four times their diameter.

**Determine Proper Sowing Rate.** The sowing rate is critical in direct sowing in order to produce a desired plant density. This rate is a minimum and should be adjusted to account for expected losses in the seed bed, determined by previous experience at that site. Many seed companies will help producers set up spacing requirements for direct-seeding precision planting equipment.

Rates will vary with the spacing pattern. Field crops or lawn seeds may be broadcast (i.e., spaced randomly over the entire area) or drilled at given spaces. Other field crops, particularly vegetables, are row planted, so that the rate per linear distance in the row must be determined. Crops may be grown in rows on raised beds, particularly in areas of low rainfall where irrigation is practiced and excess soluble salts may accumulate to toxic levels through evaporation. Overhead sprinkling and planting seed below the crest of sloping seed beds may eliminate or reduce this problem.

**Supply Postplanting Care.** Adequate moisture must be supplied to the seed once the germination process has begun. In many areas, there is adequate natural rainfall to support seed germination. In areas with irregular rainfall, supplemental irrigation is usually supplied by overhead sprinklers, subsurface furrow flooding to raised seed beds, or by trickle irrigation (Fig. 8–5, page 256). The soil should also be kept from drying out and developing a crust. This is primarily a function of seed bed preparation but may be avoided by light sprinkling, shading, and covering with light mulch. With row planting, excess seed is planted, and then the plants are thinned to the desired spacing. Thinning is expensive and time-consuming and can be reduced by precision planting. Competition from weeds must also be controlled by herbicide, tillage, or mulching to ensure a vigorous seedling stand.

**Field Nurseries for Transplant Production**

Outdoor **field nurseries** where seeds are planted closely together in beds are used extensively for growing transplants of conifers and deciduous plants for forestry (62), for ornamentals (19, 44), to provide understock liners for some fruit and nut trees species (Fig. 8–6, page 256) (28, 43, 60), and vegetable transplants (Fig. 8–7, page 257) (24). The conditions for optimum seed germination and seedling emergence are very similar to those previously described for field-seeding vegetables. However, field transplant nurseries produce seedlings at a close spacing using smaller acreage and more controlled management. It is more common to produce woody plant seedlings in transplant nurseries than direct-sowing them to a permanent location. Practices for successful production in a transplant nursery include:

1. Site selection and seed bed preparation
2. Time of the year for sowing

**BOX 8.1 GETTING MORE IN DEPTH ON THE SUBJECT**

**CALCULATING SOWING RATE**

The following formula is useful in calculating the rate of seed sowing (23, 44):

\[
\text{Density (plants/units area) desired} = \frac{\text{Weight of seeds to sow per unit area}}{\times \text{Purity percentage}} \times \frac{\times \text{Germination percentage}}{\times \text{Field factor}} \times \text{Seed count (number of seeds per unit weight)}
\]

*Expressed as a decimal.

Field factor is a correction term that is applied based on the expected losses that experience at that nursery indicates will occur with that species. It is a percentage expressed as a decimal.
Site Selection and Seed Bed Preparation  

Nursery production requires a fertile, well-drained soil of medium to light texture. Site selection and preparation for planting may include rotation with other crops and incorporation of a green manure crop or animal manure (65). Preplant measures for weed control are essential aspects of most nursery operations.

A common size of seed bed is 1.1 to 1.2 m (3.5 to 4 ft) wide with the length varying according to the size of the operation. Beds may be raised to ensure good

Figure 8–5  
Irrigation examples. (a) Spinach crop on central pivot irrigation. The elevated pipe and irrigation heads travel through the field. (b) A lettuce crop being irrigated after sowing with movable pipes. These will be located temporarily in one field and moved to other fields as necessary. (c) A sunflower crop being furrow irrigated. Water is siphoned out of the main canal to temporarily flood each row.

Figure 8–6  
Field seeding for woody plant liner production. (a) Seed bed prepared for sowing. Each bed is approximately 4 ft wide. (b) These beds are covered with burlap to help retain moisture (c and d) These pine and barberry seedlings were sown with a five-row drill to permit cultivation for weed control.
drainage, and, in some cases, sideboards are added after sowing to maintain the shape of the bed and to provide support for glass frames or lath shade. Beds are separated by walkways 0.45 to 0.6 m (1.5 to 2 ft) wide. North-south orientation gives more even exposure to light than east-west orientation.

Seeds may be either broadcast over the surface of the bed or drilled into closely spaced rows with seed planters. For economy, seeds should be planted as closely together as feasible without overcrowding, which increases damping-off and reduces vigor and size of the seedling (35), resulting in thin, spindly plants and small root systems. Seedlings with these characteristics do not transplant well (34).

**Time of the Year for Sowing** Several vegetable species, including tomato, pepper, cabbage, broccoli, and onion, can be produced from transplants produced in field nurseries. This is an alternative to direct seeding and is less expensive than container-grown transplants produced in greenhouses. Warm-season crops are usually seeded in spring and may be covered with plastic or fabric (floating) row covers to prevent frost injury (Fig. 8–7b). Cool-season crops are seeded in early spring or summer for a fall harvest.

For many species (especially woody and herbaceous native plants), seeds must be treated to overcome seed dormancy conditions (see Chapter 7). The two most common treatments used by commercial propagators include scarification for species with hard seed coats, and stratification for species that require periods of warm or chilling conditions to alleviate dormancy.

**Scarification.** Scarification is the process of physically or chemically altering the seed coverings to improve germination in dormant seeds. It is a horticultural necessity for species with physical dormancy (hard, impermeable seed coats) to permit water uptake. Such seeds include members of the legume, geranium, morning glory, and linden families. Scarification (usually in the form of brushing) is also commonly applied to cereals and grasses to remove the structures covering the caryopsis (glumes, palea, and lemma) that can reduce germination. Three types of treatments are commonly used as scarification treatments. These include mechanical, chemical, and heat treatments.

