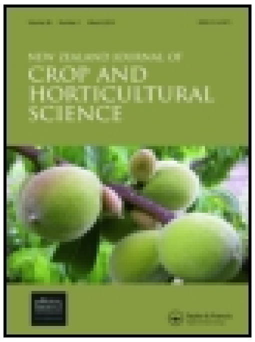

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New Zealand Journal of Crop and Horticultural Science

ISSN: 0114-0671 (Print) 1175-8783 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzc20

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To cite this article: A. D. Webster (1995) Temperate fruit tree rootstock propagation, New Zealand Journal of Crop and Horticultural Science, 23:4, 355-372, DOI: 10.1080/01140671.1995.9513912

To link to this article: https://doi.org/10.1080/01140671.1995.9513912

Published online: 22 Mar 2010.

New Zealand Journal of Crop and Horticultural Science, 1995, Vol. 23: 355–372
0114–0671/95/2304–0355 $2.50/0

Review

Temperate fruit tree rootstock propagation

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Abstract The reasons for temperate fruit tree rootstock development are briefly outlined and the principal methods of rootstock propagation described. Although ease-of-propagation was once the principal criterion when selecting clonal rootstocks, other rootstock attributes, such as resistance to pests, diseases, and unfavourable climatic conditions or ability to dwarf the scion, have now become of greater priority. New and improved methods of propagation have aided this shift in priorities by enabling propagation of recalcitrant clones. Nevertheless, new methods of propagation which bring about partial rejuvenation of the rootstock also have disadvantages. Micropropagated rootstocks frequently sucker profusely and may also show increased burrknotting.

Keywords rootstocks; interstocks; apple; *Malus domestica* Borkh.; pear; *Pyrus communis* L.; plum; *Prunus domestica* L.; sweet cherry; *Prunus avium* L.; propagation; micropropagation; layering; stooling; cuttings; budding; grafting; feathering

HISTORY OF ROOTSTOCK PROPAGATION

Rootstocks have been used for propagating fruit trees for more than 2000 years; ancient manuscripts record their use as far back as the Hellenistic period in Greek history (300–30 BC). For approximately the first two millenia since their first use the sole reason for rootstocks was as a means of propagating the scion. Most temperate tree fruit species are self-sterile and heterozygous and most scion cultivars do not come true-to-type if propagated using their own seeds. Consequently, when a tree raised from seed showed particularly desirable characteristics the only way of increasing it in number was by asexual (vegetative or clonal) propagation. Traditionally, cultivars of most tree fruit species propagate poorly on their own roots, irrespective of whether layering or cutting techniques are used. Although propagation research over the last 15 years has alleviated some of the problems associated with multiplying scions on their own roots (Jones et al. 1985), poor cropping performance, suckering, and burrknotting continue to prove problems with self-rooted trees (Webster et al. 1985).

Early horticulturalists realised that the most obvious solution to the problem of propagating recalcitrant scions was to propagate them by budding or grafting onto more easily-propagated rootstocks.

Initially, all rootstocks were raised from seed. Fruits were collected from indigenous populations of native fruit species, the seeds extracted, germinated, and grown on for use as rootstocks. Suitable wild populations of apple (*Malus domestica* Borkh.), pear (*Pyrus communis* L.), plum (*Prunus domestica* L.), sweet cherry (*Prunus avium* L.), and sour cherry (*Prunus cerasus* L.) were abundant in many parts of Europe.

Early propagators of fruit trees would have noted that graft compatibility, growth and cropping of scions raised on seedling rootstocks were often extremely variable. Trees on a few of the seedling rootstocks would have been smaller in stature or shown other differences in habit, flowering and/or fruiting. At an early stage the potential benefits of some of these rootstock effects on scion growth would have been recognised and the first clonal rootstocks selected and propagated. Quite when this began is uncertain, although records suggest

H95023
Received 3 April 1995; accepted 24 July 1995

that clonal rootstocks were in use as early as the 17th Century.

To be of any value to the early fruit tree propagator the selected clonal rootstocks must themselves have been easy to propagate. Many would have been dug up as suckers from around fruiting orchard trees; later, techniques of layering or stooling were employed for their propagation. For many years only those clones which could be propagated easily from layering/stooling techniques were selected as clonal rootstocks. It is only relatively recently that attributes other than ease of propagation have become important considerations in clonal rootstock selection.

Nowadays, with much greater emphasis being put on rootstock attributes, such as their ability to dwarf scions and their resistance to soil-borne pests and diseases, some rootstock clones have been selected which are quite difficult to propagate. This has necessitated changes and improvements in traditional rootstock propagation techniques. Some of the problems experienced with rootstock propagation and the measures adopted to overcome these are briefly reviewed in this paper.

METHODS OF ROOTSTOCK PROPAGATION

The principal methods employed for rootstock propagation are shown in Table 1. Throughout the world most rootstocks are raised from seed, although an increasing number of clonal rootstocks are now used for the propagation of apple, pear, and sweet cherry cultivars. Most clonal apple and sweet cherry rootstocks are propagated by division techniques (stooling or layering); relatively small numbers are raised by cutting techniques, including micro-propagation and root cuttings. Where a rootstock clone has particularly desirable qualities but proves difficult to root, it may occasionally be used as an interstock, grafted between the scion and some more easily-propagated rootstock clone.

Table 1 Methods of rootstock propagation.

Seed	sexual apomictic
Division	stooling layering marcotting
Cuttings	softwood root semi-hardwood micropropagation hardwood

Propagation by seed

The great majority of rootstocks for many temperate and subtropical fruit and nut species, including peaches, nectarines (*Prunus persica* L.), apricots (*P. armeniaca* L.), asian pears (*Pyrus pyrifolia* (Nakai)), and citrus species are raised by seed. Propagation by seed has significant advantages for the nurseryman; in particular, it is both simpler and cheaper to achieve than propagation by vegetative methods. Whether trees propagated on seedling rootstocks have any advantages to the fruit grower, however, is much less clear and in many instances trees on seedling rootstocks are greatly inferior to those on clonal rootstocks.

In species such as apple, where viruses are thought not to be transmitted through seed and where nurseries in some parts of the world find it difficult to maintain the health status of virus-free clonal rootstocks, seedling rootstocks may have clear benefits. Seedling propagation also offers the potential for avoiding transmission of root-borne diseases such as crown gall (*Agrobacterium tumefaciens*). Rootstock liners from infected stool or layer beds frequently transfer this troublesome disease to the new scion tree and the new site. Seedling stocks raised on soils free of crown gall avoid this problem.

Unless clonal rootstocks have been selected which confer other benefits to the scion, such as reducing vigour of growth, inducing early and abundant cropping, or conferring resistance to soil-borne pests and/or diseases, then there are less benefits gained by changing from seedling to clonal rootstocks. Nevertheless, seedlings of many heterozygous, out-crossing fruit species are extremely variable in performance when used as rootstocks and one clear benefit of changing to a clonal rootstock is the improved uniformity of growth and cropping in the scion. It is unfortunate that the change from seedling to clonal rootstocks is invariably resisted by nurserymen for both economic and logistic reasons.

