been 353%. The price of plants has only risen 60% in the same period, so the propagator has to be more efficient, fully aware of the market trends, pricing, and consumer demands at all times.

To keep up with all the demands of the 21st Century, the modern propagator should travel, which is of course a great educator; be active members of all professional societies like the I.F.A., N.F.U., I.P.P.S, and Garden Centre Association; visit the opposition and be willing to learn from your mistakes and from others. The task at hand may be getting harder, but for the dedicated propagator, the world is your oyster.

Theory of Grafting©

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INTRODUCTION

This review of the theory of grafting will examine the main requirements for a successful graft. Whatever the degree of experience in grafting a propagator has it is necessary at times to go back to the basic principles to improve the success of a particular graft or successfully graft an unfamiliar species.

To carry out a graft both the scion and rootstock have to be cut and brought together so that they will form a single plant. The initial phase of this union is the adhesion of the scion and stock by the polymerisation and deposition of cell wall materials in response to wounding. All species traditionally grafted have been found to be strong “wall compartmentalizers” (Santamour, 1996), forming a necrotic layer of cells that prevents further decay. A callus bridge of parenchyma cells then extends into the necrotic layer from stock and scion, giving tensile strength to the graft. New vascular cambium then differentiates from the parenchyma cells and finally, secondary xylem and phloem are produced by the reconstituted cambium, providing the vascular connection between stock and scion (Moore, 1983).

Several factors are required to ensure a successful graft: compatibility—often dependent on the systematic relationship between graft partners; the correct physiological stage of rootstock and scion; quality of rootstock and scion material; freedom from disease, pests, and herbicide toxicity; the physical proximity of tissues; the grafters’ skill; and the correct environmental conditions to prevent temperature stress, oxygen deprivation, and dehydration (Andrews and Marquez, 1993). The key factors will be discussed individually below.

COMPATIBILITY

Selecting compatible stock and scion is one of the most important requirements for a successful graft. Graft incompatibilty has been fully reviewed by Andrews and Marquez (1993). Incompatibility may be either localised, where the inclusion of an interstock that is compatible with both stock and scion will overcome the incompatibility problem; or translocated, where toxins still prevent successful graft union even if a compatible interstock is used (Mosse, 1962) (see list of indicators below).

Immediate graft failure is less serious than delayed incompatibility leading, for example, to reduced yields in fruit orchards or premature death of landscape plants.

Indicators of Incompatibility Type.

Localised Incompatibility.

- Necrosis of cambial initials and discontinuity of vascular tissues, usually with breakage at the graft union.
- Reciprocal combinations show similar incompatibility responses.
- The root system is gradually starved, with slow development of external symptoms proportional in severity to the degree of vascular discontinuity at the union.

Translocated Incompatibility.

- Normal vascular continuity at the union, although there may be scion overgrowth resulting in compressed bark tissues.
- Accumulation of starch in the scion and its almost complete absence below the graft union.
- Phloem degeneration, the major indicator
- Differential behaviour of reciprocal grafts
- Effects are observed during early stages of growth
- Grafts rarely die from blockage at the union.

Normally, the more closely related stock and scion are, the less likely it is that incompatibility will occur. Interspecific grafts may be used, for example, *Sorbus aria* cultivars are often grafted on to *S. intermedia* to give a stronger, faster-growing tree. A few intergeneric grafts are also important: many pear cultivars (*Pyrus communis*) have long been grafted on to quince (*Cydonia oblonga*). In the majority of grafts, however, the stock and scion are cultivars of the same species. Even here incompatibility may occur, for example, in *Quercus rubra, Acer rubrum,* and *Castanea mollissima* (Santamour, 1996). This is due to differences in peroxidases that mediate the production of lignins. If the same type of lignin is not produced in the stock and scion then incompatibility will occur (Santamour, 1992). Methods of predicting incompatibility are being developed using isozyme separation, protein analysis, or in vitro techniques which may be of practical value to the propagator in the near future (Andrews and Marquez, 1993). At present there are many sources of information on stock and scion combinations or reviews about incompatibility, for example Andrew and Marquez (1993); Nelson (1968); and Macdonald (1986).

TIMING

In general, grafting is carried out when the scion buds are dormant but there is at least some active growth in the rootstock. The timing may depend on:

The Species or the Facilities Available. *Acer palmatum* can be grafted over a long period—without heat between March and September or in winter months using heat. Other species have a smaller grafting window, for example, J.F. Schmidt's nursery in Oregon has found only late January and late March successful for grafting *Fagus sylvatica* (Meacham, 1995).