**Mechanical Scarification.** Mechanical scarification is simple and effective with seeds of many species, and commercial equipment is available that tumbles seeds in drums against an abrasive material (Fig. 8–8). These seeds are dry after such treatment and may be stored or planted immediately by mechanical seeders. Scarified seeds are more susceptible to injury from pathogenic organisms, however, and may not store as well as comparable non-scarified seeds.

Small amounts of relatively large seeds can be scarified by rubbing with sandpaper, abraded with a file, or cutting with clippers (Fig. 8–8). For large-scale mechanical operations, commercial scarifiers are used. Small seeds of legumes, such as alfalfa and clover, are...
part two seed propagation

often treated in this manner to increase germination (14). Seeds may be tumbled in drums lined with sandpaper or in concrete mixers containing coarse sand or gravel (7, 62). The sand or gravel should be of a different size than the seed to facilitate subsequent separation of the sand from the seed prior to sowing. Scarification should not proceed to the point at which the seeds are injured. The seed coats generally should be dull but not so deeply pitted or cracked as to expose the inner parts of the seed. To determine the optimum time a test lot can be germinated, the seeds may be soaked to observe swelling, or the seed coats may be examined with a hand lens.

Chemical (Acid) Scarification. Dry seeds are placed in containers and covered with concentrated sulfuric acid in a ratio of about one part seed to two parts acid (see Box 8.2). The amount of seed treated at any one time should be restricted to no more than about 10 kg (22 lbs) to avoid uncontrollable heating. Containers should be glass, earthenware, or wood—not metal or plastic. The mixture should be stirred cautiously at intervals during the treatment to produce uniform results and to prevent accumulation of the dark, resinous material from the seed coats, which is sometimes present. Since stirring tends to raise the temperature, vigorous agitation of the mixture should be avoided in order to prevent injury to the seeds. The time of treatment may vary from as little as 10 minutes for some species to 6 hours or more for other species. Since treatment time may vary with different seed lots, making a preliminary test on a small lot is recommended prior to treating large lots (36, 47).

At the end of the treatment period, the acid is poured off, and the seeds are quickly washed to remove any acid residue. Glass funnels are useful for removing the acid from small lots of seed. Placing seeds in a large amount of water with a small amount of baking soda (sodium bicarbonate) will neutralize any adhering acid, or the seeds can be washed for 10 minutes in running water. The acid-treated seeds can either be planted immediately when wet or dried and stored for later planting.

Large seeds of most legume species respond to the simple sulfuric acid treatment, but variations are required for some species (47). Some roseaceous seeds (Cotoneaster, Rosa) have hard pericarps that are best treated partially with acid followed by warm stratification. A third group, such as Hamamelis and Tilia, have very “tough” pericarps that may first need to be treated with nitric acid and then with sulfuric acid.

High Temperature Scarification. In nature, physical dormancy appears to be relieved most often by high temperature exposure. This process can be mimicked by placing seeds on moist or dry sand at temperatures above 35°C (95°F). The requirement for moist or dry heat, as well as the temperature and duration of the treatment, varies between species (4, 51).

Hot water scarification is a common alternative to acid and mechanical scarification (64), but it usually yields more variable results. Drop the seeds into 4 to 5 times their volume of hot water 77 to 100°C (170 to 212°F). Seeds can be treated for several minutes, but prolonged exposure to heat will kill them. Start by removing the seeds immediately after exposure and allow them to soak in the gradually cooling water for 12 to 24 hours. Microwave energy has also been reported to be an effective heat treatment (73). Following heat treatment and imbibition, non-swollen seeds can be separated from the swollen ones by suitable screens and either re-treated or subjected to some other treatment. Usually the seeds should be planted immediately after the hot water treatment; some kinds of seed have been dried and stored for later planting without impairing the germination percentage, although the germination may be reduced.

Stratification. Stratification is a method of handling dormant seeds in which imbibed seeds are subjected to a period of chilling or warm temperatures to alleviate dormancy conditions in the embryo. The term originated because nurseries placed seeds in

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**BOX 8.2 GETTING MORE IN DEPTH ON THE SUBJECT**

**USING ACIDS SAFELY**

Always use proper safety precautions while using acids for scarification, including personal safety equipment like gloves, face shield, eye protection, and lab coat. An eye wash and a source of running water must be available in case of an accident. Request the MSDS safety sheet from your chemical supplier for additional safety precautions. There are several web sites that offer this information including www.msdsssearch.com and www.msdssolutions.com.
stratified layers interspersed with a moist medium, such as soil or sand, in out-of-doors pits during winter (Fig. 8–8). The term moist-chilling has been used as a synonym for stratification. However, with temperate species displaying epicotyl dormancy (like Chionanthus—fringetree) or underdeveloped embryos (like Ilex—hollies), a warm-moist stratification of several months followed by a moist-chilling stratification is required to satisfy dormancy conditions, though it may require more than one season to achieve under natural conditions. Several tropical and semitropical species (like palms) require a period of warm stratification prior to germination to allow the embryo to continue development after fruit drop.

**Outdoor Planting for Stratification.** Seeds requiring a cold treatment may be planted out-of-doors directly in the seed bed, cold frame, or nursery row at a time of the year when the natural environment provides the necessary conditions to relieve dormancy (Figs. 8–9 and 8–10). This is the most common treatment for seeds with endogenous physiological dormancy. Several different categories of seeds can be handled in this way with good germination in the spring following planting.

Seeds must be planted early enough in the fall to allow them to become imbibed with water and to get the full benefit of the winter chilling period. Seeds need to be protected against freezing, drying, and rodents (Fig. 8–11, page 260). The seeds generally germinate promptly in the spring when the soil begins to warm up but while the soil temperature is still low enough to inhibit damping-off organisms and to avoid high-temperature inhibition.

