Propagation Notes

F1 Propagate nursery, field and container crops

AHPR 1034 L3A

Oct –Dec. 2018

Instructor: Maria Valana

maria.valana@kpu.ca

Seed Propagation

A seed is a biological unit of the tissues required for making a new plant.
The seed is formed during a *maturation* process, followed by *dormancy*, and brought back to life by *germination*.

Storage Factors for Medium-lived Seed

Both reducing the temperature of the surrounding environment and reducing the moisture content within the seed can preserve vigor and viability of the embryo. Poor storage with high humidity and/or high temperatures causes seed to lose first *vigor*, then secondly the capacity for normal *germination*, and finally *viability*. In contrast, appropriate storage reduces respiration and metabolic rate of the embryo without injury and preserves viability as long as possible.

The moisture content of the seed is in equilibrium with the ambient relative humidity of the storage container. The ideal storage condition for most seeds is 20-25% relative humidity (R.H.), which results in a seed moisture content (M. C.) of 4 – 6%.

Extremely low RH can damage cell membranes, which leads to cell desiccation for some seed types; High RH encourages enzyme activity in most seeds which leads to physiological deterioration (high rate of respiration which uses up the food stores).

If the moisture content of the seed increases because of an increase in relative humidity, the following problems may appear in the storage container:

> 9% M. C. in the seed encourages insect activity.

> 12-14% M. C. in the seed supports fungal activity.

> 18-20% M. C. in the seed can result in heating of seed.

> 40-60% M. C. in the seed starts the germination process.

Therefore, a *dry and cool storage* environment is ideal for extending the life of the seed. Storage temperatures below freezing (-18^{o} C) require low relative humidity (less than 70% R.H.) to prevent injury from ice formation inside the seed. (Long-term storage of conifer seed is at this temperature.)

Seed dormancy

Dormancy = A temporary suspension of visible growth of any plant structure containing a meristem as a result of physiological and environmental factors.

Dormancy in seeds:

Seed maturation is often accompanied by the initiation of a dormant state, in which the seed can remain viable for many years. No germination takes place even though the seed is in a favorable environment (proper water, temperature, and aeration). In nature, seeds can be released from dormancy through changes in weather (e.g. as temperatures rise the following spring), or through chemical action in the soil, or by seeds passing through the digestive system of birds or animals.

Quiescence (inactive) **in seeds:**

A seed germinates as soon as it is exposed to favorable environmental conditions.

External fruit wall and/or seed coat dormancies

External dormancies can be overcome by partial or complete removal of the seed coat and /or the fruit wall, or by softening the seed coat in hot water or leaching the inhibitors out of the seed coat in running water.

1 Seed-coat dormancy

Seed-coat dormancy occurs when the seed coat, endocarp or part of the pericarp is impervious to water. This outer covering becomes hard or fibrous during ripening and drying. Some seed coats (*Fabaceae*) harden and become suberized. Sowing seed immediately after collection is one way to overcome this dormancy, as the seed coat becomes harder and more impervious to water as it dries.

For stored seed, the covering must be softened or **scarified** (broken) before water can enter the seed to initiate the germination process. In nature microorganisms, digestive tracts of birds and mammals, freeze/ thaw cycles, and fire can soften the seed coat.

Propagators overcome this dormancy by using **hot** water soaks, chipping individual seeds, surface abrading the seed coat with sandpaper, by tumbling with grit, or applying sulfuric acid to remove some or all of the seed coat.

Hard seed coats and outer coverings (samaras, nuts, achenes) can be composted, which softens the outer tissues. This process is called **warm stratification**. The seeds or seed and fruit combinations are surface wetted and left in a pile at room temperature. The seed is stirred at regular intervals to prevent seeds in the centre of the pile from becoming too hot.

2 Chemical dormancy

Chemical inhibitors in the seed coat or the fleshy fruit coverings can prevent germination. The inhibitors can be leached out by soaking the seed with **hot** water or continuously running water for 48 hours. The seed must be dried before storage.

Internal embryo dormancies

In seed with internal dormancy, the embryo is either **immature** or **chemically** inhibited from germinating, even when exposed to water and proper temperatures. The embryo requires physiological and biochemical changes. Some seed can be gathered before it is fully ripe and thereby prevent the formation of germination inhibitors within the embryo. The seed must be sown immediately.

1 Inhibitors within the Embryo

For stored seed, these dormancies must be overcome with time and in some cases specific environmental conditions. This process is called **stratification** and it mimics outdoor, summer or winter weather. In all cases the seed must be completely imbibed (soak for up to 48 hours, then surface dried) before the dormancy treatment commences. Stratification is common requirement for seeds of many perennials and woody plants, and some annuals, e.g. verbena.

1a) Shallow dormancy

A short period of ripening or a short **cold, moist stratification** is required for this seed. e.g. 3-7°C for 3 to 4 weeks is used for most native conifer seed.

1b) Intermediate dormancy

For seed having an intermediate dormancy, germination percentage and rate will increase with moist-chilling. However, the **stratification** time needed is shorter (4 to 8 weeks) than for seeds having Deep-seated Dormancy.

1c) Deep-seated physiological dormancy

For seed with deep-seated dormancy a fairly long period (8 to 20 weeks) of after-ripening in a moist and cold environment is required before germination will take place. Temperature is the most important factor controlling after-ripening and is usually set between 2° and 7° C. Moisture must stay constant once the seed is imbibed. The oxygen requirement is low, but necessary.

2 Embryo immaturity

In this type of dormancy the embryo is not mature when the seed is dispersed from the ovary or fruit. The embryo neither enlarges nor matures or ripens until the seed imbibes water to begin the germination process. Therefore, warm temperatures under moist conditions are required (20° C for up to 60 days) for a substantial period of time. This process is called a “**warm stratification**”. It is used for some native conifers where cold stratification is inadequate, e.g. yellow cedar and western white pine. Warm stratification is also used to “compost” hard seed coats or fruit wall/ seed coat combinations (e.g. maple samaras, see Seed-coat Dormancy).

More than one dormancy

Double dormancy

A combination of two or more dormancies can stop the germination of some seed. In nature this might take up to two seasons. Propagators can shorten this time by artificially providing the conditions to overcome each type of dormancy. For germination to take place, all dormancies must be eliminated in order. External dormancies must be overcome before internal dormancies. (e.g. soften seed coat then moist-chill for more than 8 weeks)

Combination of dormancies

In some cases, two after-ripening treatments are required for emergence of the radicle/ hypocotyl, and then the expansion of the epicotyl. The following two protocols are typical for overcoming this type of dormancy:

a) Root and hypocotyl emerge in a moist warm period over 1 to 3 months, then chilling is required for the epicotyl to grow (lily species);

b) Moist chilling period is needed for after-ripening the embryo, then a warm period is required for the root to grow; a second moist chilling period is required to stimulate epicotyl (shoot) growth (two seasons in nature needed for some temperate, native perennials).

Secondary dormancy

When environmental conditions during germination are not favorable, secondary dormancy can occur *after germination starts*, which can stop the germination process. Examples of environmental stresses are:

- very dry conditions,
- poor light quality,
- temperatures too low or too high,
- low oxygen levels.

Germination may or may not restart after favorable conditions have been imposed. The germination rate within a tray may be unacceptable with some seed germinating, while other seedlings are ready to harden off for transplanting.

Seed sowing methods

Broadcast

Seed is spread evenly over media in an open tray. This is a recommended method with large seed.

Row seeding

Seed is sown in rows down the length of the tray, or in preformed rows in plastic tray inserts. This reduces the spread of disease, and reduces root shock when transplanting. Seed can also be sown in rows in outdoor beds, and then excess seedlings can be 'thinned' = manually removed after germination.

Direct seeding

Seed is sown directly to the container in which the plant will be sold. This eliminates transplant labour, but requires more bench space initially for germination. Seed can also be directly sown to greenhouse beds, or outdoors in beds or fields. Direct seeding is normally limited to species which germinate quickly and to prevent overwatering of slow germinating seed when sown into larger soil volumes.

Plug trays

Seed is sown mechanically (by seeding machine) into individual cells in specially designed plastic trays for bedding plants, or Styrofoam trays for forestry seedlings.

Covering seed

The general rule is to *cover seed to a depth equal to twice the seed diameter.* Seed is covered with a layer of germination media, Vermiculite, or gravel grit in the case of forestry seed. The cover is then watered lightly. Covering the seed ensures that the seed is constantly exposed to moisture during germination.

Mechanical sowing

Seeding machines are used to improve sowing speed, efficiency and accuracy. There are many models in the market today. Selection factors are:

- **Cost** What is the cost of the basic unit, vs. accessories?
- **Speed** How many trays can it sow per hour? Can the speed be adjusted? How many trays are required per variety?

- **Accuracy** How well does it handle different seed types and sizes? What percent of cells in the plug tray are empty or doubles?

Environmental factors affecting seed germination

The following environmental factors must be controlled to maximize germination percentage and rate.

Water

During storage, relative humidity and hence the moisture content of the seed is controlled to preserve viability. Germination is initiated via imbibition when seed is wetted. The seed requires an even moisture supply during the entire germination process. The growing medium must be firm, fine-textured, and seed in contact with the medium. Stress from high salts or lack of moisture will decrease the rate of seedling emergence. High salts prevent movement of water into the seed.

Temperature

For many temperate species temperature can be used to control dormancy, as cold, moist conditions (stratification) are often needed for a period of time before germination will take place. After dormancy conditions are overcome, the optimum temperature range for germination must be provided to ensure a high level of success. This optimal range will vary according to the seed type (see below). Within the optimum range germination slows at cooler temperatures. Conversely, injury can occur at the high end of the range. However, the final germination percentage may not be affected if the temperature stays within the optimum range.

Seed types and germination temperature requirements:

Cool-temperature tolerant

- temperate species
- optimum from 24^{o} to 30^{o} C, can tolerate 4.5^{o} to 30^{o} C

Cool-temperature requiring

- winter annuals (cyclamen, primula)
- temperatures must be below 25^{o} C

Warm-temperature requiring

- tropical or sub-tropical species
- will not germinate below 10^{o} or 15^{o} C

Alternating temperatures

- a difference of 10^{o} C between day and night temperatures
- important for freshly harvested seed
- for some seed this is a requirement for germination

Aeration

Germination is a high energy-requiring process. The need for *oxygen* increases during the germination process as the rate of respiration increases. There must be adequate drainage to ensure aeration within the germination medium. If the seed is covered, a surface crust, which could impede the flow of air, must not form.

Light

Light factors which affect germination
Very little information exists on specific light requirements for different species. Many references limit information on light to `light`, `dark`, or `either`. This provides little practical information for actual germination conditions; research has shown that many light factors can influence germination:

- Duration = # hours of exposure per day; and # of days or weeks of exposure.
- Light intensity (brightness)
- Light quality (wavelength)
- Species: Each plant species has particular light requirements, e.g. requires light vs. requires dark vs. not important.

Phytochrome
Some seed must be exposed to the correct light conditions (light vs. dark) before germination can take place. This dormancy is due to a light sensitive receptor in the seed coat or endosperm. The seed must be exposed to either a light or a dark environment in order to germinate. Cool or alternating day/night temperatures can offset the light sensitivity of some seed. The requirement for light is related to its **wavelength** (light quality); the wavelengths of light energy correspond to the bands of the light spectrum: Ultraviolet, violet, blue, green, yellow, orange, red, far-red, and infra-red.

Phytochrome is a photo-chemically reactive pigment found in the membrane of the seed coat or in the endosperm. The pigment is available in two forms, which convert naturally from one to the other daily. In **far-red** light, phytochrome switches to the Pr form, which inhibits germination, and changes to the Pfr form in red light, which allows germination to proceed.

