part five

Propagation of Selected Plant Species

CHAPTER 19  Propagation Methods and Rootstocks for Fruit and Nut Species
CHAPTER 20  Propagation of Ornamental Trees, Shrubs, and Woody Vines
CHAPTER 21  Propagation of Selected Annuals and Herbaceous Perennials Used as Ornamentals

The objective for the following three chapters is to provide information about propagation methods for plant species important to the major horticultural industries for which greenhouses and nurseries propagate plants, including fruit and nut crops as well as woody and herbaceous ornamental species used in the landscape. These chapters do not include all crop plants of importance. For instance, we do not include field crops, vegetables, lawn grasses, or all forest species. For all of the latter, special manuals are available and should be consulted. This part is organized into three separate chapters for fruits, woody ornamentals, and herbaceous annuals and perennials. Plants are listed alphabetically by genus names but are cross-referenced to common names in a separate plant index. Propagation of specific crops should also include a general knowledge of their taxonomy and something about their history and special needs; this information has been included where appropriate.
INTRODUCTION

Most fruit and nut crop cultivars are clones and do not reproduce true-to-type by seed, so propagation by vegetative methods is necessary. Many tree fruit and nut cultivars are propagated by budding or grafting onto rootstocks produced from seedlings, rooted cuttings, layers or micropropagated plants. Rootstocks are important. First, most fruit and nut tree cultivars are difficult to root by cuttings, except in a few species, although some can be propagated by layering. Second, rootstocks are used to resist critical soil pathogens and to adapt plants to specific areas and management conditions.

Clonal rootstocks are important and are propagated by cuttings, layering, and micropropagation. Micropropagation is used to mass-propagate some cultivars, but it is also often used to produce virus-tested sources.

Fruit and nut cultivars are examples of monocultures with the accompanying problems of vulnerability to introduce pathogens, which is why commercial propagation of fruit and nut crops has become very specialized, requiring continuing research and development. Nevertheless, large nurseries specializing in fruit and nut propagation produce millions of fruit and nut trees each year, mostly by vegetative methods.

*Actinidia deliciosa.* Kiwifruit (27). Chinese gooseberry. Large-fruited dioecious subtropical vine originating in China but now grown throughout the world. It requires male and female cultivars to ensure fruiting. *A. arguta* is a related species producing small fruits in a cluster. Kiwi vines are propagated commercially mostly by grafting cultivars to seedling rootstocks because grafted plants are believed to be more vigorous and to come into bearing sooner than those started as rooted cuttings. However, kiwis may also be propagated by leafy, semi-hardwood cuttings under mist, hardwood cuttings, and root cuttings.

*Seed.* Seedling plants have a long juvenile period and their sex cannot be determined until fruiting at 7 years or more. Seed should be taken from soft, well-ripened fruit, dried and stored at 5°C (41°F). After at least 2 weeks at this temperature, subject seed to fluctuating temperatures—10°C (50°F) night and 20°C (68°F) day—for 2 or 3 weeks before planting.
Cuttings. Leafy, semi-hardwood cuttings taken from apical and central parts of current season’s growth in late spring and midsummer may be rooted under mist in coarse vermiculite with 6,000 ppm IBA. Hardwood cuttings, taken in midwinter and planted in a greenhouse, require higher IBA concentrations.

Grafting. Seedlings are grafted successfully by the whip graft in late winter using dormant scion-wood; T-budding in late summer is also successful. Seedlings are grown 1 year in the nursery. Collect dormant wood in previous winter and store. In California, graft in April but delay if bleeding is excessive. Use 1-bud scion with a whip graft. Wrap completely with budding rubber to make an air-tight seal. Complete operations by May 15.

Rootstocks. Most California growers use seedlings of ‘Bruno’ cultivar.

Micropropagation. Kiwifruit can be propagated by using short meristem tips or longer apical shoots as the initial explants.

Almond. See Prunus dulcis.
Anacardium occidentale. Cashew (8). These tender tropical evergreen trees are usually grown as seedlings. Clonal selections including precocious dwarf types (151) have been made, but vegetative propagation and transplanting are difficult.

Seed. Two to three are planted directly in place in the orchard and later thinned to one tree per location. Dormancy does not occur, but seeds may lack embryos. Test by placing seeds in water and discard those that float. Seeds germinate in 15 to 20 days. Growing in biodegradable containers will improve transplanting success.

Grafting. Rootstocks should be 1 to 2 months old but not tall and spindly. In softwood grafting, the scions are 8 to 10 cm (3 to 4 in) long, pencil thick, with bulging tips (20). Scions are green to brown in color with terminal leaves dark green. Leaf blades are clipped off 7 to 10 days before grafting, and grafting is done when the petioles abscise. One to two leaves are retained below the graft, which is done on the soft portion. A longitudinal cut about 3 to 4 cm (1 to 1.5 in) long is made. The scion wedge is inserted and the graft and tied with polyethylene grafting tape. Grafts are kept in shade for a week before transferring to the open.

Miscellaneous Asexual Methods. Cashew can also be propagated by rooting leafy cuttings, stooling (161), approach-grafting, and air layering (158, 161). In Nigeria, cashew is air-layered (2). T-budding and patch budding have been successfully used in limited trials.

Ananas comosus. Pineapple. Tropical terrestrial monocot of the Bromiliadaceae family which originated in South America. A large number of cultivars are grown in Hawaii, South America, Africa, the Philippines, Australia, and Southeast Asia, much of them in large industrial plantings (39). The plant consists of a thick stem with the flowering rosette on the top.

Offshoots. Three main types of vegetative propagules include offshoots (offsets) from the main stem either from below or above ground (suckers), lateral offshoots from the fruiting stem (peduncle) just below the fruit (slips), and the vegetative shoot emerging above the fruit (crowns). All three types can be used for propagation by removing them from the plant and planting either by machine or by hand (see Fig. 14–21). Drying (curing) for several weeks to allow callusing on the cut surface will reduce decay after planting. Suckers are somewhat limited in number, producing a mature fruit in 15 to 17 months, and are rarely used as planting material. If used, they are removed about 1 month after peak fruit harvest. Slips, preferred and most abundant, are cut from the mother plant 2 to 3 months after peak harvest. A slip-produced plant will produce fruit in about 20 months. They can be stored for a relatively long time and retain vigor for replanting. Slips of the same size and age will produce uniform flowering. Crowns are removed at about the same time as fruit harvest and require approximately 24 months to produce fruit.

Micropropagation. Explants of axillary buds from crowns of mature fruits can be propagated in an MS medium with 24 percent coconut water followed by subculturing in reduced coconut water supplemented by BA (152).

Annona cherimola. Cherimoya, Chirimoya, Custard Apple. Sugar apple (A. squamosa). Atemoya (A. squamosa × A. cherimola). Cherimoya (A. cherimola) is evergreen, sugar apple is deciduous, and atemoyas are semi-deciduous and somewhat tolerant of frost (20, 73). These tropical plants grow as small trees in Spain, Mexico, Ecuador, Peru, Chile, and southern Africa, with limited production in California, India, and Sri Lanka. In many areas, seedlings are grown, and some selections in Mexico and South America are reported to come nearly "true." Seedling plants are vigorous, have long juvenile periods and inferior fruits.

Seed. Viability is retained for many years if kept dry. Germination takes place a few weeks after planting. Seeds have been successfully propagated in
containers transplanted from flats to small pots when 7.5 to 10 cm (3 to 4 in) high, then to small pots at 20 cm (8 in), and to larger pots or to open ground.

**Grafting.** Cultivars can be cleft grafted or T-budded. Topworking is successful with bark or cleft grafting carried out at the end of a dormant period. Seedling rootstocks are cherimoya, the related sugar apple (*A. squamosa*), which yields a dwarf plant, and custard apple (*Annona* hybrids). The latter two species are susceptible to cold, and root-rot is a problem on poorly drained soils.

**Layering (20).** Stooling (mound layering) has given promising results. Three-year-old seedlings were headed to ground level, shoots were girdled, and IBA applied.

**Apple.** *See Malus xdomestica.*

**Apricot.** *See Prunus armeniaca.*

**Artocarpus heterophyllus.** Jackfruit. A medium-sized tropical tree with fruit of unique flavor has many related genera and species including breadfruit (*Artocarpus altilis*). Although grown mostly by seed, cultivars are available. The seed has limited viability and must be germinated within 1 month. Presoaking the seed improves germination. Propagated by cuttings when stock plants are etiolated, and cuttings treated with IBA and rooted under mist. Grafting, including inarching, epicotyl grafting, and various budding methods, including chip budding, are successful (75). Can be propagated by air layering.

**Asimina triloba.** Common paw-paw and dwarf paw-paw (*A. parviflora*). *See Chapter 20, page 780.

**Averrhoa carambola.** Carambola (20, 159). This medium-sized evergreen tree originates from tropical and subtropical areas of Southeast Asia, but it is now grown in many parts of the world. The fruit is a distinctive five-cornered shaped fruit, used fresh for juice, or for decoration. Seeds will germinate within 7 days if sown immediately from the fruit. Storage can be maintained for about a week in the refrigerator if kept moist. A well-drained medium should be used for trays, and the seedlings transplanted when the first true leaves appear. Although propagated by seed, vegetatively propagated cultivars are available. Side-veneer grafting, chip budding, wedge grafting, whip-and-tongue, and approach grafts can be used. Standard air layering is highly successful. Side-veneer grafting can be used for topworking or wedge or side veneer on regrowth from stump trees.

**Avocado.** *See Persea.*

**Banana.** *See Musa.*

**Berry (Youngberry, Boysenberry, Loganberry, Dewberry).** *See Rubus.*

**Blackberry.** *See Rubus.*

**Blueberry.** *See Vaccinium.*

**Butternut.** *See Juglans cinerea.*

**Cacao.** *See Theobroma.*

**Cactus (Prickly pear).** *See Opuntia spp.*

**Carambola.** *See Averrhoa.*

**Carica papaya.** Papaya (159). These are large, tropical, fast-growing, short-lived herbaceous perennials. They come into fruiting within about 5 months and live 4 to 5 years. Plants are dioecious, require cross-pollination, and must be screened for sex form after coming into bearing. Some papaya seedling cultivars are highly inbred and come very true from seed (159). Papaya ring spot virus is a devastating aphid vectored disease for which transgenic resistant cultivars are now available (74).

**Seed.** Propagation is by seed from selected parents or controlled crosses. Seeds are equally useful if taken from stored or fresh fruit. Viability can be retained up to 6 years at 5°C (41°F) in sealed, moisture-proof bags (14). Seeds are sown in flats of soil or in seed beds in the open—and germinate in 2 to 3 weeks. Seedlings are first transplanted at about 10 cm (4 in) tall and then generally re-transplanted once or twice before they are put in their permanent location. Another technique is to plant 4 to 8 seeds per container and thin to 2 to 4 of the strongest when about 10 cm (4 in) tall. Soil pasteurization is recommended, since young papaya seedlings are very susceptible to damping-off organisms.

The usual practice in Florida is to plant seeds in midwinter and set the young plants in the field by early spring. Growth occurs during spring and summer, first fruits are mature by fall, and the plants bear all winter and the following season.

**Miscellaneous Asexual Methods.** Cuttings are used for specific cultivars with parthenocarpic fruit (20). Cuttings of branches with a “heel” are placed under mist with bottom heat. Budding is another method.

**Micropropagation.** Papaya can be micropropagated (135).
Carob. See Ceratonia.

Carya illinoinensis. Pecan (86, 140). Pecans are native to the southwest United States and northern Mexico where many natural seedling groves exist. Commercial groves use selected cultivars grafted to pecan seedling rootstocks.

Seed. Pecan seeds of certain cultivars may show vivipary, which ruins the pecan crop. Seeds start to germinate in the hulls before harvesting and lose their viability in warm, dry storage. To maintain viability, seeds should be stored at 0°C (32°F) at 5 percent moisture immediately after harvest and until planted. Pecan seeds should be stratified for 12 to 16 weeks at about 1 to 5°C (34 to 41°F) to ensure good, rapid germination. Growth restrictions of the shell have been reported to be reduced by germination at high temperatures—30 to 5°C (86 to 95°F) (51, 139, 206).

Midwinter planting, with seedling emergence in the spring, is a successful procedure. Deep, well-drained, sandy soil should be used for growing pecan nursery trees. Young seedlings are tender and should be shaded against sunburn. In the summer, toward the end of the second growing season, the seedlings are large enough to bud.

Grafting. Cultivars are propagated by budding or grafting to two-year-old pecan seedling rootstocks. Patch budding in the nursery is the usual method. After the budded top grows for 1 or 2 seasons, the nursery tree is transplanted to a permanent location. Young pecan trees have a long taproot and must be handled carefully when digging and replanting.

Seedlings may be crown grafted with the whip graft in late winter or early spring. Pecan seedling trees, growing in place in the orchard, can be topworked by inlay bark grafting limbs 4 to 9 cm (1 1/2 to 3 1/2 in) in diameter. The four-flap or banana graft can be used with smaller-sized rootstock to graft more than one cultivar on the same rootstock (see Fig. 12–12).

Miscellaneous Asexual Methods. Pecans are difficult to root from cuttings but some rooting occurs with hardwood cuttings taken in the fall and treated with 10,000 ppm IBA (190). Mound (stool) layering for clonal rootstock production is done in Peru (see Fig. 14–12) (146). Plants have been propagated by root cuttings and by air layering when treated with IBA.

Micropropagation. Seedling shoots of pecans have been micropropagated and rooted ex vitro (88).

Rootstocks (86). Pecan seedlings from the 'Apache,' 'Riverside,' 'Elliott,' and 'Curtis' cultivars are reported to produce excellent grafted plants. Pecan roots are susceptible to Verticillium wilt. Experimental trials have indicated that C. aquatica might be a possible rootstock for wet soils. Although pecan cultivars will grow on hickory species rootstocks, the nuts generally do not attain normal size.

Carya ovata. Shagbark hickory (19, 138). Shagbark hickory is native to North America and grown as a nut tree and landscape ornamental.

Seed. Most trees are grown as seedlings because of difficulties grafting and transplanting, and slow growth of the trees. Some variation in seed requirements exists. Hickory seed will germinate when planted in the spring but should be kept in moist, cool storage until planting. Seed is orthodox, it can be stored dry at low temperatures (223); it has a stratification period of 3–4 months (52). Fall planting is successful if the soil in temperate climates is well mulched to prevent excessive freezing and thawing.

Grafting. Patch budding is done by nurseries in the commercial propagation of hickories, usually in late summer. Seedling rootstocks of C. ovata or pecan (C. illinoinensis) are grown for 2 years or more before they are large enough to bud. The inlay bark graft is another option. Transplanting is a problem, so root pruning to force out lateral root growth is sometimes done.

Cashew. See Anacardium.

Castanea spp. Chestnut (19, 114, 150, 208). Chestnuts fall into three groups around the world: (a) European (C. sativa), (b) American (C. dentata and related species), and (c) Asiatic species (C. mollissima and C. crenata). The chestnut of commerce in edible nuts is the European (Spanish) sweet chestnut. It is produced in quantity from very old groves and new plantations throughout Europe, and large quantities of nuts are exported to the United States. The native American chestnut tree of eastern North America was very important for timber as well as nuts until the early 1900s when the fungal blight (Cryphonectria (Endothia) parasitica) was accidentally introduced from Asia. Essentially, all mature trees of the American chestnut have been killed to near the ground in natural woodlands of the eastern United States. The European chestnut is also susceptible but has not been as severely affected. Blight-resistant chestnut species in China and Japan provide an important source of resistance. Breeding programs both for cultivars and rootstocks are in progress and new, improved, blight-resistant materials are becoming available. In addition, a virus attacking the blight fungus
has been discovered that has the promise of providing biocontrol of the disease.

**Seed.** Seeds are used for rootstocks, breeding, and occasionally for crops. Seeds are large, fleshy, recalcitrant, and should be prevented from drying following harvest and until planting. The nuts (seeds) are gathered as soon as they drop and are either planted in the fall or cold-moist stratified for 3 months, and later spring planted. Seeds are satisfactorily stored in tight tin cans, with one or two very small holes for ventilation, at 0°C (32°F) or slightly higher; this storage temperature also aids in overcoming embryo dormancy. Weevils in the nuts, which will destroy the embryo, can be killed by hot-water treatment at 49°C (120°F) for 30 minutes. After 1 year’s growth, the seedlings should be large enough to transplant to their permanent location or be grafted to the desired cultivar.

**Grafting and Budding (99).** Clonal cultivars are propagated onto rootstocks using the splice, chip, whip, or inverted T-buds. Regular T-buds tend to “drown” from the excessive sap flow. A buried-inarch grafting technique for root chestnut cuttings has been reported (113). In this procedure, a nut that has started to germinate is cut off just above the root. A dormant scion with a wedge cut on the bottom is inserted into the inverted nut, which is then placed in a closed heated frame containing peat moss and vermiculite. After about 4 weeks of warm temperature the grafts are hardened-off and removed.

**Cuttings.** Generally difficult to root. Chinese chestnut can be propagated by rooting leafy cuttings under mist if treated with IBA (105), but the method has not been done on a large scale.

**Stooling.** This method of propagation is used in Europe for obtaining plants on their own roots, but it is expensive.

**Rootstocks.** Seedling rootstocks from seed of the cultivar being propagated are usually used. Because of hybridization, variability often results, which has been associated with graft incompatibility.

A chestnut hybrid (C. sativa xC. castanea) has been micropropagated using explants from mature trees (207).

**Ceratonia siliqua.** Carob, locust bean. Cultivated for its edible seed pods, also known as St. John’s bread, it is a tough, low-maintenance plant, tolerant of dry, harsh conditions, that also has ornamental value. This subtropical evergreen tree is usually propagated by seeds, which germinate without difficulty when freshly harvested. However, if seeds dry out and the seed coat becomes hard, they should be softened by hot-water or sulfuric acid treatment. The taproot is easily injured, so it is best to sow seeds in air-pruning flats for more fibrous root development. Transplanting bare-root seedlings gives poor results, so seeds are best planted in their permanent location or started in containers for later transplanting. Selected cultivars are chip-budded in late spring, which is faster than grafting. Cuttings can be rooted if taken in mid-spring and treated with 7,500 ppm IBA. Air layering in late summer is successful.

**Micropropagation.** Micropropagation using explants from both seedling and mature trees has been done successfully (183).

**Cherimoya.** See Annona.

**Cherry (Sour, Sweet).** See Prunus cerasus (sour), Prunus avium (sweet).

**Chinese Gooseberry.** See Actinidia.

**Citron.** See Citrus.

**Citrus spp.** Citrus (48, 185). Includes cultivars of C. aurantifolia (lime), C. limon (lemon), C. maxima (pomelo), C. medica (citron), C. reticulata xC. sinensis (tanger), C. paradisi (grapefruit), C. reticulata (mandarin orange), C. sinensis (sweet orange), C. paradisi xC. regiculata (tangelo), and related citrus species used for rootstock. In general, propagation is the same for all species of citrus. Members of this genus are readily intergrafted and grafted to other closely related genera such as Fortunella (kumquat) and Poncirus (trifoliate orange).

**Seeds.** Polyembryony occurs in seeds of most citrus species used as rootstocks due to nucellar embryony (see page 132). The sexual seedlings present within the embryo tend to be weak, variable, and are usually rogued out. The apomictic seedlings, which arise from the nucellus, are uniformly and have the same genotype as the seed tree. As commercial plants, nucellar seedlings not only have a long juvenile period but are also vigorous, thorny, upright-growing, slow to come into bearing, and undesirable as an orchard tree. Vigor, thorniness, and delayed bearing become less pronounced in consecutive vegetative generations of propagation, particularly if propagules are taken from the upper part of older nucellar seedling trees. Nucellar seedlings are largely free of viruses and other systemic pathogens. Registered clonal selections of nucellar cultivars have been identified for all the commercial citrus cultivars and are the basis of citrus nursery source usage.
Budwood should be taken only from known high-producing, disease-free trees, preferably registered clones (Citrus Clonal Protection Program http://ccpp.ucr.edu).