Seeds with a hard endocarp, such as Prunus species (the stone fruits, including cherries, plums, and peaches), show increased germination if planted early enough in the summer or fall to provide 1 to 2 months of warm temperatures prior to the onset of chilling (43). Thus, seeds that require high temperatures followed by chilling can be planted in late summer to fulfill their warm-temperature requirements followed by the subsequent winter period that satisfies the chilling requirement.

**Refrigerated Stratification.** An alternative to outdoor field planting is refrigerated stratification (Fig. 8–12, page 260). This is a useful technique for small seed lots or valuable seeds that require special handling. Dry seeds should be fully imbibed with water prior to refrigerated stratification. Soaking at a warm temperature for 12 to 24 hours may be sufficient for seeds without hard seed coats or coverings.

After soaking, seeds are usually mixed with a moisture-retaining medium for the stratification
period. Almost any medium that holds moisture, provides aeration, and contains no toxic substances is suitable. These include well-washed sand, peat moss, chopped or screened sphagnum moss [0.6 to 1.0 cm (1/4 to 3/8 in.)], vermiculite, and composted sawdust. Fresh sawdust may contain toxic substances. A good medium is a mixture of one part coarse sand to one part peat, or one part perlite to one part peat, moistened and allowed to stand 24 hours before use. Any medium used should be moist but not so wet that water can be squeezed out.

Seeds are mixed with 1 to 3 times their volume of the medium or they may be stratified in layers, alternating with similarly sized layers of the medium. Suitable containers are boxes, cans, glass jars with perforated lids, or other containers that provide aeration, prevent drying, and protect against rodents. Polyethylene bags are excellent containers either with or without media. Stratification of seeds in a plastic bag without a surrounding medium has been called naked chilling (18). A fungicide may be added as a seed protectant. Seeds may also benefit from surface disinfection prior to

Figure 8–11
(a) Wire screen used to protect acorns from rodent and squirrel predation. (b) Nursery fabric used to protect outdoor seed beds.

Figure 8–12
(a) Examples of refrigerated stratification. (a) Small batches of seeds can be mixed with moist vermiculite and placed in polyethylene bags. (b) Conifer (pine) seeds are hydrated and placed in polyethylene bags without any substrate. (c) Hazelnut (Corylus) seeds mixed with a bark substrate in large plastic tubs were placed into large refrigerated storage units. (d) A technician removing seeds that had germinated while being stratified.
imbibition and stratification with a 10 percent bleach solution for 10 to 15 minutes followed by multiple rinses with water to remove the bleach.

The usual chilling stratification temperature is 1 to 10°C (33 to 50°F). At higher temperatures, seeds often sprout prematurely. Lower temperatures (just above freezing) may delay sprouting. No progress toward dormancy release occurs above 15°C (60°F) (26). Warm stratification temperatures are usually above 25°C (77°F) and can be quite high in tropical species, like palms (Fig. 8–13) at 30 to 35°C (85 to 95°F).

The time required for stratification depends on the kind of seed and, sometimes, on the individual lot of seed as well (see Chapter 7). For seeds of most species, 1 to 4 months is sufficient. During this time, the seeds should be examined periodically; if they are dry, the medium should be remoistened. The seeds to be planted are removed from the containers and separated from the medium, using care to prevent injury to the moist seeds. A good method is to use a screen that allows the medium to pass through while retaining the seeds. The seeds are usually planted without drying to avoid injury and reversion to secondary dormancy. Some success has been reported for partially drying previously stratified seeds, holding them for a time at low temperatures, then planting them “dry” without injury or loss of dormancy release. Beech (*Fagus*) and mahaleb cherry seeds were successfully dried to 10 percent and then held near freezing (72). Similarly, stratified fir (*Abies*) seed has been dried to 20 to 35 percent and then stored for a year at low temperatures after stratification (20).

**Sowing Rates for Outdoor Seeding** The optimum seed density primarily depends on the species but also on the nursery objectives. If a high percentage of the seedlings is to reach a desired size for field planting, low

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**Figure 8–13**
Palm seed (a) has morphological dormancy in which the embryo is small (b) and must develop within the seed at moist, warm temperatures before germination can occur. Several seeds are planted in each container that are placed in racks (c), watered, and covered with plastic (d) for several months to relieve morphological dormancy. Containers are moved to the greenhouse where (e) several seedlings emerge per container.
part two seed propagation

densities might be desired; but if the seedlings are to be transplanted into other beds for additional growth, higher densities (with smaller seedlings) might be more practical (Fig. 8–14). Once the actual density is determined, the necessary rate of sowing can be calculated from data obtained from a germination test and from experience at that particular nursery (see Box 8.3).

Seeds can be planted by (a) broadcasting by hand or seeders, (b) hand spacing (larger seeds), or (c) drilling by hand with push drills, or drilling with tractor-drawn precision drills. Seeds of a particular lot should be thoroughly mixed before planting to ensure that the density in the seed bed will be uniform. Treatment with a fungicide for control of damping-off is often desirable. Small conifer seeds may be pelleted for protection against disease, insects, birds, and rodents. Depth of planting varies with the kind and size of seed. In general, a depth of three to four times the diameter of the seed is satisfactory. Seeds can be covered by soil, coarse sand, or by various mulches.

Figure 8–14
Planting density depends on the ultimate use of the seedlings. (a) Oak seedlings were planted at a high density and will be sold as seedling liners. (b) These ginkgo seedlings were drilled at a lower density and may be used as seedling liners or could be field budded.

BOX 8.3 GETTING MORE IN DEPTH ON THE SUBJECT
SEEDING TIMES FOR HERBACEOUS AND WOODY PERENNIAL SEEDLING PRODUCTION

Seeds are planted in the nursery in the summer, fall, or spring depending on the dormancy conditions of the seed, the temperature requirements for germination, the management practices at the nursery, and the location of the nursery (in a cold-winter or a mild-winter area). Planting time varies for several general categories of seed (44, 62).