Red light comes from:
a. fluorescent light
b. full sunlight (two times more red than far-red light in normal sunlight)

Far-red light comes from or is found:
a. inside of fruit
b. under shade caused by overhead foliage, e.g. crowded plants
c. incandescent light
d. twilight (dawn and dusk)

Viability and vigour

Viability, seed's ability to germinate under suitable environmental conditions. It is indicated by:
a. **Seed purity**, degree of physical contamination by weeds, dirt, debris, etc.
b. Germination capacity

Vigour is the potential for rapid, uniform germination and development. Vigour is measured by:
a. Germination % = % of seedlings which germinate.
b. Germination rate e.g. T50 = # days till 50% of seed germinate.
c. Uniformity e.g. T90- T10 = # days difference between 10% and 90% germination. The smaller the T90-T10 value, the more uniform the germination.

d. Growth rate e.g. # seedlings which reach a specified size by a selected date.

Seedling growth

Seedlings are usually grown on at lower temperatures than required for germination which results in a shorter and studier plant. Light intensity is increased and a long photoperiod (more than 12 hours of light) is provided. Fertilizer is applied to ensure healthy and rapid growth. The concentration of fertilizer is low at first then increases as the seedling develops into a plant. Often increases in CO_2 are needed for vigorous seedlings grown in a closed greenhouse. A clean environment must prevail at all stages.

For most annual species, these stages require 5-7 weeks.
Each plug stage has distinct cultural requirements: As each stages progresses to the next, culture is modified as follows:

- Reduce watering frequency, increase water volume
- Gradually reduce temperature
- Increase fertilizer level in stages 2-3, stop in stage 4
- Apply growth retardants in stages 2-3

Media Components for Container Potting Mixes

Organic Components

Peat Moss

Peat is a general term for a range of organic materials, which are naturally formed in wet areas such as bogs. Peat is partially decomposed plant residue.

Peat moss that is light tan to brown in colour is the least decomposed and is mostly formed from **Sphagnum** mosses at the top of the bog. This peat has a very high water holding capacity, holding up to 60% of its volume in water. Finer and /or darker peat has even greater water and nutrient retention, but lower drainage capacity. The pH of peat moss is very low (3 to 4).

The Turf industry makes used of two alternative forms of peat moss. **Hypnum** moss peat is composed of leaves and stems from various *Hypnum* species. This peat has a high pH and is generally more decomposed than sphagnum peat. **Reed-sedge** peat is brown to reddish-brown in colour and is formed from swamp plants including reeds, sedges, marsh grasses, and cattails. It has less structure than sphagnum peat and a lot of fine particles which hold water less well.

Bark

In BC the primary sources of bark are Douglas fir and hemlock. In eastern Canada pine is the primary source of bark. The bark used for growing media is ground up and screened to various sizes for potting mixes (1" minus and 3/8 inch minus). The piles of screen bark are left to age in the rain or under irrigation sprinklers to leach out any salt accumulation (logs are often floated to the mills in salt water). In the past five years barked-based media suppliers have actively composted the bark to rid it of any possible *P. ramorum* (plant disease that can live in bark media) infestation. The piles of bark are wetted, aerated, and turned when the temperature reaches 50 to 70° C which kills the pathogen. The heating process is repeated three times before the bark is mixed with other components and sold. Bark absorbs plant growth regulators and keeps them from getting to the plant. When using bark a 25% increase in volume of growth regulators applied is required.

Coir or coco fiber

Coir is composted coconut husk fiber (mesocarp). It consists of both small particles (looks like coarse coffee grounds) and short fibers. Most coir is produced in Southeast Asia and shipped to North America in compressed block-like bricks. The bricks are left out in the rain for several weeks to expand (up to seven times) and leach (a lot of salt absorbed by the coconuts floating in ocean water depending on source). The properties of coir are similar to peat in that it holds a great deal of moisture but provides a lower level of aeration (large pores). It is less hydrophobic than peat and the pH is higher (4.9 to 6.8).

Sawdust

In the 1970s and 1980s sawdust mixed with peat moss was used for nursery container mixes. Sawdust retains some moisture but also assists drainage. However, it breaks down quickly into smaller particles. As a result a sawdust based mix will shrink in volume and drain poorly by the end of a growing season. The high carbon to nitrogen ratio in sawdust also ties up nitrogen at the beginning of the season because microorganisms use the sawdust particles for a food source. Sawdust is still used but in small quantities by the horticulture industry. Greenhouse vegetable growers use sawdust filled bags as a growing medium (substitute for rock wool).

Rice Hulls

Rice hulls are thin, feather-light with the thin, pointed shape of rice grains. They can be used on their own, to lighten soil and improve both drainage and water retention. Or they can be added to potting mixes for seedlings and containers. Are often used in soil mixes instead of perlite. Rice hulls provide a less dusty mixing environment, lower basic cost and decomposition over time, while remaining stable during the typical plant production cycle. Can substitute bark as there is no need for an increase in growth regulators. The pH of rice hulls ranges from 5.7-6.5

Inorganic Components

Vermiculite

Vermiculite is a specific alum inosilicate mineral rock, similar to mica. The structure of the mineral is plate-shaped or layered. After mining, vermiculite rock is processed by rapidly heating to 1000^{o} C. Water trapped between the layers within the rock evaporates and the pressure of the water vapor causes the vermiculite particles to expand to 15 to 20 times their original volume. In a potting mix water and nutrients are retained between the mineral layers of each vermiculite particle. The principal value of vermiculite in any potting medium is providing aeration and improving water drainage, similar to perlite but with the advantage of having some nutrient content, magnesium, potassium and calcium. Particle size varies with product grade. Vermiculite is used in indoor propagation and potting mixes as it is expensive and easily crushed. Its pH is neutral.

Perlite

Perlite is crushed volcanic rock that is heated rapidly to approximately 1000^{o} C. The rock particles expand to form a lightweight, white granule. The outside of each granule wets easily, but the pores within the granule are sealed and not available for water or nutrient retention. Perlite is very stable and chemically inert. It is used to 'loosen' a mix and improve drainage without adding weight. It is used in indoor propagation and potting mixes as it is expensive and easily crushed.

Pumice Stone

Pumice is a naturally occurring rock of volcanic origin. It is formed from the quickly cooling rock that is blown out of the volcano. As the mixture of molten rock and hot gases (froth or foam) cools, the sponge-like material becomes pumice. It is mined ground, and screened to various sizes. As it is porous, it will retain some water and nutrients (much less than most organic components). It adds weight and loosens a potting mix to provide extra drainage. It is often used in herbaceous perennial and green roof mixes.

Cutting Propagation

Plant Cultivars are Clones

Cloning is vegetative propagation with reproduces progeny identical in genotype to the single source plant.

A Clone is the resulting population of plants; usually genetically identical.

A Clonal selection is the result of the evaluation of two or more clones of the same species for specific characteristics. The best *clone* is selected and named as a cultivar of that species.

A Stock plant is the parent plant or 'mother plant' from which cuttings or propagules are harvested.

Reasons for using cloned cultivars:

- **Fixed genotype -** Improved plants can be reproduced without loss of unique characteristics that could happen if reproduced by seed.

- **Uniformity of populations -** Uniform plant size, growth rate, time of flowering, time of harvesting, etc. make commercial production of clones practical, predictable and more saleable.

- **Facilitate propagation -** More predictable and reliable methods of propagation can be used (cuttings, grafting, division), but they are usually more expensive than using seed.

- **Shorter time to flower than seed –** Progeny plants will flower at an earlier age since they are usually in a more mature phase of development when transplanted than seedlings.

- **Combining more than one genotype into a single plant -** *Grafting* joins two or more genotypes with different attributes e.g. hardy root system and large, showy flowers of a rose plant.

- **Control phases of development -** Vegetative propagation can be used to maintain, enhance or reverse a specific growth phase (juvenile vs. mature).

- **Improved vigour –** Plants that have been propagated from cuttings are often fuller, stockier plants, i.e. with more substance, which grow more vigorously than seedlings.

Origin of a cultivar or clone

1. **Mutation**
   A genetic mutation can cause a growing point or lateral bud to change noticeably in appearance. A **sport** is a chance mutation which occurs randomly over time. Mutations can also be induced artificially by chemical or radiation treatments. Many shrub cultivars have resulted from selecting one bud that exhibits unusual but desirable characteristics. The growth from this bud will look strikingly different than the rest of the plant. Mutation that produces dwarfing, variegation, or attractive coloring can be stable enough to be carried from generation to generation if propagated vegetatively (cuttings and grafting).

2. **Breeding program**
   Breeders produce hybrids that display superior characteristics. Breeders will cross specific parent plants to produce large numbers of hybrid seed. The seedlings are rated for desirable characteristics. One out of 40 to 100 seedlings (one out of 100,000 for roses) with sales potential is chosen for either further breeding work or for vegetative propagation. The new clone is tested in a number of different environments and geographic locations to ensure adaptation and stability.

3. **Transgenic plants**
   Biotechnology techniques can be used to insert genes (often from a different organism) that will change the genotype and produce a unique characteristic. Genes from other plants or animals can be inserted into plants and carried from generation to generation (seed or vegetatively). So far this technique has mainly been used for seed generated crops which are referred to as Genetically Modified Organisms (GMOs).

Causes of variation within cultivars/ clones

Chimeras

Chimera = an "island" of mutant cells within a growing point of a stem resulting from the mutation of a single cell; e.g. a single flower can have two different colours in an irregular pattern.

Variable gene expression

Some plants exhibit a regular variation in the expression of individual genes, which produce specific patterns, and colors in time and location e.g. bicolored petunia, coleus. This variegation is seed stable.

Environmental influence

Together, ***nature*** (genetics) ***and nurture*** (environment) influence an organism`s appearance. The environment where selection took place can influence the growth characteristics of the clone. Therefore, field-testing in various environments is necessary. For example, a clone found at a high mountainous elevation could have desirable attributes such as compact habit, hardiness, drought tolerance, etc. However, when planted at a normal elevation with a higher annual rainfall, the growth habit may become lanky and weak, and therefore undesirable.

Legislation to protect cultivars

Cultivar Name

The cultivar name is registered with the International Commission for the Nomenclature of Cultivated Plants and is indicated in the botanical name in 'single quotes'. This name is in the public domain. This means that the cultivar name cannot be used as a valid trademark. However, the cultivar name is used in the Plant Breeders' Rights legislation.

Legislation

Plant sports, mutants, or hybrids can be **patented** for 20 years (renewal is possible). The plant must be propagated asexually and must be distinct in some attribute: disease resistance, drought or cold tolerance, tolerance of heat, wind or soil conditions, flowering, colour of flower, leaf, fruit, and/or stems, fragrance, productivity, ease of propagation, or storage qualities. Plant Breeders' Rights protect asexually propagated cultivars in Canada and Europe. Plant Patents protect asexually propagated cultivars in the United States.

Trademark™

A trademark is any word, name, or symbol that will be used to identify and distinguish a product from those sold by others. The trademark name must be different than the 'cultivar' name. A trademark can be registered ® for 10 years and is renewable.

COPF

The Canadian Ornamental Plant Foundation is an independent group formed in 1964, which allows breeders of ornamental greenhouse and nursery crops to voluntarily register varieties in Canada. While Plant Breeders' Rights provide legal protection to breeders, the COPF provides financial support to breeders by collecting royalty fees from growers. Varieties do not have to be bred in Canada, nor does the breeder have to be a Canadian company.www.copf.org

With the increasing market for annuals grown from cuttings, and the number of varieties and breeders involved, COPF launched a monitoring program in 2007 to monitor cuttings imported into Canada. e.g. In one year, for one species, Calibrachoa, they checked hundreds of Canadian growers, and millions of cuttings from 34 breeders. 10% of the growers were fined for illegal propagation. They also monitor impatiens, petunia and other annual species. A US organization called Plant Watch is modeled after the COPF program.

www.plantwatch.org

Canadian Legislation

Bill C-15, which legislates **Plant Breeders' Rights**, was passed in 1990. Breeders have exclusive rights over the cultivars they develop through selection and breeding programs. If other growers wish to propagate and sell these cultivars, they must first obtain the breeder's permission and pay a **royalty** per cutting. To be covered by PBR, *cultivars must be new, distinct, uniform, and stable*. Seed varieties are also covered by this legislation.

www.inspection.gc.ca/english/plaveg/pbrpov/guidee.shtml

Summary of PBR Legislation

New: The sale of a candidate variety prior to application for protection is restricted in Canada. Varieties of herbaceous plants can be sold up to four years outside of Canada. Varieties of woody plants can be sold for up to six years outside of Canada.