Rootstock Selection. Next to scion source selection, the choice of rootstock is critical in commercial citrus production. Rootstocks vary greatly in their relative susceptibility to diseases (Phytophthora sp.); viruses (particularly tristeza); interactions with scion; quality of fruit, size, and vigor; and tolerance to soil problems, such as chlorosis, salt, and boron excess.

Field Production of Nursery Plants. Avoid using soils infested with citrus nematodes (Tylenchulus semipenetrans) or burrowing nematodes (Radopholus similis), or soil-borne diseases, although citrus is resistant to Verticillium wilt. For nurseries, it is preferable to use virgin soil or at least a soil that has not been formerly planted with citrus. For small operations, raised seed beds enclosed by 12-in boards can be used. A soil mixture of sandy loam and peat moss is satisfactory. Treating the soil with a fumigant such as DD mixture of sandy loam and peat moss is satisfactory. Treating the soil with a fumigant such as DD (dichloropropane-dichloropropene) will minimize the chances of nematode infestations. The seed bed and nursery site can be fumigated with methyl bromide to reduce the hazard of fungus infection. Planting should be delayed for 6 to 10 weeks following treatment to allow the fumigant to dissipate. Some soils in California, however, have remained toxic to citrus for a year following such treatment. The seed bed should be in a lathhouse, or some other provision should be made for screening the young seedlings from the full sun. The fruit of certain species, such as the trifoliate orange (Poncirus trifoliata) or its hybrids, matures in the fall. If the seeds are to be planted at that time, they should be held in moist storage at -1 to 4°C (30 to 40°F) 4 weeks before planting. Trifoliate orange seedlings, if grown during times of the year having short days, will respond strongly with increased growth when supplementary light is provided to lengthen the day. The same is true for seedlings of certain citrange and sweet orange cultivars (209).

The best time to plant the seeds is in the spring after the soil has warmed [above 15°C (60°F)]. Seeds should be planted in rows 5 to 7.5 cm (2 to 3 in) apart, and 2.5 cm (1 in) apart in the row. They are pressed lightly in the soil and covered with a 2 cm (3/4 in) layer of clean, sharp river sand. The sand prevents crusting and aids in the control of “damping-off” fungi. The soil should be kept moist at all times until the seedlings emerge. Either extreme, allowing the soil to become dry
and baked or overly wet, should be avoided. PVC pipe with circulating hot water is placed below the seed bed to maintain a temperature of 27 to 29°C (80 to 85°F)—which hastens germination. By this method, seeds may be planted in the winter months, and the seedlings will be large enough to line out in the nursery in the spring. Many can be budded by fall or the following spring, a technique that often shortens the propagation time by 6 to 12 months.

After the seedlings are 20 to 30 cm (8 to 12 in) tall, they are ready to be transplanted from the seed bed to the nursery row, preferably in the spring after danger of frost has passed. The seedlings are dug with a spading fork after the soil has been wet thoroughly to a depth of 45 cm (18 in), because then they can be loosened and removed with little danger of root injury. All stunted or off-type seedlings, or those with crooked, misshapen roots, should be discarded.

The nursery site should be in a frost-free, weed-free location on a medium-textured, well-drained soil at least 61 cm (24 in) deep and with irrigation water available. Old citrus soils should be avoided unless fumigated before planting. The seedlings should be planted at the same depth as in the seed bed, and spaced 25 to 30 cm (10 to 12 in) apart in 90 to 120 cm (3 to 4 ft) rows.

Citrus seedlings are usually budded in the fall in Florida and California, starting in mid-September, early enough so that warm weather will ensure a good bud union, yet late enough so that bud growth does not start and the wound callus does not grow over the bud itself.

The best type of budwood is that next-to-the-last flush of growth, or the last flush after the growth hardens. A round bud-stick gives more good buds than an angular one. The best buds are those in the axils of large leaves. The bud-sticks are usually cut at the time of budding, the leaves removed, and the bud-sticks protected against drying. Bud-sticks may be stored for several weeks if kept moist and held under refrigeration at 4 to 13°C (40 to 55°F).

The T-bud method is extensively used for citrus. The bud piece is cut to include a sliver of wood beneath the bud. Fall buds are unwrapped in 6 to 8 weeks after budding, spring buds in about 3 weeks. In California and Texas the buds are usually inserted at a height of 30 to 45 cm (12 to 18 in), but in Florida the buds are inserted very low on the stock—2.5 to 5 cm (1 to 2 in) above the soil. Such low budding is often necessitated by profuse branching in rough lemon and sour orange rootstock seedlings, which is caused by partial defoliation due to scab and anthracnose spot.

Buds inserted in the fall are forced into growth by “lopping” or “crippling” the top of the seedlings 5 to 7.5 cm (2 to 3 in) above the bud just before spring growth starts, and consists of partly severing the top, allowing it to fall over on the ground. The top thus continues to nourish the seedling root, but forces the bud into growth. Lopping of spring buds is done when the bud wraps are removed—about 3 weeks after budding. If possible, the “lops” should be left until late summer, at which time they are cut off just above the bud union. Although lopping is necessary, it may make irrigation and cultivation difficult. An alternative practice is to cut the seedling completely off 30.5 to 35.5 cm (12 to 14 in) above the bud, then later cut it back immediately above the bud. However, this practice does not force the bud as well as lopping or cutting the seedling just above the bud.

Young citrus nursery trees may be dug “balled and burlapped” or bare-root. Bare-rooted trees should have the tops pruned back severely before digging. Transplanting of such trees is best done in early spring, but balled trees can be moved any time during spring before hot weather starts.

Container Production of Nursery Plants (56). Citrus seeds are mechanically extracted and washed, then germinated in special elongated square plastic pots in a greenhouse. After 3 or 4 months the seedling rootstock plants are large enough for inverted T-budding; finished budded trees can be developed in about 12 months when grown in plastic containers. Sometimes cleft grafting is used on the young seedlings after they are growing in their final containers (144). Citrus nursery trees grow well in containers and develop into good orchard trees upon field planting, providing they are not held in the container so long that root binding occurs (153).

Miscellaneous Asexual Methods. Citrus plants can be propagated by a variety of vegetative methods. Many citrus species can be propagated by rooting leafy cuttings, or by leaf-bud cuttings, although nursery trees are not commonly propagated in this manner (48). The Persian lime (Citrus aurantifolia) is propagated to some extent by air layering, as is the pummelo (Citrus grandis) in southeast Asian countries. Citron (Citrus medica) is propagated from softwood or hardwood cuttings, because it tends to overgrow rootstock. Etrog (Citrus medica) must be grown on its own roots to be acceptable for Jewish holidays.

Micropropagation. Citrus can be micropropagated, but it is not a commercial method. Primary use is production of virus-free clones through micrografting procedures (177).
Rootstocks for Citrus (31, 48, 210). The principal characteristics of citrus are listed in the chart below. Information on recommended citrus rootstock for Florida can be found at [http://news.ifas.ufl.edu/1999/04/14/new-florida-citrus-rootstock-selection-guide](http://news.ifas.ufl.edu/1999/04/14/new-florida-citrus-rootstock-selection-guide). Sweet orange (C. sinensis) is a good rootstock for all citrus cultivars, producing large, vigorous trees, but due to its high susceptibility to gummosis (Phytophthora spp.), it is not grown much today.

Sour Orange (C. aurantium). This is historically the most important rootstock species, used all over the world due to its vigor, hardiness, deep root system, resistance to gummosis diseases, and ability to produce high-quality, smooth, thin-skinned, and juicy fruit. Its high susceptibility to the tristeza virus, which produces quick decline, has eliminated its use in California and reduced its use in Florida, but this rootstock is still used in Texas, Mexico, Cuba, Venezuela, Honduras, Sicily, and Israel. The scion top may be tolerant to the virus, but a hyperreaction with the rootstock at the graft union kills the phloem tissues and the roots starve.

Rough Lemon (C. jambhiri). This has been the most important rootstock in Florida because its high vigor is well adapted to warm, humid areas with deep, sandy soils. Its primary drawback is the low quality of fruit that is produced, evidently a function of the high vigor, but it is also very cold-sensitive. Because of its susceptibility to blight and Phytophthora, its use is declining in Florida. However, the rootstock remains important in Arizona.

Trifoliate Orange (Poncirus trifoliata). This deciduous species is important because of its cold tolerance and tendency to dwarf the scion. It is the principal citrus rootstock in Japan and used in China as a stock for satsumas and kumquats. In northern Florida and along the Gulf Coast of Texas, it has been used as a stock for Satsuma oranges and kumquats, for which it is excellent. Trifoliate orange is commonly used as a stock for ornamental citrus and in home orchards for dwarfed trees. Trees on this stock yield heavily and produce high-quality fruits.

Trifoliate orange fruits produce large numbers of plump nucellar seeds that germinate easily. The upright-growing, thorny seedlings are easy to bud and handle, but their slow growth often necessitates an extra year in the nursery before salable trees are produced.

‘Cleopatra’ Mandarin (C. reshni). This is a good rootstock, particularly in Florida, for oranges, grapefruit, and other mandarin types, and has come into use in California and Texas as a replacement for sour orange rootstock. Its resistance to gummosis, comparative salt tolerance, and resistance to tristeza has justified its greater use. Its chief disadvantages are the slow growth of the seedlings, slowness in coming into bearing, and susceptibility to Phytophthora parasitica root rot.

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<td>Nucellar Incompatibility</td>
<td>70–90% OK</td>
<td>90–100% OK</td>
<td>60% OK</td>
<td>80% OK</td>
<td>80% ‘Eureka’</td>
<td></td>
</tr>
<tr>
<td>Vigor</td>
<td>large, vigorous</td>
<td>large, vigorous</td>
<td>very vigorous</td>
<td>semi-dwarf good</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>Fruit quality</td>
<td>high tolerant</td>
<td>very good</td>
<td>tends to be low</td>
<td>susceptible</td>
<td>susceptible</td>
<td></td>
</tr>
<tr>
<td>Tristeza</td>
<td>very susceptible</td>
<td>resistant</td>
<td>resistant</td>
<td>resistant</td>
<td>resistant</td>
<td></td>
</tr>
<tr>
<td>Phytophthora</td>
<td>resistant</td>
<td>resistant</td>
<td>resistant</td>
<td>resistant</td>
<td>resistant</td>
<td></td>
</tr>
<tr>
<td>Nematodes</td>
<td>susceptible</td>
<td>susceptible</td>
<td>susceptible</td>
<td>susceptible</td>
<td>susceptible</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>light, well drained</td>
<td>lighter soils, well drained</td>
<td>tender</td>
<td>hardy</td>
<td>salt-tolerant</td>
<td></td>
</tr>
<tr>
<td>Hardiness</td>
<td>medium</td>
<td>hardy</td>
<td>hardy</td>
<td>hardy</td>
<td>hardy</td>
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</tr>
</tbody>
</table>
Nucellar seedlings of citrange cultivars develop strong, single trunks, easily handled in the nursery. As with trifoliolate orange, only exocortis-free buds should be used on citrange rootstocks; otherwise, dwarving—and eventual low production—will result. 'Troyer' and 'Carriazo' are the two commercially most important citrus rootstocks in California and Arizona. 'Carriazo' is an important rootstock in Florida.

Rangpur Lime (C. aurantifolia x C. reticulate). This is the most widely used citrus rootstock in Brazil, producing vigorous, fruitful trees, which are resistant to tristeza. It is highly susceptible to exocortis. In Texas, it has been more salt-tolerant than other citrus rootstocks. Some strains of Rangpur lime are susceptible to Phytophthora.

Alemow (Citrus macrophylla). This rootstock is used in California for lemons because of its tolerance in high-boron areas. It is susceptible to tristeza when sweet orange scion cultivars are used, and to a rootstock necrosis first detected about 1960.

Coconut. See Cocos.

Cocos nucifera. Coconut (37). This tropical monocot is probably the most important nut crop in the world. There are two forms—tall and dwarf—with named seed-propagated cultivars of each, based on their origin in specific "seed gardens" collected from isolated groves. Some named cultivars maintain their characteristics quite dependably, but some of these are also susceptible to the highly lethal golden disease. Seeds should be collected from trees that produce large crops of high-quality nuts.

The nuts are usually germinated in seed beds. The nuts, still in the husk, are set at least 30 cm (12 in) apart in the bed and laid on their sides with the stem end containing the "eyes" slightly raised. The sprout emerges through the eye on the side that has the longest part of the triangular hull. As soon as this occurs (about a month after planting), the sprout sends roots downward through the hull and into the soil. In 6 to 18 months the seedlings are large enough to transplant to their permanent location.

Coconut is also tissue cultured for clonal propagation and safe germplasm exchange.

Coffee (214). Coffee comes from three species, Coffea arabica, which is self-compatible, but also from Coffea canephora var. robusta, which is self incompatible, and C. liberica. Coffee comes relatively true from seed. C. arabica is the most important, such as seed propagated cultivars like 'Mondo Nova', 'Caturra' in Brazil, 'Villalbos' and 'Hibrido' in Central America, and 'Moko' in Saudi Arabia.

Seed. The most common method of propagation is by seed, preferably obtained from selected superior "mother" trees. Coffee seeds lose viability quickly and are subject to drying through the seed coverings. Seeds held at a moisture content of 40 to 50 percent and at 4 to 10°C (40 to 50°F) will keep for several months. There is no seed dormancy. Seeds are usually planted in seed beds under shade. Sometimes the seedlings are started in soil in containers formed from leaves, or in polyethylene bags, to facilitate transplanting. Germination takes place in 4 to 6 weeks. When the first pair of true leaves develop, the seedlings are transplanted to the nursery and set 30 cm (12 in) apart. After 12 to 18 months in the nursery the plant has formed 6 to 8 pairs of laterals and is ready to set out in the plantation.

Cuttings. Coffee can be propagated vegetatively by almost all methods. Leafy cuttings have potential for commercial use, but the resulting plants show strong tophophysis. Cutting material should be taken only from upright shoot terminals in order to produce the desired upright-growing tree. Leafy cuttings of partially hardened wood treated with auxin can be rooted fairly easily with mist and partial shade (187).

Grafting. Coffee plants have been grafted using a hypocotyl-edonary grafting technique, primarily to utilize interspecific rootstock for nematode control (17).

Micropropagation. Coffee plants have been propagated by the formation of adventitious embryos in aseptic callus cultures (96).

Rootstocks. Seedlings of C. canephora var. robusta have been used for topworking to increase production in nematode-infested soils, but may not be desirable in uninfested areas (17).

Coffee. See Coffea.

Cola nitida. Kola. This tropical tree produces a caffeine-containing nut used to make refreshing beverages.

Seed. Plants are grown from seed sown directly in the field or in nurseries for later field planting. Seeds for planting should be harvested only when completely mature. Seedling plants have shown pronounced juvenility; 7 to 9 years are required for the seedlings to flower.

Miscellaneous Asexual Methods. Vegetative propagation using mature propagules can generate early production, but propagation is difficult. Rooting terminal leafy cuttings in polyethylene-covered frames
without auxin has been successful. Air layering with IBA treatment is successful—commercial nut production is induced 12 to 18 months after planting the rooted layers. Patch budding is also a successful method of vegetative propagation.

*Corylus* spp. Filbert, Hazelnut (125). Cultivars of hazelnut (*C. avellana*) are widely grown in Europe, but are called filberts in the Willamette valley of Oregon, where they are primarily grown in the United States. Native species in North America include *C. americana*.

**Seed.** Freshly harvested seeds of *C. avellana* are not dormant, but develop dormancy with drying in a complex interplay of inhibitors and growth promoters. Seed dormancy can be overcome with stratification for 3 months at 0 to 4°C (32 to 40°F). Seeds are mostly planted in the nursery in the fall.

**Layering.** The usual method of commercial filbert propagation is by simple layering in the spring using suckers arising from the base of vigorous young trees 4 to 8 years old. Special stool mother plants can be maintained in a bush form just for layering purposes. After one season's growth, a well-rooted plant 0.6 to 1.8 m. (2 to 6 ft) tall may be ready to set out in the orchard. Old orchard trees are not suitable to use for layering. Sometimes suckers arising from the roots are dug and grown in the nursery row for a year or, if well rooted, planted directly in place in the orchard. Stool layering using girdling and spraying IBA at 750 mg/L-1 produces well-rooted liners ready for planting directly in the orchard (59).

**Grafting.** Using a whip graft in midwinter has been successful with the aid of a “hot grafting” procedure. (125). Commercial cultivars are grafted on seedling *C. avellana* rootstock.

**Cuttings.** Propagation is difficult, but some reports indicate that with careful timing in mid-June to mid-July while inactive, growth rooting can occur (52). Cuttings are treated with a 5,000 to 10,000 ppm IBA quick-dip or talc, and rooted under mist in a well-drained medium. Too much water results in decline, which is why fog is preferred to mist.

**Micropropagation.** Corylus can be micropropagated but is not a commercial procedure (7). Successful rooting is the chief limitation for large-scale micropropagation (10).

*Custard Apple.** See *Annona*.

*Cydonia oblonga.* Quince. The quince is a small bushy tree that is grown for the jelly-making qualities of the fruit, due to its high pectin content, and as a dwarfing rootstock for pears; see the rootstock section for *Pyrus communis*.

**Cuttings.** Quince roots readily by hardwood cuttings using “heel” cuttings attached to one-year-old wood. Cuttings from two- to three-year-old wood also root easily. The burrs or knots found on this older wood are masses of adventitious root initials. Cuttings usually make sufficient growth in one season to transplant to their permanent location.

**Grafting.** Quince cultivars can be T-budded on rooted cuttings (such as ‘Angers’) or sometimes on quince seedlings.

**Layering.** Quince can be propagated readily by mound layering, which has been a traditional method of propagation.

**Micropropagation.** Methods for large-scale clonal production of ‘Provence’ quince has been described for use as a dwarfing pear rootstock (1).

*Date Palm.** See *Phoenix*.

*Diospyros kaki.* Japanese persimmon (180, 191). Subtropical tree species with many cultivars is grown widely in the Orient—and to a limited extent in the United States—for its large fruit. Cultivars are propagated by grafting onto seedling rootstocks. American persimmon (*D. virginiana*) is a hardy species that grows throughout the midwest and southern part of the United States. Some named cultivars are grown in home yards.

**Seed.** Seeds of *D. lotus*, *D. kaki*, and *D. virginiana* are stratified for 120 days at about 10°C (50°F). Dry seeds should be soaked in warm water for 2 days before stratification. Excessive drying of the seed is harmful, especially for *D. kaki*. Seeds are planted either in flats or in the nursery row. Young persimmon seedlings require shading.

**Cuttings.** Softwood cuttings with bottom heat, under mist, and treated with IBA will root, whereas hardwood cuttings do not root successfully.

**Grafting.** Crown grafting by the whip-and-tongue method or cleft can be done in early spring when both scionwood and rootstock are still dormant. Bench grafting may also be used; budding is less successful than grafting (180). *D. virginiana* is primarily
produced by budding and grafting onto *D. virginiana* seedlings.

**Rootstocks for Japanese Persimmon.**

*Diospyros lotus.* This rootstock, widely used in California, is very vigorous and drought-resistant. It produces a fibrous type of root system that transplants easily. This rootstock is susceptible to crown gall (*Agrobacterium*) and *Verticillium*, will not tolerate poorly drained soils, and is highly resistant to oak root fungus (*Armillaria*). ‘Hachiya’ does not produce well on *D. lotus* stock because of excessive shedding of fruit in all stages (180). ‘Fuyu’ scions usually do not form a good union with *D. lotus*, although ‘Fuyu’ topworked on a compatible *D. kaki* interstock on *D. lotus* roots makes a satisfactory tree.

*D. kaki.* This rootstock is the most favored in Japan and is probably best for general use. It develops a good union with all cultivars, is resistant to crown gall (*Agrobacterium*) and oak root fungus (*Armillaria*), but is susceptible to *Verticillium*. Seedlings have a long tap-root with few lateral roots, making transplanting somewhat difficult.