The uniformity of performance of seedling rootstocks may, however, be improved to some extent by: (1) using seed of a single clonal variety (e.g., 'Red Delicious' apple or 'Bartlett' pear) or seed from a self-fertile cultivar grown in a monoculture; (2) using seed collected from virus-free mother orchards planted in isolation (e.g., Pontavium and Pontaris *Prunus avium* lines of

Mazzard rootstocks available in France); and (3) using seed of apomictic rootstock selections.

Apomictic seedlings, with their intrinsic uniformity, are quite widely used in citrus tree propagation. Some success was also achieved in selecting apomictic types of *Malus* rootstock for apple (Sax 1949; Luckwill & Campbell 1954; Schmidt 1982) but these lines proved unpopular with both nurserymen and fruit growers. One problem was that the apple apomicts were of the facultative type, producing zygotic as well as apomictic seeds in their fruits. Culling these out at the nursery stage proved difficult. Other reasons for their poor acceptance were their strong vigour when used as rootstocks, incompatibility with some scions and sensitivity to virus infection.

In comparison with vegetative propagation relatively little research is now conducted into the techniques of seedling rootstock propagation for temperate fruits. The techniques of after-ripening and dormancy-breaking, essential with seed of many Rosaceae, are now well elucidated. Aids to dormancy-breaking, such as scarification, and stratification are widely adopted by commercial nurserymen.

Treatment with hormones, which may also aid dormancy breaking are less frequently adopted, however. Treatment with gibberellic acid (GA_3) and benzyl adenine (BA), (both at 20 mg/litre), of peach seeds which had previously been stratified at 10 and 15°C enhanced germination, whereas treatment with thiourea was ineffective in Thai trials (Siyapananont 1990). Similar results were recorded by Shatat & Sawwan (1985) who demonstrated that germination of *Prunus mahaleb* seed was improved significantly by treatment with Promalin (a mixture of GA_{4+7} and BA) at 3000 mg/litre.

Research in Poland on germination of plum rootstock seeds (Grzyb & Czynczyk 1990) showed that soaking seed in a solution of 500 ppm ethephon just before sowing improved germination. This work also demonstrated that autumn sowing of partially stratified seeds produced better results than spring sowing of fully stratified seeds.

Little recent work has focused on the biochemistry of dormancy in temperate fruit tree seeds although research by Kar & Bhartiya (1987) indicated that the quantities of ortho-diphenols present in apple seeds were associated with their depth of dormancy.

Many innovative changes in seedling rootstock propagation now focus on the development of improved machinery for undertaking the various operations associated with land preparation, seed sowing, seedling management, and lifting operations.

PROPAGATION BY DIVISION

Division techniques have the advantage compared with cutting techniques in that the propagule is not severed from the mother plant until rooting has occurred. Rooting and weaning of the propagule is, therefore, a less demanding operation than that needed for cuttings.

Stooling or layering

Stooling or layering, the division techniques used in tree rootstock propagation, were ably described many years ago (Knight et al. 1927) and little of significance has since changed in how these techniques are executed (MAFF 1969). They involve inducing part of the rootstock stem to produce adventitious roots while still attached to the mother plant. Rooting is usually stimulated by excluding light from the targeted section of stem, either by blanching or etiolation; this is achieved using soil, another medium (sawdust/peat), or covering with an opaque material such as plastic. Also necessary are adequate temperatures coupled with sufficient moisture and oxygen at the edaphic zone immediately peripheral to the targeted rooting zone. Problems with stooling and layering are usually attributable to the above requirements not being properly met. Poor natural soil conditions or the use of inappropriate media for earthing-up stool or layer beds are a common reason for poor stool or layer bed performance. Sawdusts are often used for earthing-up stool/layer beds in many parts of the world and care should be taken that the wood species used contain no chemicals, natural or introduced, likely to be inhibitory to stool shoot rooting. Some nurserymen in Britain have incorporated a layer of moist peat close to the base of the shoots to encourage stool shoot rooting. Delays in earthing-up and insufficient moisture are other common problems which frequently lead to poor rooting.

Another occasional problem with stooling concerns the high proportion of sub-standard shoots produced by some apple rootstock clones on mature stoolbeds. One solution to this problem, suggested by Vasek & Howard (1984), is to harvest the layers biennially rather than annually.

Plant growth regulators have been little used as an aid to stool or layer bed propagation. However, Polish trials (Grzyb & Radwan-Pytlewski 1990) did indicate that sprays of ethephon at low concentrations (300 mg/litre) in mid June increased the number of rooted shoots on stool beds of M.26 apple rootstock. In contrast, further research in Poland (Grzyb et al. 1990) showed no benefit of sprays of the growth retardant Cyclocel to stool or layer beds of the dwarfing apple rootstock clone P.2.

Stool and layer beds are also subject to attack from numerous soil-borne pests and diseases. Many nematode species severely limit production, as do attacks by bacterial (e.g., *Agrobacterium* spp.) and fungal (e.g., *Thielaviopsis, Phytophthora* spp.) diseases.

In Canadian trials (Quamme & Brownlee 1990) more than 30 different apple clonal rootstocks were compared for rooting on the stoolbed in the period 3, 4, and 5 years after planting. The mean number of rooted shoots produced per m of stooled row increased from the third to the fourth year and then levelled off with little variation thereafter between years. The apple rootstocks V5–38, MM.111, M.26, Budagovsky 118, MM.106, Morden 56–4, M.4, B.490, B.491, M.27, B.54–233, Alnarp 2, M.7, Jork 9, Robusta 5, P.18, P.16, Mark, and B.54–146 all produced either similar or significantly greater numbers of rooted shoots in comparison with M.9, whereas P.22, B.9, P.2, P.1, Ottawa 3, and M.20 produced significantly fewer. Antonovka and M.25 produced very few rooted shoots (0.2–0.3/m). The most productive rootstocks tended to produce the highest number of shoots/m and the amount of root formation was greatest on shoots of the most productive rootstocks.

Marcotting

Marcotting has occasionally been used as an aid to propagating difficult-to-layer fruit tree rootstocks. This relies on the same principal as that used for aerial layering, where the stem is partially or wholly girdled to encourage formation of adventitious roots at or immediately above the girdle. Stretching strong, small-gauge wire mesh over the stool or layer bed before the first earthing-up in the spring can sometimes aid root formation. As the shoots grow through the mesh and begin to thicken the wire cuts into their bases, causing a constriction which can aid root development.

The benefits of a form of marcotting in combination with auxin treatment have been shown in India when stooling F.12/1 sweet cherry rootstocks (Pandey et al. 1983). In May the stool shoots were girdled and treated with indolebutyric acid (IBA) at 2500–10 000 ppm. The treated shoots were earthed-up and later assessed for rooting. Rooting was 20% in the control and 62.5, 75.0, 100.0, and 62.5% in shoots treated with IBA at 2500, 5000, 7500, or 10 000 ppm, respectively.