Summer Seeding
Seeds of some species, such as maple (Acer), poplar (Populus), elm (Ulmus), and willow (Salix), ripen in spring or early summer. Such seeds should be planted immediately after they ripen, as they do not tolerate drying and their viability declines rapidly (see recalcitrant seeds, page 189). Other species with morphological and morphophysiological dormancy, like Clematis, holly (Ilex), ash (Fraxinus), windflower (Anemone) and twinleaf (Jeffersonia), should be planted in summer or early fall to allow 6 to 8 weeks of warm stratification in the seed bed prior to the winter chilling (4).

Fall Seeding
Seeds of species with physiological dormancy that require moist-chilling can be fall seeded where winter temperatures have appropriate periods of cold temperature to satisfy dormancy. Certain species (apple [Malus], pear [Pyrus], Cherry [Prunus], and yew [Taxus]) are adversely affected by high germination temperatures, which produce secondary
dormancy. Germination temperatures of 10 to 17°C (50 to 62°F) are optimum. Seeds of these species should be planted in the fall, and germination will take place in late winter or early spring.

**Spring Seeding**
Many kinds of seeds—including most conifers (pine, fir, spruce) and many deciduous hardwood species—benefit from moist-chilling stratification but do not germinate until soil temperatures have warmed up, and are not inhibited by high soil temperatures. Optimum germination temperatures are 20 to 30°C (68 to 86°F). Such seeds can be fall planted, but spring planting following refrigerated stratification often results in superior germination and seedling emergence. Non-dormant seeds or those with only physical dormancy (black locust (Robinia), yellowwood (Cladrastis) and Kentucky coffeetree (Gymnocladus)) are planted in the spring either outdoors or under protected cultivation (greenhouse or coldframes) to take advantage of the long growing season. Soil firming may be done to increase the contact of seed and soil. It is used for California lettuce, for example, and carried out with a tamper, hand roller, or tractor-drawn roller either before sowing or immediately afterward. Rodent and bird protection may be necessary.

**Plant After-Care**
During the first year in the seed bed, the seedlings should be kept growing continuously without any check in development. A continuous moisture supply, cultivation or herbicides to control weeds, and proper disease and insect control contribute to successful seedling growth. Fertilization (especially nitrogen) is usually necessary, particularly when mulch has been applied, since decomposition of organic material can reduce nitrogen availability. In the case of tender plants, glass frames can be placed over the beds, although for most species a lath shade is sufficient. With some species, shade is necessary throughout the first season; with others, shade is necessary only during the first part of the season (Fig. 8–15).

**Harvesting Field-Grown Transplants**
Vegetable transplants can be harvested after 6 to 10 weeks in the seed bed. These are usually "pulled," bundled, and used as bare-root transplants. In the United States, vegetable transplant beds are either located on the producer's farm or shipped to northern growing areas from southern transplant nurseries. A large number of vegetable and tobacco transplants are being produced in plug systems and “float beds” (see page 272), which are replacing the more traditional field-nursery-produced transplants.

In contrast, woody plants can remain in the “liner” bed for a year or more before being transplanted to a permanent location (see Chapter 3). For some species, the plants may be shifted to a transplant bed after 1 year and then grown for a period of time at wider spacing (Fig. 8–14). This basic procedure is used to propagate millions of forest tree seedlings, both conifer and deciduous species.
Liners produced in a seed-bed nursery are often designated by numbers to indicate the length of time in a seed bed and the length of time in a transplant bed. For instance, a designation of 1–2 means a seedling grown 1 year in a seed bed and 2 years in a transplant bed or field. Similarly, a designation of 2–0 means a seedling produced in 2 years in a seed bed and no time in a transplant bed (Fig. 8–16).

Seedling liners are lifted mechanically by undercutting the plants and shaking off the soil around the roots (Fig. 8–17). Bareroot liners are graded into size classes prior to being overwintered in large refrigerated coolers for spring sales.

**Specialty Systems for Direct-Seeded Crops**

**Direct-Seeded Nursery Row Production**  Planting directly in separate nursery rows is one of the primary methods used to propagate rootstocks of many fruit and nut tree species (28, 60). Cultivars are budded or grafted to the seedlings in place (see Chapters 12 and 13). The method is also used to propagate shade trees and ornamental shrubs, either as seedlings or on rootstocks as budded selected cultivars (Fig. 8–18).

Deciduous fruit, nut, and shade tree propagation usually begins by planting seeds or liners in nursery rows. Where plants are to be budded or grafted in place, the width between rows is about 1.2 m (4 ft) and the seeds are planted 7.6 to 10 cm (3 to 4 in) apart in the row (see Fig. 8–17). Seeds known to have low germination must be planted closer together to get the desired stand of seedlings. Large seed (walnut) can be planted 10 to 15 cm (4 to 6 in) deep, medium-sized seed (apricot, almond, peach, and pecan) about 7.6 cm (3 in), and small seed (myrobalan plum), about 3.8 cm (1.5 in). Spacing may vary with soil type. If germination percentage is low and a poor stand results, the surviving trees, because of the wide spacing, may grow too large to be suitable for budding. Plants to be grown to a salable size as seedlings without budding could be spaced at shorter intervals and in rows closer together.

Fall planting of fruit and nut tree seeds is commonly used in mild-winter areas such as California (28). Seeds are planted 2.5 to 3.6 cm (1 to 1.5 in) deep and 10 to 15 cm (4 to 6 in) apart, depending on size, and then covered with a ridge of soil 15 to 20 cm (6 to 8 in) deep, in which the seeds remain to stratify during winter. The soil ridge is removed in the spring just before seedling emergence. Herbicide control of weeds and protection of the seeds from rodents become important considerations during these procedures.