*D. virginiana.* Seedlings of this species are utilized in the southern United States due to their wide soil adaptation but have not proven satisfactory in some localities. ‘Hachiya’ growing on this rootstock in California is dwarfed, has sparse bloom, and yields poorly (180), but most other Oriental cultivars make a good union with this rootstock. However, diseases of an unknown nature carried in *D. kaki* scions will cause death of the *D. virginiana* roots. Otherwise, this rootstock seems to be tolerant of both drought and excess soil moisture. Its fibrous type of root system makes transplanting easy but increases suckering.

**Micropropagation.** Oriental persimmon cultivars can be micropropagated (42, 199) and produced from somatic embryogenesis (200).

*Eriobotrya japonica.* Loquat. This subtropical evergreen pome fruit is grown for its fruit which is used fresh, or in jams and jellies. The species is also used as a landscape plant. Many of the trees in use are unselected seedlings. Improved cultivars exist, but are difficult to propagate.

**Seed.** No treatment is apparently required, but seeds tend to germinate spontaneously. Should be sown soon after extraction, because heat and light tend to reduce quality of germination.

**Grafting.** Scions are T-budded or side-grafted to loquat seedlings. Established seedling trees may be topworked, using the cleft graft. Quince can also be used as a rootstock, producing a dwarfed tree. Inarching is also used, and topworking is easily done with bark grafting.

**Layering.** Air layering is successful and can be improved by auxin application (188). Three-month-old shoots are ringed and layered (20).

*Euphoria longana.* Longan (20). A tropical tree from southwest Asia and China. Seedlings have a long juvenile period and are variable. There are many vegetatively propagated cultivars in southern China.

**Seed.** Easily grown from seed.

**Grafting.** Cleft, whip, side, and inarch grafting are successful. The scions are semihard terminal shoots—about 0.5 cm (1/4 in) in meter, with leaves still attached. Grafts are made into a node subtended by a leaf and enclosed with a polyethylene bag, which is shaded. Seedling rootstocks of the cultivar to be grafted are used.

**Cuttings.** Leafy cuttings with thick hard terminal wood, about 25 cm (10 in) long, are taken in winter and rooted with bottom heat and mist.

**Layering.** Marcottage (air layering) is the preferred method. This practice is carried out in spring with well-matured, recently flushed growth. See the procedure described in Chapter 15. The layer is removed after 2 to 4 months when roots have turned from white to creamy brown. Establish in plastic bags or pots and transplant to the field after 6 to 12 months.

**Feijoa sellowiana.** Feijoa. Pineapple Guava (109). This small subtropical evergreen tree is grown for its edible fruit, useful for jelly and juice.

**Seed.** Seeds germinate without difficulty. They are started in flats of media and later transplanted to the nursery row.

**Cuttings.** Leafy softwood cuttings treated with auxin and started under closed frames can be rooted. Rooting under mist is usually quite difficult, otherwise layering can be successful.

**Grafting.** Scions are grafted to feijoa seedlings using a whip graft or a cleft graft (63).

*Ficus carica.* Fig. The cultivated fig is an ancient fruit crop from the Mediterranean area that grows into small trees (40, 123). Specific cultivars have been propagated by hardwood cuttings for centuries.

**Seed.** Seeds are used only for breeding new cultivars. The fruit is a fleshy receptacle bearing many small
achenes inside. Some of these are sterile and others fertile. The heavier fertile seeds can be separated from the lighter ones by floating them in water. Seeds can be germinated easily in flats of soil mix.

**Cuttings.** Hardwood cuttings of 2- or 3-year-old wood or basal parts of vigorous 1-year shoots with a minimum of pith are suitable for cuttings. For best results cuttings should be prepared in early spring, well before bud-break, with the bases allowed to callus for around 10 days at about 24°C (75°F) in slightly moist bark or peat media before planting. IBA will enhance rooting. The cuttings are grown for one or two seasons in the nursery and then transplanted to their permanent location. Figs can also be grown in containers in the nursery. A method in European countries is to plant long cuttings, 0.9 to 1.2 m (3 to 4 ft), with their full length in the ground where the tree is to be located permanently. Sometimes two cuttings are set in one location to increase the possibility that at least one will survive. Pregirdling of fig shoots 30 days before removal for rooting is beneficial (20).

**Grafting.** The fig can be budded, using either T-buds inserted in vigorous 1-year-old shoots on heavily pruned trees, or patch-budded onto older shoots.

**Layering.** Figs are easily air layered. One-year-old branches, if layered in early spring, are usually well-rooted by midsummer.

**Micropropagation.** Figs can be micropropagated (173).

**Fig.** See Ficus

_Fragaria xananassa_. Strawberry (76, 85). The strawberry is an herbaceous perennial whose basic vegetative structure is a thickened vertical stem, known as a “crown.” It produces a rosette of leaves and inflorescences in the spring, and runners (see Fig. 14–18) in the summer. In the normal annual cycle, the plant is induced to initiate flowering in the fall by warm days and shortened photoperiod, followed by chilling of the crown during winter to stimulate spring vegetative growth. Flowering and fruiting occur for about 6 weeks in spring. Runners are induced in the long days of summer and grow out from the main crown to start new plantlets at every other node. In some strawberry cultivars, runner formation is inhibited and the plant expands by increasing its crown (“everbearing types”). In recent years, “day-neutral” genotypes have been produced by breeding, which make flowering possible at any time of the year. Natural vegetative reproduction is by runner development or by crown division.

Modern commercial strawberry production has manipulated the strawberry plant annual growth cycle by combining breeding, nursery, and plant management and environment control into an integrated system, depending upon the region where grown (85). In areas of warm winters and hot or warm summers (e.g., California, Florida), the plants are planted as crowns, maintained in a “hill” system managed as an annual crop, and replanted each year after fumigating the previously planted ground. Annual production has increased more than tenfold and the fruiting season has been expanded from a few weeks in the spring to literally year-round production, depending on cultivar, management, and climate. In areas with shorter growing seasons and cold winters (northern or southern latitudes), the _matted row_ is used, because it requires less inputs and produces over 3 to 5 seasons. Other systems utilize plastic high tunnels for production under controlled environments.

Strawberry has many disease problems that must be controlled both during propagation and production. These include fungal soil and foliage diseases, nematodes, viruses spread by aphids and nematodes, and mycoplasma diseases spread by aphids. Control involves cultivar resistance, pathogen-free propagation and planting material, chemical control, and sanitation.

**Seeds.** Seed propagation is used only in breeding programs for the development of new cultivars. The strawberry fruit is an expanded receptacle upon which are borne the true “fruit” or achenes. These are usually extracted with a blender. The achenes are quite hard, and scarifying with sulfuric acid for 15 to 20 minutes prior to planting improves germination (182).

**Micropropagation.** In the United States, meristem culture is used mostly in virus control programs. In Europe, on the other hand, millions of nursery plants are produced annually by micropropagation (47, 143). The first stage (establishment) is to excise a 0.1 to 0.5 mm meristem dome from surface-sterilized, newly formed runner tips. These are planted on a basal culture medium. Stage 2 (proliferation) is a transfer to a medium containing cytokinin to promote axillary buds development (may include several subcultures). Stage 3 is a transfer to an auxin medium for rooting, and stage 4 is acclimatization and transplantation (see Chapters 17 and 18). Long day and gibberellin treatment stimulate runnering.

Some genetic instability may occur as off-type individuals, apparently due to somaclonal variation. The effect can be minimized by regular inspection, rogueing, and limiting subcultures to 3 to 5 times.
Virus Control. Stock plants are heat pretreated at 36°C (97°F) for 6 weeks. From here, shoot tips are meristemmed and individual stock plants are indexed by grafting to indicator plants (see Fig. 16–30), or tested by ELISA or DNA hybridization (see Chapter 16). Programs for certifying virus free, true-to-type plants are available in many countries [see UC Strawberry Links - http://www.innovationaccess.ucdavis.edu/strawberry/links.htm](41). Certification includes the following steps: I. Nuclear stock plants from virus-tested meristemmed cultured plants are grown in an insect proof greenhouse or screenhouse. II. The next generation provides registered foundation plants that are grown in fumigated fields to produce plants to be distributed to commercial nurseries. III. The next generation (daughter) plants that are produced are sold as certified plants to commercial strawberry producers.

Production of Planting Stock. Three different kinds of plants (crowns) are produced: (a) actively growing green plants, (b) fully dormant crowns, and (c) semidormant crowns. Active green plants are dug directly from production fields or by rooting runners as plug plants under mist in the greenhouse. Fully dormant plants are produced in strawberry nurseries located in areas (such as northern California) where they have a long, warm growing season and are exposed to adequate winter chilling. Nurseries are located in a favorable location, and isolated from other crops, including wild strawberries. Field nurseries are planted at relatively high elevations where there is little rainfall but lots of sunlight to maximize starch reserves. Land is fumigated the previous fall. Nursery plants are planted in the spring and subsequently maintained under irrigation for rapid growth and rooting of runners. Mature runner plants are dug with special machines in the fall when mature and desired dormancy is achieved. Immediately thereafter, the leaves and petioles are removed and the plants are packed with roots toward the center in unsealed cardboard or wood boxes lined with polyethylene (0.75 to 1.5 mil) to keep plants from drying out. These bare root crowns are stored until planting at slightly below freezing (−1°C). Semidormant plants with varying levels of chilling geared to different cultivars and planting dates are generated by digging plants from the field at different times in the autumn at different geographical locations (i.e., elevation and latitude).

Boxes of 1,000 or 2,000 plant units can be stored and kept in good condition up to one year at −2 and −1°C (28 and 30°F). During storage, the plants not only remain dormant but physiological changes occur that overcome endodormancy and enhance vigor when the plants are later removed and planted in the production area. The time schedule for digging, storage, and planting is geared to the individual cultivar, the production schedule at the production fields, and the environment at the growing site.

Crown Division. Everbearing cultivars that produce few runners are propagated by crown division. Certain cultivars may produce 10 to 15 strong crowns per plant by the end of the growing season. In the spring, such plants are dug and carefully cut apart; each crown may then be used as a new plant.

Garcinia mangostana. Mangosteen (159). This slow-growing evergreen tree of the Southeast Asian tropics produces a parthenocarpic, soft, sweet, and delicious fruit (20). There are no known wild progenitors; apparently Mangosteen originated as an interspecific hybrid of unknown species. Also, there are no known cultivars because the plants are reproduced apomictically. Plants are nucellar seedlings that may take 8 to 15 years to produce fruit. Seeds have low viability but can germinate in 4 to 6 days. Grafting with a top wedge is successful, but the rootstock must be compatible. Layering is improved by IBA treatment.

Gooseberries. See Ribes.

Grape. See Vitis.

Grapefruit. See Citrus.

Guava (Common or Lemon; Cattley or Strawberry). See Psidium.

Guava (Pineapple). See Feijoa.

Hickory (Shagbark). See Carya.

Jackfruit. See Artocarpus.

Juglans cinerea. Butternut. This tree is native to the eastern United States where it is grown mostly as a timber tree (19). Several butternut cultivars have been selected for nut production. Butternut canker, caused by a recently introduced fungus Sirococcus clavigignenti-juglandacearum, is now threatening its existence as a native species but propagation and maintenance of selected germplasm and the few cultivars may insure its preservation (170).

Seed. The very hard-shelled seeds are enclosed within a husk that must be removed after collection. Nuts may be stored at 3 to 4°C (37 to 39°F) at 80 to 90 percent humidity. Seeds have dormant embryos and
should be either planted in the fall out-of-doors or stratified for several months and planted in the spring.

Grafting. Cultivars are propagated by chip budding or bench grafting (using the whip graft) on Persian (J. regia) or black (J. nigra) walnut seedling rootstocks. Butternut is also bark grafted onto J. nigra seedlings. Excessive sap “bleeding” is a problem in grafting, and necessary steps must be taken to overcome it.

Cuttings. There was enhanced rooting of softwood cuttings treated with 62 and 74 ppm K-IBA, and high survival of rooted cuttings overwintered in cold storage and acclimated to the field (171).

Juglans nigra. Black Walnut (71). This species is native to eastern North America where it is an important timber tree. It also produces excellent nuts, although they are very hard-shelled.

Seed. The hard-shelled nuts apparently are benefited by warm stratification to soften the shells, followed by cold stratification to overcome embryo dormancy. Early fall planting could provide both conditions. Seedlings are started in nurseries and only the strongest, most vigorous trees are set out in the plantation. Careful planting is necessary to obtain the essential rapid, early growth.

Cuttings. Cuttings are possible but difficult to root.

Grafting. Black walnut cultivars selected for their nut qualities are propagated by patch or ring budding or side grafting on J. nigra rootstocks (34, 189). This method is suitable for seedling stocks up to about 2.5 cm (1 in) in diameter.

Juglans regia. Persian or English Walnut (66). This important commercial nut is produced in California, Oregon, and in the Mediterranean region. Its origin is southwestern Asia, particularly from the area occupied by present-day Iran. “Carpathian walnuts” are a cold-hardy strain of J. regia, which originated in cold winter areas of the Carpathian Mountains of Poland and the Kiev and Poltava regions of the Ukraine. Carpathian cultivars have been developed that are winter-hardy in the eastern United States (79).

Seed. Nuts of Juglans species used as seedling rootstocks for J. regia should be either fall-planted, or stratified for about 2 to 4 months at 2 to 4°C (36 to 40°F) before they are planted in the spring. It is better to plant the seeds before they start sprouting in the stratification boxes, but with care, sprouted seeds can also be planted successfully. At the end of one season, the seedlings should be large enough to bud. Seedlings of walnut are very sensitive to waterlogged soil conditions under which they will not survive (33).

Grafting. J. regia is propagated by patch budding, T-budding, or whip grafting on one-year-old seedling rootstocks. Topworking-established seedling trees in the orchard that are 1- to 4-years old can be done by bark grafting in late spring. Patch budding in the spring or summer works well when topworking smaller sized material.

Micropropagation. J. regia cultivars (66) and clonal sources of Paradox walnut can be micropropagated but have difficulty in establishment.

Rootstocks

Northern California Black Walnut (J. hindsii). This rootstock is the most commonly used in California. The seedlings are vigorous and make a strong draft union. They are somewhat resistant to oak root fungus (Armillaria mellea), and root-knot nematode (Meloidogyne spp.), but are susceptible to crown and root rot (Phytophthora spp.), and the root-lesion nematode (Pratylenchus vulnus). Persian walnut trees on this rootstock are susceptible to a serious problem known as “blackline” caused by a pollen-transmissible virus, cherry leaf roll, which occurs in California, Oregon, England, Italy, and France. Symptoms include a breakdown of tissues in the cambial region at the graft union, leading to lethal girdling of the trees. The Persian walnut scion above the graft union is tolerant of the virus but the hypersensitive J. hindsii rootstock tissue at the union is killed. As a result the girdled top dies and the rootstock survives.

Persian Walnut (J. regia). Worldwide, this species is probably the most common rootstock for Persian walnut cultivars due to availability of seeds. Seedlings of this species as a rootstock produce good trees with an excellent graft union. The roots are susceptible to crown gall (Agrobacterium), oak root fungus (Armillaria), and salt accumulation in the soil. They are not as resistant to root-knot nematodes (Meloidogyne) as J. hindsii. Nurserymen object to the slow initial growth of the seedlings. This rootstock is used in Oregon, where blackline is a very serious problem. Seedlings of the ‘Manregian’ clone (of the Manchurian race of J. regia), imported by the USDA as P. I. No. 18256, are used as rootstocks. They are vigorous, cold-hardy, and—in Oregon—no more susceptible to oak root fungus than J. hindsii seedlings (166).
Paradox Walnut (J. hindsii ×f. regia). First generation (F₁) hybrid seedlings are obtained from seed taken from J. hindsii trees, whose pistillate (female) flowers have been wind-pollinated with pollen from nearby J. regia trees. Seed source trees are found when seeds from a J. hindsii tree are planted and some of the seedling progeny are hybrids (an example of genotypic selection). The numbers vary widely, from none to almost 100 percent, depending upon the individual source tree. The hybrids are easily distinguished by their large leaves in comparison with the smaller-leaved, self-pollinated J. hindsii seedlings. Seed from Paradox trees should not be used for producing rootstocks, because of their great variability in all seedling characteristics. Although first-generation (F₁) seedlings are variable in some characteristics, most of them exhibit hybrid vigor and make excellent vigorous rootstocks for the Persian walnut. They are more resistant than either parent to crown rot (Phytophthora), and are tolerant of saline and heavy, wet soils. Paradox seedlings are susceptible to crown gall (Agrobacterium). Persian walnut on Paradox roots are just as susceptible to the blackline virus as J. hindsii seedlings. Trees on Paradox rootstocks grow and yield as well as, or better than, those on J. hindsii roots, and may produce large-size nuts with better kernel color. In heavy or low-fertility soils, trees on Paradox rootstock grow faster than those on J. hindsii.

Since Paradox seeds are difficult to secure in quantity, clonal selection efforts with accompanying vegetative propagation systems have been attempted but no mass propagation systems have yet evolved. Leafy cuttings under mist, hardwood cuttings, and trench layering can be rooted but with difficulty, and there are major problems when transplanting.

Eastern Black Walnut (J. nigra). This species has been recommended as a rootstock for Persian walnut cultivars in Europe and the former Soviet Union, but not in California. As compared with J. regia roots, it is reported to have greater tolerance to nematodes, oak root fungus, Phytophthora, and crown gall, but in California rootstock trials, trees on this stock showed poor yields.

Jujube. See Zizyphus.
Kiwifruit. See Actinidia.
Kola. See Cola.
Lemon. See Citrus.
Lime. See Citrus.

**Litchi chinensis.** Lychee. Evergreen subtropical tree fruit with delicious, juicy fruit that has been grown in China since ancient times. It is currently grown in most of the subtropical countries in the world. Many vegetatively propagated cultivars exist. It is typically propagated by air-layering mature tree branches. Growth can be enhanced by mycorrhizal fungi after air-layering (112).

**Seed.** The seeds are used in breeding, but have a long juvenile period of 10 to 15 years (20, 38); they are also used to produce seedling rootstocks. Litchi seeds germinate in 2 to 3 weeks if planted immediately upon removal from the fruit. They lose their viability within a month if not planted.

**Cuttings.** Cultivars are generally difficult to root from cuttings. Tip cuttings from a flush of growth in the spring have been rooted in fairly high percentages under mist in the full sun. Auxin is beneficial. Semi-hardwood cuttings from an active flush of new growth root more readily than those from dormant hardwood cuttings.

**Grafting (20).** Some success has been reported for splice grafting using subterminal portions of shoots for the scion. It is best to retain leaves on the rootstock. Approach grafting is also successful, as is chip and T-budding. Poor results may be attributed to graft incompatibility (159).

**Layering (Marcottage).** Air layering is the most important method of propagation and has been used in China for centuries. Layering can be done at any time of the year, but best results are obtained in spring or summer (137). Rooting takes place within 8 to 10 weeks with a success rate up to 100 percent. Large limbs with mature vegetative growth air layer more easily than small ones with recently flushed wood. Auxin applications may be beneficial. Stooling (mound layering) has also been reported to produce good results (20).

**Loganberry.** See Rubus.
**Longan.** See Euphoria.
**Loquat.** See Eriobotrya.
**Lychee.** See Litchi.

**Macadamia spp.** Macadamia nut. M. integrifolia and M. tetraphylla are the two principal species (84). These subtropical evergreen nut trees may be grown as seedlings, but clonal cultivars are preferred. Macadamia is highly resistant to Phytophthora cinnamomi and will tolerate heavy clay soil.

**Seed.** Fresh seeds should be planted in the fall as soon as they mature, either directly in the nursery or in sand boxes in a lathhouse. Seedlings are transplanted to
the nursery or into poly containers after growing 10 to 15 cm (4 to 6 in) tall. Seeds should not be cracked because they are readily attacked by fungi. Only seeds that sink when placed in water should be used (84). Seeds retain viability for about 12 months at 4°C (40°F), but at room temperature viability starts decreasing after about 4 months. Scarifying or soaking the seed in hot water hastens germination.