PROPAGATION BY CUTTINGS

Most new research on rootstock propagation in recent years has focused on improving the success achieved with conventional cutting techniques and developing the allied technique of micropropagation. Usually, cutting techniques have been developed to aid the propagation of recalcitrant rootstock clones or to circumvent disease, soil or site problems experienced with the more conventional division techniques.

There are two main types of cutting employed in rootstock propagation, softwood (summer) and hardwood (winter) cuttings. Recently, micropropagation, another cutting technique, has been increasingly used for propagation of recalcitrant subjects and for rapid multiplication of rootstocks which are in short supply. A less frequently used technique is that of semi-hardwood (greenwood) cuttings which is sometimes employed for propagation of *Prunus* rootstocks. Finally, root cuttings are also occasionally employed for rootstock propagation.

In Britain, much research work has focused on developing successful hardwood cutting techniques for apple, plum, and quince (*Cydonia oblonga* Mill.) rootstock clones. Elsewhere, methods of softwood cutting propagation, usually based on intermittent misting techniques, have been developed for many *Prunus* rootstock clones. Recently, fogging systems have been shown to give better results than misting techniques with softwood cuttings of some species. Many research studies in the last few years have focused on the micropropagation of fruit tree rootstocks.

For successful propagation using any type of cutting there are three principal considerations. First, the propagule must be healthy and in the appropriate physiological condition; this is achieved by good stockplant management before cutting excision. Second, the cutting may need physical or chemical treatment to aid its rooting and, finally, the cutting must be placed in an environment conducive to survival, root induction, and/or root development.

Softwood cuttings

These are usually taken from the stockplant either in late spring or early summer when shoot growth is at its most active or in mid summer when the cuttings are beginning to lignify slightly. Only experience with each subject can determine the appropriate timing.

Stockplant management before harvesting the cutting

Cuttings of most rootstock types root best if collected from healthy stockplants which are grown on fertile soils and provided with adequate water and balanced nutrition.

Hard pruning of stockplants is recognised as an effective method of improving the rooting success of many plant species (Hartmann & Kester 1983). One contributory reason why stoolbed shoots root more easily than those from nursery hedges is thought to be the more severe annual pruning associated with the former. Research at East Malling, United Kingdom has shown that increasing the severity of hedge stockplant pruning also increases the propagation success with leafy cuttings of M.9 and MM.106 rootstocks (Howard et al. 1985). Improved rooting percentage and increased numbers of roots per cutting were responses to increasing severity of pruning.

Hartmann & Kester (1983) reported that adventitious rooting of cuttings could be improved by **etiolation** and/or **blanching** of the cutting base. The term etiolation is generally used when the whole plant is covered with black polythene or some other similar semi-opaque material for a short period in the spring; blanching is used when light is excluded from just a portion of the cutting stem. The technique of blanching cutting bases before detachment from the stockplant has been shown to aid the rooting of apple rootstocks MM.106, M.9, and MM.111 (Harrison-Murray & Howard 1982). Usually black adhesive tape bands (25 mm wide) are applied to the bases of new shoots on hedges or stoolbeds in late May or early June and the cuttings harvested c. 1 month later. With blanched shoots of the apple rootstock MM.106, the stem beneath the blanching tape develops preformed roots which are visible at the time of removal of the tape and excision of the cutting.

Sun & Bassuk (1991) demonstrated that blanching of apple rootstocks M.9 and MM.106 could be achieved using bands of Velcro tape. Application of the tapes, which were pretreated with an IBA powder, 10–20 days before taking the cuttings, significantly improved both the percentage rooting and the number of roots formed per cutting. It is suggested that the slight wounding caused by the Velcro material may have aided IBA uptake by the cutting stem. The treatments also stimulated bud-break on cuttings and the amount of shoot growth made in the first 4 months after planting; both of these supplementary effects were shown to be correlated with the number of roots formed per cutting.

Grzyb et al. (1989) demonstrated that covering hard-pruned hedges of apple rootstocks P.2, B.9, and P.22 in the spring with black polythene increased the rooting of cuttings compared with uncovered controls; IBA treatments had an additive effect to this response.

It has been suggested that the benefits of blanching are mainly attributable to light exclusion and increases in temperature beneath the tapes and not to other observed effects of the treatments, such as changes in the gaseous environment or increased humidity at the targeted stem zone (Howard et al. 1985).

Treatment of the excised cutting

Softwood cuttings should not be allowed to desiccate after collection, but moved to the propagation environment in shaded polythene bags containing a few drops of water. Most softwood cuttings of rootstocks root best if trimmed horizontally below a node and have several leaves above the base removed. Usually cuttings of 5–20 cm length are chosen. Although many rootstock varieties will root without further treatment it is usual to dip the bases of cuttings into powder or liquid formulations of IBA to aid rooting. Where fungal rots are an anticipated problem the cuttings may also be drenched in a suitable systemic fungicide before insertion in the rooting medium.

Propagation environment

Traditionally, softwood cuttings were propagated within an enclosed case on a glasshouse bench or within a frame. The necessary high humidities were established within the enclosed area and shading used, as necessary, to moderate excessively high temperatures. Bottom heat, a useful stimulant to rooting, was created by placing fermenting manure beneath the rooting medium. Unfortunately, the system was labour intensive requiring regular and careful monitoring if optimal aerial and soil moisture levels and temperatures were to be coupled with sufficient light exposure to support photosynthesis.

The closed case systems were superseded more than 30 years ago by intermittent misting systems. The leaves of the cuttings were kept moist by the application of fine water droplets; this had the effect of maintaining reasonably high humidities and also cooling the cuttings. Much research has focused on optimising misting treatments for rootstocks, in particular *Prunus* species.

More recently, fogging systems, where much finer water droplets are applied to the cuttings, have been compared with misting systems. For leafy cuttings dependent on photosynthetic assimilation during rooting, a propagation environment is required which minimises transpiration demand without excessive reduction of light intensity. Fogging systems may provide these conditions better than the more common intermittent misting systems. In comparisons, made by Harrison-Murray et al. (1988) M.9 and MM.111 apple rootstocks, rooted in greater numbers in fog than in mist. In more critical comparisons comparing fogging with polyethylene-enclosed mist at matched irradiance, the benefits of fogging compared with misting remained with some of the more difficult-to-root species.

Only 1% of water uptake by unrooted cuttings is via the cut stem; almost all loss and uptake of water is via leaves and stems. Evapotranspiration rate of cuttings is usually closely correlated with irradiance. However, the rate of water loss by the cutting and the associated cooling of the leaves and stem may be influenced by modifications to the vapour pressure gradient in the propagation environment. Lowering this vapour pressure gradient is one of the most effective methods of reducing water loss by cuttings. Often this is achieved by shading and most cuttings need only 25% of ambient light levels for adequate photosynthesis. Another alternative is to use evaporating surface water to cool the cuttings and create low vapour pressure gradients; this is the principal of misting. Finally, and often most effectively, wet fogging systems may be employed to lower vapour pressure gradients. Studies by Harrison-Murray & Thompson (1988) showed that net water loss from apple rootstock MM.111 cuttings was almost 50% lower in ventilated fog than in enclosed mist, probably as a result of more even wetting of the foliage in the wet fog.