**Field Seeding for Reforestation or Naturalizing**  Field seeding of forest trees is accomplished in reforestation either through natural seed dissemination or planting. Costs and labor requirements of direct seeding are lower than those for transplanting seedlings,
provided soil and site conditions favor the operation (17). The major difficulty is the very heavy losses of seeds and young plants that result from predation by insects, birds, and animals; drying, hot weather; and disease (62). A proper seed bed is essential, and an open mineral soil with competing vegetation removed is best. The soil may be prepared by burning, disking, or furrowing. Seeds may be broadcast by hand or by special planters, or drilled with special seeders. Seeds should be coated with a bird and rodent repellent.

Wildflower seed mixtures can be naturalized to provide landscape color for public or private lands at a low cost. In many locations, wildflower establishment has become an alternative to mowing on highway

Figure 8–17
Harvesting bareroot liners. (a, b, and c) The liners are mechanically undercut and lifted. The lifting tines vibrate to shake off as much soil as possible. (d) Workers collect the plants and group them in bundles. (e) Liners are graded into size classes before being placed into (f) cold storage.

Figure 8–18
Some fruit and ornamental trees (like these dogwoods) are direct seeded with wide spacing so the plants can be budded in the nursery row.
right-of-ways. Seed germination and seedling establishment are improved by tillage for seed bed preparation and a straw mulch covering for seeds (15). For highly erodible sites, a “nurse” grass crop plus wildflower seed mixture can improve wildflower establishment (16). Weed competition is a serious problem for wildflower plantings, which must be managed to ensure a successful stand. Successful strategies include the use of herbicides, tillage, fumigation, and solarization (covering soil with plastic to trap solar radiation and allow heat to pasteurize soil).

**Production of Transplants Under Protected Conditions**

Seedling production is used extensively to produce flowers and vegetables for outdoor transplanting. Historically, this method has been used to extend the growing season by producing seedlings under protection for transplanting to the field as soon as the danger of spring frosts is over, or by placing seedlings under individual protectors to avoid freezing. This procedure also avoids some of the environmental hazards of germination and allows plants to be placed directly into a final spacing. Optimum germination conditions are provided in greenhouses, cold frames, or other structures to ensure good seedling survival and uniformity of plants.

Seedling growing has become an extensive bedding plant industry to produce small ornamental plants for home, park, and building landscaping, as well as vegetable plants for home gardening (2, 38). Commercial vegetable growing also relies heavily on the production of transplants, involving highly mechanized operations beginning with seed germination and ending with transplanting machinery that place individual plants into the field.

**Production Systems for Transplants** Traditionally, bedding plants and vegetables have been produced by germinating seeds in flats and transplanting seedlings to larger containers prior to field or landscape planting. However, modern greenhouse producers have adopted plug production as the preferred method for transplant production (1, 38, 69, 75). Plug production provides numerous advantages over conventional flat seeding, and specialized plug growers produce acres of plugs under glass each spring. Many bedding plant growers find they can purchase plugs from specialized plug producers more economically than producing seedlings themselves. In either case, seedlings are moved to larger cell packs by the bedding plant grower for “finishing” prior to sale to the consumer. The advantages of plug production include:

1. Optimization of the number of plants produced per unit of greenhouse space.
2. Specialization in plug production allows growers to invest in equipment to control environmental conditions during germination.
3. Fast production (most plugs are sold within four to six weeks of seeding) allows growers to seed multiple crops per season, permits accurate crop scheduling, and allows plugs to be shipped easily to the end user.
4. Because plugs are transplanted to larger-size containers with the roots and original medium intact, plugs transplant easily with a high degree of uniformity. Plugs do not experience the same “transplant shock” and check in growth as seedlings removed from seedling flats.

**Flat Production.** Traditional bedding plant production relied on flat production of seedlings. Seeds were planted in a germination flat or container, and later germinated seedlings were “pricked out” and transplanted to develop either in a transplant flat at a wider spacing or in individual containers where they remained until transplanted out-of-doors (Fig. 8–19). This method is still utilized by small bedding plant producers but has largely been replaced by mechanized plug production.

**Plug Production.** The first crops to be produced in plugs were vegetable transplants in the 1960s by the Florida-based Speedling Corporation (6). Today, millions of vegetable and flower transplants are produced annually in greenhouses under carefully controlled environmental conditions for optimizing germination and plant growth. This has become possible mainly through the development of the plug system (2, 13, 69, 75).

A plug is a seedling produced in a small volume of medium contained in a small cell, of which between 72 to 800 are contained on a single sheet of polystyrene, Styrofoam, or other suitable material (Fig. 8–20). Plug flats are filled mechanically with a growing substrate, and seeds are sown mechanically into each cell. Standard plug trays are 55 × 28 cm (21.5 × 11 in) or 25 × 51 cm (10 × 20 in), and individual cell sizes may range down to 1 × 1 cm (3/8 × 3/8 in). Cell size dictates the length of time a crop of plugs takes to produce and the time required for the bedding plant grower to finish the crop. Generally, the larger the cell, the longer it takes the plug grower to produce the plug. For the bedding plant grower, the larger the cell (plug), the less time it takes to finish the crop (32). Considerations for the bedding plant grower include crop scheduling, economics between purchasing
larger plugs and greenhouse production costs, number of greenhouse turns (using the same space for multiple crops), and mechanical transplanting equipment requirements.