Cuttings. Macadamia can be propagated by rooting leafy, semi-hardwood cuttings of mature, current season’s growth. Tip cuttings 8 to 10 cm (3 to 4 in) work best. Treatment with IBA at 8,000 to 10,000 ppm is beneficial. Cuttings should be placed in a closed propagating frame or under mist for rooting. Bottom heat at 24°C (75°F) is beneficial. Cultivar differences exist in ease of rooting. M. tetraphylla cuttings root more readily than those of M. integrifolia. Rooted cuttings are not widely used in commercial plantings because of their shallow root system.

Grafting. One of the side graft methods is used. Leaves should be retained for a time on the rootstock. Rapid healing of the union is promoted if, prior to grafting, the rootstock is checked in growth by water or nitrogen deficiency to permit carbohydrate accumulation. Ringing the branches that are to be the source of the scions for 6 to 8 weeks before they are taken increases their carbohydrate content and promotes healing of the union (145). Wrap the entire scion with clear Parafilm or buddy grafting tape to prevent drying out; keep plants well hydrated after grafting. Budding has generally been unsuccessful (53). Seedling rootstock of M. tetraphylla is preferred for grafting M. integrifolia cultivars (84, 198). Macadamia can also be propagated by the cutting-graft method.


*Malus xdomestica.* Apple. This deciduous fruit crop is one of the oldest and most widely grown fruit crops in the world. Thousands of cultivars exist, many of which are chimeras and bud-sports.Viruses and virus-like organisms are serious problems for apples (see Chapter 16) such that essentially all commercial nurseries utilize virus-tested foundation clones and produce trees in a program of Registration and Certification (87).

Seed. Seeds are used for breeding and are the rootstock for many older orchards in the United States. At present, seedling rootstocks are used in limited parts of the world. The principal source of commercial seeds has been the pomace from processed apples. For spring sowing, seeds require stratification for 60 to 90 days at 2 to 7°C (35 to 45°F) to germinate. Some nurseries fall-plant seeds so that they receive the natural winter chilling. Soil should be raked over in the spring to avoid seedlings that become crooked in breaking through the crust. To obtain a branched root system, the seedlings may be undercut while small to prevent the development of a taproot. However, a straight root may be preferred for bench grafting. Seedlings that do not grow to a satisfactory size in 1 year should be eliminated.

Layering. The principal method of propagating the widely used clonal rootstocks is by mound layering (see Chapter 14). Large nursery areas in the Pacific Northwest, the eastern United States, and in northern Europe and England are devoted to stool beds.

Cuttings. Propagation of cultivars by hardwood cuttings is not successful, but certain clonal rootstocks can be propagated by special methods described in Chapter 10 (91). Softwood cuttings can be rooted under mist, but this method is not used commercially. Propagation of long cuttings [30 to 70 cm (12 to 28 in)] from semi-hardwood cuttings rooted under high pressure fog systems is being used as an alternative to replace more expensive mound layering systems for ‘M9’ and ‘M27’ dwarfing apple rootstock (195, 196).

Grafting. Root grafting either by the whip graft or by machine has been a traditional method of propagation (see Chapter 12). Seedling or layered liners are obtained from rootstock nurseries during the dormant season and stored at low temperatures until the time to graft. Plants are grafted during the dormant season and lined-out in the nursery in the spring as the outside temperatures become warm.

T-budding is a traditional method of field propagation, done either in the fall or in the spring. Dormant liners are obtained from rootstock nurseries and planted in late winter. In a mild winter area, such as California, rootstocks are budded (T- or chip) in April or early May with nursery trees produced by the end of the same season. In other areas, the rootstock may grow for the remainder of that season and are fall-budded to grow an additional year. In recent years, fall chip budding has become widely adopted in different parts of the world.

Micropropagation. Methods to micropropagate apple scions and rootstock have been developed (111, 126, 226). Nevertheless, commercial application is limited.

Micropropagated plants are more expensive than conventionally propagated ones and plants on their own roots are more vigorous and larger in size than those desired in commercial orchards. Rooting spur-type and
dwarf genotypes may be possible (117). Clonal rootstock propagation is more feasible, and some commercial production occurs. Use of micropropagated source material has application to nursery production of apple rootstocks.

Rootstocks (64). All apple rootstocks, either seedling or clonal, are in the genus Malus, although the apple will grow for a time and even come into bearing while grafted on pear (Pyrus communis) rootstock. At one time, apple seedling rootstocks were widely used in the western and southeastern United States, but the trend has been almost entirely towards using clonal size-controlling rootstocks.

Seedling Rootstocks. Apples on seedling roots produce large-sized trees. Seedlings of ‘Delicious,’ ‘Golden Delicious,’ ‘McIntosh,’ ‘Winesap,’ ‘Yellow Newtown,’ and ‘Rome Beauty’ (but particularly ‘Delicious’) have been the most successful, being uniform with no incompatibility problems. In purchasing seed it is sometimes difficult to determine the seed source. In the colder portions of the United States—the Dakotas and Minnesota—the hardy Siberian crab apple (Malus baccata) and seedlings of such cultivars as ‘Antonovka,’ containing some M. baccata parentage are favored. In Poland, ‘Antonovka’ seedlings are the chief apple rootstock. Some nurseries in British Columbia, Canada, have used ‘McIntosh’ seedlings because of their winter-hardiness, upright growth in the nursery, and early fall shedding of leaves, but they tend to be somewhat susceptible to hairy root, a form of crown gall (Agrobacterium), and to powdery mildew (Podosphaera teucotricha). Trees tend to be variable in size and performance.

Apples with the triploid number of chromosomes, such as ‘Gravenstein,’ ‘Baldwin,’ ‘Stayman,’ ‘Winesap,’ ‘Arkansas,’ ‘Rhode Island Greening,’ ‘Bramley’s Seedling,’ ‘Jonagold,’ ‘Mutsu,’ and ‘Tomkins King,’ produce seeds that are of low viability and are not recommended as a seed source. Seeds of ‘ Wealthy,’ ‘Jonathan,’ or ‘Hibernal’ have given unsatisfactory results.

Apple roots are resistant to root-knot (Meloidogyne) and root-lesion nematodes (Pratylenchus vulnus), moderately susceptible to oak root fungus (Armillaria), and highly resistant to Verticillium wilt.

Clonal Rootstocks. Numerous clonal, asexually propagated apple rootstocks have been developed. Most are in the species Malus xdomestica. Rootstock breeding and testing programs are underway in various apple-producing countries to develop new dwarfing and semi-dwarfing rootstocks to replace them.

Malling and Malling-Merton Series. This rootstock selection program, which began in 1912 at the East Malling Research Station in England, included both a program of rootstock selection and standardization of propagation. Size of grafted cultivars (see Fig. 11–10) range from very dwarfed to very invigorated, although size control was also a function of the scion cultivar. Fruit size was large, especially on young dwarfed trees, often larger than on standard-sized trees. The Malling rootstocks are compatible with most apple cultivars, and trees grafted to these rootstocks have been planted in varying amounts all over the world. In 1928, a second phase of this program was instigated jointly by the John Innes Horticultural Institution and the East Malling Research Station (174). A new series of apple rootstocks, referred to as Malling-Merton (or MM), was produced that added resistance to woolly aphids, and to provide a further range in tree vigor.

Other improved cultivar characteristics associated with these rootstocks include high yield, precocity of flowering (with some rootstocks), well-anchored trees (with some rootstocks), freedom from suckering, and good propagation qualities. All of the Malling and Malling-Merton rootstocks are readily propagated, mostly by stool-bed layering. A number of rootstock clones, notably ‘Malling 26,’ ‘MM 106,’ and ‘MM 111,’ propagate well by hardwood cuttings (92). Virus-tested material of both of these groups of rootstocks has been developed by a further joint effort by East Malling and Long Ashton Research Stations in England. “Clean” material is distributed under the designations EMLA 7, EMLA 9, EMLA 26, EMLA 27, EMLA 106, and EMLA 111. In many cases, these “clean” rootstocks produce trees with 10 to 15 percent or more increased vigor than the older virus-infected stocks of the same cultivar.

Dwarfing Clonal Rootstocks

‘Malling 27.’ This most dwarfing of all the Malling roots produces trees 1 1/2 to 2 m (4 to 6 ft) tall. They are one-half to two-thirds the size of those on ‘Malling 9,’ which makes it useful for high-density plantings. Virus-tested propagating material was released by the East Malling Research Station in 1970. ‘Malling 27’ can be used as an interstock to give a dwarfing effect.

‘Malling 9’ (Jaune de Metz). This rootstock originated as a chance seedling in France in 1879 and has been used widely in Europe for many years as an apple rootstock. It is a dwarfed tree itself and a valuable dwarfing rootstock much in demand for producing small trees for the home garden or for commercial high-density plantings. Recommended tree spacing is
first few years. Suggested tree spacing is 4.2 m (6 × 12 ft). Such trees are seldom over 3 m (9 ft) tall when mature, usually starting to bear in the first year or two after planting. There are a number of clonal selections of 'Malling 9,’ all dwarfing but somewhat different otherwise.

‘Malling 9’ has numerous thick, fleshy, brittle roots and requires a fertile soil for best performance. The trees require staking or trellising for support. It is resistant to collar rot (Phytophthora cactorum) but susceptible to mildew (Podosphaera teucotricha), crown gall (Agrobacterium), fire blight (Erwinia amylovora), and woolly apple aphid (Eriosoma lanyerum). Roots are sensitive to low winter temperatures. Propagation is by stooling.

‘Malling 9’ can be used as an interstock in double-worked trees, but the dwarfing of the scion cultivar is less than when it is used as the rootstock.

‘Malling 26.’ This rootstock was introduced in 1959 at the East Malling Research Station, originating from a cross between ‘Malling 16’ and ‘Malling 9.’ Better anchored than ‘M 9,’ it produces a tree somewhat larger and sturdier than ‘Malling 9’ but less so than ‘Malling 7’ or ‘MM 106.’ It still requires staking. Suggested tree spacing is 3 × 4.2 m (10 × 14 ft). It can be propagated by softwood cuttings under mist or by hardwood cuttings, but produces poorly in stool beds. Although quite winter-hardy, it does not tolerate heavy or poorly drained soils, and is especially susceptible to fire blight (Erwinia amylovora) but less to collar rot (Phytophthora cactorum).

Semi-dwarfing Clonal Rootstocks

‘Malling 7a.’ Malling 7 was originally selected at East Malling from a group of French rootstocks known as Doucin. This rootstock produces trees somewhat larger than those on ‘Malling 26’ roots. The ‘Malling 7a’ designation indicates a clonal selection free of certain viruses present in the original ‘Malling 7,’ the viruses having been removed by heat therapy. A virus-indexed EMLA clone was introduced in 1974. ‘Malling 7a’ has a strong, deeper root system than ‘Malling 9’ and produces an early bearing, semi-dwarf tree. It is tolerant of excessive soil moisture, but susceptible to crown gall. Well-anchored staking is required for the first few years. Suggested tree spacing is 4.2 × 4.8 m (14 × 16 ft). This rootstock has the undesirable characteristic of suckering badly, and the trees are not very winter-hardy. ‘Malling 7a’ is easily propagated by stooling or by leafy cuttings under mist.

‘Malling-Merton 106.’ This clone originated as a cross between ‘Northern Spy’ and ‘Malling 1,’ producing trees two-thirds to three-fourths the size of trees on seedling rootstocks. Although once popular, its planting has decreased because of crown rot (Phytophthora) problems. On good soils, with some scion cultivars, it can produce a large tree. The roots are well anchored and do not sucker. Suggested planting distances are 4.2 × 5.4 m (14 × 18 ft). In some areas ‘MM 106’ is susceptible to mildew (Podosphaera) and highly susceptible to collar rot (Phytophthora), which may be its chief weakness. It has not been affected by fire blight. It grows well in the nursery but drops its leaves later in the fall than most other understocks and is not resistant to early fall freezes. hardwood and softwood cuttings root easily and stool beds are quite productive.

Vigorous Clonal Rootstocks

‘Malling-Merton 111.’ This stock originated as a cross between ‘Northern Spy’ and ‘Merton 793’ (‘Northern Spy’ × ‘Malling 2’). A virus-indexed EMLA clone was introduced in 1969. Grafted trees are about 75 to 80 percent the size of seedlings in most orchards where they are grown. It produces more precocious bearing than those trees on seedlings, but less than those on ‘MM 106,’ ‘M 7,’ and ‘M 26.’ It does well on a wide range of soil types. It is susceptible to mildew but not to collar rot or woolly aphid. Stool beds are highly productive, with heavy root systems developing. Hardwood cuttings root well with proper treatment, as do softwood cuttings under mist. ‘MM 111’ is more winter-hardy than ‘Malling 7’ or ‘MM 106.’ Suggested planting distances are 4.8 × 6 m (16 × 20 ft). It shows excessive vigor in some situations.

Clonal Rootstocks from Miscellaneous Sources

‘Alnarp 2.’ This rootstock, developed at the Alnarp Fruit Tree Station in Sweden, is widely used there for its winter-hardy properties. The roots are well anchored and give about 20 percent size reduction as compared to trees on seedling roots. It is susceptible to woolly apple aphid and to fire blight.

‘Robusta No. 5’ [M. robusta (M. baccata ×M. prunifolia)]. This vigorous, very hardy clonal apple rootstock, propagated by stooling or stem cuttings, originated in 1928 at the Central Experimental Farm, Ottawa, Canada. It is apparently resistant to fire blight (Erwinia amylovora) and crown rot (Phytophthora), and seems to be compatible with most apple cultivars. It is extensively used as an apple rootstock in eastern Ontario and Quebec, as well as in the New England states. It is the best rootstock for use where extreme winter-hardiness is required. However, its low chilling requirement produces the unfavorable habit of starting growth too early in the spring following three or four warm days in late winter. It is not a dwarfing rootstock.
Polish Series. These rootstocks were the result of a breeding program started in Poland in 1954. Six clones (P-1, P-2, P-14, P-16, P-18, and P-22) are available (64) with a range of tree size potential and other characteristics. As a group, they were selected for hardiness.

Budagovski Series. This material originated from a breeding program in Russia to produce very hardy apple rootstocks (64). ‘Budagovski 9’ is very dwarfing and is recommended as an interstock in cold regions. ‘Budagovski 118’ (75 percent size), ‘Budagovski 490’ (65 percent), and ‘Budagovski 491’ (20 percent) are other promising rootstocks of the series.

Mandarin. See Citrus.

Mangifera indica. Mango (35, 159). Most plantings of this tropical evergreen fruit tree are seedlings that may be sexual (monoembryonic) or nucellar (polyembryonic) in origin—both conditions may occur simultaneously in the seed. Growth of several shoots from one seed does not necessarily indicate nucellar embryos, since certain cultivars develop shoots from below ground, arising in the axis of the cotyledons of one embryo, which may or may not be of zygotic origin (9). Polyembryonic cultivars commonly occur in mango. Monoembryonic cultivars should not be propagated by seed, as they do not come true.

Seed. Mango seeds are used for rootstocks, although seedlings of polyembryonic cultivars are apomictic. Seedlings have long juvenile periods and are overly vigorous. Seeds should be planted within a week of maturation. Storage is possible within the fruits or in polyethylene bags at about 21°C (70°F) for at least 2 months. Low-temperature (below 10°C, 50°F) storage and excessive drying should be avoided. By removing the tough endocarp that surrounds the seed and germinated seedlings are lifted, decapitated about 5 cm above the stone, and wedge-shaped scions are inserted into a vertical split. Buds are wrapped with poly tape, and grafted plantlets are planted in poly bags or outdoors in a trench, after which they are then shifted to the field.

Cuttings. Cuttings are difficult, but some success is reported from India using etiolation, IBA treatment, mist, and bottom heat (142).

Grafting. Mangos are commonly propagated in Florida by veneer grafting or by chip budding. A week after budding, the top of the rootstock is removed two to three nodes above the bud—with final removal back to the bud when the bud shoot is 7.5 to 10 cm (3 to 4 in) long. The best budwood is prepared from hardened terminal growth 6 to 10 mm (1/4 to 3/8 in) in diameter. The leaves are removed, with the exception of two or three terminal ones. The buds swell in 2 to 3 weeks, and are then ready to use. If the buds are to be used on stocks older than 3 weeks, ringing the base of the shoots from which the buds are to be taken about 10 days before they are used increases their carbohydrate supply and seems to promote graft union formation.

Budding is best done when the rootstock seedlings are 2- to 3-weeks old—in the succulent red stage. Four to six weeks after budding, the inserted bud should start growth (137). T-budding has also been successful. Patch, shield, and Forkert budding is done in India (142).

Approach grafting, termed inarching in India, has been used since ancient times in propagating the mango. Veneer grafting is also successful (156), as is saddle grafting (203). Veneer grafting is recommended in India (142) either for nursery propagation or topworking. The scion should be a terminal nonflowering shoot of 3 to 4 months’ maturity. The scions are defoliated 7 to 10 days before they are removed for grafting, keeping a part of the petioles attached, which helps the buds to swell. This defoliation is done from March to September in northern India. In India, assorted rootstock seedlings are mostly used. Monoembryonic rootstocks can be multiplied by air layering or by cuttings, and subsequently clonally propagated by stooling (155).

A method called epicotyl/stone grafting has been described in India (142). Seeds are germinated in a sand bed covered with leaf mold. Eight- to fifteen-day-old germinated seedlings are lifted, decapitated about 5 cm above the stone, and wedge-shaped scions are inserted into a vertical split. Buds are wrapped with poly tape, and grafted plantlets are planted in poly bags or outdoors in a trench, after which they are then shifted to the field.

Layering. Air layering is successful, especially when etiolated shoots are treated with IBA at 10,000 ppm; such treatments have given high rooting and survival (157). Pot-layering and stooling are also suggested in India (142).

Mango. See Mangifera.

Mangosteen. See Garcinia.

Manikara zapota. Sapodilla, Nispero. Tropical fruit tree originating in Mexico and Central America but grown throughout the tropics (20, 29, 149). M. chicle is a medium-sized evergreen tree that produces chicle, an ingredient in chewing gum. Many cultivars exist in different parts of the world; ‘Proliﬁc’ and ‘Brown Sugar’ are grown in Florida. Although seedling may be
readily grown, the plants are variable and have a very long juvenile period of 5 to 8 years. Seedlings are used as rootstocks. Fruits are depulped, washed, and dried. Soak seed overnight and sow in seed beds or pots. Germination takes about 4 weeks. Seedlings are transplanted to small pots when 15 cm high. While side veneer grafting is the most important graft, budding can also be done. Air layering is done in India. Cuttings are difficult.

*Morus* spp. Mulberry. Mulberry cultivars grown for their fruit are mostly *M. alba* or *M. nigra*, but some of *M. rubra* occur. Seeds are easily grown but produce weedy trees.

Cutting propagation is readily started by hardwood cuttings 20 to 30 cm (8 to 12 in) long and planted in early spring. Leafy softwood or semi-hardwood cuttings treated with 8,000 ppm IBA root easily under mist (52).

Mulberry can be commercially micropropagated (107).

**Mulberry.** See *Morus*.

*Musa* spp. Banana. Edible bananas apparently originated in the tropical lowlands of Malaysia as seedless, triploid mutations with year-long production. They since have become not only an essential food resource around the world, but perhaps the most important fruit export to the rest of the world. The banana “tree” is a large herbaceous perennial monocot whose “stem” (pseudostem) grows horizontally as a rhizome (see Chapter 15 and Fig. 15–32), consisting of compressed, curved bases of leaf stalks arranged spirally at nodes. Lateral buds develop at the nodes of a new segment of the stem and grow into upright “suckers” that soon develop their own roots and a large leaf base. The older fruiting section (i.e. “parent”) is cut after the fruit is harvested. A banana plant may live for many years, but as a succession of new plants, each arising as a sucker (daughter shoot) from the rhizome; any given sucker fruits only once, then dies.

**Asexual Methods.** Edible clones rarely produce seeds, and commercial propagation is asexual. Two primary methods are division of the rhizome (locally called corms) and suckers. A large rhizome is cut into pieces, which are termed heads, suckers, or pups, weighing 3 to 4.5 kg (7 to 10 lb), depending on the cultivar. Larger suckers are the preferred planting material. Each head should contain at least two buds capable of growing into suckers. Before planting, the pieces are pared to remove old roots and disease and are immersed in water at 52°C for 20 minutes, or treated with pesticides to control nematodes and borers. Each sucker produces two branches in the first crop.