Softwood cutting propagation of different rootstock clones

Softwood cutting techniques have generally proved most popular when propagating peach, apricot, plum, or cherry rootstock clones. Their use for apple and pear rootstocks has proved less popular. One example is their use for propagation of the new Belgian cherry rootstocks Inmil (GM.9), Damil (GM.61/1), and Camil (GM.79). These were successfully rooted under mist in a glasshouse (Trefois 1988a,b), although equally good results were obtained when the cuttings were rooted under a plastic cover, either on glasshouse benches or in the field. Acclimatisation of the rooted cuttings in the propagation medium, instead of the usual method of transferring the plants to containers, produced good quality plants and was cheaper, but had the disadvantage that bench/bed space was occupied by the same cuttings throughout the season. The best results were obtained when cuttings were taken in June and the latest recommended date for taking cuttings was mid August.

Although softwood cuttings have been less frequently used for apple rootstock propagation there are, nevertheless, reports of good success. Norwegian research has shown that it may be feasible to propagate apple rootstocks commercially from summer cuttings (Hansen 1990b). Rooted cuttings of the apple rootstocks MM.106 and M.26 were produced in one growing season by forcing stockplants in spring, obtaining cuttings (4–8 cm long) of newly-developed shoots, treating them with IBA-talc, rooting them under mist or fog, and then growing the rooted cuttings in an unheated greenhouse for the remaining part of the growing season. About 800 and 1400 cuttings/m^2 were obtained during April and May from 1- and 2-year-old stockplants, respectively. The rooting percentage and the number of roots per cutting were both high for those cuttings collected from the stockplants early in spring (c. 90% in MM.106 and c. 70% in M.26), but decreased in batches of cuttings harvested later. Treatment with 1.0% IBA-talc was more effective than no treatment or treatment with higher IBA concentrations. The greatest percentage of saleable rootstocks (of basal stem caliper > 6 mm) was obtained when the rooted cuttings were planted in May at 50–70 plants/m^2. About 65% of the MM.106 cuttings and 45% of the M.26 cuttings reached saleable size during the remaining part of the growing season.

In other Norwegian research (Hansen 1990a) softwood cuttings of a range of new apple rootstock clones gave better propagation success than when either hardwood or semi-hardwood techniques were used. MM.106, Budagovski 9, and the Czech clones J-TE-B, J-TE-F, J-TE-G, and J-TE-H had the highest rooting potential (80–90%); M.26, the Swedish stock Bemali, the Polish stocks P.1, P.2, P.22, and the Czech stocks J-TE-C and J-TE-E showed 50–70% rooting and only the German Jork 9 rooted poorly (21%).

Many quince rootstocks will also propagate quite easily from softwood cuttings taken under mist or fogging conditions. Clonal *Pyrus* are, however, rather more difficult although Howard (pers. comm.) has had good success propagating several of the French Brossier selections in trials at East Malling using fogging environments.

Hardwood cuttings

Many fruit tree rootstocks may be propagated from hardwood or winter cuttings. These are taken from stockplants in the dormant season, either after leaf-fall in the autumn or before budbreak in the spring. Cuttings taken in the mid winter period usually root and establish less successfully.

Stockplant management before cutting excision

As with softwood cuttings, it is essential that stockplants used for hardwood cuttings are healthy and grown in ideal environmental conditions. Cuttings are best produced from hard-pruned hedges grown with adequate irrigation and nutrition in sheltered nurseries established on fertile soils. Severity of hedge pruning has a highly positive effect upon rooting success with hardwood cuttings.

Size of cutting is known to have a significant effect upon success when propagating by hardwood cuttings. Early work showed that establishment of hardwood cuttings of the plum rootstock Pixy increased as cutting basal stem diameter increased up to 10 mm or greater (Howard 1980) but recent work has shown that given an ideal environment smaller cuttings root better than large ones (Howard & Ridout 1991b). Cuttings of ideal size can only be produced in quantity on well-managed nursery hedges.

Stockplant manipulation may occasionally be used to aid rooting of hardwood cuttings. Fachinello et al. (1988) have shown that in Brazilian conditions girdling shoots of MM.106 on stockplants, c. 15 weeks before their collection as cuttings, may enhance dry weight and also subsequent rooting. Campen et al. (1990) in trials at East Malling demonstrated that growing the apple rootstock MM.106 during the spring and summer within polythene tunnels enhanced rooting in comparison with cuttings taken from hedges grown outside in the nursery. Etiolation and blanching of stock hedges or shoots may also enhance propagation success with hardwood cuttings, as it does with softwood cuttings.

Treatment of the excised cutting

For success when propagating leafless, hardwood cuttings of rootstocks, they should have their bases dipped in solutions of IBA dissolved in ethanol or acetone (Howard 1968). The concentration of IBA used may have a great effect on the rooting success, as will the depth to which it is dipped, the duration of the dipping and the amount of solution taken up. The amount taken up is in turn influenced by the water loss by the cutting between collection and treatment. Howard et al. (1983) demonstrated that variable uptake of IBA from organic solvent was associated with liquid running over the epidermis and being absorbed through the cut base.

Where liquid formulations of IBA are not available, good results may also be achieved using powder formulations, which have a more localised effect than liquid treatments and may be particularly effective in inducing rooting via the stem epidermis (Howard 1985). When using powder formulations it is important to wet the cutting base, preferably with an organic solvent, to aid adhesion of the powder and uptake of the auxin. Consistent response to IBA, applied to apple cuttings at 2500 mg/litre and to plum cuttings at 5000 mg/litre (both in organic solvents), was obtained by regulating factors that influenced the amount of solution collecting at and being absorbed through the cut shoot base. These included dipping depth, dipping duration, and the suction developed at the cut base because of water lost between collection and treatment. For powder formulations the main variables were those factors determining the amount of powder adhering to the cutting base and epidermis, including pre-dipping in water or an organic solvent, and retaining the powder through careful handling.

Occasionally, other substances have been used in combination with auxins to aid rooting. Gur et al. (1988) showed that phloridzin and phloroglucinol acted synergistically with IBA to improve the rooting of hardwood cuttings of certain apple rootstock clones, but were ineffective or even harmful with others. Their findings demonstrated the role of high levels of both endogenous phloridzin and polyphenol oxidase in promoting the rooting process. Externally applied phloroglucinol improved rooting only in clones with sufficient polyphenol oxidase activity to promote its intense oxidation. Bassuk & Howard (1981) showed a positive correlation between endogenous root-inducing cofactor activity and seasonal rooting of M.26 apple hardwood cuttings.