Distinct: A candidate plant variety must be measurably different from all other varieties, which are known to exist within common knowledge at the time of the application was made. Common knowledge includes varieties already being cultivated or exploited for commercial purposes in Canada and those varieties described in a publication that is available to the public.

Uniform: A candidate plant variety must be uniform in that any variation should be predictable to the extent that it can be described by the breeder. Any variations in the uniformity of a variety must be commercially acceptable.

Stable: A candidate variety must remain true to its description over successive generations. The variety must be stable in its essential characteristics to ensure that further generations of seed or other propagating material exhibit the same characteristics as described in the original description for which rights were granted.

The breeder must pay fees, both initially for the application ($1,600) and yearly ($300) to maintain the PBRs for each plant clone. Maintenance of a plant trial for one or two years is also required to prove stability and uniqueness of the new clone. PBR's are granted for a period of up to 18 years.

Grant of Rights

The holder of a plant breeder's right has the exclusive right to:

1. Sell and produce the variety/cultivar in Canada for the purpose of selling the propagating material of the protected variety;
2. Make repeated use of the protected variety/cultivar as a step to commercially produce another variety;
3. Make repeated use of the protected variety/cultivar for use in the production of ornamental plants or cut flowers; and
4. License a third party to do any of the above acts, conditionally or unconditionally.
   e.g. A breeder can license a propagator to be one of their ***'rooting stations'***.

Stem development

Stem juvenility versus maturity

(see Figure 7.1, next page)

Juvenility refers to the chronological age of the tissue.

Maturity refers to the physiological age of the tissue.

Juvenile stem tissue can be obtained by:

1. Selection from juvenile part of the plant (base)
2. Use of sprouts or suckers (adventitious shoots and latent buds) that elongate from the roots, crown, or nodes
3. Use of hedge rows, where stock plants are cut back 15 to 30 cm from the crown forcing multiple branches to elongate at or just above the crown
4. Tissue culturing from an embryo or a very young seedling.

Stem Development from the Germination to Flowering

Embryo Phase

⇓

Juvenile Phase
(better rooting success)

⇓

Adult Phase (flowers)

⇓

Senile Phase

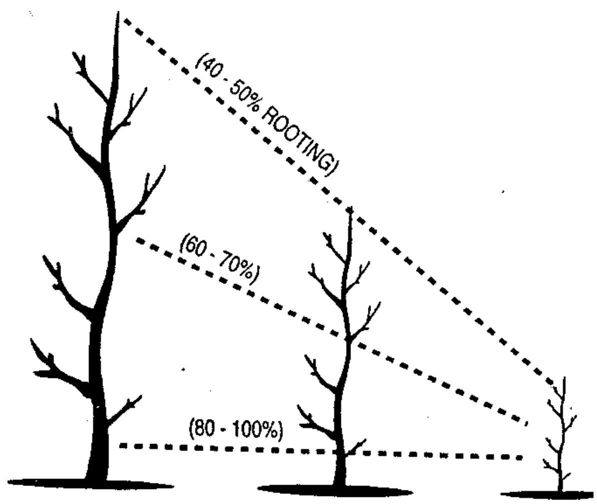


Figure 8.1: Potential rooting success decreases as the plant matures from the base to the top of the crown.

A plant exhibits changes in maturity from the base to the top of the plant. Woody plants naturally mature as they increase in size from an embryo to an adult flowering form. However, tissue created at a particular **phase** does not mature. For example, the base of a seedling develops right after germination and is in the juvenile phase. The base becomes older *chronologically* and thicker as it ages, but its maturity phase does not change. The base of a shrub or tree cannot bear flowers. However, tissue at the apex of each branch develops at a more mature state and can produce flowers, fruit and cones, even though chronologically it is younger than the base.

The apical meristem becomes more mature, *physiologically*, as the shoot grows. Cuttings taken at a certain height in the plant will retain that level of maturity at that height. Wood taken from the top of the plant will flower more quickly when grafted on a juvenile seedling. Wood taken from the base of a plant will root more successfully. For some plants the juvenile phenotype or appearance can be different than a mature phenotype.

Growth pattern

For some plants, mostly conifers, the position of the propagule on the adult plant is reflected in the growth pattern subsequently shown by the rooted cutting. This is a positional or orientation effect. For example, an upright shoot will produce upright plants. A lateral shoot will grow horizontally after rooting. (See figure 7.2)

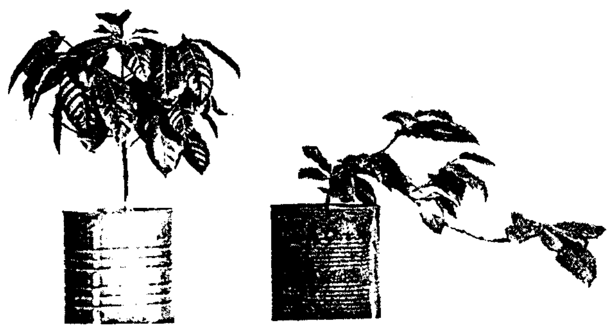


Figure 7.2: A coffee plant propagated from a vertically oriented cutting maintains an upright growth pattern (left) and a lateral shoot produces a horizontal growth habit (right).

Ripeness

Fully ripe wood means that the plant tissue is fully developed. The stem tissue ripens as it ages over a season of growth. *(Note that ripeness and maturity mean two different things).* Increased ripeness means that the bark is more developed and the stem becomes more rigid (less bendy). Generally, the riper the wood is, the longer the rooting time and the lower the rooting success.

The ripeness of the wood will also be influenced by the growing environment. Plants that are inside protected structures will start to grow earlier in the season and ripen more quickly in the spring. Plants that are protected in the fall may not progress to the hardwood stage unless they experience very low temperature, i.e. close to or at 0˚C.

Rooting Hormones

Auxin is **only** responsible for the initiation of roots. It is not needed for root elongation and growth stages.

Note: Co-factors or chemicals within the cutting are also necessary for root initiation.

Ease of rooting categories

1. **Easy to root**: No auxin required, both auxin and cofactors are supplied by the plant in sufficient quantities; rooting hormones may actually damage the cutting.
2. **Somewhat difficult to root**: Synthetic auxin must be applied, but the concentration varies with the type of cutting, time of year, and species.
3. **Very difficult or impossible to root**: Plant lacks chemical compounds or enzyme systems to initiate cell division; means that rooting cannot occur even when auxin is applied. These plants are usually **grafted** (e.g. pine).

Auxin advantages

Auxin at the base of the cutting results in the following advantages from either the natural supply within the plant or applied by the propagator:

1. Increase in the number of cuttings that successfully root.
2. Quick root initiation.
3. Increase in the number and quality of roots.
4. Improvement in the uniformity of the new root system.

Synthetic rooting hormone products

i. IBA = indole butyric acid;
ii. most common commercial preparation
iii. NAA = naphthalene acetic acid
 or IAA = indole acetic acid

Carrier:

i. Powder formulations use finely ground talc (dyed for color)
ii. Liquid formulations use an organic solvent (ethyl alcohol or acetone)

Powder Application (Stim-root™)

#1 Stim-root = 0.1% IBA (1,000 ppm)
#2 Stim-root = 0.4% IBA (4,000 ppm)
#3 Stim-root = 0.8% IBA (8,000 ppm)

Liquid Application - Quick Dip (3 - 5 seconds)

Concentration	Cutting type (somewhat difficult to root)
500 - 1,000 ppm	Softwood cuttings, easy-to-root semi-hardwood cuttings, narrowleaf evergreen cuttings, and hardwood cuttings
2,000 - 2,500 ppm	Moderate-to-root semi-hardwood cuttings, narrowleaf evergreen cuttings, and hardwood cuttings
5,000 - 7,500 ppm	Difficult-to-root semi-hardwood cuttings, narrowleaf evergreen cuttings, and hardwood cuttings

or soak for 12-24 hours, dilute to 20 - 250 ppm.

Suggested timing of cutting propagation

In general newly formed stem tissue is easier to root and roots more quickly than stem tissue that has ripened over the season. However, newly formed stem and leaves are more easily bruised when handled, desiccate more quickly if not kept evenly and consistently moist, and are much more susceptible to disease.

More expensive and closely monitored propagation benches with fog or mist systems are necessary for ‘soft’ cuttings. Therefore, low value plant species are often rooted later in the season, provided that the level of rooting success is satisfactory. High value plant species or those that root poorly are rooted as ‘softer’ cuttings to improve efficiency and success.

Conifer cuttings are for the most part exceptions. Many conifer species are difficulty to root, but need to be propagated during the dormant season, as rooting softwood tissue is usually not successful.

Cutting type	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Leaf												
Leaf-bud												
Softwood												
Semi - ripe												
Hardwood (deciduous)												
Hardwood (evergreen)												

Cutting Type Comparison Chart[1]

Cutting Type	Length Suggested	‘Ripeness’ of wood	Handling Requirements
Leaf	Usually not a consideration	The ‘cutting’ consists of the leaf blade and sometimes the petiole. They are taken from non-woody herbaceous plants (often tropical)	The humidity from mist or fog must be very high as leaf tissue loses water rapidly. The wounded tissue must be pressed well into the propagation medium.
Leaf-bud	2.0 to 7.5 cm (1 to 3 inches)	These cuttings can be taken from either herbaceous or woody plants. The cutting consists of one leaf blade and petiole and a short length of stem with an Axillary bud. The stem ripeness varies with the plant species.	The short stem acts as an anchor to secure the bud and leaf just at the surface (sometimes just below the surface) of the propagation medium. The humidity from mist or fog must be very high as leaf tissue loses water rapidly. Rooting hormone is optional depending on species.
Herbaceous	7.5 to 12.5 cm (3 to 5 inches)	These cuttings are from non-woody plants and therefore there is no secondary growth. The stems are succulent and easily bruised	The humidity from mist or fog must be very high as both stem leaf tissue loses water rapidly. Rooting should occur in about three weeks. Rooting hormone may not be needed or should be at the lowest concentration. Rooting hormone is usually not necessary.
Softwood	7.5 to 12.5 cm (3 to 5 inches)	Secondary growth is just starting to form as the new stem growth has just extended. The stems are very pliable (bendy) and succulent.	This cutting type is handled in the same way as an herbaceous cutting. The humidity from mist or fog must be very high as both stem leaf tissue loses water rapidly. Rooting should occur in about three weeks. Rooting hormone (lowest concentration) is optional depending on the ‘root ability’ of the plant species.

[1] Information based on Table 10-1 *Hartmann & Kester’s Plant Propagation Principles and Practices*, 8th Edition.