Type of Graft Being Used. T-budding of roses or other species needs to be carried out in the summer, once the bark can be easily lifted without tearing.

Production System. Apples, for example, are usually budded onto field-grown stock in the summer to produce new planting material for orchards. Some nurseries may splice graft apples on to pot-grown stock in winter to grow on in containers for garden centres.

Location. The time of making a graft and even the type of graft used will vary depending on geographical location.

When attempting to propagate unfamiliar taxa grafts should be tried at several times of the year to find the most successful time. As well as initial take, establishment should also be recorded. A plant may graft well in late summer or autumn but may not overwinter well, making spring the best time in fact to graft (Meacham, 1995).

Timing may also be affected by the weather. Grafting records kept in Australia attributed more than 99% of major losses to wet weather during budding or grafting. The theory is that fully turgid tissue which has been collected during wet conditions is liable to being bruised to a depth of 5 to 10 cell layers into the cambium when cut and this prevents compartmentalisation and growth of healthy callus tissue while encouraging bacterial soft rots to develop. To avoid this problem it is recommended that scion material is collected mid-morning or afternoon, or 24 h after the last rain, and that you never graft onto wet rootstocks (Young, 1992). On the other hand studies on variability of take over several years on *A. platanoides* 'Crimson King' showed no correlation between bud take and whether it had been a wet or dry growing season (Howard, 1993).

QUALITY

Stock and scion must be true-to-type and free from disease. For most fruit crops, certified stock is available to ensure propagation material is of a high health status and this must always be used. For ornamental species, where certified stock is not widely available, propagation material should be grown on designated stock plants or bought in from a reputable supplier. Rootstock diameter should be "pencil thick", about 6 to 10 mm, and have a strong, healthy root system. *Acer platanoides* 'Crimson King' has been studied because of its difficulty and variability to graft. The diameter of the stock is important with a first-season small-diameter stem giving an average take of 76% compared with 26% take on a 2nd-year very-large-diameter stem (Howard 1993). Howard and Oakley (1997) also showed that the growth of larger structured roots improved the graft take significantly. In all types of grafting the quality of roots is very important. In bench grafting the roots need to be active at the time of grafting. Bush (1995) likes to see 6.5 mm of fresh white root prior to grafting.

ALIGNING STOCK AND SCION

The callus bridge connecting the graft partners differentiates primarily from cortex and pith tissues. Tissues such as the pericycle and cambium are involved to a lesser extent. These observations disprove the concept that the vascular cambium was the only source of callus for bridging. It is now accepted that anatomical similarities between graft partners and the presence of cambia or its direct contact are not essential for the formation of a successful graft. It is still recommended, however, that the cambia of stock and scion be well aligned, so that new vascular elements are formed longitudinally, providing greater mechanical strength (Kollmann et al., 1985). The value of aligning the cambia of stock and scion was illustrated by work on budding carried out by Howard et al. (1974). Chip budding gave higher percentage takes than T-budding in fruit and ornamental trees. This was attributed to the closer contact of the cambia by replacing a section of stock with the chip-bud rather than adding extra bud material to the stock in T-budding. It was also noted that the subsequent maiden and lateral growth was also superior with chip budding, as was frost resistance of the maiden plant.

THE GRAFTERS SKILL

The skill of the propagator is an important element in ensuring that the cuts of the stock and scion align. Practical tips on how to correct faults in your technique are useful. For example, the IPPS GB&I Region's grafting workshops are valuable for the new grafter and also as a refresher course for those more experienced. Papers published in *Combined Proceedings International Plant Propagators' Society* also help. The author has found the tips from McPhee (1992) of particular value when teaching grafting to students.

BAD HABITS IN GRAFTING.

Scooping. Caused by forward wrist movement, usually associated with a tightening of the grip

Tails. Caused by movement in the non-cutting hand (when the cut is made towards the body) or elbows move backwards or downwards or straighten instead of moving straight out and up (when the cut is made horizontal with the chest). This problem can also be a result of forcing the knife through rather than allowing it to slice along the full blade length.

Twisted Cuts. These result from a rotation of the arm usually at the wrist.