Fairly large “sword” suckers 90 to 180 cm (3 to 6 ft) high with well-developed roots are also used, but the leaves must be shortened considerably to reduce water loss after the sucker is cut from the parent plant. Suckers are removed with a sharp cutting tool inserted vertically about halfway between the parent stalk and stem of the sucker. These sword suckers produce only one bunch of fruit in the first crop, but they are often preferred, because of the large size of the bunch.

**Micropropagation** (106). Millions of banana plants are now produced annually around the world by micropropagation from sources free of *Fusarium* wilt. These are started from explants obtained from a decapitated shoot apex from “clean” banana suckers. In 1 year, about 1 million pathogen-free plantlets can be produced for commercial plantings. Similarly, mosaic-free plants obtained after meristem tip culture and thermotherapy (20) can be propagated. These protocols have been standardized for commercial production (179). A majority of intensive, commercial banana production utilizes micropropagation. Field tests have shown that micropropagated plants yield somewhat better than sucker-derived plants (24). A low percentage of off-type plants of ‘Lady Finger’ could be controlled by early detection and roguing in the production process (192). Because of the clonal nature of banana and the difficulty in breeding, biotechnology has provided much promise in banana improvement and propagation to control its many problems (80).

**Nectarine.** See *Prunus persica*.

*Nephelium lappaceum*. Hairy Litchi. A tropical evergreen fruit tree similar to litchi and longan (20). Seedlings are variable and have a long juvenile period. Cultivars are grafted to seedling rootstocks. Seeds are sown immediately upon ripening because drying causes loss of viability. Seeds are removed from the fruit, washed, and sown horizontally. Two leaved seedlings are produced within 2 weeks. The greatest success is with patch budding or Forkert budding onto 1- to 2-year-old rootstocks of the same cultivar. Inarching is successful, as is air layering.

**Olea europaea**. Olive (90, 186). Many cultivars of this ancient crop originating in Southwest Asia exist. They are mostly propagated by budding or grafting onto seedling or clonal rootstocks, hardwood or semi-hardwood cuttings, or “suckers” from old trees.

**Seed.** Seeds are used primarily for rootstocks. Germination is somewhat difficult due to the hard
stony endocarp ("pit") that surrounds the seed. Seeds of small-fruited cultivars germinate more easily than those of large-fruited ones. Since germination is sometimes protracted over 1 or 2 years, a common practice is to plant more seeds than will be needed as seedlings to offset the low germination percentage. Clipping the end of the endocarp will hasten germination. Softening the endocarp with sulfuric acid or sodium hydroxide, then warm-stratifying at 15°C (59°F) will improve germination, as will stratifying the seeds (still in the endocarp) at 10°C (50°F), removing the endocarp, and planting at 20°C (68°F) (186). Removing the seed from the pit, removing the seed coats, and germinating at 20°C in Petri dishes on moist filter paper will give high germination if the fruits are collected shortly after pit hardening.

**Cuttings.** hardwood cuttings may be made from two- to three-year-old wood about 2.5 cm (1 in) in diameter and 20 to 30 cm (8 to 12 in) long. All leaves are removed. IBA aids rooting. An older technique is to soak the basal ends of the cuttings in 15 ppm IBA for 24 hours, followed by storage in moist sawdust at 15 to 21°C (60 to 70°F) for a month preceding spring planting in the nursery (90).

Semi-hardwood cuttings are made from vigorous, 1-year-old wood about 6 mm (1/4 in) in diameter. Cuttings are taken in early summer or midsummer, and trimmed to 10 to 15 cm (4 to 6 in) long with two to six leaves retained on the upper portion of the cutting. Cuttings are treated with a 4,000 ppm IBA quick-dip and rooted under mist. Cultivars vary greatly in their ease of rooting (93).

**Grafting.** Seedlings tend to grow slowly and may take a year or two to become large enough to be grafted or budded. Successful methods include T-budding, patch budding, whip grafting, and side-tongue grafting. A widely used method in Italy is bark grafting small seedlings in the nursery row in the spring. The stocks are cut off several centimeters above ground, and one small scion is inserted in each seedling, followed by tying and waxing. After grafting or budding, it takes 1 or 2 more years to produce a tree large enough for transplanting to the orchard.

**Rootstocks.** *Olea europaea* seedlings are commonly used, although they vary considerably in tree vigor and size and are susceptible to Verticillium wilt (93). Using rooted cuttings of a strong-growing cultivar such as 'Mission' may be more desirable because of uniformity and vigor. Clonal rootstocks 'Oblonga' or 'Swan Hill' are resistant to Verticillium wilt (90). Other *Olea* species do not make satisfactory rootstocks for the edible olive. (72)

**Olive.** See *Olea*.

**Opuntia spp.** Prickly pear cactus (61, 130). The most important species in the Cactaceae family, produced on five continents. It is a multi-purpose crop, used for production of fruits, vegetables, forage for animal feed, and as an ornamental plant. Also used as a raw-industrial material to produce wine, candies, flour, and as the host for the cochineal insect (*Dactylopius*) to obtain the natural-dye carminic acid, which is used for coloring fabrics, food, and cosmetics. Can be propagated from sexually produced or apomictic seed. Primarily, vegetatively propagated from single or multiple cladodes (see Fig. 10–14); also with small portions of cladodes comprising two or more areoles, or by using fruits as propagules. Wounding and applying auxin can enhance rooting and propagation rates of cladodes (130). Can also be grafted and micrografted (60). Micropropagation has higher propagation rates and reduced requirements for space than other clonal regeneration techniques, and can produce healthy, pathogen-free plants (61).

**Orange (Mandarin, Sour, Sweet).** See *Citrus*.

**Papaya.** See *Carica*.

**Passiflora edulis.** Passion fruit (54). The genus has about sixty species that produce edible fruit grown in tropical and subtropical areas. In Hawaii, Brazil, Sri Lanka, Kenya, and New Zealand, production is based on seedlings of the yellow form (*P. edulis f. flavicarpa*). The plant grows as a vine.

**Seed.** Must be extracted from freshly harvested fruit and removed from fruit and juice after fermentation for about 3 days. Seeds are washed, dried, and kept in sealed containers in a refrigerator where they will remain viable for at least three months. Germination takes place in 2 to 3 weeks after planting in pots, whereupon they are transplanted in the two- to three-leaf stage.

**Grafting.** Cleft-grafting is done when seedlings are 30 to 40 cm high. Rootstock is cut off about 15 to 20 cm above ground and split. The scion is a small piece of vine wood about 8 to 10 cm long with larger leaves removed. The wedge at the scion base is inserted into the rootstock cleft and the union is bound with plastic budding tape. Callusing takes 4 to 6 weeks, at which time plants are transplanted to the field. Scions of purple-fruited hybrid cultivars are grafted to seedling rootstocks...
of golden passion fruit (P. edulis forma flavicarpa), which are resistant to Fusarium and to nematodes (202).

**Passion Fruit.** See Passiflora.

**Peach.** See Prunus persica.

**Pear.** See Pyrus.

**Pecan.** See Carya.

**Persea americana.** Avocado (21, 159). This subtropical and tropical tree has been grown in South America for centuries, apparently originating in three areas which identify the three important horticultural races. These areas are the highlands of central Mexico (Mexican race), the highlands of Guatemala (Guatemalan race), and coastal regions of Guatemala (West Indian race). Many cultivars exist and are grafted onto seedling or clonal rootstocks. A major limitation in avocado production is susceptibility to Phytophthora cinnamomi.

**Seed.** Seeds are used for the production of seedling rootstocks. To avoid sun-blotch viroid, the seeds (and budwood) must be taken from source trees that have been registered by state certifying agencies as free of the disease (218). Seeds are generally planted shortly after removal from fruit taken from the tree (not picked from the ground), care being taken not to allow them to dry out. Seeds can be stored 6 to 8 months if packed in dry peat moss and held at 5°C (41°F) with 90 percent relative humidity.

Seeds are immersed in hot water at 49 to 52°C (120 to 125°F) for 30 minutes before planting to eliminate infection from avocado root rot (Phytophthora cinnamomi) (225). Germination of the seeds is hastened by removing the brown seed coats and cutting a thin slice from the apical and basal end of each seed before planting. The seed coats can be removed by wetting the seeds and allowing them to dry in the sun. Seeds are then sown in nursery rows or into containers.

**Cuttings.** Semi-hardwood stem cuttings from mature trees of the Mexican race have been rooted under intermittent mist using bottom heat at 25°C (77°F), provided seven or more leaves are retained on a 20-cm (8-in) cutting. If the leaves drop, rooting ceases (178). Cuttings taken from mature trees of the Guatemalan and West Indian races are difficult to root. Avocado cultivars started as rooted cuttings eventually make satisfactory trees, but in general, grow poorly in their initial stages.

Rooting has been produced by etiolation (see Chapters 9 and 14). Frolich (69) first showed the advantage of etiolation by covering the base of developing shoots with Velcro or black electrical tape to keep the attached shoot base in darkness while allowing the terminal part in light to develop five to six leaves. Shoots with etiolated bases were then detached and rooted in a propagating case (70). See Chapters 9 and 10 for discussions on banding and etiolation systems for stock plants. Brokaw (22) developed this concept into the commercial practice known as the nurse-seed etiolation procedure, which with further modifications have become the standard procedure for propagating avocado cultivars on clonal rootstocks (16).

**Grafting.** Nursery trees are commercially propagated by tip grafting (splice or whip graft) (201), or wedge or cleft grafting on avocado seedlings or clonal rootstocks (22). T-budding is used occasionally in Florida and some of the Caribbean countries—but the usual nursery practice is to graft mature tip scions, either as side-veneer or cleft grafts, on young succulent rootstock seedlings.

Scion and budwood must be selected properly. The best buds are usually near the terminal ends of a completed growth cycle with fully matured, leathery leaves. The leaves should be removed when the budwood is taken to prevent drying.

**Nursery Field Propagation Systems.** Seeds of the Mexican race, which ripen their fruit in the fall, may be planted in beds in late fall or early winter. They should be placed with the large basal end down, just deep enough to cover the tips. If grown in a warm area, the sprouted seeds are ready to line-out in the nursery row the following spring. By summer or fall, the seedlings are usually large enough to permit T-budding; if not, they can be budded the following spring.

Four to six weeks after budding, the seedling rootstock is cut off 20 to 25 cm (8 to 10 in) above the bud, or bent over a few inches above the bud. The remaining portion of the seedling above the bud is not cut off until the bud shoots have completed a cycle of growth. The new shoots are usually staked and tied. In digging from the nursery, the trees are “balled and burlapped” for removal to their permanent location following the first or second growth cycle or just as the first flush starts.

**Container Production of Nursery Plants.** Container production has become standard in the industry because of the greater ease in controlling Phytophthora (11) and its use in Certification programs (see Chapter 16) (16).

(a) **Seedling rootstock production.** Seeds are planted in polyethylene bags and the resulting seedlings
are cleft or wedge grafted about 9 cm above the seed 2 to 4 weeks after germination. Scions are taken from freshly cut terminal shoots showing strong plump buds. The plastic containers, with the grafts, are placed on raised benches in plastic-covered houses, which facilitates sanitation procedures to avoid \textit{P. cinnamomi}. After 4 to 6 weeks, the grafts are moved to a 50 percent shade house to acclimatize, then are transplanted into large containers for moving to an outdoor area (172).

In Florida, young, succulent West Indian seedlings (137), grown in gallon containers, are grafted when they are 15 to 25 cm (6 to 10 in) high and 6 to 10 mm (1/4 to 3/8 in) in diameter. The scions are shoot terminals, 5 to 7.5 cm (2 to 3 in) long, with a plump terminal bud, taken just as it resumes growth.

(b) \textit{Nurse seedlet} isolation method (21). A seed is planted about one-third of the way from the bottom of a \(300 \times 70\) (12.2 in) polyethylene bag, the top of which has been folded down on the bottom half of the bag. The seedling shoot is grafted close to the surface using a single strong shoot. When scion shoot growth starts, the plant is placed in darkness. When new etiolated shoots have grown 300 to 400 mm (12 to 16 in) they are removed from the dark, a metal or plastic "C" ring is clamped around the base of the shoot, and the bag is extended to its full length and filled with moist potting medium. The ring gradually constricts and eventually kills the "nurse" seedling, usually within one year. The rooted scion is the new clonal rootstock which can be grafted to the fruiting scion, usually at 200 to 250 mm (8 to 10 in).

This method has since been modified (16) for nursery use by encouraging more than one seedling shoot, which is individually grafted, each to be enclosed in a micro-container of plastic. Each shoot is grafted, the new shoot is allowed to grow, subsequently wounded and treated with 7,000 ppm IBA, surrounded by rooting media, and placed in the dark. After the grafted shoot has reached 300 mm (12 in) the plant is returned to the light and grafted to a fruiting scion. When this shoot reaches 55 mm (2 in) the nurse seedling is pruned off and the rooted clone/fruiting cultivar grown on a salable nursery tree. The entire process takes 16 to 20 months. Other changes include increasing temperature from 20 to 25°C (68 to 75°F) to 27°C (81°F) for rooting and surrounding stem with a clear plastic cup to monitor rooting.

\textbf{Rootstocks}

\textit{Mexican Race (P. americana var. drymifolia)}. Seedlings of this race are preferred in California for their cold-hardiness and their partial resistance to \textit{Phytophthora cinnamoni}, lime-induced chlorosis, and \textit{Dothiorella and Verticillium}. They are, however, susceptible to injury from high salinity. In Florida, where seedlings of large diameter are preferred for grafting, the Mexican types are little used, owing to their thin shoots.

\textit{Guatemalan Race (P. americana)}. These are occasionally used in California when there is a scarcity of Mexican seeds. Guatemalan seedlings are often more vigorous initially than Mexican seedlings, but are more susceptible to diseases and to injury from cold.

\textit{West Indian Race (P. americana)}. These seedlings are susceptible to frost injury in California but are widely used in Florida. The large seed produces a pencil-sized shoot suitable for side grafting in 2 to 4 weeks after germination.

\textbf{Resistant Rootstocks}. Research toward the selection of disease-resistant avocado rootstocks began in the 1940s (225). This research led to the introduction of clonal selections ‘Duke 6’ and ‘Duke 7,’ the latter becoming commercially important. These were individual seedling selections from the original ‘Duke’ cultivar. More recently ‘Thomas,’ from a survivor tree in an orchard, has become an important rootstock, although a number of others are undergoing orchard testing. ‘Toro Canyon’ is a nursery-selected clonal selection (148).

\textbf{Persimmon (American, Japanese).} See Diospyros.

\textit{Phoenix dactylifera}. Date palm (100, 101, 102, 160). This monocotyledonous plant is propagated by seeds, offshoots, and more recently by micropropagation (somatic embryogenesis). Date palms are dioecious. In a commercial planting, most of the trees are female, but a few male trees are necessary for cross-pollination.

\textbf{Seed}. Date seeds germinate readily. However, seedling populations have a long juvenile period and about half of the trees are males. Seedling female trees produce fruits of variable and generally inferior types.

\textbf{Offshoots (100, 101, 102)}. Superior clonal cultivars exist, some since ancient times. The natural method of vegetative propagation is from offshoots which arise from axillary buds near the juvenile base of the tree. Roots develop on the base after 3 to 5 years and are ready to be removed. To promote rooting, soil should be added to the base of the offshoot. Large, well-rooted offshoots, weighing 18 to 45 kg (40 to 100 lb), are more likely to grow than smaller ones. Offshoots higher on the trunk can be induced to root by placing moist rooting medium against the base of
the offshoot in a box or polyethylene tube. Unrooted offshoots arising even higher on the stem can be cut off and rooted in the nursery, but percentages may be reduced. A single date palm may yield 10 to 25 offshoots during its first 10 to 15 years.

Considerable skill is required to cut off the date offshoot properly. Soil is dug away from the rooted offshoot, but a ball of moist earth as thick as possible should remain attached to the roots. The connection with the parent tree should be exposed on each side by removing loose fiber and old leaf bases. A special chisel, with a blade flat on one side and beveled on the other, is used to sever the offshoot. The first cut is made to the side of the base of the offshoot close to the main trunk. The beveled side of the chisel is toward the parent tree, which gives a smooth cut on the offshoot. A single cut may be sufficient, but usually one or more cuts from each side are necessary to remove the offshoot. The offshoot should never be pried loose; it should be cut off cleanly. After removal, it should be handled carefully, replanted as soon as possible, and roots should be prevented from drying out (see Fig. 14–20).

**Micropropagation.** Commercial micropropagation has become an important alternative because of its greater efficiency and speed (163). Two general methods can be used. One is production of somatic embryos from callus generated from shoot tips; this technique produces a larger number of plants but has greater danger of variability. The second method is rooting axillary shoots produced from the shoot apex of offshoots. The general procedure is described in Chapters 17 and 18.

**Pineapple.** See *Ananas*.

**Pistacia vera.** Pistachio (83, 116). This popular nut crop originated in the deserts of southwest Asia where it has been a food staple for centuries. In recent years, a major pistachio industry has developed in California.

**Seed.** Seeds are used in commercial production for rootstocks. Obtain fruits when the hulls turn blue-green. Pinkish seeds are blank. The hulls contain a germination inhibitor and should be removed. *P. terebinthus* seed should be held in moist sand at 5 to 10°C (41 to 50°F) for 6 weeks before sowing and then germinated at 20°C (68°F). With early planting of seed, the more vigorous seedlings may reach budding size by fall.

Seed may be affected by chalcid larvae.

**Nursery and Field Production.** Because of their long taproot, best results are obtained by planting seedling rootstocks in their permanent orchard location, then T-budding them 0.6 m (2 ft) or more above ground after the seedlings are well established. Soak seed for 24 hours at room temperature in loosely rolled damp burlap in the dark at 20 to 30°C (70 to 90°F). When germinated, plant seedlings in double Jiffy pots with one-third each of humus, fumigated sand, and loam. When danger of frost is past, and seedlings are 4 to 6 inches in height, transplant into 18 inch peat pots. Buds of *P. vera* cultivars are quite large, requiring a fairly large seedling to accommodate them. Budding is possible over a considerable period of time, but if done before mid-spring, when sap flow may be excessive, the percentage of takes is low. A marked improvement in bud union occurs as budding is extended through the summer and fall. Seedlings can be grown in long tubular, biodegradable pots ready for planting in the orchard.

**Rootstocks.**

*P. atlantica.* Seedlings of this species were used in earlier commercial orchards in California but have been found highly susceptible to *Verticillium* wilt (*Verticillium dahliae*), a serious soil-borne fungus of pistachio.

*P. integerrima.* Seedlings of this species show resistance to *Verticillium*, and is being used in areas having such problems.

*P. terebinthus.* Seedlings of this species may have some resistance to *Armillaria*, and are cold-tolerant, but grow slowly.

*P. atlantica* x *P. integerrima.* The F₁ hybrid seedlings between these species are vigorous and have been found to have both superior cold tolerance (as compared to *P. integerrima*) and resistance to *Verticillium*. In California, specific hybrid seed sources are available from the University of California under the name of “UCB-1” (68) and from some private nurseries under the name of Pioneer Gold. Some roguing for off-type seedlings should be practiced. Clonal rootstocks from selected seedlings may be propagated by softwood cuttings (5) or by micropropagation.

*P. khinjuk.* Used as rootstock in Turkey for its drought resistance, adaptability to poor soils, and resistance to *Meloidogyne* sp. It can be micropropagated (204).

**Micropropagation.** Cultivars of *P. vera* have been micropropagated (12, 164, 167), and somatic embryos developed into plantlets (165).
ornamental orchards (44). See cutting propagation methods for wood cuttings has been used to produce high density stocks varies greatly by species and cultivar. Producing and 9 to 11 mm wide) from the upper portion of parent wood cuttings root well under high pressure fog systems. Long cuttings [62 cm (24 in)] producing clonal rootstocks that have been selected specifically for ease of rooting. Long cuttings [62 cm (24 in)] of Prunus ‘Gisela 5’ rootstock taken from semi-hardwood cuttings root well under high pressure fog systems (195, 196). Collecting hardwood cuttings (20 cm long and 9 to 11 mm wide) from the upper portion of parent shoots and quick-dipping in 1,000 ppm IBA yielded 50 percent rooting of ‘Gisela 5’ (62).