Cutting Type	**Length Suggested**	**'Ripeness' of wood**	**Handling Requirements**
Semi-ripe or semi-hardwood	7.5 to 15 cm (3 to 6 inches)	The current season stems taken late spring to late summer are fully extended and firming up. New buds have formed. Stem colour is often still green, transitioning to brown at the base.	Semi-hardwood cuttings are used to propagate broadleaf evergreens. The foliage can be quite resistant to water loss at the end of the growing season. The humidity from mist or fog must be relatively high depending on the plant species, temperature and 'toughest' of the cutting. Rooting will occur in several weeks. Rooting hormone is always recommended (medium to high concentrations). Bottom heat will also speed up rooting.
Hardwood (deciduous)	10 to 76 cm (4 to 30 inches) Longer cuttings are field stuck.	These stems are dormant and therefore the wood and bark are fully formed. The wood is lignified and therefore, quite rigid. The wood is usually from the previous season's growth but may be 2-year-old wood for some species.	These cuttings are leafless and do not lose water rapidly. Light mist or a humidity tent will increase the humidity without over wetting the cuttings. The cutting should have at least two nodes and the cutting base should be just below one of these nodes. Rooting hormone (high concentration) is always recommended. Cuttings taken toward the base of branches (thicker diameter) generally root better. This type of cutting can be field rooted.
Hardwood (evergreen)	10 to 20 cm (4 to 8 inches) Some propagators will use 12 inch cedar cuttings.	These stems are completely dormant or quiescent (Cupressaceae). The wood is lignified. However, the firmness depends on the species (i.e. Cedar cuttings can be quite bendy at the tips).	As this type of cutting has foliage (dormant) it will need mist, fog, or a humidity tent to prevent desiccation. Cuttings should be taken after a few frosts to ensure quiescent in genera belonging to the Cupressaceae family. Rooting will occur in several weeks. Rooting hormone (high concentration) is always recommended. Bottom heat will also speed up rooting. However, most plant species are very slow to root.

Wounding

The stem is "wounded" when the cutting is taken. This starts the rooting process. "Extra wounding" or the removal of bark tissue involves the slicing of a small amount of bark on the side of the stem at the base of the cutting. ***More rooting*** is stimulated along the cut edge, as there is a natural accumulation of auxins and carbohydrates at the wounded sites. Also, ***water uptake*** by the cutting can be increased through more exposed xylem. Because this extra handling adds to the cost of production, usually only difficult-to-root cuttings are wounded. Small wounds caused by leaf or needle removal are sufficient to wound easy- and moderate-to-root species.

Advantages

- Increases quality and quantity of roots;
- Increased sites for root initiation by providing more wounded tissue for development of root primordia;
- If rooting hormone is applied to all wound sites, more can be absorbed;
- Roots can now break through tough outer fibrous rings or bark that occur in some species

Disadvantages

- Can increase basal rotting
- Basal tissue can be crushed
- Extra labour, cost

Leaf area reduction

The foliage at the base of the cutting must be removed as the more delicate leaf tissue must not touch the surface of the propagation medium (it will rot). Additional leaf reduction is carried out for large-leafed species e.g. Hydrangea, where part of the leaf blade is removed on all of the remaining foliage. Generally, not more than one-half of the leaf blade is removed per leaf.

Advantages

- Decreased transpiration and therefore, water loss from the cutting
- Less leaf overlap means more air circulation
- Mist moves through leaves to wet rooting media
- Increases ease of handling
- Can increase cutting density on the bench or in the bed

Disadvantages

- Increases risk of disease entering through cut surfaces
- Decreases amount of photosynthesis (minor role as the energy needed for rooting comes mostly from carbohydrates stored in the stem)

Cutting storage before sticking

Sometimes softwood cuttings cannot be stuck immediately after they are removed from the stock plant. The cuttings must be stored properly to avoid both water loss and too much expenditure of energy via respiration. To reduce respiration**,** cuttings are stored at a *low temperature* that is non-injurious to the cutting (typically 4 to 8˚C). Maintain *high relative humidity* (100%) to reduce transpiration by either misting the cuttings or storing them in polyethylene bags.

Disadvantages of storing the cuttings in a refrigerated unit include:

- light exclusion that reduces the quality of the cutting;
- period of time in which pathogens can invade;
- ethylene build-up, which causes injury to plant tissue.

Hardwood cuttings (fully dormant) can be stored for several weeks if deciduous and a week to 10 days if foliated (conifers, broadleaf evergreens). Broadleaf and conifer cuttings are placed in plastic bags. The foliage should be moist but not wet. The bags are kept in a cooler (2 to 4˚C). They are prepared and stuck in plug flats or open flats which are placed in a cool propagation house with bottom heat in the bench or floor.

Deciduous hardwood cuttings are cut to uniform lengths, bundled and placed in boxes filled with slightly moist peat or sawdust. Often the bases of the cuttings are dipped in rooting hormone powder to stimulate callusing during storage. These cuttings can be stuck in field rows when the soil starts to warm up in the spring. Otherwise they can be stuck in tall pots or plugs in a cool greenhouse with some bottom heat.

Figure 9.1: Preparation of softwood basal cuttings. The shoot is cut immediately below a node or leaf at the base (a) and the lower leaves are cut off (b).

Cutting preparation

A cutting is often prepared for sticking by re-cutting the stem just under a node. The node provides more exposed vascular tissue to generate roots and a hard end to push into the rooting medium. (See Fig. 8.1.) Easy-to-root cuttings will root along the internode as well and only require re-cutting to ensure uniform size. Soft herbaceous tip cuttings taken from stock plants that have been bred for easy rooting do not have to be re-cut and can be stuck directly.

Wound healing

Dedifferentiation *Mature parenchyma cells near vascular tissue return to a meristematic condition. As the cells divide and multiply, they form a new growing point and differentiate into a root initial. These in turn become adventitious roots.*

Location of adventitious root initiation

Root initials usually form adjacent to the vascular system. In herbaceous stems, root initials are found just outside or between the vascular bundles. For woody stems, the initial is generally within the newly formed **secondary phloem**.

Leaf and root cuttings both require adventitious shoots and roots to form. In leaf cuttings the shoots form just beneath the **epidermis** and the roots between the vascular bundles.

Callus

Callus is an irregular mass of parenchyma cells in various stages of **lignification**. It may form at the basal end of the cutting in the region of vascular system (cortex and pith also possible). Formation is normally independent of rooting, but indicates that environmental conditions are generally favorable for rooting. Excessive callus production and little or no rooting indicate incorrect environment (e.g. too cool).

Polarity

Polarity refers to the natural vertical orientation of the cutting, which is important to maintain because the active transport of **auxins** between parenchyma cells in the phloem always occurs downward from the stem tip. Polarity can easily be compromised (Which way is up?) when making several cuttings from a single stem, or from a long succulent leaf, e.g. *Sansevieria* or *Yucca*.

Buds and Leaves

Buds and leaves produce **auxin** and other root-promoting substances. These chemicals travel in the phloem to the base of the cutting. The **carbohydrates** generated via photosynthesis also play a role in root promotion, although most of the 'energy' for root generation comes from stored carbohydrates in the stem.

Cutting environment while rooting

High relative humidity is required to reduce water loss from the cutting caused by transpiration. (See Section 9.11 page 46.)

Temperature must be adequate for metabolic activity at the base of the cutting. Heat stress of the shoots must be avoided. In general, higher temperatures are needed for root initiation than for root development and growth.

Air temperatures: 21° - 27° C day; 15° C night (4° C for dormancy); over 30° C is usually injurious

Soil temperature: Due to high humidity and misting, media is usually constantly moist. Soil and root temperature are lower than air temperature, due to constant ***evaporation from moist soil.*** Media temperature should usually be 18° - 25° C, depending on the plant species. It is recommended to monitor soil temperature with soil thermometers or sensors.

'Bottom heating' is often required to compensate for low soil temperature. Systems used include:

- **Electric heating cables** on top of benches under containers, connected to a temperature controller
- **Hot water tubing** on top of benches
- **Under-bench heating**, using hot water pipes or forced air heating

The effectiveness of bottom heating systems can be enhanced by adding:

- **Plastic 'skirt'** mounted on the sides of propagation benches, which extends down to the floor and directs under-bench heating directly to the bench top
- **Plastic tent** mounted on the top of the bench to trap heat around containers and plants

Light levels must be maintained for the production of carbohydrates via photosynthesis, although these sugars play a minor role in the rooting process. Most carbohydrates needed for the rooting process come from stored starch in the stem. Low light levels are best, as high levels can injure foliage and create excess heat especially in summer.

Photoperiod may have an effect on some species. In general root formation is best under long days.

Air circulation is necessary to avoid stagnant, moist air, which can stimulate the growth of disease organisms. Reduction in leaf size, even spacing of each cutting, and horizontal airflow will promote air movement around each cutting.

Rooting media

The properties of the rooting medium are critical in the initiation and subsequent growth of roots. The rooting medium must provide:

1. Anchorage and darkness at the base of the cutting
2. Moisture retention
3. Aeration (must be well drained)
4. Clean, i.e. freedom from pathogens
5. Nutrients at low levels as soon as rooting occurs

Specialized propagation units

There are a variety of commercial products which serve as rooting units for individual cuttings. These are popular with growers who propagate small herbaceous cuttings. Most have pre-formed holes for seed or cuttings. However, some hole diameters do not match the cutting stem diameter.

Examples:

Organic products: Jiffy™ peat pellets, Ellepots™, Fertiss™, Preforma™, Q plugs

Advantages: Better water retention, biodegradable, organic

Inorganic products: Oasis™ foam cubes, rockwool plugs, the Rooting Sponge™.

Advantages: May be stronger (= better for handling, shipping), less prone to disease and insects

Maintenance of turgor in cuttings

Turgor must be adequate for the cutting to initiate and develop a root system. High relative humidity is necessary to reduce transpiration demand from the leaves, since there are no roots yet for water uptake at the base of the cutting.

Intermittent Mist

Advantages:

1. Misting keeps cuttings turgid.

2. A film of water on the upper surface of the leaves evaporates and cools the leaf.
3. Under mist, light intensity can be increased for photosynthesis. Shading (60-80%) is still required in summer to reduce the temperature.

Disadvantages:

1. Misting also cools the rooting media, which can delay rooting. A film of water at the bottom of the pot or tray can form where oxygen is depleted.
2. Mist will leach nutrients from the leaves of the cuttings
3. A large loss of water via transpiration from the leaves can occur between mist cycles (especially summer cuttings). Accurate monitoring and control of misting cycles is required.

Fog

Advantages:

1. Fog cools the air and less shading is required in summer.
2. Very fine water droplets can remain suspended and keep a more constant humidity between 93 and 100%.
3. Very fine water droplets can remain suspended without an unnecessary layer of water on leaves and media.

Disadvantages:

1. More expensive than most misting systems; requires higher pressure and a higher quality of nozzles and water lines.
2. Fog water droplets can drift easily in air currents.
3. Wet and dry spots can occur in the rooting medium.
4. The whole greenhouse is fogged and cannot be used for other crops.

Plastic tents on top of benches

Advantages:

1. Tent enclosures are cheap to build.
2. The enclosure reduces amount of mist required (good for winter cuttings). Mist can be applied by a mist system set up inside the tent or by misting by hand as required.

Disadvantages:

1. There is less evaporative cooling in the summer which can result in heat build-up.
2. Heavy shade is required (up to 80% in summer and up to 40% in winter) under bright conditions.

Humidity control

Various devices are used commercially to monitor and control relative humidity:

- **Timers:** Simple mechanical, analog or digital time clocks can be used to control misting cycles.
- **Humidity sensors**: Various sensors are used in greenhouses to monitor *relative humidity*, *vapour pressure* and *humidity deficit*.
- **Light level:** Since light energy directly affects air and leaf temperature, and the rates of transpiration and evaporation, it can be used to control misting frequency.
- **Electronic leaf:** This is a simple device which duplicates the natural rate of evaporation from leaves, and turns ‘on’ and ‘off’ a *solenoid valve* which controls the misting cycle.

Hardening-Off the Cuttings:

As roots develop on the cuttings, progressively less misting is required to maintain turgor in the cuttings. The frequency and duration of misting cycles can be gradually reduced to harden the cuttings from the initially optimum humidity level. If adequately rooted, cuttings should not be left under heavy mist as root quality deterioration and leaf drop can occur. The mist will leach out nutrients from the leaves and the rooting process is disrupted (air/ moisture balance).