Wounding the bases of winter cuttings is a well tried technique for enhancing rooting success. With the apple rootstock M.26 it was shown to increase both the numbers of cuttings rooting and also the numbers of roots per cutting when applied in combination with IBA treatment. A wounding technique which involved splitting the base of the cutting was of particular value with cuttings with intrinsically poor rooting potentials, such as non-basal, internodal cuttings (Howard et al. 1984). M.26 was, however, more responsive to wounding than either MM.106 or MM.111 (Howard & Blasco 1979). It is believed that the wounding response may be attributable to improved uptake of auxins (Majumder & Howard 1973).

Most of the factors affecting success with hardwood cuttings interact. Howard (1985) has suggested that auxin treatment allows expression of a latent rooting potential in cuttings inherent in the genotype or the physiological status of the shoot.

For subjects capable of some degree of rooting the response to applied auxin was increased by severely pruning the stockplant in the previous winter (including reducing the permanent framework), by preventing light reaching the stem during growth, by wounding the stem after cutting collection and by providing an environment conducive to cutting survival and maximum metabolic activity.

Propagation environment

Hardwood cuttings of many rootstocks, taken after leaf-fall in the autumn and inserted directly into the soil outside, frequently establish poorly. This poor establishment has been attributed to low nursery soil temperatures in autumn. Research conducted more than 30 years ago (Hatcher & Garner 1957) showed that the problem was alleviated by heating the bases of the cuttings to c. 7°C for 8–10 weeks following collection. Subsequent research indicated that even better rooting of hardwood cuttings was achieved if their bases were heated to higher temperatures for shorter periods (Howard 1968; Howard & Nahlawi 1969). Temperatures of 21°C were found to be most suitable for most rootstocks, whereas higher temperatures were required for successful rooting of apple scions (Webster et al. 1990). Although normally only the bases of cuttings are heated to stimulate rooting, heating of the whole cutting is equally beneficial and may in some instances stimulate even more rooting.

These days, root initiation on hardwood cuttings is generally stimulated by insertion into beds of compost (constructed over low or high voltage cables to provide basal heat) and later transferred outside to the nursery or to specially prepared raised beds where root development takes place.

During the critical pre-rooting stage water is absorbed from the rooting medium and lost to the atmosphere. Cuttings may experience net gains or losses in water content depending on the water available in the compost, the vapour pressure gradient between the plant and the environment and the area of cutting surface exposed to the atmosphere (Howard & Harrison-Murray 1988). Highest rooting frequency of M.26 4 weeks after insertion was associated with either no change or just a small decrease in water content during the first 9 days of propagation. Changes of the order of 3% in fresh weight in some situations proved detrimental. Cuttings were affected adversely by water loss in autumn and late winter/spring, and by water gain during mid winter. Conventional seasonal rooting curves for M.26 apple were inverted by counteracting these tendencies. This suggests that in addition to phenolic cofactors, water status could be instrumental in determining seasonal changes in rooting.

Loss of water at low aerial relative humidities was reduced by wrapping bundles of cuttings in polyethylene. Unfortunately, this was often detrimental to rooting, probably because water condensed on the inner surface of the polyethylene and dripped down onto the cutting base. The effect of the polyethylene, therefore, was to increase water uptake while reducing water loss.

Previous work by Howard et al. (1983) had shown that increased aeration of the rooting medium, through increased water suction, decreased cutting death at supra-optimal IBA concentration, and increased rooting. In addition, high compost temperature enhanced the response to sub-optimal and optimal IBA concentrations.

Recent research indicates that much of the poor performance previously noted using small hardwood cuttings is because of rotting of the cutting bases. In well-aerated media (for example with cutting bases placed on free draining sand with a mulch of wet granulated pine bark), shorter and thinner cuttings rooted better than their larger counterparts (Howard & Ridout 1991a,b). For success thinner cuttings must, however, be given environmental conditions conducive to rapid rooting.

Progress with hardwood cutting research was extensively reviewed some years ago by Howard (1987).

Hardwood cutting propagation of different rootstock clones

Many apple rootstocks such as M.26, MM.106, and MM.111 have been successfully propagated from hardwood winter cuttings; others such as M.9 have proved much more difficult to propagate using this method. In Norwegian trials (Hansen 1990a) heat-callused hardwood cuttings of the apple rootstocks Jork 9, P.1, P.2, and P.22 did not root; Bemali gave 19%, MM.106 9%, and M.26 12% rooting and this method was not considered suitable for commercial production. Quite why the rootstocks such as MM.106 and M.26 should have rooted so poorly in this trial is not understood.

Quince rootstocks generally root quite easily from hardwood cuttings, whereas most *Pyrus* clones prove rather more difficult by this technique. Oydvin & Hansen (1986) showed, however, that using the East Malling method (i.e., dipping the basal 4–5 cm of the cutting in 2500 mg/litre IBA for 5 s and placing the bundles of cuttings in a rooting bin over basal heat), the pear rootstock Old Home × Farmingdale 333 (OH × F333) was successfully propagated from cuttings.

Plum rootstocks, such as Myrobalan B (*Prunus cerasifera*), St. Julien A, and Pixy (*Prunus insititia*) are commercially propagated from hardwood cuttings in Britain.

Semi-hardwood or greenwood cuttings

As with softwood cuttings, the technique of semi-hardwood cuttings has found most favour with nurserymen propagating *Prunus* rootstocks. Bernhard & Claverie (1986) showed that leafy cuttings from current year's shoots of various *Prunus* clones, taken as their growth ceased and dipped in 1000 mg/litre IBA, could be rooted successfully under a misting system erected under a light shelter outside in southern France. The shelter was removed and misting stopped when roots appeared, c. 3 weeks after insertion. Rooting percentages were >80% for several different clones of *Prunus mahaleb*, 70% for the Mahaleb × Mazzard hybrid *P. fontanesiana* and *P. cerasus*, 95% for the Marianna clone GF8–1 and the Myrobalan clone P.2944, 85% for the peach clone GF.305 and a plum × peach hybrid, and 80% for the peach × almond hybrid GF.677. Interestingly, however, with Colt (*P. avium* × *P. pseudocerasus*) cherry rootstock, which roots easily from both soft and woody cuttings, only 10% rooted using this semi-hardwood technique.

Stockplant etiolation may also improve propagation from semi-hardwood autumn cuttings. Skolidis et al. (1990) showed that covering hard-pruned Myrobalan bushes (used as plum rootstocks) for 6 weeks with black plastic in spring resulted in etiolation of the newly sprouted shoots. These shoots taken as cuttings in the following autumn had much better callus and root development than normal shoots. The establishment of these cuttings was also much better. Histological examination of the etiolated shoots revealed no preformed root primordia and the formation of vascular bundles was inhibited. However, in fluorescence microscopy investigations, weaker lignification of the vascular bundles was demonstrated in the etiolated shoots. In trials at East Malling, in which the additive effects of etiolation and blanching were assessed, Harrison-Murray & Howard (1982) noted the formation of preformed roots on treated apple rootstocks.