Direct rooting of hardwood cuttings in the nursery is a preferred method, and variations of this method are described in Chapter 10. Clones of many species can be rooted by softwood cuttings under mist (91, 147), although the method is not usually commercially practiced. Hard-to-root rootstock clones have been rooted commercially by trench layering (‘F12/1’ cherry) or mound layering (‘Colt’).

Budding. The most important method of propagation of stone fruits is to bud or graft cultivars to rootstocks in the nursery and transplant trees to the orchard. Seedling rootstocks are prepared either by stratifying the seeds during the winter and planting early in the spring, or planting in the fall and allowing natural chilling in the ground to bring about the moist-chilling process. Seedling liners that have been produced during the previous year may be purchased and lined-out in the nursery row for later budding.

T-budding is the usual practice and may be done in the fall, early spring or late spring, or summer depending on the length of the growing season. Chip budding may also be utilized in areas with a relatively short growing season. Trees are produced within 1, 2, or 3 years, depending upon the nursery site and conditions, the species, and the desires of the propagator.

In California, budding of plum, almond, or apricot to hardwood cuttings of ‘Marianna’ plum is done in the spring (April) directly onto hardwood cuttings in the nursery that had been inserted for rooting in the previous fall. Dormant budwood is stored over winter. Quick removal of the cutting top allows the new shoot to grow enough during the remainder of the season to produce a nursery tree in 1 year.

Micropropagation (55, 65, 108). Much research and development has been devoted to micropropagation of Prunus cultivars and rootstocks. Success has been achieved with plum, cherry, peach, and peach almond hybrid rootstocks. European micropropagation nurseries have produced millions of commercial plants of cultivars such as ‘GF677’ peach almond. Production has not been economical in the United States, and tissue–culture-based nursery systems have not replaced conventional propagation.

Embryo rescue and ovule culture are effective tools in breeding programs which make possible the propagation of early ripening cultivars or interspecific hybrids whose embryos abort when the fruits are ripe. Meristem culture is used for removing viruses from infected plants in initiating foundation clones.
**Prunus cerasus.** Sour cherry. *P. avium* (sweet cherry). Cultivars of both species are propagated by T-budding or chip budding on either seedling or clonal rootstocks. In addition to source selection in virus control programs, clonal selection is necessary to control genetic disorders such as cherry crinkle leaf and deep suture (194).

**Nursery Production.** Rootstock seedlings can be grown in a closely planted seed bed or nursery row for 1 year, dug, and then lined-out in the nursery row about 10 cm (4 in) apart and grown a second season before budding. Under favorable growing conditions, stratified seeds may be planted directly in the nursery in early spring, and the seedlings will be large enough for budding by late summer or early fall.

**Rootstocks for Cherry (169).** Historically, cherry rootstocks have been going through several generations of development. The first generation involved the selection and evaluation of the two most common rootstocks for sweet cherry and sour cherry cultivars throughout the world,—mazzard (*Prunus avium*) and mahaleb (*P. mahaleb*) seedlings.

**Mazzard (P. avium).** Considerable variation exists among sources of mazzard seeds. Mazzard seedlings used in the United States are virus-tested seed source clones selected in Oregon and Washington and need to be maintained in isolated seed orchards because infected plants can produce a certain proportion of infected seedlings. To germinate mazzard seeds it is beneficial to pre-soak them in water that is changed daily for about 8 days prior to stratification. A warm, moist stratification period at 21°C (70°F) for 4 to 6 weeks followed by a cold (4°C, 40°F) stratification period of 150 days should improve germination. When seeds show cracking of the endocarp with root tips emerging, they should be removed and planted (128).

Sweet cherry cultivars on mazzard roots produce an excellent graft union, as well as vigorous and long-lived trees, but are generally thought to grow too large for economical management. Mazzard roots do not grow particularly well on heavy, poorly aerated, wet soils, but will tolerate such conditions better than mahaleb. Mazzard seedlings have a shallow, horizontal root system. Mazzard rootstocks are susceptible to Verticillium wilt and moderately resistant to oak root fungus (*Armillaria*). Mazzard roots are immune to root-knot nematode (*Meloidogyne incognita*), resistant to *M. javanica*, but susceptible to the root-lesion nematode (*Pratylenchus vulnus*).

**Mahaleb (P. mahaleb).** This species is heterogeneous with considerable variability in many characteristics. Seeds are obtained from specific virus-tested clonal selections maintained in seed orchards. The seeds should be soaked in water for 24 hours and then stratified for about 100 days at 4°C (40°F). Mahaleb is the principal rootstock in the United States for ‘Montmorency,’ the leading sour cherry cultivar. Mahaleb rootstocks produce a somewhat dwarfed tree, particularly if budded high, [38 to 50 cm (15 to 20 in)] on the rootstock. Mahaleb roots are resistant to the buckskin virus and have been used to produce high-worked multitrunked trees with sweet cherry scions. Infected limbs can be cut off and regrafted below the union without losing the entire tree.

Mahaleb-rooted trees are not satisfactory in heavy, wet soils with high water tables, and are susceptible to Phytophthora root rot. Under dry, unirrigated conditions, Mahaleb is more likely to survive than Mazzard, presumably because of its deep, vertical rooting habit. Trees on Mahaleb roots are more cold-hardy than those on Mazzard. Sweet cherries often grow faster for the first few years on Mahaleb, produce precocious heavy bearing, and may result in dwarfing. Reports are that trees on Mahaleb roots are relatively short-lived in England but not in the United States. Mahaleb roots are more resistant to root-lesion nematode (*Pratylenchus vulnus*) than Mazzard. They are also resistant to the root-knot nematode (*Meloidogyne incognita*) but susceptible to *M. javanica*. Mahaleb roots are more resistant to bacterial canker (*Pseudomonas*) than Mazzard roots.

The second generation of rootstocks was the selection and release of the following two clonal rootstock cultivars by the East Malling Research Station, UK.

‘F12/1.’ This clone of *P. avium* was selected because it is vigorous and has high resistance to bacterial canker (*Pseudomonas*). Propagation is primarily by trench layering (see Chapter 14) but it has been produced by micropropagation. This rootstock is widely used in the UK, Australia, New Zealand, and South Africa. In Oregon, this stock has worked well as a root, trunk, and primary scaffold system onto which the scion cultivar is topworked.

‘Colt’ (*Prunus avium × P. pseudocerasus*). A semi-dwarfing clonal cherry ‘Colt’ rootstock was released in 1958 at the East Malling Research Station. A virus-tested strain, EMLA Colt, was released in 1977. This rootstock, used for both sweet and sour cherry cultivars, is easily propagated by hardwood cuttings as well as by mound layering. Tree size is about 60 to 70 percent of trees on F12/1 and 80 percent of trees on mazzard seedlings. It produces early heavy cropping, and is
resistant to bacterial canker (*Pseudomonas*), stem pitting virus, and replant problems. It is susceptible to crown gall (*Agrobacterium*), but size and yield have a high genotype xenvironmental interaction in that the size and vigor varies with location. It is somewhat cold-sensitive (30).

The third generation of cherry rootstocks began to emerge around the 1980s from research programs in Oregon to various stations in Europe (30). These have been extensively tested throughout the cherry growing regions of the world during the past few decades and some appear to be promising. Additional rootstock selections are being tested (224).

'M x M Clones (P. avium x P. mahaleb). A series of rootstock clones identified by number were selected from large hybrid seedling populations in Oregon (197). 'M x M 14'; a semi-dwarving clone, appears to be the most favored and is used in Europe.

'G.M. Series. Two clonal rootstocks named 'Damil' (*Prunus dawyckensis*) and 'Camil' (*P. canescens*) were introduced among others by Fruit and Vegetable Research Station, Gembloux, Belgium (169). These produce about 60 percent of the size trees on F12/1. They are propagated by softwood cuttings or micropropagation.

*Gisela Series. Five clonal rootstocks known by number (148-1, 148-2, 148-8, 148-9, and 195-1) were developed at the Justus Liebeg University, Giessen, Germany (169) which originated from progenies of crosses among various *Prunus* species, including *P. canescens, P. fruticosa*, and *P. avium*. Three rootstocks have been named 'Gisella 1' (17 to 45 percent of F12/1), 'Gisella 5,' and 'Gisella 10' (40 to 60 percent of F12/1). Trees on these rootstocks appear to be precocious, heavy bearing, well anchored, and hardy.

*St. Lucie (P. mahaleb).* Clonal selection was made at INRA, Grande Ferrade, France. Propagates from softwood and semi-hardwood cuttings. Grown in Europe. Adapts to a wide range of soils, including calcareous, but requires good drainage. Trees are compact and intermediate in vigor.

'Adara'. This is a Spanish selection of *P. cerasifera* which is vigorous and highly tolerant to calcareous and heavy soils (30).

*Prunus armeniaca.* Apricot. Cultivars of apricot are propagated commercially by T-budding or chip budding on various seedling *Prunus* rootstocks. Fall budding is the usual practice, but spring and June budding may be used. Bench grafting also has been successful (46).

**Rootstocks for Apricot (46).** Rootstocks include apricot seedlings, peach seedlings, and myrobalan plum (*P. cerasifera*) seedlings and recently clonal *Prunus* hybrids. Seeds of all these species require low-temperature 5°C (41°F) stratification before planting.

**Apricot (P. armeniaca).** Seedlings of local apricot cultivars are best on good, well-drained soils. Seeds of 'Royal' or 'Blenheim' produce excellent rootstock seedlings in California. In the eastern United States, seedlings of 'Manchurian,' 'Goldcot,' and 'Curtis' are recommended. In Europe local selections are used.

Apricot root is almost immune to the root-knot nematode (*Meloidogyne* spp.). In addition, it is somewhat resistant to the root-lesion nematode. It is susceptible to crown rot (*Phytophthora* spp.) and intolerant of poor soil-drainage conditions. Apricot roots are not as susceptible to crown gall (*Agrobacterium tumefaciens*), as are peach and plum roots. Apricot seedling roots are susceptible to oak root fungus (*Armillaria*) and highly susceptible to *Verticillium* wilt.

**Peach (P. persica).** In California, 'Nemaguard,' 'Nemared,' and 'Lovell' peach seedlings are satisfactory as rootstocks for apricot cultivars. See under *Peach* for characteristics. In the eastern United States and Canada, some apricot cultivars show incompatibility on peach seedlings (32, 127).

**Myrobalan Plum (P. cerasifera).** Although successful high-yielding apricot orchards grow on this rootstock, some instances have been observed where the trees have broken off at the graft union in heavy winds or where die-back conditions occur. Nurseries often have trouble starting apricots on myrobalan roots. Some of the trees fail to grow rapidly and upright or else have weak or rough unions. After those weaker trees are culled out, the remaining trees seem to grow satisfactorily. This rootstock is useful for apricot when the trees are to be planted in heavy soils or under excessive soil moisture conditions.

'Marianna 2624.' This clonal plum rootstock is being used to replace myrobalan plum seedlings on which apricot trees do well. See *plum* for characteristics.

'Citation.' This clonal rootstock is being used in new plantings in California.

*Prunus dulcis.* Almond (118). The almond is an ancient crop in the Mediterranean, Southwest Asia, and North Africa where at one time it was widely grown as seedling populations, topworking bitter individuals with better selections. Commercial almond orchards in the Mediterranean region have traditionally
been T-budded in the fall onto almond seedling rootstocks, but more recently to ‘GF 677’ (P. dulcis x P. persica). In California, almond orchards followed the same practice initially, but as the industry came under irrigation, rootstocks shifted to peach seedlings. There is limited use for ‘Marianna 2624’ plum, and more recently peach-almond hybrids have been used. While success with rooting almond stem cuttings has been low, some progress has been made in clonal selection (118).

Virus-tested clonal selection should be used (28). In addition, genetic disorders such as noninfectious bud failure (119, 120) need to be controlled through clonal source selection and source tree management.

Rootstocks for Almond

Almond (P. dulcis). Seeds of bitter types or certain commercial cultivars are used. In California, ‘Texas’ (‘Mission’) seeds are commonly used. In the Mediterranean, seeds of ‘Garrigues,’ ‘Atocha,’ and ‘Desmayo Royo’ are typically used. Almond seeds require limited stratification of 3 to 4 weeks before planting. Almond roots are adapted to deep, well-drained soil. In poorly drained soils, almond roots are often unsatisfactory, owing to their susceptibility to waterlogging, infection by crown rot (Phytophthora spp.), and susceptibility to crown gall (Agrobacium tumefaciens). Their deep-rooting tendency is an advantage in orchards grown on unirrigated soils or where drought conditions occur. Almond seedlings are tolerant of high-lime soils and, of the rootstocks available for almonds, are the least affected by excess boron salts (91). Almond seedlings are susceptible to root-knot nematodes (Meloidogyne) and root-lesion nematodes as well as to oak root fungus (Armillaria mellea). Root-knot nematode-resistant almond selections ‘Alnem 1,’ ‘Alnem 88,’ and ‘Alnem 201’ have been selected in Israel.

Peach (P. persica). Peach seedlings are used as rootstocks for almond where irrigation is practiced, such as in California. ‘Lovell’ and ‘Halford’ are typically used in nonnematode soils but ‘Nemaguard’ and sometimes ‘Nemared’ are used in nematode-infested areas or where nematode concern exists. For characteristics of peach rootstocks see under Peach.

‘Marianna 2624’ Plum. This clonal rootstock is used in California where dense soils occur or where oak root fungus is present. Almond cultivars vary in their relative size and in their degree of incompatibility on this rootstock. In general, trees are about one-third smaller than those on the other available rootstocks. Not all almond cultivars are compatible with this rootstock. (See under Plum for characteristics.)

Peach-almond Hybrids (118). These first-generation hybrids of peach and almond can be produced as seedling populations by natural crossing in seed orchards between adjoining trees of the two species. Combinations of ‘Titan’ almond and ‘Nemaguard’ have been used. Seedling hybrid plants are identified in the nursery row by their high vigor, intermediate appearance between the parents, and red foliage color in certain combinations using a redleaf red parent.

Clonal hybrids have been developed. ‘GF 677,’ discovered as a chance seedling in France, is resistant to alkaline soils and is widely used in the calcareous soils of the Mediterranean region for both almonds and peaches. It is susceptible to all species of nematode. Commercial propagation by micropropagation is widely practiced in the Mediterranean. ‘Hansen 536’ and ‘Hansen 2168’ are hybrid rootstock clones released by the University of California in 1983 of which the first has achieved a commercial role. Both are immune to root knot nematodes (Meloidogyne javanica and J. incognita acrita). A new hybrid clone ‘Nickels’ has been released (121) which has the same nematode resistance potential as ‘Nemaguard,’ one of its parents, and a higher chilling requirement than ‘Hansen 536’ and ‘Hansen 1268,’ both of which are low. Rooting is possible by hardwood cuttings treated with IBA plus a fungicide, planted directly in the nursery row in the fall. Peach-almond hybrids can be rooted by semi-hardwood cuttings under mist if given IBA treatments (147). These rootstocks are noted for their vigor and excellent compatibility with scion cultivars. ‘Hansen 536’ has some susceptibility to crown rot (Phytophthora) and shows somewhat reduced survival in commercial orchards, whereas ‘Nickels’ has shown greater survival in early tests. All can be rooted well by micropropagation.

A number of additional clonal PA hybrid rootstocks have now been introduced in Europe, and additional programs are underway (175).

Prunus persica. Peach and Nectarine. Peach and nectarine cultivars are budded to peach seedling rootstocks. Most other species (almond, plum, apricot) tend to be incompatible to various degrees.

Cuttings (44). Some peach cultivars can be propagated by leafy, succulent softwood cuttings taken in spring or summer, treated with auxin, and rooted in a mist-propagating bed (44). Also, in areas with mild winters, some peach cultivars can be started from hardwood cuttings if they are treated with a 4,000 ppm IBA quick-dip, then set out in the nursery in the fall. Direct rooted peach cultivars have been used with
high-density tree production systems, requiring large numbers of inexpensive nursery trees.

**Budding.** Nursery trees of peaches are propagated by T-budding or chip budding on seedling rootstocks. In California and other areas with a long growing season, trees are produced in 1 year by June budding. Seeds planted in early fall and allowed to stratify over winter germinate in early spring (March) to produce vigorous large plants by May. Fall budding may be used, but a 2-year production cycle is required.

**Rootstocks for Peach (49, 129, 175)**

Peach (**P. persica**). Peach seedlings are the most satisfactory rootstock for peach and should be used unless special conditions warrant other rootstocks. Seeds of ‘Halford,’ ‘Lovell,’ ‘Elberta,’ or ‘Rutgers Red Leaf’ are usually used, since they germinate well and produce vigorous seedlings. Seedlings of these cultivars are not resistant to root-knot nematodes, however, and where these are problematic, resistant peach stocks should be considered. Seeds from peach cultivars whose fruits mature early in the season should not be used because their germination percentage is usually low. It is best to obtain seeds from the current season’s crops, since viability decreases with storage. In the eastern United States, seeds have historically been obtained from wild types such as Tennessee Naturals or Indian peaches.

Peach roots are susceptible to the root-knot nematode (**Meloidogyne** spp.), especially in sandy soils, as well as to root-lesion nematode (**Pratylenchus vulnus**). ‘Nemaguard,’ a **P. persica** x **P. davidiana** hybrid rootstock introduced by the USDA in 1959, produces seedlings that are uniform and resistant to both **M. incognita** and **M. javanica**, but not to the ring nematode (**Glicocenella xenoplax**). Nemaguard roots give strong, well-anchored, high-yielding trees, although certain peach and plum cultivars have not done well on them and they have shown susceptibility to bacterial canker (**Pseudomonas syringae**) and to crown rot (**Phytophthora**). ‘Nemared’ is a red-leaved selection from ‘Nemaguard.’ ‘Guardian,’ a peach rootstock clone whose seedlings are tolerant of ‘peach tree short life’ syndrome (PTSL), has been released in the southeast United States (175).

Cold-tolerant rootstock cultivars have been sought. ‘Siberian C,’ a winter-hardy peach rootstock—withstanding 11°C (12°F) soil temperatures—introduced in 1967 by the Canadian Department of Agriculture Research Station at Harrow, Ontario, has not remained satisfactory. Similarly ‘Harrow Blood’ and Chinese cultivars (‘Tzim Pee Tao,’ ‘Chi Lum Tao’) have not been completely satisfactory. Future advancement may come from recent programs in Russia, Germany, and the Czech Republic (175).

Nursery trees on peach roots often make unsatisfactory growth when planted on soils previously planted to peach trees. Peach roots are susceptible to oak root fungus (**Armillaria**), crown rot (**Verticillium**), and crown gall (**Agrobacterium**), and Verticillium wilt.

**Plum.** Some plum rootstocks, including **Prunus insititia** (‘St. Julien d’Orleans,’ ‘St. Julien Hybrid No. 1,’ ‘St. Julien GF 655.2’); **P.erasifera** (myrobalan plums); **P. domestica** (‘GF 43’); and **P. domestica x P. spinosa** (‘Damas GF 1869’), are used for budding peach cultivars to produce somewhat smaller trees and to grow on heavy, dense soil. In the UK, rootstocks such as these have been compatible with all peach and nectarine cultivars worked on them, and produce medium-sized to large trees. Plum rootstocks are especially adapted to wet, waterlogged soils.

**Apricot (P. armeniaca).** Apricot seedlings are occasionally used as a rootstock for the peach. The graft union is not always successful, but numerous trees and commercial orchards of this combination have produced fairly well for many years. Seedlings of the ‘Blenheim’ apricot seem to make better rootstocks for peaches than those of ‘Tilton.’ The apricot root is highly resistant to root-knot but not to root-lesion nematodes.

**Almond (P. amygdalus).** Almond seedlings have been used with limited success as a rootstock for peaches. There are trees of this combination that are growing well, but in general it is not a satisfactory combination. The trees are often dwarfed and tend to be short-lived.