MAINTENANCE OF THE CORRECT ENVIRONMENT

Tying. The tie needs to be tight enough to keep the cuts together without moving while the new vascular cambium is produced. It may also maintain the moisture around the cuts which enables the callus to differentiate into the new vascular system. The type of tie used depends on the species and graft being undertaken as well as the personal preference of the propagator. Studies on *A. platanoides* 'Crimson King', for example, gave a 38% bud take using polyethylene ties compared to 17% take using self-degrading rubber ties, because of the premature degradation of the latter (Howard, 1993). Meacham (1995) prefers rubber ties for conifers to allow bleeding.

The author has used “Buddy-tape”, a parafilm tape, with success. It is easy to tie, has kept the graft secure but has proved a little difficult to remove.

If rubber ties are used then the graft can be sealed by wax. Paraffin wax has been effective in the wax dip method developed at Kinsealy Research Station in the Republic of Ireland (Lamb and Nutty, 1981). Problems can arise with cell damage resulting from the relatively high melting temperature of paraffin wax.

Temperature. The production of callus is temperature dependent. In apple, little callus occurs below 0°C or above 40°C, with temperatures above 32°C causing callus production to be retarded and cell injury becoming apparent as the temperature increases. In grape vines, a temperature of 24 to 27°C is optimum. Temperatures above 29°C result in profuse formation of a soft type of callus tissue that is easily injured at planting but at 20°C formation is slow and below 15°C it almost ceases.

With bench grafting, callusing will proceed slowly for several months at 7 to 10°C or rapidly at a higher temperature for a shorter time (Hartmann et al., 1997). Bench grafting deciduous material such as apple requires cooler temperatures to be maintained to avoid early bud break in the scion. An alternative to this is the increasingly popular hot pipe callusing in which the union is kept warm but the roots and scion buds are kept cool, at around 7°C. Optimum temperatures at the graft union will vary with species, for example *Corylus* gives best results at 18°C while *Aesculus* is best at 27°C (Dunn, 1995).

Moisture. The callus tissue produced at the initial stage of grafting needs to be protected from desiccation. Inhibition of callus production has been found to occur when air moisture levels are below saturation point and successful healing is reduced (Hartmann et al., 1997). Moisture can be maintained by tying with polyethylene or parafilm which seals the cuts; or with sealing ties of rubber or raffia with wax, placing in a closed polythene case that is maintained at a high humidity or covering the tied graft with moist material such as peat.

CONCLUSION

Practical skill and a sound knowledge of the theory of grafting help the propagator achieve a consistently high success rate. In addition accurate record keeping will ensure that the detailed requirements for the successful propagation of each plant will be developed from the theory. Our understanding of how to graft plants is still developing and significant improvements can still be made. One area of research that offers much to the propagator is the potential to predict incompatibility. Research to understand the theory of grafting, however, will be only be valuable if the experience of putting theory into practice continues to be shared by propagators.

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The Science of Hybridisation©

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INTRODUCTION

The future of all sectors of commercial horticulture is in part dependent on the production of new cultivars of plants that possess improved characteristics, such as growth habit; attributes of flowers, fruit, and foliage; and resistance to pests and diseases. The genetic improvement of plants by selection has been practised for centuries, going back to the beginnings of agriculture, and is still used today, for example in tree breeding programmes. In contrast, it is only in much more recent times that the potential of artificial hybridisation has been realised and used to improve specific traits of plants. In the late 1700s, crosses were made between many species of *Nicotiana* and to produce new fruit varieties. At this time, from studies on peas, it was concluded that male and female parents contribute equally to offspring in the first filial generation (F1) and that segregation occurs in the F2. Later, in 1866, Gregor Mendel, in crossing different varieties of peas and studying their progenies, established Laws of Inheritance based on individual heritable characters. However the importance of his work was not recognised until 35 years later, after which, in the early 1900s, rapid developments in plant breeding took place. Mendel determined that plant characters were inherited as pieces of information from each of the parents. We now know that these parts are genes, sequences of the deoxyribose nucleic acid (DNA) which makes up the chromosomes present in the nucleus of plant cells.

CHROMOSOMES AND HYBRIDISATION

In hybridising plants, either naturally or through man's activities, discrete units of very large molecules of DNA contained within the chromosomes in the nucleus of cells are passed to the next generation. Most of the genetic information in plant cells is contained within the nucleus. However, small amounts are also present in the mitochondria and chloroplasts. The number of chromosomes varies with plant species and each chromosome is comprised of a series of units (sequence of nucleotides), termed genes, that usually code for a single characteristic. Many