Experiments in Norway have examined the feasibility of propagating apple rootstocks from semi-hardwood cuttings (Hansen 1989). Ten experiments were carried out using MM.106 and M.26 to examine the effects on rooting of shading the stockplants, type of cutting material, auxin treatments, and the rooting environment. Cuttings of MM.106 rooted more readily than those of M.26 using this method. Shading the stockplants increased the rooting percentage in both cultivars but was most effective with M.26 when applied in the latter part of the growing season. Three-node and 4-node stem cuttings rooted more readily than 2-node stem cuttings and terminal cuttings, especially when the lowest leaf was removed from each cutting, and distal stem cuttings rooted more easily than proximal stem cuttings. Wounding the base of each cutting improved rooting only slightly. Auxin application increased rooting; 1% IBA was the optimum talc concentration, but a 24-h soak in 200 ppm K-IBA was the most successful treatment. Three-node and 4-node stem cuttings treated with 1% IBA-talc grew most vigorously and produced the largest rootstocks in the first growing season.

Many other apple rootstock clones have been successfully rooted using semi-hardwood techniques in Norwegian experiments (Hansen 1990b). Most rootstocks tested, including the Czech clones J-TE-C, -E, -F, -G, and -H, the Swedish-bred Bemali, and the German-bred Jork 9, showed 50–60% rooting. The Czech clone J-TE-B was the easiest to root

(82%) whereas the Polish P.1, P.2, and P.22, the German Jork 9, and the Russian B.9 were the most difficult (0–30%). With this method, stem cuttings produced roots more readily than terminal cuttings with eight of the 10 rootstocks tested.

Micropropagation

Micropropagation has become fashionable in recent years and many commercial micropropagation laboratories have targeted rootstocks as suitable subjects. In the last 10 years new and improved micropropagation techniques have been developed for many rootstocks including the apple clones M.9 (Webster & Jones 1989), M.26 (Lee et al. 1990; Welander 1991), M.27 (Amitrani et al. 1989), and MM.111 (Arello et al. 1991), as well as pear rootstocks (Dolcet-Sanjuan et al. 1990a,b; Wang 1991), quince rootstocks (Gulsen & Dumanoglu 1991; Morini & Sciutti 1991), plum rootstocks (Morini et al. 1990b), sweet cherry rootstocks, (Paul & Feucht 1985), and peach rootstocks (Almehdi & Parfitt 1986).

In some instances, where micropropagation is the only method by which the clone may be propagated, its use is entirely justified. The technique also has value in rapidly building up new rootstock types or in facilitating the movement of healthy materials over national borders whilst satisfying plant importation and health regulations.

Micropropagation has proved particularly valuable in aiding the propagation of recalcitrant rootstocks, such as the apple clones Ottawa 3 (Pua et al. 1983; Hogue & Neilsen 1991; Webster & Jones 1991) and M.9 (Webster & Jones 1989) and the Brossier pear rootstocks (Webster 1993). Even micropropagation is not a success with all rootstocks. The Polish and Russian apple rootstocks P.2 and Budagovski 9 respectively, both responded poorly to the technique in extended tests by Webster & Jones (1991) at East Malling.

Physiology of rooting in vitro

Alvarez et al. (1989) showed that the differences in in vitro rooting noted when comparing a difficult clone (M.9) with an easy one (M.26) were associated with relative amounts of free indoleacetic acid (IAA) in the shoot bases. The poor rooting M.9 had higher amounts of its IAA in bound, inactivated forms. Collet & Nowbuth (1994) have suggested that differences in rooting between recalcitrant M.9 clones, such as EMLA and Lancep, and easier-to-root clones, such as Cepiland, is associated with their capacity to rapidly organise new cells into primordia and also to their ability to divide cells rapidly after induction by auxin.

In recent research on the apple rootstock Jork 9, Auderset et al. (1994) have suggested that the first initiating signal for rooting may be the wounding of the stem at cutting excision and this response may be amplified by an exogenous supply of auxin. They further suggest that the whole process of initiation through to root development is very complex involving endogenous regulators, such as free IAA, peroxidases, and phenols. The maximum amounts of free IAA are noted at the end of the root induction stage which is often only 1 day after treatment. Thereafter, the amounts of free IAA decline and reach their lowest levels just before root formation. Root primordia were observed c. 100 h after treatment as a result of dedifferentiation and mitotic activity in cells of the interfascicular parenchyma neighbouring the vascular bundles. This followed a thickening of the interfasicular cambium.

Influence of the stockplant on micropropagation

Paul & Feucht (1985) showed in micropropagation experiments with *P. avium* and *P. cerasus* rootstocks that the original position of the explant on the mother plant could affect the subsequent performance of the culture. Similar effects have been noted when micropropagating apple rootstocks. Webster & Jones (1989) showed that different shoots tips from the same M.9 stockplant were very different physiologically in how they responded to micropropagation. More recent research by de Klerk & Caillat (1994) has indicated that with the apple rootstock Jork 9, whilst different shoots from the same stockplant do differ, of more importance is the precise position where the explant is cut.

Recent studies by Harrington et al. (1994) have indicated that root suckers may provide the best source of explants when endeavouring to initiate micropropagation cultures of mature trees of *P. avium*.

Micropropagation media and propagation environment

Most media used in micropropagation contain nutrients, minerals and sugars, and various hormones and vitamins (Murashige & Skoog 1962). These are incorporated into a solid carrier, such as agar or alternatively dissolved to form a liquid medium. Sometimes, both are combined in a dual, liquid plus solid medium (Ivanova 1989).

Almost every paper published seems to recommend a slightly modified medium and it must be difficult for the commercial propagator to find any consensus opinion on appropriate media. Recent research by Navatel & Bourrain (1994) has shown that rooting and subsequent plant quality of in vitro-raised Lancep and Cepiland clones of apple rootstock M.9, was improved if exfoliated vermiculite was included with the agar to alleviate the anaerobic conditions common in normal media.

Occasionally, micropropagation of recalcitrant clones of apple rootstock is reported to be improved by addition of phloroglucinol or increasing the cytokinin concentration in the culture medium. Treatment of microcuttings with chlorogenic acid has also been shown to increase rooting of the apple rootstock Jork 9 (Caboni et al. 1994).

Use of too high a concentration of cytokinin may induce mutation in culture or cause increased vitrification of cultures. Vitrification is a common problem with micropropagation cultures and work by Singha et al. (1990) on the Quince C rootstock showed that the problem could be reduced by increasing levels of calcium in the culture medium. Unfortunately, the increased calcium also reduced culture growth. Standardi & Micheli (1988) working with M.26, showed that use of explants with 4–6 leaves resulted in less vitrification than use of explants with only two apical leaves. Peroxidase activity was higher in vitrifying shoots of M.26 than in normal shoots, and reduced glutathione, added to the liquid medium at 500 mg/litre, modified peroxidase activity in the proliferating shoots so reducing the incidence of vitrification.