Many propagators remove the flats of rooted cuttings and place them in a hardening-off area that is shaded and somewhat protected from the extremes of temperature and humidity. Gradually, the flats will be exposed to higher light intensities, increased air movement and greater swings in temperature. When the root system has filled the rooting medium pot or liner cell, the cuttings can be transplanted into the appropriate container size for growing on. If the hardening-off phase is prolonged, the rooted cuttings should be fertilized with either soluble or controlled release fertilizer at half the normal application rate. Cuttings that are dormant should not be fertilized until they begin to flush out in the spring.

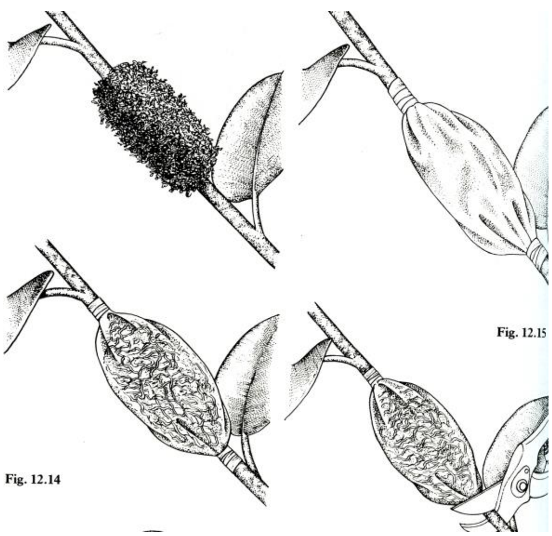
Propagation by Layering

Layering

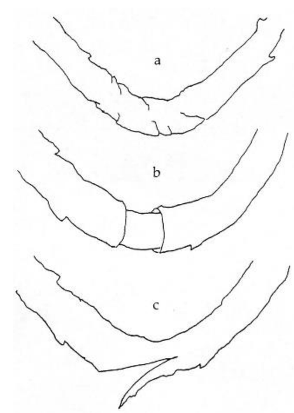
Layering is used to propagate plants which produce adventitious shoots and roots from nodes along their stems when the stems contact soil. Some plants can self-layer, in which case stems are bent and pinned to or buried in the ground; for other plant species stems must first be wounded to encourage adventitious growth. In either case, new plants are removed from the layered stem and planted when ready. Like division, layering produces new plants quickly, but a limited number from each parent.

Air layering:

In air layering, the stem is wounded without contact with the ground. The wound is usually wrapped with moist sphagnum moss and plastic. Once roots form from the wound, the layer is cut off the parent stem and the plastic is removed. This is equivalent to rooting a stem cutting while still attached to the mother plant.



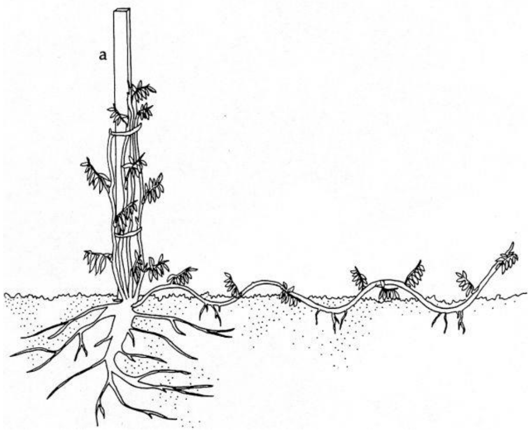
Steps in air layering

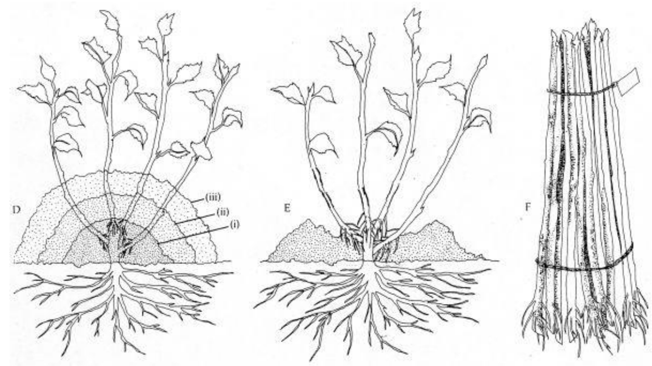


Stem restriction options

Serpentine and Stool Bed Layering

Serpentine: Vines can be layered by laying down a branch and covering at nodes with soil (illustration below, left). **Stooling**: Plants that branch at the base (can be cut back to force branching) can be covered with soil successively as the branches extend (illustration below, right). Over a full season (May to November) the branch bases will root if the covering material is kept uniformly moist.



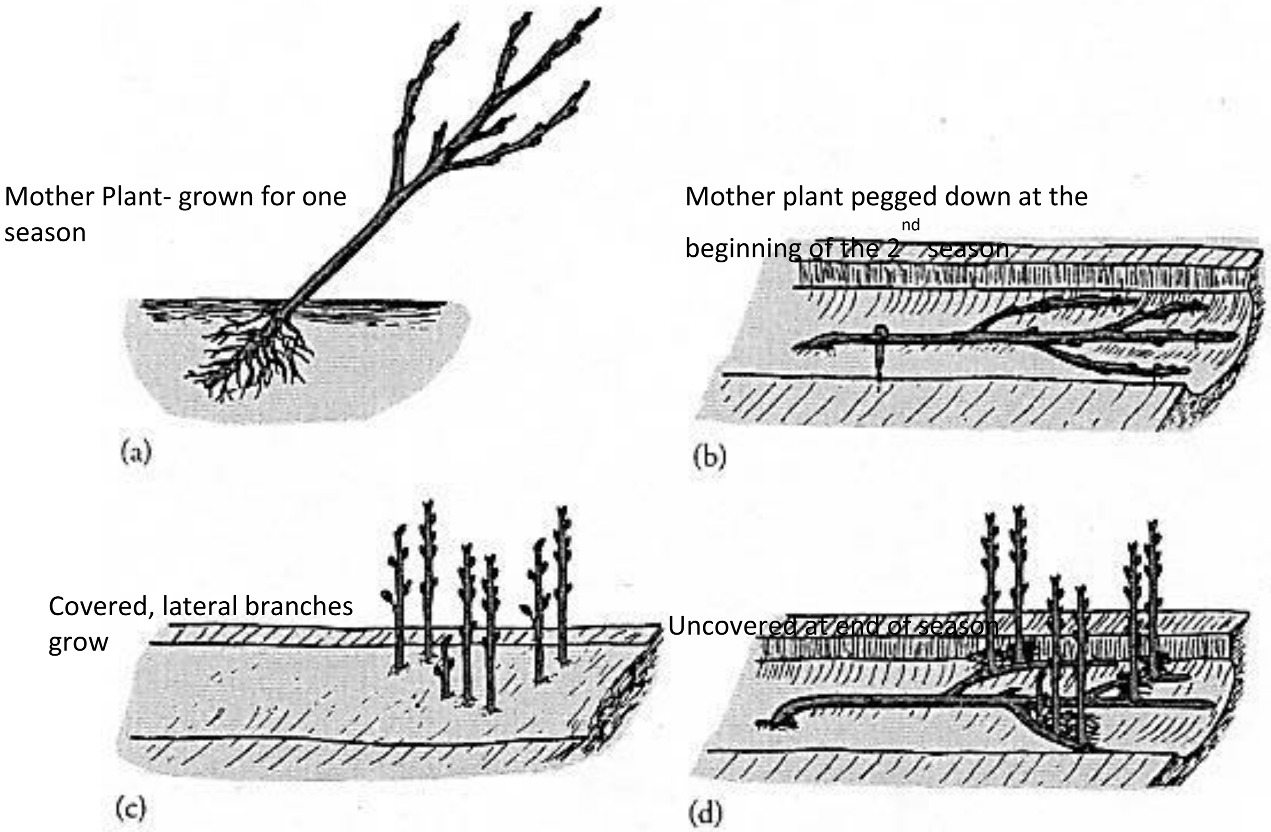


Layers from Stool Bed, Trench Layering

Rooted Cuttings while Attached to the Mother Plant i.e. Fruit trees

Rootstock for apple and cherry tree fruits must be from a certified virus-free source. The rootstock sports specific desirable characteristics such as vigor, disease resistance, soil condition tolerance, etc. Specific apple rootstocks can also dwarf the scion portion of the plant to a greater or lesser degree. There are rootstocks used for commercial plantings (very dwarf) and others used for residential use (semi-dwarf). The rootstock must be a clone so that the beneficial characteristics are uniform from plant to plant. Apple and some cherry rootstocks do not root successfully as cuttings. Tissue culture is very expensive and usually restricted to the propagation of mother plants. Layering has been the most successful propagation method in terms of rooting percentage and low cost for large quantities.

Mother plants are planted in the spring in rows about 10 to 15 cm apart. After they have established strong root systems for one season, the shoots are bent down along the ground and covered with a layer of sandy soil or sawdust. Lateral shoots growing up from the horizontal branches are covered with more sandy soil or sawdust at the base to promote rooting several times over the season. Not more than 50% of the stem length is covered at one time. Early in the fall the base of each lateral branch starts to root. The soil or sawdust is removed in early November and the rooted branches are cut from the mother plant main branches. The rooted branches are called “layers”. They are graded into sizes (mostly based on caliper) and stored over the winter. They are lined out in rows the following spring in preparation for budding in the early fall.



- Layers are produced on mother plants planted in trenches
- The mother plants are planted on a 30 to 45° angle and grown on for one season. The following season the main stems are bent down to the ground and either braided together or pegged down into a shallow trench.
- Mother plants are then buried with either 5 cm of sandy soil or sawdust.
- Vertical shoots spring up from the buried lateral branches and are gradually covered at the base as they grow. This provides a dark, moist environment, which promotes rooting.
- The shoots or layers root in the early fall and are removed from the mother plants in the late fall. First the sawdust or soil mounds are brushed off of the mother plants. The layers can then be cut with either a machine or by loping shears from the mother plant without injuring the layer-producing stems. The layers are graded (usually by caliper), the roots are trimmed and the plants are placed in cold storage (roots are buried in moist sawdust).

Budding and Grafting Propagation

6.1 Grafting terms

Grafting – The art of connecting two pieces of living tissue together in such a manner that they will unite and subsequently grow and develop into one plant

Scion - Short piece of detached shoot containing several dormant buds; will become the shoot portion of the plant

Budding - A form of grafting where the scion is reduced in size to contain only one bud

Rootstock - The lower portion of the plant including the root system and crown; may also be part or all of the main stem. Rootstock can also be called *understock*.

Interstock - A piece of stem inserted between scion and root stock (2 graft unions)

Callus – A mass of parenchyma cells that develop from and around wounded plant tissue at the graft union; originate from both the scion and the rootstock; the cell masses interlock in the first steps of the healing process.

Why graft?

1. Perpetuating clones that cannot be readily maintained by other asexual methods.
2. Obtaining the benefits of certain rootstocks, e.g. vigour, disease resistance.
3. Changing cultivars of established plants. This is the only asexual method which can combine the genotypes of two different plants into one without sex.
4. Hastening the reproductive maturity of seedling selections in hybridization programs.
5. Hastening plant growth rate and reducing production time.
6. Obtaining special forms of tree plant growth - weeping, standard, etc.
7. Repairing damaged parts of trees.

Formation of graft union

A graft union is essentially a wound in the root stock in which an additional foreign piece of tissue has been incorporated. The scion must have at least one dormant bud which obtains water and nutrients from the rootstock. The rootstock must be physiologically active (roots growing) when grafted.

1. <u>ining up of vascular cambiums</u>: Cambial regions of both the scion and the rootstock must be in close proximity.

<u>Graft Union Environment</u>

Temperature should be between 15° to 32° C (activity rate related to temperature). Above 32° C and below 4° C there is no activity. Ideally, the union is kept at 20 to 25° C.

Humidity inside the tissue must be at 100% to ensure that new thin-walled parenchyma cells stay turgid. The graft union is either waxed or placed in a moist medium to prevent drying. Bench grafted plants can be placed in a tent or under a cover.