High seed germination and seedling uniformity are critical for good plug production (67, 71). Seed germination may be on the greenhouse bench in sophisticated computer-controlled environments or in specialized germination rooms that provide optimum temperature and moisture conditions, and light, if necessary. It is important to have high-quality, high vigor seed to maximize germination rate, seedling uniformity, and mechanical handling (8). Pelleting and seed priming (see Chapter 6) are common seed enhancements for plug production.
Plug Growth Stages. The four morphological stages of seedling growth are: (29, 69, 75)

Stage 1: sowing to germination (radicle emergence)
Stage 2: germination to full cotyledon spread and root system establishment
Stage 3: seedling plug growth (unfolding of three or four leaves; root growth)
Stage 4: seedling plug getting ready to transplant or ship (more than four leaves)

Providing precise environmental control for each of the stages is essential in plug production. Warm temperature and consistent moisture are essential for stage 1 but usually are reduced in stage 2 and in later stages (see Table 8–1). Light may be required for germination in stage 1 for some crops and relative humidity is held at least 95 percent, often provided by fog in growth rooms. A starter fertilizer charge may be applied to the substrate in stage 1. A moderate light level and low fertilization is typical for stage 2 growth. Substrate water content is reduced compared to stage 1 and varies depending on the crop. High light and a complete fertilization (N, K, P) is particularly important in stage 3 (74) but must be monitored carefully (63). Plant growth regulators may be applied in stage 3 to control seedling height. As seedlings enter stage 4, they are usually “toned” in preparation for shipping and transplanting. Therefore, substrate moisture and temperature are usually reduced, compared to stage 3. Nitrogen fertilization is reduced or may be withheld in stage 4.

Production of Woody Plant Seedlings in Containers. Production of seedling trees and shrubs in containers is an intensive alternative to field production (Figs. 8–21 and 8–22). Seeds may be sown in germination flats or direct-seeded into plug-trays (48, 57). Later they are moved to slightly larger containers or transplanted directly into the containers where they will remain until transplanted out-of-doors.

Container-grown tree seedlings are grown in deep containers, and root pruning is essential to induce a desirable, well-branched root system (45). Root pruning can be done physically prior to the first transplanting, soon after the roots reach the bottom of the flat (30, 31). More commonly, plants can be grown in open-bottom containers where air-pruning removes roots that protrude from the bottom of the container (Fig. 8–21). Metal or plastic screen-bottomed flats (25) can also stimulate formation of branch roots. Seedlings may be produced in plastic containers from which the seedling plug is removed prior to planting, or they may be containers made of substances such as peat or fiber blocks that are planted with the seedling (Fig. 8–22).

Control Methods to Maximize Transplant Production
Efficient indoor transplant production can be a very sophisticated operation with a substantial monetary investment in greenhouse facilities. In many cases, profit is determined by producing a high density of seedlings in as short a time as possible. Factors to consider include:

1. Germination facilities
2. Substrate
3. Mechanical seed sowing

### Table 8–1
**Requirements for Seed Germination During Plug Propagation of Three Popular Bedding Plants**

<table>
<thead>
<tr>
<th></th>
<th>Petunia</th>
<th>Pansy</th>
<th>Impatiens</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>75–78°F (24–26°C)</td>
<td>62–68°F (17–20°C)</td>
<td>75–80°F (21–27°C)</td>
</tr>
<tr>
<td>Moisture</td>
<td>100% RH</td>
<td>100% RH</td>
<td>100% RH</td>
</tr>
<tr>
<td>Light</td>
<td>90 µmol · sec⁻¹ · m⁻²</td>
<td>80 µmol · sec⁻¹ · m⁻²</td>
<td>90 µmol · sec⁻¹ · m⁻²</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>25–75 ppm KNO₃, 1 application (1–3 days)</td>
<td>25–50 ppm KNO₃, (1–7 days)</td>
<td>None</td>
</tr>
<tr>
<td><strong>Stage 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>75°F (24°C)</td>
<td>66°F (18°C)</td>
<td>72–75°F (22–24°C)</td>
</tr>
<tr>
<td>Moisture</td>
<td>85% RH</td>
<td>75% RH</td>
<td>75% RH</td>
</tr>
<tr>
<td>Light</td>
<td>90 µmol · sec⁻¹ · m⁻²</td>
<td>80 µmol · sec⁻¹ · m⁻²</td>
<td>90 µmol · sec⁻¹ · m⁻²</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>50 ppm 20–10–20 (3–7 days)</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Source: Ball, 1998.
Figure 8–21
An alternative to field production in conifers is container production.
(a) Conifer production in an open roof greenhouse.
(b) Conifer plug production on movable benches.
(c and d) Pine seedlings in deep, narrow containers held in trays that permit air circulation beneath the container for air pruning.

Figure 8–22
Conifer production in alternative substrates. (a and b) Spruce seedlings in expanded peat and (c) foam-like peat product.

4. Watering systems
5. Temperature control
6. Seedling growth
7. Transplanting

Germination Facilities. Indoor seedling production occurs in several types of structures including greenhouses, cold frames, and hotbeds, as described in Chapter 3. Some bedding plant operations have special germination growth rooms (Fig. 8–23, page 270) where seed flats are placed on carts or shelves in an enclosed area and subjected to controlled environments for germination prior to being moved to the greenhouse (68).

Growth rooms
Structure used by large bedding-plant producers that control germination conditions to optimize seedling emergence in plug flats.

Cold frame
Structure that uses passive solar heating to protect transplants. Cold frames are often used as a transition environment for transplants between greenhouse and field conditions to "harden" transplants and reduce transplant shock.
plug growth stage — radical emergence—and are then moved to the greenhouse.

Substrates (Media). Substrates and fertilizer used for seedling propagation are discussed in detail in Chapter 3. Germination substrate for herbaceous bedding plants must retain moisture, supply nutrients, permit gas exchange, and provide support for the seedling (22). Common mixes are combinations of peat moss, perlite, ground or shredded bark, coconut coir, and vermiculite, and they may be fortified by mineral nutrients or slow-release fertilizers. These mixes are available commercially, but may be made on-site for custom blends. Air and water content should be maintained for good germination and seedling growth (49). Small seeds should have a finer and more compact medium than is used for larger seeds. Plug flats are usually filled with substrate mechanically.

Mechanical Seed Sowing. 