**Peach xAlmond Hybrids.** These clonal rootstocks, such as ‘GF556’ and ‘GF667,’ are important in France and other Mediterranean countries. They are excellent rootstocks for peach cultivars and can be propagated by rooting semi-hardwood cuttings under mist (44). Micropropagation is used commercially for ‘GF667’.

**Western Sand Cherry (P. besseyi).** When used in limited experiments as a dwarfing rootstock for several peach cultivars, the bud unions appeared excellent, but about 40 percent of the nursery trees failed to survive. The remainder grew well, however, and developed into typical dwarf trees with healthy, dark-green foliage. The trees bore normal-sized fruit in the second or third year after transplanting to the orchard.
Nanking Cherry (P. tomentosa). May be suitable for some peach cultivars as a dwarfing rootstock.

Newer rootstock selections (175). During the 1980s and 1990s another generation of clonal rootstocks has begun to appear, particularly in Europe, many of which are being propagated by micropropagation.

Prunus domestica. European plums and prunes. P. salicina. Japanese plums. Plum cultivars are propagated by T-budding or chip budding in the fall on seedling rootstocks or, with certain rootstocks, on rooted cuttings or layers. Budding can also be done in the spring. Plums tend to be easier to root than other species, being propagated by hardwood cuttings (52) and some by leafy, softwood cuttings under mist (91). Bench grafting in winter and planting the grafts in the nursery in spring gives good results using the whip graft (49). Japanese plum (P. salicina) nursery trees have been produced by micropropagation (55).

Rootstocks for Plum (162)

Myrobalan Plum (P. cerasifera). This widely used plum rootstock is particularly desirable for the European plums (P. domestica) (which includes the commercially important prune cultivars), but it is also satisfactory for Japanese plums. However, some cultivars of plum—‘President,’ ‘Kelsey,’ ‘Stanley,’ and ‘Robe de Sergeant’—are not entirely compatible with this stock. Cultivars that are Japanese-American hybrids (P. salicina x P. americana) are best worked on American plum seedlings (P. americana).

Myrobalan roots are adapted to a wide range of soil and climatic conditions. They will endure fairly heavy soils and excess moisture, and are resistant to crown rot but susceptible to root-knot nematodes and oak root fungus. They grow well on light sandy soils.

Myrobalan seeds require stratification for about 3 months at 2 to 4°C (36 to 40°F). Then they may be planted thickly in a seed bed for one season and then transplanted to the nursery and grown for a second season before budding; or the seeds may be planted directly in the nursery row and grown there for one season, the seedlings being budded in late summer or fall.

Certain vigorous myrobalan selections are propagated by hardwood cuttings. One of these, ‘Myro 29C,’ is immune to root-knot nematodes. A selection, ‘Myrobalan B,’ was developed at the East Malling Research Station and is propagated by hardwood cuttings. It is particularly valuable in producing vigorous trees, although there are cultivars not completely compatible with it. Most plum cultivars in England belong to the P. domestica species.

Marianna Plum (P. cerasifera x P. munsoniana). This clonal rootstock originated in Texas as an open-pollinated seedling of the myrobalan plum, apparently a hybrid with P. munsoniana. It is propagated by hardwood cuttings. Some plums have grown well on it; others have not. An exceptionally vigorous seedling selection of the parent ‘Marianna’ plum, made by the California Agricultural Experiment Station in 1926, is widely used under the identifying name ‘Marianna 2624.’ It is adaptable to heavy, wet soils and is immune to root-knot nematodes (Meloidogyne), resistant to crown rot (Phytophthora), crown gall (Agrobacterium), oak root fungus (Armillaria), and Verticillium wilt, but is susceptible to bacterial canker (Pseudomonas). It suckers badly from roots and is sensitive to “brownline” virus. Propagated as rooted cuttings, the rootstock has a shallow root system for the first few years, but older trees develop a deeper root system. Hardwood cuttings root well if fall-planted (in mild winter climates) after IBA treatments (52).

Peach (P. persica). Some plum and prune orchards in California are on peach seedling rootstocks. The stock has proved satisfactory for light, well-drained soils or where bacterial canker has been a problem. However, peach rootstocks should be avoided if the trees are to be planted on a site formerly occupied by a peach orchard. In some areas, plum on peach roots tend to overbear and develop a die-back condition under low potassium conditions. Peach is not satisfactory as a rootstock for some plum cultivars, including ‘Sugar’ prune and ‘Robe de Sergeant.’

Apricot (P. armeniaca). Apricot seedlings can be used as a plum stock in nematode-infested sandy soils for those cultivars that are compatible with apricot. Japanese plums tend to do better than European plums on apricot roots.

Almond (P. dulcis). Some plum cultivars can be grown successfully on almond seedlings. The ‘French’ prune does very well on this rootstock. The trees grow faster and bear larger fruit than when myrobalan roots are used. Plum cultivars on almond roots tend to overbear, sometimes to the detriment of the tree. This stock probably should not be used for plums except where plantings are to be made on well-drained, sandy soils, high in lime or boron.

‘Brompton’ and ‘Common’ Plum (P. domestica). These two clonal plum rootstocks are chiefly used in England. ‘Brompton’ seems to be compatible with all plum cultivars and tends to produce medium-to-large
trees. ‘Common’ plum, which produces small-to-medium trees, has shown incompatibility with some cultivars. Propagation is by hardwood cuttings.

‘St. Julien,’ ‘Common Mussel,’ ‘Damas,’ and ‘Damson’ (P. insititia). The first three stocks are used mostly in England. ‘Damas C’ produces medium-to-large trees, whereas ‘Common Mussel’ generally produces small-to-medium trees. The latter stock seems to be compatible with all plums. ‘St. Julien A’ produces small-to-medium trees for all compatible scion cultivars. Results have been variable with these stocks, since they vary widely in type. At the East Malling Research Station, ‘St. Julien,’ ‘Mussel,’ and ‘Damas’ clones have been selected and listed as A, B, C, D, and so forth. ‘St. Julien’ has been used to some extent as a plum stock for the P. domestica cultivars in the United States. ‘Pixy’ has been released by the East Malling Research Station as a dwarfing plum rootstock.


Florida Sand Plum (P. angustifolia). This species may be useful as a dwarfing rootstock for compatible plum cultivars. In California, after 16 years, ‘Giant,’ ‘Burbank,’ and ‘Beauty’ on this stock were healthy and very productive, with a dwarf type of growth.

Japanese Plum (P. salicina). Seedlings of this species are used as plum rootstocks in Japan but apparently not elsewhere. European plums (P. domestica), when topworked on Japanese plum rootstocks, result in very short-lived trees; the reverse combination, though, produces compatible unions.

Western Sand Cherry (P. besseyi). This rootstock has produced satisfactory dwarf plum trees of the Japanese and European types, but poor bud unions and shoot growth developed when it was used as a rootstock for cultivars of P. insititia.

Hybrid Prunus Rootstocks. A number of clonal rootstocks originating as interspecific hybrids of a number of species have been developed and introduced. Among these are the following:

‘Citation’ (Interspecific Hybrid of Peach and Plum). Compatible with apricot and plum. Induces early bearing in the orchard, and early defoliation and dormancy in the nursery. Tolerant of waterlogging and resistant to root-knot nematodes (Meloidogyne). Susceptible to crown gall (Agrobacterium) and oak root fungus (Armillaria). Not suitable for peach and almond.

‘Viking’ (Interspecific among Peach, Almond, Plum, and Apricot). Extremely vigorous and precocious. May have resistance to root-knot nematodes. Intolerant of wet soil conditions.

‘Myran’ (Prunus cerasifera xP. salicina x‘Yunnan’ peach). Compatible with almond and peach cultivars. Tolerates wet soil conditions and has some tolerance to Armillaria. Propagated by hardwood cuttings.

‘Ishtara’ (P. myrobalan xP. myrobalan xP. persica). Introduced by INRA, France. Used for prunes in Europe but compatible for apricot, almond, plum, and some cultivars of peach.

Psidium spp. Guava. Cattley or Strawberry guava (P. cattleanum), and Common or Lemon Guava (P. guajava) (20, 141, 159). The Cattley guava has no named cultivars, and nursery plants are propagated by seed. This species comes nearly true from seed—large-fruited, superior trees are used as the seed source—but it is difficult to propagate by vegetative methods. Indigenous to tropical America, the common guava (P. guajava) is widely grown in the world as a tropical and subtropical fruit tree. The common guava has several cultivars, but they are not grown extensively because of difficulties in asexual propagation.

Seed. Seeds are short-lived and must be planted immediately. They are grown in poly bags or in a nursery, and transplanted to the field when 6 to 8 weeks old. Most trees of these two species are propagated by seeds, which germinate easily and in high percentages. Seedlings are somewhat susceptible to damping-off organisms, and should be started in sterilized soil or otherwise treated with fungicides. When about 4 cm (1 1/2 in) high, the seedlings should be transplanted into individual containers. In 6 months the plants should be about 30 cm (12 in) high and can be transplanted to their permanent location.

Cuttings. Cuttings are somewhat difficult to root. Best results are obtained by treating softwood and semi-hardwood cuttings with IBA and rooting under mist (168).

Grafting. For large-scale propagation of common guava cultivars, grafting or budding is necessary. Chip budding has been successful when done any time during the summer using hardwood buds from selected cultivars inserted into seedling rootstocks about 5 mm in thickness. Plastic wrapping tape is used to cover the buds. The rootstock is cut off above the inserted bud after about 3 weeks (110). Inarching is an important method of propagation, but labor is expensive. Side-veneer grafting is also possible, using scions
from terminal growth flushes with well-developed axillary buds. Several species of *Psidium* are used as seedling rootstock: *P. cajanillis*, *P. molle*, *P. cattleianum*, and *P. guineense*, but they tend to sucker from the base.

**Layering.** For the common guava, air layering is one of the most important commercial propagation methods, as described in Chapter 14. With both species, simple and mound layering are also effective methods of starting new plants; the layers may be tightly wrapped with wire just below the point where roots are wanted, or can be ringed, and treated with 500 ppm IBA in lanolin prior to earthing up. Two series of shoots can be produced in one year (141).

**Micropropagation.** Can be micropropagated with explants from mature trees (6).

*Pummelo.* See *Citrus.*

*Pomelo.* See *Citrus.*

*Punica granatum.* Pomegranate. Small tree or shrub of subtropical and tropical Mediterranean and south-west Asian areas. Both deciduous and semi-deciduous types exist and are adapted to semiarid climates. Seedlings are grown but cultivars can be readily propagated by hardwood cuttings. Cuttings are taken from fully mature 1-year-old wood or suckers from the base of the tree. Cuttings are trimmed to 20 to 25 cm (8 to 10 in) long, and treated with IBA. Softwood cuttings root successfully under mist. Suckers are produced; these may be dug during the dormant season, leaving a piece of root attached, and then planted.

*Pyrus* spp. Pear. Over 20 species of pears exist around the world (136). The most important edible types are the European pear (*P. communis*), including a number of related species in Europe) and the Asiatic pears (mostly *P. pyrifolia*, but also complex hybrids). Pears are ancient fruit crops in Europe, North America, China, and Japan, respectively. Many named cultivars are hundreds of years old, and many of the related species are involved in rootstock selection.

The history of the pear illustrates the problems of monocultures and the changing patterns of disease and insect vectors. European pear cultivars are highly susceptible to the bacteria fire blight (*Erwinia amylovora*). “Pear decline” is a graft union failure caused by a mycoplasma-like organism (98) which was spread by the pear psylla (*Psylla pyricola*) first in Europe (184) and then in western North America (15, 18). Certain pear species are highly susceptible and, when used as a rootstock, they cause decline or death of the tree. Other rootstock species produce a serious defect on the fruit known as “black-end” or “hard-end.” Serious viruses and virus-like diseases affect the pear, and production must be carried through a virus control program (181).

**Seed.** Seeds are used for rootstocks and in breeding programs. Pear seeds must be stratified for 60 to 100 days at about 4°C (40°F). Then they are planted thickly about 13 mm (1 1/2 in) deep in a seed bed, where they are allowed to grow during one season. The following spring they are dug, the roots and top are cut back, and then they are transplanted to the nursery row, where they are grown a second season, ready for budding in the fall.

**Budding.** Essentially all pear cultivars are propagated by budding to rootstocks in the fall (T- or chip budding). Pear trees can also be started by whole-root grafting, using the whip-and-tongue method.

**Cuttings.** Some pear cultivars, such as ‘Old Home’ and ‘Bartlett,’ can be propagated by hardwood cuttings or by leafy cuttings under mist if treated with IBA (91, 94, 216). Own-rooted ‘Bartlett’ trees have shown excellent production with large, well-shaped fruit, are resistant to pear decline (78, 91), and with age become partially dwarfed—a desirable attribute for high-density plantings. However, rooting percentages are not high, and cutting propagation is not widely practiced. Long cuttings [23 to 62 cm (9 to 24 in)] of *Pyrus* ‘Pyrodwarf’ dwarfing rootstock from semi-hardwood cuttings root well under high pressure fog systems (195, 196).

**Micropropagation.** Pear cultivars and rootstocks can be micropropagated (36, 227). Commercial production has occurred primarily in Italy and France where own-rooted ‘Bartlett’ (‘Williams’) have been grown for commercial orchards. Micropropagation has been used to enhance the rooting potential of hard-to-root clones in the establishment of stock blocks.

**Rootstocks for Pear (77, 136, 217)**

**Pear Seedlings.** Seed selection is very important if rootstocks of a specific species are desired. Various *Pyrus* species hybridize freely, some bloom at the same time, and cross-pollination is necessary for seeds to develop. Use isolated groups of trees as the seed source of a known species and avoid collecting seeds from several different species, since hybrids are likely to be produced.

**French Pear (P. communis).** French pear seedlings are generally grown from seeds of ‘Winter Nelis’ or ‘Bartlett.’ This rootstock is moderately vigorous and winter-hardy, produces moderately productive, uniform trees with a strong, well-anchored root system,
and is resistant to pear decline. French Pear forms an excellent graft union with all pear cultivars and will tolerate relatively wet (but not waterlogged) and heavy soils. French pear roots are resistant to Verticillium wilt, oak root fungus (Armillaria mellea), root-knot (Meloidogyne), and root-lesion nematodes (Pratylenchus vulnus) and crown gall (Agrobacterium).

French pear rootstocks are susceptible to pear root aphid (Eriosoma pyricola) and fire blight (Erwinia amylovora). Millions of pear trees on French pear roots have died from fire blight, due to the high susceptibility of this stock. Seedlings of the ‘Kieffer’ pear—a hybrid between *P. communis* and *P. pyrifolia*—have been satisfactorily used for many years in Australia as a pear rootstock.

**Blight Resistant French Pear Clonal Rootstocks and Interstocks.** Pear selections resistant to blight include ‘Old Home’ (94) and ‘Farmingdale’ (176), and have been used as an intermediate stock grafted on seedling rootstocks. The desired cultivar is topworked after the trunk and primary scaffold branches develop. A blight attack in the top of the tree will only go to the resistant interstock, which can then be regrafted after blight has been cut out. Thirteen clonal selections from an ‘Old Home’ x ‘Farmingdale’ progeny have been made in Oregon to be propagated by hardwood cuttings to provide blight resistance and give a range of dwarfing that will be of potential value in pear production.

*P. calleryana.* This stock is blight-resistant and produces vigorous trees with a strong graft union; fruit quality is good, with no black-end. ‘Bartlett’ orchards with this rootstock have produced well in California, and it is popular in the southern part of the United States for ‘Keiffer’ and other hybrid pears. In areas with severe winters it lacks winter-hardiness. Where good pear psylla control has been practiced, trees on *P. calleryana* roots are resistant to pear decline. However, trees with *P. calleryana* roots show less resistance to oak root fungus (Armillaria) than those with *P. communis* roots. Seedlings of a selection of this species, known as ‘D-6,’ are widely used as a pear rootstock in Australia.

*P. ussuriensis.* This east Asian stock has been used in the past to some extent; many pear cultivars on this root develop black-end, although not to the extent found with *P. pyrifolia* roots. It produces small trees that are susceptible to pear decline, and should not be used in areas where this problem may occur.

*P. betulaefolia.* This species has vigorous seedlings, resistance to leaf spot and pear root aphid, tolerance to alkali soils, an adaptability to a wide range of climatic conditions, good resistance to pear decline, and produces large high-yielding trees.

*Cydonia oblonga. Quince (215).* This species has been used for centuries as a dwarfing stock for pear and is widely used as a pear rootstock in Western Europe. Some cultivars fail to make a strong union directly on the quince, hence double-working with an intermediate stock such as ‘Hardy’ or ‘Old Home’ is necessary. Cultivars that require such a compatible interstock when worked on quince roots include ‘Bartlett,’ ‘Bosc,’ ‘Winter Nelis,’ ‘Seckel,’ ‘Easter,’ ‘Clairgeau,’ ‘Conference,’ ‘Guyot,’ ‘Clapp’s Favorite,’ ‘Farmingdale,’ and ‘El Dorado.’ A selection of ‘Bartlett’ (‘Swiss Bartlett’), compatible with ‘Quince A’ rootstock, originated in Switzerland, presumably as a bud mutation from an incompatible form. The following pears also appear to be compatible when worked directly on quince: ‘Anjou,’ ‘Old Home,’ ‘Hardy,’ ‘Packham’s Triumph,’ ‘Gorham,’ ‘Comice,’ ‘Flemish Beauty,’ ‘Duchess,’ and ‘Maxime.’

Quince roots are resistant to pear root aphids and nematodes, but are susceptible to oak root fungus, fire blight, and calcareous soil, and are not winter-hardy in areas where extremely low temperatures occur. In some areas, trees on quince roots have developed pear decline, but in others they have not, possibly because different quince rootstocks were used. The black-end trouble has not developed with pears on quince roots. There are a number of quince cultivars, most of which are easily propagated by hardwood cuttings or layering. ‘Angers’ quince is commonly used as a pear rootstock because its cuttings root readily, it grows vigorously in the nursery, and it does well in the orchard. ‘Provence’ quince roots produce larger pear trees than ‘Angers’ and are more winter-hardy.

The East Malling Research Station has selected several clones of quince suitable as pear rootstocks and designated them as ‘Quince A,’ ‘B,’ and ‘C.’ ‘Quince A’ (‘Angers’) has proved to be the most satisfactory stock. ‘Quince B’ (Common quince) is somewhat dwarfing, whereas ‘Quince C’ produces very dwarfing but highly productive trees. It is important to use only virus-tested quince stock.

‘Provence’ quince (LePage Series C and BA-29C) originated in France. These are winter-hardy and, when used as rootstocks for pears, give trees one-half to two-thirds the size of standard pear trees. The BA-29C series is a virus-free selection of LePage Series C.

*Pyrus pyrifolia (P. serotina).* Asiatic pear. Cultivars of Asiatic pear are propagated on seedling rootstocks of this species in Japan. This rootstock was once widely
used in the United States as a pear rootstock from about 1900 to 1925, but is no longer recommended due to its high susceptibility to pear decline and to the physiological defect black-end (or “hard-end”), which may occur when ‘Bartlett,’ ‘Anjou,’ ‘Winter Nelis,’ and other cultivars are grafted to it (95).

**Quince.** See Cydonia.

**Rambutan.** See Nephelium.

**Rasberry.** See Rubus.

**Ribes** spp. Currants and gooseberries. Specific species, hybrids, and cultivars are found in the northern hemisphere, where they grow as bushes, and produce small berries used in making jams, jellies, and pies. Cultivars include *R. grossularia* and its hybrids, while European gooseberries are in *R. uva-crispa*. All of the species are alternate hosts of white pine blister rust, and their planting is restricted by law. Propagation is similar for cultivars of all of these species.

**Cuttings.** Currants are propagated by collecting hardwood cuttings 20 to 25 cm (8 to 10 in) long in late fall, precallusing them at low temperatures over winter, and planting in the spring. Cultivars of gooseberry can also be rooted but with more difficulty.