Oxygen is required because the healing process is a high respiration (energy) process.

Secure hold is achieved with a grafting rubber strip, plastic grafting tape, or a plastic clip.

2. Wound response Cells on both the scion and rootstock are killed at least one cell deep when wounded. A necrotic layer forms from cell contents and cell walls of the killed cells. It may be reabsorbed or remain imbedded.

3. Callus bridge formation The outer exposed layers of the undamaged cells in the cambial regions of both the scion and the rootstock produce parenchyma cells. A binding material is secreted by these cells which binds the graft partners. The parenchyma cells interlock and fill up the spaces in the union 1 to 7 days after grafting. Mechanical support can be achieved in 2 to 3 days with some movement of water and nutrients to the scion from the rootstock.

4. Cambium formation Selected cells of this newly formed callus, that bridge between the cambium layers of the intact scion and rootstock, differentiate into new cambium cells. This takes place 2 to 3 weeks after the graft is made. A continuous connection between scion and rootstock is required.

5. Vascular tissue formation New cambial cells produce new vascular tissue, both new xylem and phloem, which must be completed before bud expansion can take place on the scion.

Formation of Graft Union

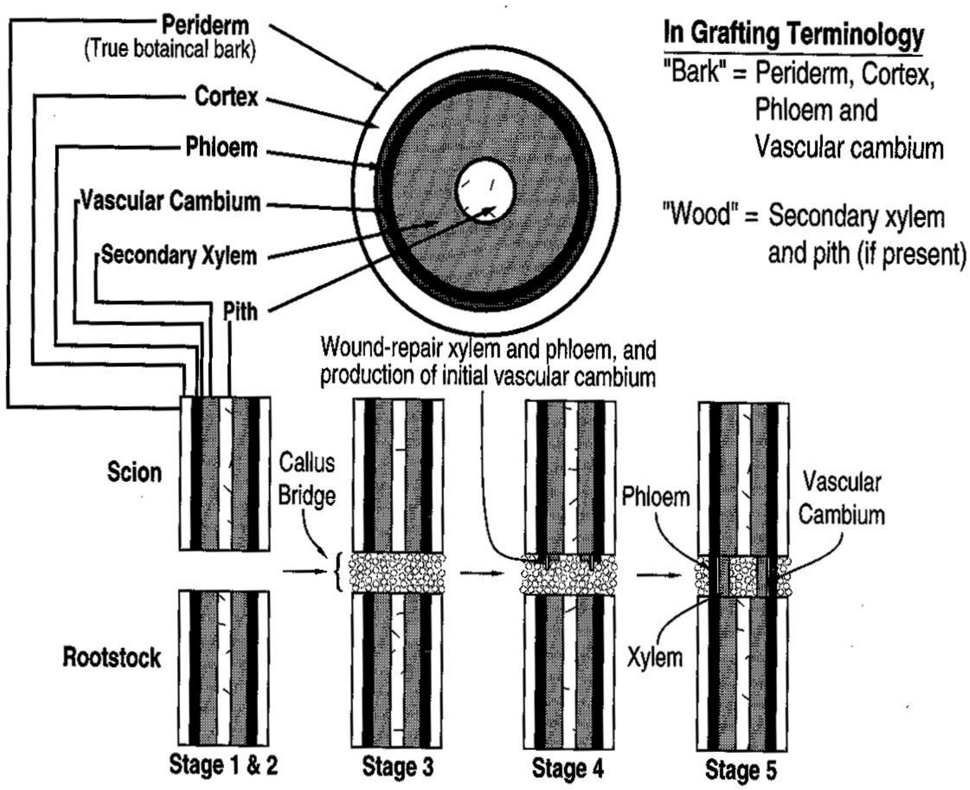


Figure 11.1:
Top: A young woody plant stem with grafting terminology of the "bark" and "wood" and associated tissues. (In Botany: Inner bark = primary + secondary phloem;
Outer bark = cork + cork cambium)

Bottom: Stages of graft union formation:

Stage 1: Lining up of vascular cambiums of the rootstock and scion

Stage 2: Subsequent wound healing response

Stage 3: Callus bridge formation

Stage 4: Wound-repair xylem and phloem occur in the callus bridge just prior to initial cambium formation

Stage 5: The vascular cambium is completed across the callus bridge and is forming secondary xylem and phloem.

Budding healing process

Bud shield – Consists of periderm, cortex, phloem, cambium and some xylem tissue

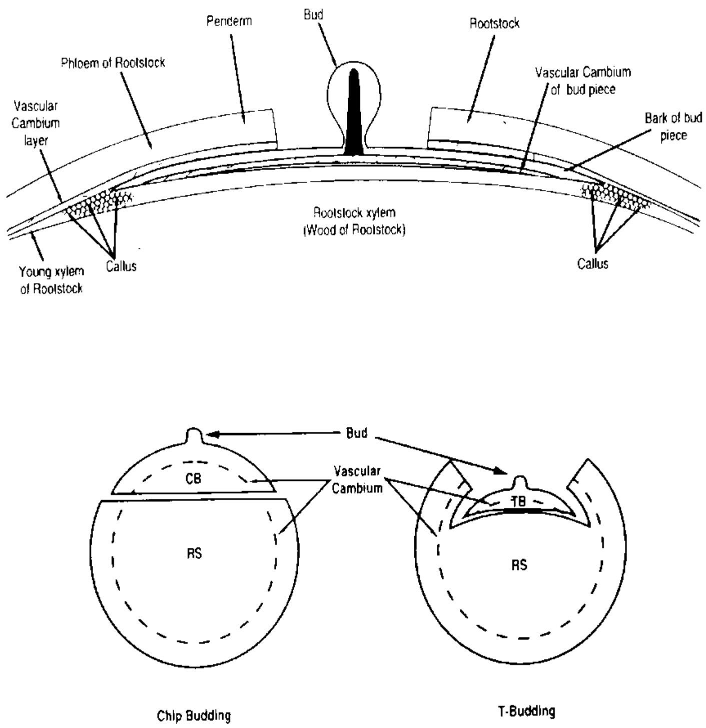


Figure 11.2: **Top Right**: Tissues involved in healing of an inserted T-bud as prepared with the "wood" (xylem) attached to the scion bud piece.
Bottom Right: A cross section of a chip bud (CB), T-bud (TB) and rootstock (RS)

Graft failure

Symptoms of graft failure

1. High failure rate at the graft union.
2. Yellowing foliage in the latter part of the growing season and early defoliation.
3. Death in a year or two after grafting.
4. overgrowths at, above, or below the graft union. Note that scion overgrowth is not necessarily a symptom of incompatibility.
4. Marked differences in the growth rate of the scion and rootstock, which result in
5. Differences between scion and rootstock in the time at which vegetative growth for the season begins or ends.
6. Excessive suckering of rootstock.
7.
8. Graft components breaking apart cleanly at the graft union after growing for some time.

Causes of graft failure

1. An overactive rootstock results in 'bleeding'. The sap flow is too high for the size or growth rate of the scion. The union is flooded and healing is delayed;
2. Presence of insects or disease may result in infection or infestation of the grafting wound.
3. Poor matching of cambium and uneven cuts mean that too much time and energy are used to fill the void between the scion and the rootstock with callus before a new cambial bridge can be created. The scion, cut off from a water supply, may not survive.
4. Poor or delayed waxing can result in drying of the graft union especially in unprotected, outdoor environments.
5. Desiccated scions will have plugged or non-functional xylem. Callus production and cambium bridging from the scion cannot occur.
6. Polarity maintains the proper orientation of the scion. It will not survive if inserted upside down.
7. Genetically unrelated scion and rootstock can result in no functional cambium bridge being formed.

Timing

Bench Grafting is preformed when the rootstock is growing **in a pot**. This type of grafting is usually done *inside a greenhouse*. The grafter is sitting at a bench. Some tree species, for example Japanese maple, can be grafted almost any time of the year. Other shade trees can be chip budded in early spring using seedling rootstock planted into special grafting pots (tall and narrow). *Conifers***,** however, must be grafted when they are dormant, typically in the months of *December to February*.

Field Grafting is preformed in the field. The scion must have fully formed dormant buds and the rootstock which often includes a sizable portion of the main stem, must be just starting to grow. Therefore, early in *March through April* is the best time for field grafting of standards and other tree forms.

Budding is preformed in the *summer months* **only**. Buds must be from current season wood, dormant, and fully formed. The bark on the rootstock must be growing so that the bark “slips” away from the wood when cut. **T-budding** is performed from mid-July to late August. **Chip budding** can be done at the same time and extend into September, as bark slipping is not required for this technique.

Budding techniques

Bud sticks are gathered from stock plants in mid-July. The stem tissue must be from current season growth, the buds fully formed and dormant. The leaves are removed, but a short piece of the petiole is left on to mark the bud and to provide a handle. The bud sticks are bundled and wrapped in paper and plastic. They are placed in a cooler out in the field and then placed in refrigerated storage until required for budding (within one to two weeks). Although budding can be preformed on potted rootstock, it is more typically preformed on *2-year-old rootstock* which has been planted in **field** rows. The base of the rootstock may be hilled up with soil to keep the bark moist and tender. This soil is removed just before budding using a rotating brush mounted on a tractor.

The budder and the tyer work in pairs. The budder makes the appropriate cuts and inserts the bud. The tyer ties the bud using grafting tape, rubber strips, or a budding patch. Grafting wax is not necessary. The bud will heal during the fall and expand or `break` the following spring. (`Break`= begin active growth.) Just before bud break, the rootstock shoot is removed.

T-budding

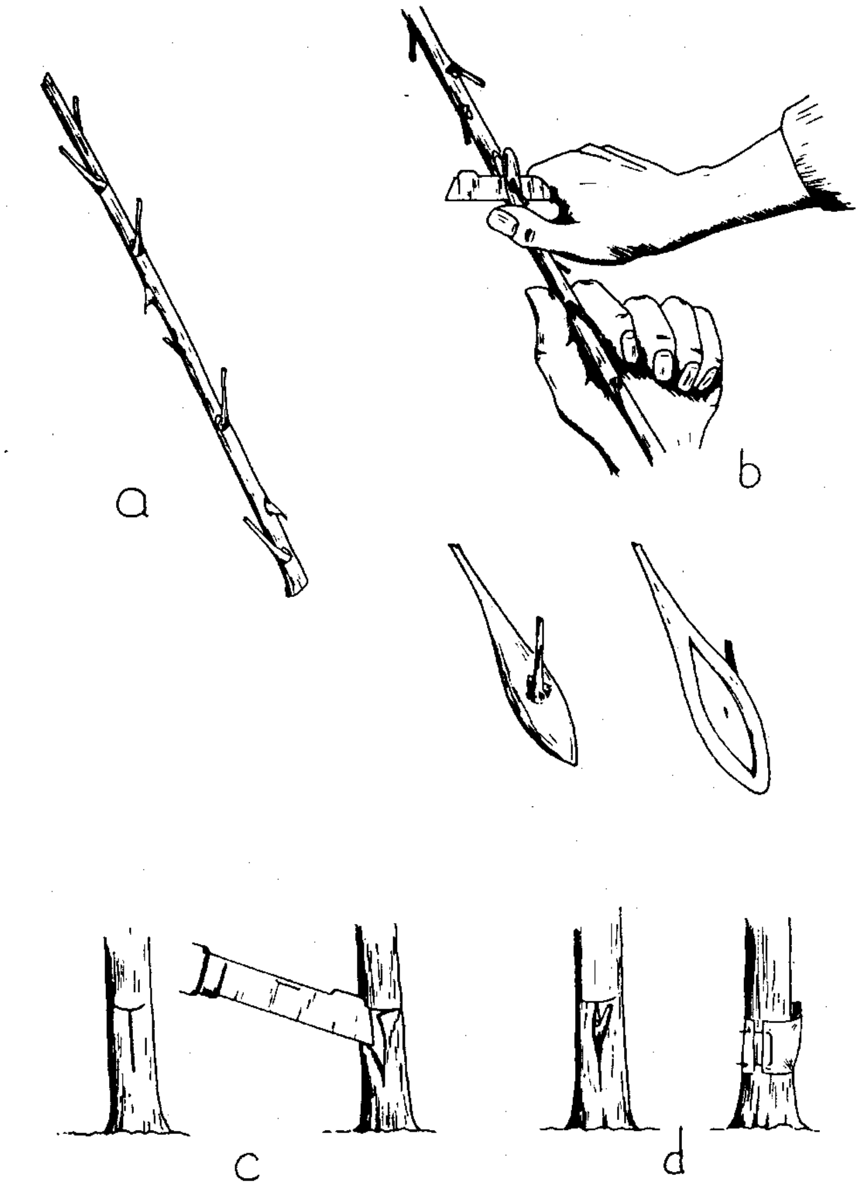


Figure 7.1: **Rose budding**: (a) A bud stick of the cultivar to be budded. Note that the petioles have been left on and that there are plump buds in the axils. (b) Removing a bud on a shield-shaped piece of bark. The thin sliver of wood behind the bud should be carefully removed to expose the back of the bud as in the right-hand drawing. (c) A T-shaped cut being made in the bark of the rootstock. Lift the bark on either side. (d) The bud is slipped down under the bark of the rootstock and is held in place with a rubber **tie**.