Seeds may be broadcast over the surface of the transplant flats or planted in rows (Fig. 8–19, page 267). Advantages of row planting are reduced damping-off, better aeration, easier transplanting, and less drying out. Planting at too high a density encourages damping-off, makes transplanting more difficult, and produces weaker, non-uniform seedlings. Suggested rates are 1,000 to 1,200 seeds per 29 × 54 cm (11 × 22 in) flat for small-seeded species (e.g., petunia) and 750 to 1,000 for larger seeds. Small seeds are dusted on the surface; medium seeds are covered lightly to about the diameter of the seed. Larger seeds may be planted at a depth of two to three times their minimum diameter.

Efficient plug production requires the use of a mechanical seeder (3). The objective of plug production is to get a usable seedling in each cell. The choice of seeder depends on several factors including cost, seeding speed, number of flats to be seeded, and the need for flexibility to sow a variety of seed shapes and sizes. When evaluating a seeder, growers must consider the machine’s ability to deliver seeds at the desired speed without skipping cells due to poor seed pickup or delivery, sowing multiple seeds per cell, and sowing seeds without seed “bounce” that can reduce the precise location of the seed in each plug cell.

Three types of seeders are commonly available to plug growers. These are template, needle, and cylinder (drum) seeders (Figs. 8–24 and 8–25, page 272).

The template seeder (Fig. 8–24a) is the least expensive type of seeder. It uses a template with holes that match the location of cells in the plug flat. Template seeders use a vacuum to attach seeds to the template. Releasing the vacuum drops the seeds either directly into the plug flat or into a drop tube to precisely locate seeds in each cell of the plug flat. Templates with different size holes are available to handle different size and shape seeds. A differently sized template is also required for each plug flat size. It is a relatively fast seeder because it sows an entire flat at once. However, this is the least mechanized of the commercially available seeders. It requires the operator to fill the template with seeds, remove the excess, and then move the template to the flat.
Techniques of Propagation by Seed  

Chapter Eight

271

for sowing. Template seeders work best for round, semi-round, or pelleted seeds.

The needle seeder (Fig. 8–24b, c, and d) is an efficient and moderately priced seeder. It is fully mechanical, requiring little input from the operator. Individual needles or pickup tips, under vacuum pressure, lift single seeds from a seed tray and deposit one seed directly in each plug cell or into drop tubes for more accurate seeding. A burst of air can be used to deposit seeds and clean tips of unwanted debris. The needle seeder can sow a variety of seed sizes and shapes including odd-shaped seeds like marigold, dahlia, and zinnia. Although slower than the cylinder seeder, it is still relatively fast, sowing up to 100,000 seeds per hour. Small- and moderate-sized plug growers choose needle seeders because of the flexibility in seeding and cost.

The cylinder or drum seeder (Fig. 8–25, page 272) have a rotating cylinder or drum that picks up seeds using vacuum from a seed tray and drops one seed per plug cell. This is the fastest, most precise, and most costly of the commercial seeders. It is fully mechanical. Most drum seeders require a different drum for each plug flat, but newer models of cylinder seeders have several hole sizes per cylinder that can be selectively put under vacuum pressure and can be computer-adjusted for different flat types. These can sow single or multiple seeds per cell at a time. Sophisticated seeders “eject” seeds from the drum using an air or water stream for precise seeding location in the flat. These seeders work best with round, semi-round, or pelleted seeds. Large plug growers must have the capacity to sow millions of plugs per year of over 100 different types of bedding plants (66). They choose cylinder seeders because they sow a high volume of seeds quickly—up to 800,000 seeds per hour.

Watering Systems. The moisture content of the growing medium can be critical to germination success (5, 12). Species like coleus, begonia, and alysium require a wet medium (saturated); impatiens, petunia, and pansy require a moist medium (wet but not saturated); while asters, verbena, and zinnia prefer a drier medium (watered only prior to sowing) for good germination (67).

For smaller growers, seed flats may be held under polyethylene tents (see Chapter 3) or, in small operations, covered with spun fabric or vermiculite to keep the surface from drying out (Fig. 8–26a and b, page 273). Covered flats should not be exposed directly to sunlight, as excessive heat buildup injures the seedling.

Several systems for delivering water to seed flats are available including automated watering systems (Fig. 8–26). These include overhead and subirrigation systems (42). Overhead irrigation can be as simple as a hose with a fine-holed “rose”. automated watering systems A system that reduces labor costs and can provide more even moisture to plug trays.
irrigation nozzle or a timed mist system. Automated boom sprayers provide fine control of overhead irrigation. The boom travels the length of the greenhouse, providing a spray of water to the flats. The speed of the boom and irrigation timing can be computer-controlled.

Subirrigation systems have the advantage of providing even moisture while reducing water runoff. Capillary mat systems (Fig. 8–26e) deliver water from a reservoir to the mat where the growing medium “pulls” water into the flat or plug cell by capillary action. Ebb and flood systems use a sealed bench that is flooded periodically, and then the nutrient solution drains passively back into a holding tank (58). A variation on these systems is “float bed” production (Fig. 8–26f), in which a Styrofoam flat is floated in a water bed containing a nutrient solution (46). Regardless of the system used, water quality must be monitored during production (42).

In most cases, seeds are sown on the surface of the medium by mechanical seeders. Seeds can be covered with vermiculite or porous fabric or plastic sheets to maintain even moisture until seedlings emerge. In modern palletized greenhouse operations, germination occurs in specialized germination rooms or in greenhouse sections designed to optimize germination conditions, then the entire movable bench is transferred on special rails to additional greenhouse sections designed for seedling growth.

Temperature Control. Temperature requirements for germination vary depending on the plant species being grown. In general, most bedding plants can be germinated in one of three temperature regimes: 26 to 30°C (78 to 80°F), 21 to 22°C (70 to 72°F), or 18 to 19°C (64 to 66°F). Non-optimal temperatures can lead to erratic or poor germination and emergence. In many cases,
techniques of propagation by seed chapter eight

heat is used to warm the germination medium to the appropriate temperature. However, high temperature during germination may also lead to thermoihibition or thermodormancy in some crops. See Chapter 21 for specific germination temperatures for different plant species.