Light quality is influential in micropropagation success. Hennig & Gliemeroth (1989) showed that micropropagation cultures of new German apple rootstocks differed in their response to light quality. Although red light favoured shoot proliferation and blue light rooting in some clones, in others white light gave the best overall response. Baraldi et al. (1988) studied the effect of light quality and quantity and their possible interaction with BA in the control of in vitro proliferation of the rootstock *Prunus insititia* GF 655–2. BA acted as a promoting agent of shoot formation only in the presence of light. The concentration response curves for BA-induced proliferation were very similar under the different light sources, irrespective of proliferation rates. The results suggest the action of a low-energy response in the red waveband and under the low photon fluence rate of blue and white. The inhibition of shoot elongation induced by BA in the dark as well as under all light treatments indicates that, whereas the BA-induced suppression of apical dominance is light dependent, BA inhibition of shoot elongation is entirely light independent.

Daylength has also been shown to affect micropropagation of rootstocks. Morini et al. (1990a) showed that when micropropagating *P. cerasifera* and GF677 (a peach × almond hybrid rootstock) short cycles of light and dark (4 h light followed by 2 h dark) gave the best culture growth rates.

Webster & Jones (1989) in experiments on the micropropagation of M.9 noted that although etiolation of the cultures enhanced rooting it also reduced establishment success. Addition of phloroglucinol to the medium in this instance had inconsistent effects.

Problems of acclimation (weaning) and establishment

Although much effort has been devoted to determining appropriate culture media and in vitro techniques for the propagation of tree fruit scion and rootstock cultivars, insufficient attention has been given to improving the acclimation and subsequent growing-on of micropropagules. Poor survival is often experienced during the acclimation of micropropagated rootstocks and this is often attributed to desiccation of the transplanted micropropagules. However, work by Marin & Gella (1988) on a micropropagated sweet cherry rootstock indicates that factors other than desiccation play a role in this poor survival. Previous work has shown that difficulties in the hardening of micropropagated cuttings can derive from the fact that morphologically well-developed roots may not be functionally adequate, and that roots formed in the presence of callus may have little or no vascular connection with the shoot.

Acclimated micropropagules are frequently very variable in their growth needing rigorous grading if uniform liners or trees are to be produced. More attention needs to be given to the reasons for this inconsistency of growth. Some subjects, such as the more dwarfing clones of the Brossier *Pyrus* rootstocks, pose particular problems of establishment and growing-on following micropropagation. Techniques have been developed that enable them to be grown and rooted in culture quite successfully (Webster 1993), but after rooting they are very difficult to establish in conventional media and grow-on so slowly that their value as commercial rootstocks must be questioned. Progress with weaning some micropropagated rootstocks has been made. Howard & Oehl (1981) demonstrated that either chilling or treatment with sprays of GA aided the establishment and subsequent growth of weaned micropropagules of the plum rootstock Pixy. Without these treatments the rooted Pixy plants had a tendency to form rosettes of leaves with very small internodes and no extension growth.

Simmonds (1983) was one of several researchers to demonstrate that when rooting micropropagules, direct sticking of the small shoots into mist or fogging environments may give better rooting than the more usual rooting in vitro.

Micropropagation as an aid to conventional propagation

Often recalcitrant clones are initially difficult to micropropagate, showing poor proliferation in culture and poor rooting. However, as the number of sequential monthly subcultures increases so does the speed of shoot proliferation in culture and the success of rooting. The clones appear to become "rejuvenated", showing typical juvenile characteristics such as improved rooting and, when grown-on, increased branching and a shyness to flower.

Once removed from micropropagation and established in stoolbeds or hedges the benefits of any induced "juvenility" and easier rooting can persist (Jones 1993). One of the first instances of this was reported following micropropagation of the plum rootstock Pixy by Howard et al. (1989). The enhanced rooting potential of cuttings taken from hedges raised from micropropagated Pixy persisted for at least 9 years after weaning from micropropagation and hedge establishment. Similar rejuvenation has also been demonstrated with micropropagated *Pyrus* rootstocks (Jones & Webster 1989). It may be argued that this apparent juvenility is not a phase change, as plants raised from rejuvenated and normal Pixy hedges come into flower at about the same time. Work by Howard & Ridout (1991a,b) suggests that at least one reason why hedges which are either raised from micropropagated (rejuvenated) plants or are very hard-pruned, produce cuttings which are relatively easier to root, lies in the size of cuttings produced. Both produce shoots which are long and relatively thin in diameter and both stockplant types may have enhanced root : shoot ratios.

Orchard performance of micropropagated rootstocks

Opinions differ as to the relative vigour of micropropagated and conventionally propagated rootstocks when worked with scions. In French field trials (Navatel & Bourrain 1994) no differences in vigour were found between micropropagated and conventionally propagated peach rootstocks Damas 1869 and Saint Julien GF 655. With the apple rootstock Pajam 1 (an M.9 selection), micropropagated rootstocks showed slightly less vigour than the standard rootstocks. With three peach cultivars, in contrast, scion vigour on the micropropagated seedling rootstock GF 305 was similar to or greater than that on normal rootstocks. Navatel et al. (1988) showed in French trials that the rootstocks (M.27 and Pajam 1 (M.9)) produced by micropropagation showed greater vigour in the stoolbed, more rapid stock production, and a bigger root system than rootstocks produced by conventional methods. In the orchard, little difference in vigour and yield was shown between trees on M.26 rootstocks produced by stooling and those produced directly by micropropagation. Trees ('Golden Delicious') on the rootstock Pajam 1 produced by stooling of micropropagated plants showed slightly less vigour than on rootstocks produced by stooling of non-micropropagated plants, but fruit production of grafted trees was not significantly affected. In some instances the number of graft rejections was higher with micropropagated than with normal stocks. Studies in France and Italy (Edin et al. 1987) with four peach cultivars on the rootstock GF 677 (produced by cuttings or micropropagation) showed no significant differences in quantitative or qualitative aspects of production between the two rootstock sources.

Webster & Jones (1989, 1992) showed with increasing duration of sub-culture of shoots in vitro, the ease of subsequent conventional propagation of rootstocks from the micropropagated source material increased as did the production of suckers (from the rootstock roots) and burrknots (nodules of callus with root initials on the bark) on weaned micropropagules. Increased suckering and burrknotting of micropropagated rootstocks was also reported in France by Villeneuve (1986). These effects are, however, not always consistent, as Jones & Hadlow (1989) showed that micropropagation had no effect on the suckering or burrknotting of the apple rootstock M.27, although it did increase suckering of M.9 and M.25. Navatel et al. (1988) showed that although micropropagation increased burrknotting and suckering of a Pajam selection of M.9 compared with conventional propagation, the severity of the problem was greatly influenced by where the trees were eventually grown in France.