Chip budding

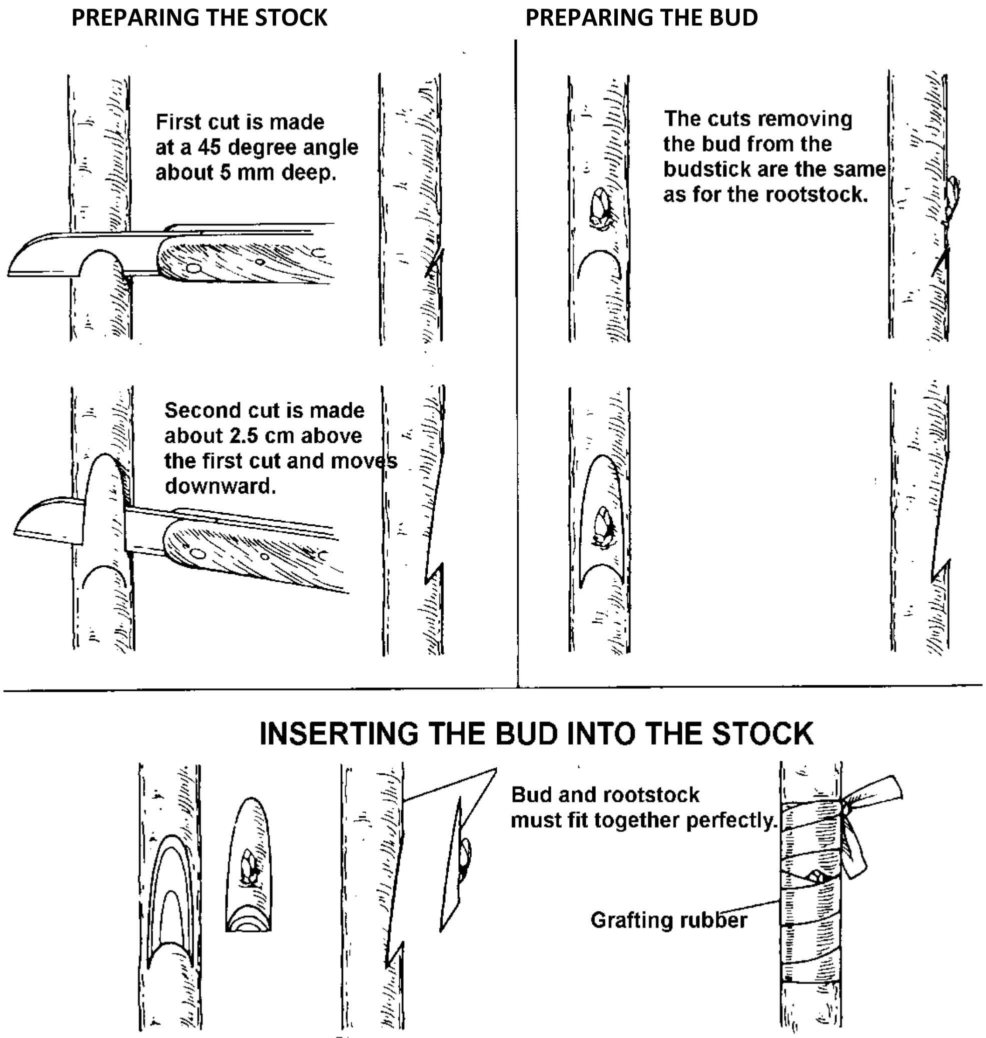


Figure 7.2: Chip budding is widely used in propagating woody ornamentals and fruit trees. The bud piece is cut as shown here and covered completely with poly tape.

Chip budding can also be preformed in spring. Field grown root stock or potted root stock can be used. Bud sticks are collected from dormant wood in the late winter and are stored, wrapped in plastic, in a cold room at 2° C. The chip bud is wrapped with plastic tape. The bud is covered to preserve moisture until the cambiums heal together. The tape is cut off up to 40 days after budding.

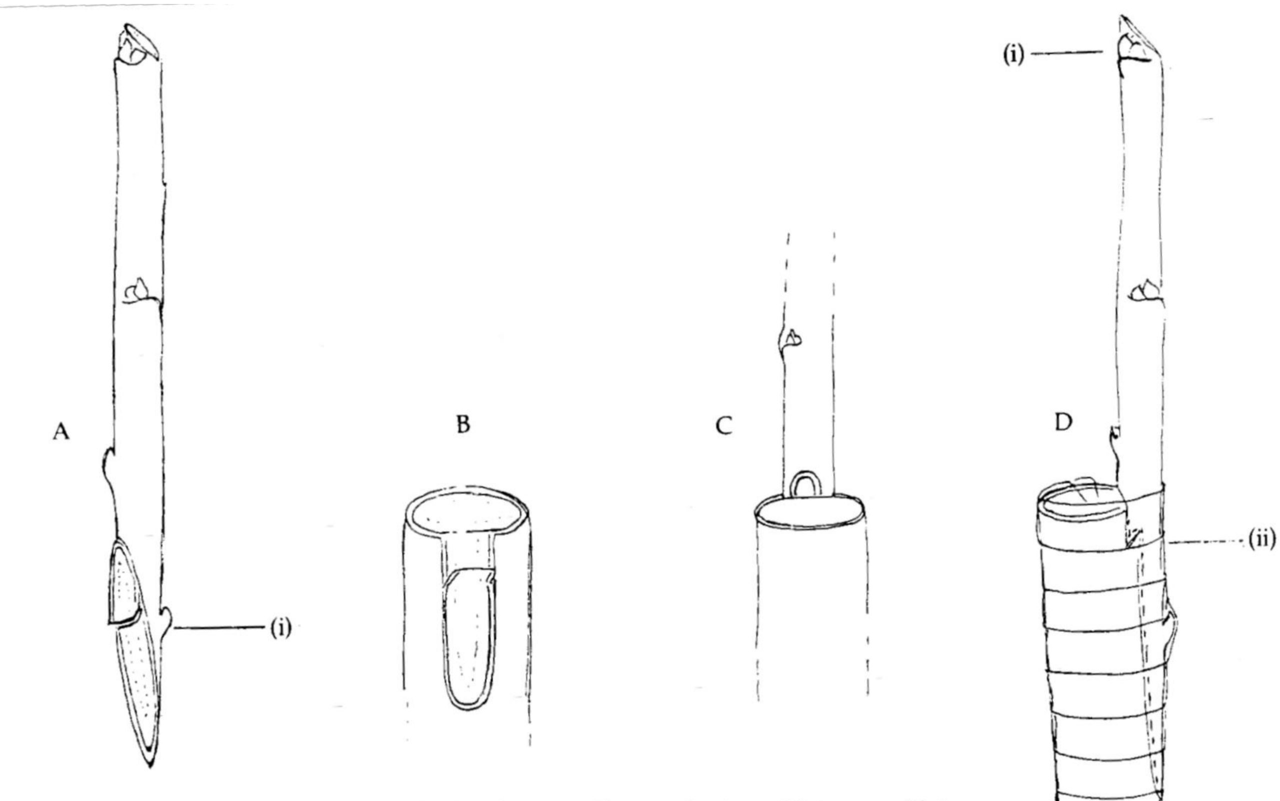
Field grafting

Field grafting is often done on rootstock that has grown 3 to 4 years to produce a substantial root system and a straight stem. The graft is inserted at the top of the stem at a specified height 60 to 120 cm) above the ground. The resulting tree from is called a “standard”. The scion may weep or have a unique shape. The foliage or flowers may be of a desirable cultivar.

Often a **whip and tongue graft** is used for this purpose: The rootstock shoot is completely severed at the specified height and the scion is grafted on. This graft is very strong and will withstand wind and birds landing on the top of the plant.

The graft union must be completely covered with grafting wax, as well as the cut tips of the scion, to prevent drying. Sometimes small plastic bags are used to cover the scion and graft union for the first few days while the cambiums “knit” together. The diagram below illustrates the method used when grafting a scion onto a rootstock of larger diameter.

Figure 12.3: Whip and tongue graft



Whip and tongue graft of *Malus* cv. A. Prepared scion with tongue. Note the position of the “stock” bud at the base of the scion (i). B. Prepared rootstock with tongue. C. Scion and rootstock matched to leave a small “church window”, 3–5 mm (1/8–1/5″) in length,of exposed scion tissue. D. The completed graft following tying-in. Note (i) the position of the terminal scion bud in relation to the apex of the rootstock; (ii) the interlocking of scion and rootstock; and (iii) that the tie is continued below the base of the scion to ensure a good seal. (The exposed cut surfaces of the scion and rootstock apex both will require waxing.)

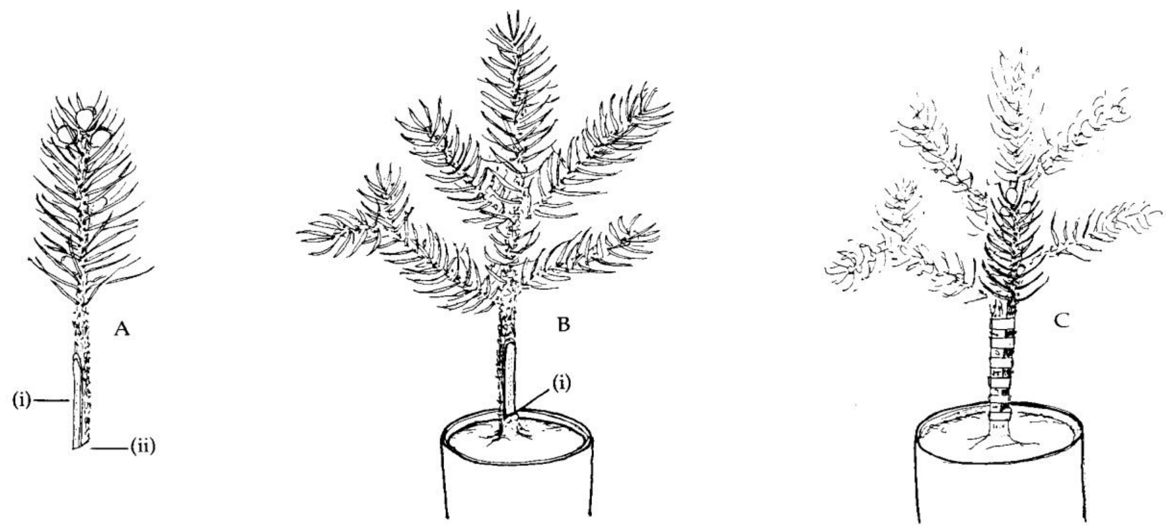
Bench grafting

Bench grafting is performed on rootstock that has been grown for **one year**, and then transplanted into a grafting pot. The rootstock is grown on for 4 to 12 months in this pot. The rootstock must be slightly dry, but active. In the winter, bring the rootstock into a warm greenhouse (15˚C) two to three weeks before grafting. The base (10 to 15 cm) of each stem is cleaned, which means that any foliage, buds and stems must be removed before grafting can be performed. Scion material, one year old wood, is gathered from stock plants and stored in plastic bags in a cooler until use.