Seedling Growth. The principal objective of seedling production is to develop healthy, stocky, vigorous plants capable of further transplanting with little check in growth. The usual procedure in production is to move the flats to lower temperatures (10°C or less) compared to germination temperatures, and expose them to full sunlight. High temperatures and low light tend to produce spindly, elongated plants that will not survive transplanting. Such growth is termed "stretching."

Height control for quality plant production may require the use of growth regulators (10) or strict environmental control like water management (70) or temperature differentials (50). For example, plant height can be reduced by growing plants with a cooler day time temperature compared to the night time temperature. This is referred to as a negative DIF.

Once root systems grow into the medium, irrigation can be scheduled to keep the medium somewhat dry on the surface but moist underneath. Such irrigation helps prevent disease and produces sturdy seedlings. Fertilization should provide a good root-to-shoot ratio in the plug without excessive shoot growth, because a good root system is as important as above-ground shoot growth for plugs. Poor root systems will negatively impact the vigor of the transplant and hamper mechanical transplanting, which relies on a firm plug for the robot's "fingers" to lift. Plugs are hardened or toned in stage 4 by reducing
the frequency of irrigation and fertilization in preparation for transplanting (11).

**Transplanting.** For seedlings grown in community flats, transplanting should begin when the first true leaves have fully expanded. Holes are made in the medium at the correct spacing with a small dibble. The roots of each small seedling are inserted into a hole, and the medium is pressed around them to provide good contact. Dibble boards are often used to punch holes for an entire flat at once (Fig. 8–19, page 267). As soon as the flat is filled, it is thoroughly watered.

Plug-grown seedlings are transplanted at stage 4 (see page 268). These can be transplanted by hand, but as seasonal labor has become relatively more costly and difficult to acquire, even smaller bedding plant growers are increasingly using mechanical transplanters in place of hand labor to transplant plugs. These transplanters lift or push seedlings from the plug flat into six or four packs for growing on before sale. To be efficient, every cell in the plug flat must have a usable seedling, otherwise there will be skips in the transplant containers. Plug growers must backfill flats with missing plants. This may be done by hand or with machine vision robots (Fig. 8–27).

Mechanical transplanters may be as simple as a mechanical press that pushes seedlings into dibbled cell packs or as sophisticated as robots that lift tightly spaced plugs and expand to transplant them to larger spaced cell packs (Fig. 8–28). These machines are a substantial investment for the grower, but there is often a long-term cost saving due to the increase in transplanting rate and the reduction in the temporary labor force required for spring transplanting.

**Transplanting Seedling Material to Permanent Locations**

The final step in seedling production is transplanting to a permanent location (59). Seedlings may be transplanted bare-root (vegetable transplants or deciduous fruit, nut, and shade trees), in cells or modular containers (bedding plants, vegetables, forest trees), balled and burlapped (evergreen trees), or containerized (ornamental shrubs and trees).

Bare-root transplanting invariably results in some root damage and **transplant shock**, both of which check growth. Some transplant shock can be observed even in container transplants. With vegetable plants these may result in premature seed-stalk formation, increased susceptibility to disease, and reduced yield potential. Handling prior to transplanting should involve hardening-off, achieved by temporarily

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**Figure 8–27**

It is essential to fill as many cells as possible in a plug tray with usable seedlings. (a) A worker backfilling a plug flat that had poor or non-uniform seedling production. (b) A machine vision robot that automates the backfilling process. (c) Flats enter the machine and a computer determines cells to be removed and refilled. (d) The robot literally blows out the cell with an air jet, making it easy to mechanically refill with a usable seedling.
withholding moisture, reducing temperature, and gradually shifting from protected to outdoor conditions over a period of 1 week to 10 days (Fig. 8–29). Hardening-off can cause carbohydrates to accumulate, making the plant better able to withstand adverse environmental conditions.

**Ornamental and Vegetable Bedding Plants** During the transition to the new site, deterioration must be prevented if the plants are bare-root. Following planting, conditions must be provided for rapid root regeneration. Planting should be done as soon as possible. If not, transplants can be kept (no more than 7 to 10 days) in moist, cool (10°C, 50°F) storage. Long-term (several weeks) plug storage is possible (33) by maintaining high humidity but avoiding direct watering in order to prevent disease.

Field beds should be moderately well pulverized, although not necessarily finely prepared, and well watered but not saturated (59). Transplanting is done in the field by hand or by machine. Afterward, a good amount of irrigation should be applied to increase moisture to the roots and settle the soil, but not saturate it. A starter solution containing fertilizers that are high in phosphorus can be applied, but if the soil is dry, it should be diluted. Temporary shade may be used for the first few days.

**Trees and Shrubs** Transplanting of bare-root evergreen forest trees follows principles similar to those described. Seedling plants should be dug in the nursery in the fall after proper physiological “hardening-off.” Seedlings are packed into moisture-retaining material (vermiculite, peat moss, sawdust, shingletoe) and kept in low-temperature (2°C, 35°F), humid (at least 90 percent RH) storage. Polyethylene bags without moisture-holding material are satisfactory. Some kinds of sawdust can be toxic, particularly if fresh. Bare-root nursery stock of deciduous plants and container-grown stock are handled as described for rooted cuttings in Chapter 10.
DISCUSSION ITEMS

This chapter brings together all the concepts presented in previous seed chapters into production techniques for horticultural and forestry crops, including treatments to overcome dormancy, use of pretreated seeds, and optimizing seedling emergence. The major production schemes to propagate nursery, vegetable, and flower crops from seed are included in this chapter:

1. Compare field, greenhouse flat, and greenhouse plug systems for transplant production.
2. Compare plug production with float-bed production for transplants.
3. Compare mechanical seeders used for field vs. greenhouse sowing.

REFERENCES