**Layering.** Mound layering is used for American gooseberry. Shoots usually root well after one season. They are then cut off and transferred to the nursery row for a second season’s growth before they are set out in their permanent location. The slower-rooting layers of European cultivars may have to remain attached to the parent plant for two seasons before they develop enough roots to be detached.

**Micropropagation.** Gooseberries can be easily micropropagated and the rooted plantlets stored under refrigeration for as long as 130 days with 100 percent survival (212).

**Rubus** spp. Raspberry, Blackberry, Youngberry, Boysenberry, Loganberry, Dewberry. This group includes a complex of species growing worldwide from which a large number of commercially important cultivars have been produced. Commercial propagation requires vegetative methods. Seeds are used in breeding programs. Raspberry and blackberry produce clusters of drupelets surrounding a hard-coated achene.

**Asexual Methods**

**Upright Type.** Blackberries (*Rubus*; subgenus *Eubatus*). Reproduce by suckers removed in the spring with roots attached and replanted to a new location or to a nursery row for an additional year (115). Also propagate by root cuttings, conventional stem cuttings, one-node cuttings, and leaf-bud cuttings under mist with auxin (26). They are commercially micropropagated (see below).

**Trailing Types.** Youngberry, Boysenberry, Loganberry, or Dewberry (*Rubus* spp.). These do not produce many suckers but reproduce naturally by tip layering (see Chapter 14). They can be propagated by root cuttings, but some thornless forms are periclinal chimeras and revert to the nonmutated (thorny) type. Thornless cultivars that do not revert to thorny types have been developed through biotechnology (see Box 16.7, page 612). Boysenberry types can also be propagated by conventional stem cuttings, one-node stem cuttings (228), or leaf-bud cuttings rooted under mist with auxin hormones. They are commercially micropropagated (see below).

**Black Raspberry** (*R. occidentalis*). Usual method is by tip layering but can be rooted from leaf-bud cuttings in about 3 weeks under mist.

**Purple Raspberry** (*R. occidentalis xR. idaeus*) (115). Tip layering is the usual method of propagation but roots less easily than the black raspberry.

**Red Raspberry** (*R. strigosus xR. idaeus*). Propagated usually by removing 1-year old suckers in early spring with a piece of old root attached (97). Young, green suckers of new wood may also be dug in the spring shortly after they appear above ground. Leave piece of old root attached. Survival requires removal during cool weather and irrigation following transplanting. Sucker production is stimulated by inserting a spade deeply at intervals in the vicinity of old plants to cut off roots, or mulch with straw or sawdust.

Viruses and crown gall can be problems with red raspberries, so suckers should be taken only from clean plants obtained from nurseries specializing in certified plants. Root cuttings (97) should be thick; use 15 cm (6 in) root lengths; for thin roots use 5 cm (2 in) long pieces. Cuttings are planted very shallow—13 mm (1 1/2 in). Strong nursery plants may be produced in one year.

**Cuttings.** Leafy softwood cuttings can be made in early spring from young sucker shoots just emerging from the soil. The shoots should have a 2.5 to 5 cm (1 to 2 in) etiolated section from below the surface, and be placed in a propagating frame. Shoot cuttings taken directly from the canes are difficult to root, although success has been reported with pre-etiolated shoots, treated with IBA, and rooted under ventilated high-humidity fog (103).
Micropropagation. Blackberry and raspberry (23, 213) cultivars are commercially micropropagated by shoot-tip cultures on a large enough scale to allow mass propagation. In practice, micropropagation is used as part of a system to produce virus-free stock plants in virus control programs (see Chapter 16).

*Sapodilla (Nispero)*. See Manikara.

*Strawberry*. See *Fragaria xananaassa*.

*Tangelo*. See *Citrus*.

*Theobroma cacao*. Cacao. The dried, partly fermented fatty seeds of this native South American tree are used in the production of cocoa, chocolate, and cocoa butter. Large commercial cacao plantings have been established in West Africa and South America. Production is mostly from seedling trees, which are highly variable.

*Seed*. Seeds are obtained from selected high-yielding clones as well as from hybrid seeds resulting from cross-pollination between parents that are propagated vegetatively. Freshly harvested mature seeds are planted immediately, since cacao seeds quickly deteriorate after harvesting, normally losing all capacity to germinate within a week after removal from the pod. Longer seed life can be produced by keeping seeds from drying and storing at 24 to 29°C (75 to 85°F) (13).

Cacao is often directly field planted, 3 to 4 seeds to a planting site, retaining all seedlings surviving as branches of one tree. Seedlings may be started in a nursery bed and later transplanted to their permanent site. Seedlings may also be started in poly bags, baskets, bamboo or paper cylinders, or clay pots, or containers from which they are removed later and planted. The germination temperature should be about 26°C (80°F).

*Miscellaneous Asexual Methods*. Air-layering cacao is quite successful. Grafting is done using patch budding, T-budding, or top wedge-grafting on seedling rootstocks. Top wedge-grafting using orthotropic budwood that contains one or two buds of selected seedlings is being used for accelerated hybrid clone selection (58). There is 70 to 90 percent rooting success with semi-hardwood cuttings rooted close to 100 percent relative humidity and low light–15 to 20 percent normal light (World Cocoa Foundation, http://search.worldcocoafoundation.org). Cocoa is commercially micropropagated (205).

*Vaccinium* spp. Blueberry and Cranberry. Lowbush blueberry (*V. angustifolium*), Rabbiteye blueberry (*V. ashei*), Highbush blueberry (*V. corymbosum* L. and *V. austral*), Cranberry (*Vaccinium macrocarpon*) (57). The blueberry and cranberry are native to North America and are grown, respectively, as a small bush or trailing vine.

*Seed*. Seed propagation is used for breeding. There is no pregermination treatment for blueberry, but with cranberry, optimum seed germination occurs after a 3-month cold stratification. Seeds are removed from ripe berries and spread over a well-drained, acid-type soil mix containing one-third peat moss. Seeds are covered with a layer of finely ground sphagnum moss and kept moist until they germinate, usually in 3 to 4 weeks. Seedlings 2 cm (3/4 in) tall are transferred to peat pots.

*Miscellaneous Asexual Methods*. Lowbush Blueberry (*V. angustifolium*) (82). Cultivars of this species are probably best propagated by leafy softwood cuttings under intermittent mist with bottom heat, using sand and peat moss (1:1) as a rooting medium. Cuttings taken in late spring and early summer from actively growing shoots root well, some clones giving almost 100 percent rooting. Rooted cuttings are transferred to peat pots for further growth and overwintering. Cuttings made from rhizomes also can be rooted; they are best taken in early spring or late summer and fall, avoiding the midsummer rest period of the rhizome buds.

Rabbiteye Blueberry (*V. ashei*). Cultivars of this species can be propagated by hardwood cuttings as well as by leafy softwood cuttings taken in midsummer, treated with a 10,000 ppm IBA talc, and rooted under mist. Using supplementary light to give a 16-hour daylength may improve root production (43). Micropropagation is also possible (227). The inlay bark graft has been used with ‘Tif Blue’ blueberry (*V. ashei*) on a farkelberry (*V. arboreum*) rootstock, which tolerates a more basic soil pH; this allows the acid-loving blueberry to be produced in a site with higher soil pH (see Fig. 11–2).

Highbush Blueberry (*V. corymbosum* L. and *V. austral*) (57). Dormant hardwood stem cuttings are used. The blueberry can also be started by leaf-bud cuttings. Cuttings should be spaced about 5 cm (2 in) apart in the rooting bed and set with the top bud just showing. When leaves appear, the frame should be raised slightly to allow for ventilation. Either mist or frequent watering to maintain a high humidity is required. Roots start to form in about 2 months. Both softwood and hardwood cuttings treated with a 8,000 ppm IBA talc root well (52). To take advantage of
different soil types, *V. corymbosum* can be grafted on *V. ashei* and *V. arboreum* rootstock. Grafting has been by cleft, whip, side graft, and T-budding (52).

Cranberry (*V. macrocarpon*) (45, 81). This vine type of evergreen plant produces trailing runners upon which are numerous short upright branches. Propagation is by cuttings made from either runners or upright branches. Cutting material is obtained by mowing the vines in early spring before new growth has started. The cuttings are then set directly in place in their permanent location without previous rooting at distances of 6 to 18 inches apart each way. Two to four cuttings are set in sand in each “hill.” The cuttings are 13 to 25 cm (5 to 10 in) long and set deep enough so that only an inch is above ground. A more rapid method of starting a cranberry bog is to scatter the cuttings over the ground and work them into the soil with a special disk-type planter. This is justifiable when there is an abundance of cutting material and a scarcity of labor for setting the cuttings by hand. Water is applied to the bog immediately after planting. The cuttings root during the first year and make some top growth, but the plants do not start bearing until 3 or 4 years later.

*Vitis* spp. Grape (219, 222). The grape is an ancient crop used for fresh fruit, raisins, and making wine. Although there are many species, cultivated grape cultivars come into several groups. The first group, European grapes, includes cultivars originating from *V. vinifera*, which tend to lack hardiness but are easy to root by hardwood cuttings. Many ancient clonal cultivars exist today and are grown in Europe, California, and many countries of the world with a Mediterranean climate. The second group includes American type cultivars originating from *V. labrusca* (and hybrids). These cultivars tend to be winter-hardy and differ in fruit characteristics from *V. vinifera*. The third type of grape cultivar originated from *Vitis rotundifolia*, the muscadine grape from southern United States. Cultivars of this origin have a distinct flavor and are often difficult to root.

Historically, grape cultivars as own-rooted clones are highly vulnerable to pests such as nematodes (*Meloidogyne* spp.) and phylloxera (*Daclysophaera vitifolae*), as well as systemic virus and virus-like organisms. Since these are propagation-related problems, the worldwide grape industry is highly dependent upon pathogen control, “clonal selection,” “clean stock” programs, and resistant rootstocks (68).

Grapevines are propagated by seeds, cuttings, layering, budding, or grafting (4). Grape propagation methods have been modernized by the use of virus-indexed “clean” planting stock, mist propagation techniques for leafy cuttings, and rapid machine-grafting procedures. Root-knot nematodes can be eradicated from grapevine rootings by dipping them in hot water [52 to 55°C (125 to 130°F)] for 5 to 3 minutes, respectively (131).

**Seeds.** Seeds are used in breeding programs to produce new cultivars. Grape seeds are not difficult to germinate. Best results with *vinifera* grape seeds are obtained after a moist stratification period at 1 to 4°C (33 to 40°F) for about 3 months before planting (89).

**Hardwood Cuttings.** Grape cultivars and clonal rootstocks have traditionally been propagated by dormant hardwood cuttings, which root readily. Cutting material should be collected during the winter from healthy, vigorous, mature vines. Well-developed current season’s canes should be used; which are medium in size and have moderately short internodes. Cuttings 8 to 13 mm (1/3 to 1/2 in) in diameter and 36 to 46 cm (14 to 18 in) long are generally used and planted in the spring deep enough to cover all but one bud. One season’s growth in the nursery should produce plants large enough to transplant to the vineyard. Auxins have not been needed to root hardwood grape cuttings. Muscadine grapes are normally hard to root, but some success has occurred.

**Leafy Cuttings.** Leafy greenwood grape cuttings of *V. vinifera* cultivars root profusely under mist in about 10 days if given relatively high [27 to 30°C (80 to 85°F)] bottom heat and treated with IBA. Scarce planting stock (such as virus-indexed material) can be increased very rapidly using one-node stem cuttings, then consecutively taking additional cuttings from the shoots arising from each node on the rooted cutting. Several consecutive cycles of cuttings can be taken to increase the supply of rooted cuttings to very high numbers in a short period.

**Layers.** Grape cultivars difficult to start by cuttings can be propagated by simple, trench, or mound layering (see Chapter 15). Layering has been used to root muscadine grapes.

**Micropropagation.** Grapes have been produced by several *in vitro* techniques, including somatic embryo formation and fragmented shoot-tip cultures (124, 227).

**Grafting.** Budding or grafting onto resistant rootstocks is necessary to increase vine life, plant vigor, and yield specifically where pests, such as phylloxera (*Daclysophaera vitifolae*) or root-knot nematodes (*Meloidogyne* spp.) are present. Bench grafting (211) is widely used where scions are grafted either onto rooted
or unrooted disbudded rootstock cuttings. Methods include the whip graft, or better, machine grafting (see Chapter 12). Grafting is done in late winter or early spring from completely dormant scion and rootstock material. The stocks are cut to 31 to 36 cm (12 to 14 in) with the lower cut just below a node and the top cut 2.5 cm (1 in) or more above a node. All buds are removed from the rootstock to prevent subsequent suckering. Scionwood should have the same diameter as the stock.

After grafting with a one-bud scion, the union is stapled together or wrapped with budding rubber. The grafts are placed for 3 to 4 weeks in boxes or plastic bags with well-aerated, moist wood shavings or peat moss at about 26.5°C (80°F) for callusing. When callusing is complete, the grafts are removed from the callusing boxes or plastic bags and any roots and the scion shoot are carefully trimmed back to an 18 mm (1/2 in) stub. The scion is dipped into a temperature-controlled container of melted (low melting point) paraffin or rose wax to a depth of 2.5 cm (1 in) below the graft union and then quickly into cool water. The paraffined bench grafts can then be planted into 5.0 cm (2 in) or more above a node. All buds are removed from the rootstock to prevent subsequent suckering. Scionwood should have the same diameter as the stock.

An older method of establishing grape cultivars on resistant rootstocks is to field bud onto rapidly growing, well-rooted cuttings that had been planted in their permanent vineyard location the previous winter or spring. T-budding can then be done in late spring using dormant budwood held under refrigeration. Shortly after budding, the “trunks” should be cut with diagonal slashes at the base to allow “bleeding” to take place (3). An alternate method is to chip bud in late summer or early fall as soon as fresh mature buds from wood with light brown bark can be obtained and before the stock goes dormant. In areas where mature buds cannot be obtained early in the fall, growers may store under refrigeration the bud-sticks collected in the winter and bud them in late spring or early summer.

The bud is inserted in the stock 5 to 10 cm (2 to 4 in) above the soil level, preferably on the side adjacent to the supporting stake, tied in place with budding rubber, or poly budding tape, but not waxed. The bud is then covered with 13 to 25 cm (5 to 10 in) of well-pulverized, moist soil to prevent drying. In areas of hot summers, or in soils of low moisture, variable results are likely to be obtained, and bench or nursery grafted vines should be used. If the buds are tied with white 13 mm (1/2 in) plastic tape, it is unnecessary to mound them over with soil.

**Top-Grafting Grapevines.** Cultivars of mature grapevines can be changed by cutting off the tops of the vines in early spring 30 to 53 cm (12 to 21 in) below the lower wire. Stocks are side whip-grafted, using a two-bud scion of the desired cultivar. The scions are primarily grafted to 'Couderc 3309,' 'Tekeki 5C,' and '101–14 Mgt.' Other stocks that are occasionally used include 'Couderc 1616,' and 'Kober 5BB.' Some inland areas still derive scion vigor from American hybrid rootstocks, such as 'Cynthiana' or 'Lenoir.'

**Rootstocks for American Hybrid Grapes (104)**

'Ramsey' ('Salt Creek') and 'Dog Ridge.' Widely used as rootstocks for grapes in the southern United States, they have also been used successfully to resist nematodes on low fertility sites in California.

The northeastern grape-growing regions are largely own-rooted, but in areas where *V. vinifera* cultivars are grown, or where more vigor is desired, scions are primarily grafted to 'Couderc 3309,' 'Tekeki 5C,' and '101–14 Mgt.' Other stocks that are occasionally used include 'Couderc 1616,' and 'Kober 5BB.' Some inland areas still derive scion vigor from American hybrid rootstocks, such as 'Cynthiana' or 'Lenoir.'

**Rootstocks for Vinifera Grapes (132, 133, 220, 221).**
The rootstock AXR#1 (*V. vinifera* × *V. rupestris*), although widely used in California through the early 1980s, does not possess sufficient resistance to phylloxera and its use is declining within the state. The replanting effort is proceeding with a wide range of new rootstocks, although current evaluation data indicating which rootstocks are best suited for which areas is not complete. The following list describes the most widely used rootstocks at this time. Most of these rootstocks were developed in Europe about 100 years ago and were designed to resist phylloxera and grow well under European conditions.

*Rupestris St. George.* This pure *V. rupestris* rootstock was one of the original rootstocks developed to address the phylloxera crisis in France. It is only moderately resistant to phylloxera but has not collapsed to this pest. It is very susceptible to nematodes, but roots and grafts well. ’St. George’ is best suited to shallow soils, or soils with moderate fertility, and can produce very vigorous scions on fertile soils or on sites with excessive soil moisture.

*Teleki 5C.* This widely used *V. berlandieri* × *V. riparia* rootstock (104) is low to moderate in vigor and well adapted to fertile soils. It resists phylloxera and many nematode species, but is sensitive to water stress and performs best with adequate irrigation. Its cuttings root relatively easily and its low-to-moderate vigor produces good fruit quality.

*3309 Couderc.* This *V. riparia* × *V. rupestris* hybrid is widely used in California, as is the similar ’101–14 Mgt.’ These two rootstocks are suited to fertile soils and need adequate irrigation. Both are phylloxera resistant, but are susceptible to nematodes. They root and graft well and produce vines of moderate vigor (scions on ’101–14’ are relatively more vigorous) with good fruit quality.

*110 Richter.* This *V. berlandieri* × *V. rupestris* rootstock is widely used for drought tolerance on sites with shallow soils and limited rainfall. The similar rootstock ’1103 Paulsen’ is also used on these sites, and is slightly more vigorous. Both rootstocks are phylloxera resistant, but susceptible to nematodes. They are tolerant of limestone soils, and root and graft well.

*Ramsey.* This pure *V. champinii* rootstock is used on soils with low fertility and nematode problems. It resists most root knot nematode strains but can produce an overly vigorous vine on more fertile soils leading to problems with fruit set and fruit quality. Its phylloxera resistance is only moderate, but phylloxera pressure is usually low on the sandy soils for which ’Ramsey’ is best suited. ’Dog Ridge’ is a *V. champinii* rootstock with similar characteristics, but slightly less vigor. Both rootstocks root with difficulty, but graft well once rooted.

’Freedom.’ This widely used rootstock was developed in the 1960s at the USDA-Fresno station as a cross between a seedling of open-pollinated ’Couderc 1613’ × (seedling of open pollinated ’Dog Ridge’). Both rootstock parents are female vines and the pollen source is unknown. ’Couderc 1613’ is 1/4 *V. vinifera* and is moderately susceptible to phylloxera; this fact and the open pollinated nature of this cross cast suspicion on the phylloxera resistance of ’Freedom’ and the similar rootstock ’Harmony.’ However, ’Freedom’ has excellent nematode resistance and is used on many sites throughout California. ’Freedom’ imparts relatively high vigor to the scion and is best suited for sandy or low fertility soils. It can be difficult to root and graft well.

’039–16.’ This *V. vinifera* × *V. rotundifolia* rootstock was released by UC Davis in 1989 to resist fanleaf degeneration (220), a virus vectored by the dagger nematode, *Xiphinema* index. Although this rootstock allows the nematode to vector the virus, it moderates the virus’ negative effect on fruit set. Because it is half *V. vinifera,* 039–16’s phylloxera resistance is questionable. It is only recommended for sites where fanleaf degeneration is severe, and no alternative exists. ’039–16’ can impart excessive vigor to the scion and is very sensitive to water stress. Its *M. rotundifolia* percentage makes this rootstock difficult to root, but once rooted it will graft moderately well.

Walnut (Black). See *Juglans nigra.*

Walnut (Paradox). See *J. hindsii* × *J. regia.*

Walnut (Persian or English). See *Juglans regia.*

Zizyphus jujuba. Jujube, Chinese date. Deciduous temperate-zone tree adapted to hot, arid regions. Other evergreen tropical species with cultivars also exist in India. The leading jujube cultivars in the United States are ’Lang’ and ’Li.’ Seeds should be stratified at about 4°C (40°F) for several months before planting. Can be rooted by hardwood stem cuttings and root cuttings. T-budding is done on jujube seedling rootstock.
REFERENCES