Side veneer graft

This is the simplest bench graft and probably the most popular. The rootstock shoot is left on and the scion is fitted to the side of the stem. The base of the scion stem is cleaned of any foliage. A slice about 3 to 5 cm long is made with a short back slice at the base. The same cuts of similar size are made at the base of the rootstock. The scion is fitted onto the rootstock stem matching the **cambiums** as closely as possible. The graft is held together by using **grafting tape or a rubber strip**. The bottom of the graft should not be tied as the force of the tie can damage delicate stem tissue. The graft union can be covered with grafting wax, but more commonly, the grafted plants are placed under a **plastic tent** where humidity is kept high for about three weeks. The plastic is gradually removed as the union "knits". The rootstock shoot is removed about 6 weeks later. Some propagators will remove the rootstock in sections to keep the sap flowing to the scion.

Figure 12.4: Side veneer graft



Diagrammatic representation of side veneer graft of *Picea pungens* cv. (Colorado Spruce). A. Prepared scion. (i)—slightly angled cut, 2.5–3 cm (1–1¼") long; (ii)—reverse cut, 3 mm (⅛") long. B. Prepared rootstock. (i)—4 mm (1/6") cut at the base to form a veneer. C. Completed graft matched and tied-in.

Side wedge graft

The side wedge graft is similar to the side veneer graft. However, in the side wedge graft, the back of the scion is also sliced to match the sliver of bark that is sliced when preparing the rootstock. See below.

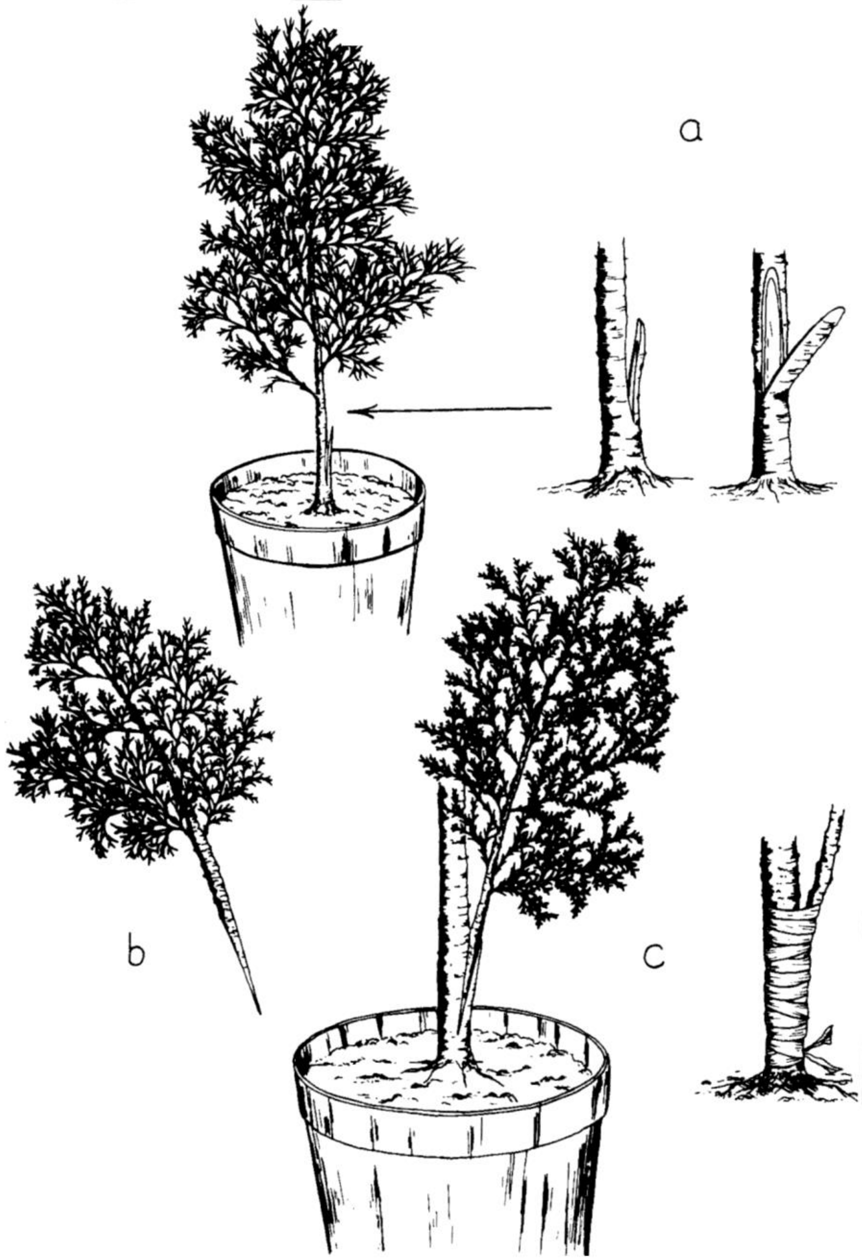


Figure 7.5 Side wedge graft

A) A sliver of bark is cut at the base of the rootstock, but **not removed**. B) The scion base is sliced on both sides, one side starts a little further down than the other. The scion cut ends are matched with the cut bark on the rootstock (the longer cut side faces toward the stem. C) The graft union is tied with plastic grafting tape or a rubber strip.

Apical Wedge Graft

This graft is used for deciduous standard forms. The height of the graft conforms with the height of the head of the standard. Side wedge grafts are used on two sides in increase the symmetry of the 'head'.

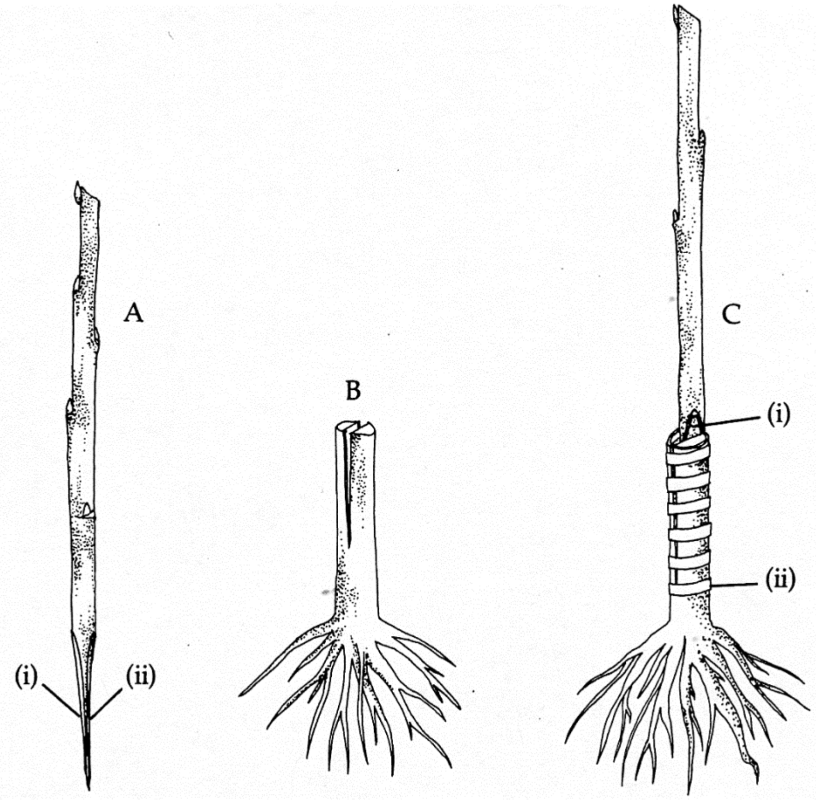


Diagram 19-4. Apical wedge graft of *Hibiscus syriacus* cvs. (Rose-of-Sharon). A. Prepared scion. (i) and (ii) are two opposing sloping cuts to make the wedge. B. Prepared rootstock. Note that the vertical cut is made well down into the hypocotyl (root "collar" or "neck"). C. The completed graft following matching and tying-in. (i)—"church window" of exposed scion tissue; (ii)—tying-in completed below the vertical cut on the scion.

Splice or whip grafting

A splice or whip graft can be used for tomatoes or other small stem diameter, easily grafted plants. A single slice at the same angle on both the root stock and the scion and a complete match in diameter are required for success.

Propagation by Division

Division involves physically separating a plant into sections, each with its own shoots and roots. This propagation method produces a mature plant in the shortest time, but only yields a few plants from each parent. It is normally used for herbaceous perennials and succulents, but can be used with some woody shrubs which produce clumps of shoots from underground suckers. Timing is important, and it is recommended to divide in the *fall or early spring* when the parent plant is not in active growth.

Most underground storage stems, i.e. bulbs and corms, produce '**offsets**' = 'daughter' bulbs which can be removed from the mother bulbs; so this is also considered a form of division.

In addition to propagation, division is also used to *rejuvenate* older plants by creating new, healthy, vigorous plants from older, 'tired' ones. This is recommended every 3-4 years for some perennials.

Site of division

Crown: The crown is the upper part of the root zone, at or just below the soil surface, from which shoots form. In most herbaceous perennials, division is through the crown.

Suckers: Suckers are shoots which form from underground roots, or adventitiously from stems of shrubs and some trees. They are often physically different from normal stems, detract from the aesthetic appeal of a woody plant, and can divert energy from more desirable stems, so are often removed by pruning. But they can be removed as a new plant. e.g. raspberry.

Rhizome: A rhizome is a type of swollen, horizontal, underground storage stem. Unlike bulbs, they do not produce *offsets*, but they branch and produce adventitious shoots and roots, so can be divided. (See chapter 10.) e.g. ferns, Iris, perennial grasses.

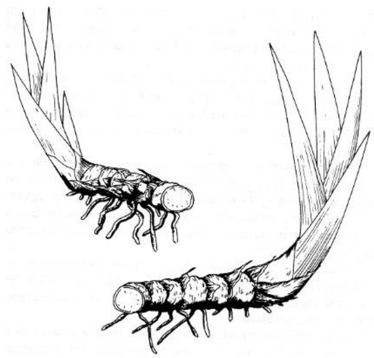
Stolons: Stolons are thin, horizontal above ground stems which produce adventitious shoots and roots at nodes.

'Runners' are stolons which grow ('run') along *above* the ground and root at the nodes. *Plantlets* which form along the stems can easily be removed and planted. This is also considered a form of *self-layering* (see 6.2 below). e.g. strawberry, Chlorophytum.

Offsets: Short shoots or whole new plants which form at the crown of the mother plant. e.g. bulbs, Hosta, some succulents.

Rhizomes

Rhizomes are underground, horizontal stems, which have nodes, internodes, axillary buds and adventitious roots. The end of the rhizome can terminate in a flower stalk (Iris). Rhizomes can be thick and fleshy, e.g. Iris, or slender, e.g. perennial grasses and some ferns. Rhizomatous plants are propagated by division. Individual sections are taken with at least one node (eye).



Examples of rhizomatous plants include bamboo, grasses, ferns, German iris, *Alstroemeria*, *Sansevieria* (snake plant), and some orchids.

Divisions of German or bearded Iris Each division consists of a portion of rhizome, some roots, and a fan of leaves.

Tubers

Tubers function like bulbs without basal plates or scales. They have nodes called **'eyes'** which form adventitious leaves and shoots. Examples of tuberous plants include *Cyclamen,* tuberous begonia, potato, *Dahlia* and some orchids.