It follows, therefore, that propagation of rootstocks by micropropagation may not always be desirable and may result in problems of suckering and burrknotting when trees are planted in the orchard. 'Cox's Orange Pippin' scions budded directly onto weaned micropropagated M.9-EMLA at East Malling produced excessive numbers of suckers and burrknots in the first year of growth in the nursery in comparison with 'Cox's Orange Pippin' budded on M.9-EMLA raised conventionally from stoolbed liners (Webster & Jones 1992; Jones & Webster 1993). These problems of suckering and burrknotting have persisted and are still evident on the trees several years after planting in an orchard.

Future use of micropropagation for rootstocks?

Research indicates that although there is little evidence of significant somaclonal variation occurring as a result of micropropagation, epigenic effects such as induced juvenility are fairly commonly noted. Although often real value in aiding subsequent conventional propagation, this rejuvenation may present problems of suckering and burrknotting if scions are directly budded onto weaned micropropagules. Wherever possible techniques other than micropropagation should, therefore, be used for propagating rootstocks. Rootstocks in very short supply in Britain (e.g., new or virus-free clones) have been rapidly multiplied by budding them onto a vigorous, virus-free, understock which has distinct red leaves and stems. The rootstock "maidens" then produced are deep-planted to form a stoolbed and any red-leaved shoots which emerge from below ground are easily recognised and removed. Where this is not possible and micropropagation must be resorted to, the micropropagated rootstocks should only be used to establish stoolbeds or hedges for subsequent conventional propagation. Liners or cuttings taken from these can generally be safely used for budding or grafting. Just a short 2-year period as a hedge or stoolbed may be sufficient to alleviate the suckering and burrknotting problems associated with use of micropropagated dwarfing apple rootstocks.

Root cuttings

Root cuttings are used only occasionally in rootstock propagation on account of the high labour demands of the technique. The Mazzard cherry rootstock F.12/1 is, however, propagated by one specialist nursery in Australia using this technique. In Russian trials (Samus & Sukhotskii 1986) where M.4, M.7, M.11, 5–35–3, MM.104, and A2 root cuttings were compared, M.4 and M.11 grew best (89.6 and 72.8%, respectively) and MM.104 worst (11.3%). Rootstocks which grew well also gave high numbers of standard plants. In another trial MM.106 produced 40 000 standard rootstocks/ha in 2 years using this technique.

Osborne (1983) showed that softwood cuttings of the apple rootstock Ottawa 3 could be successfully rooted using material from shoots grown from root pieces of adult (fruiting) plants. Reversion of the material to the "juvenile" state was directly related to the changes brought about by using root pieces. Rooting percentages were increased by 0.8% IBA treatment, wounding the base cuttings and using apical cuttings.

Florov (1981) demonstrated that whilst M.2, M.4, M.5, M.6, M.7, M.9, M.10, M.11, M.13, A2, Budagovskii Paradise, and U–25-III were successfully propagated by root cuttings, M.3 and M.8 were not.

ROOTSTOCKS USED AS INTERSTOCKS

Some rootstock clones have excellent merits, such as resistance to winter cold injury, good control of scion vigour and good induction of cropping, but prove very difficult to root by conventional propagation techniques. An example is the apple rootstock Ottawa 3. Micropropagation is one expedient in such situations; another is to employ the clone as an interstock over some easier-to-root rootstock.

Interstocks are also used to alleviate incompatibility, such as that between many pear scions and quince rootstocks. Dwarfing interstocks are also used to improve tree growth and anchorage on marginal soils where trees worked directly on the dwarfing clone are too weak or have root systems unsuited to the edaphic conditions.

The performance of a clone as a rootstock is not always indicative of its performance as an interstock; for example, B.9 performs well as an apple rootstock but poorly as an interstock (Webster unpubl. data).

Unfortunately, although dwarfing interstocks confer their beneficial effects when used in raising apple and pear trees, they are generally much less effective when employed for stone fruits. Research at East Malling showed that although "genetic dwarf" clones of *Prunus avium* and a clone of *Prunus mugus* all effectively dwarfed sweet cherry trees when used as rootstocks, they had minimal effects on tree vigour when used as interstocks.

Research with apple demonstrated when using dwarfing rootstock clones as interstocks that the dwarfing effect was increased with the length of the interstock used (Parry & Rogers 1972). This is similar to the increased dwarfing effect noted with dwarfing rootstocks as the height of budding is increased. These associated effects, which have also been reported with dwarfing quince rootstocks, indicate that the rootstock shank is responsible for part of the dwarfing effect noted with these two species.

Often another scion cultivar is used to form the trunk of a tree between the rootstock and the scion; these may be referred to as interstems or interstocks. Traditionally, their function was to provide a winter cold tolerant lower trunk. This is still in evidence in eastern Germany where the cold tolerant cultivar 'Hibernal' is commonly used as a stem builder over M.9 rootstock.

More recently, apple cultivars such as 'Delicious', and 'Zoet Aagt' have been employed as interstems. These are reported to increase scion yield precocity. There is, however, little objective evidence that these increases in precocity are attributable to use of any particular cultivar as an interstem. A more likely explanation is that the beneficial effect on cropping is associated with the way in which the trees are raised. Most trees with interstocks/interstems take an extra year to raise in the nursery and at lifting have different shoot : root ratios compared with maiden, single worked trees. It is speculated that differences in the degree of transplanting shock or in root : shoot ratios or ages at time of planting may be associated with the improved precocity frequently observed on trees with interstems.

All trees with either interstems or interstocks of 30 cm or more also have the advantage of forming their lowest feathers (laterals) at the ideal height for modern systems of tree management.

RAPID FRUIT TREE PROPAGATION TECHNIQUES

Interest has occasionally been shown in shortening the time period required for raising fruit trees. The most commonly used shortcut is to bench graft scions onto pre-rooted rootstocks and plant these directly into the orchard. Another technique involves rooting newly bench-grafted rootstock shoots under misting or fogging conditions. In Italian research (Morini 1984) hardwood cuttings of MM.106 apple, Myrobalan B plum, and Quince A rootstocks were collected in November and February, treated with IBA and grafted with scions of 'Cooper 7 SB 2' apple, 'Burmosa' plum, and 'Conference' and 'Williams' Bon Chretien' pear cultivars, respectively. Different procedures were tested: (1) cuttings were bench-grafted at both the collecting times using an Omega machine and planted directly in the field; and (2) cuttings were planted in the nursery in November and grafted in February using a portable Omega machine, or grafted by hand (kerf grafting). With pear, the percentages of maiden trees produced were very high, either with bench-grafted cuttings or with cuttings planted in November and kerf-grafted in February. With apple and plum, the latter procedure gave better results. Bottom heat was shown to slightly increase rooting and graft-take. A grafted fruit tree was produced in less than 1 year by these techniques.

More recently, Canadian researchers have demonstrated rapid propagation techniques which, using in vitro raised rootstocks and glasshouse culture, enable feathered apple trees to be produced in 1 year (Hogue & Neilsen 1990).

All of these techniques can, if successful, reduce the time taken to raise trees by 1 or 2 years. Unfortunately, in most instances tree quality is much less uniform and generally poorer using such techniques.

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